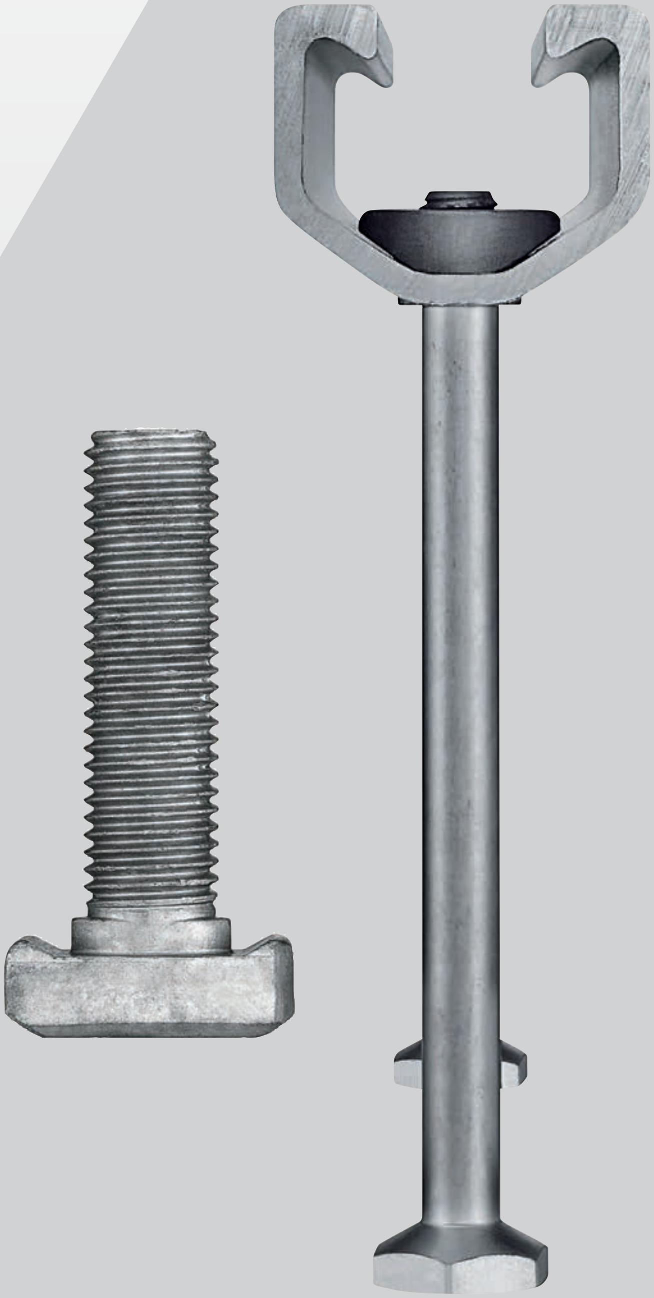
# NORTH AMERICAN PRODUCT TECHNICAL GUIDE

## Cast-In Anchor Channel Fastening Technical Guide, Edition 1

**A guide to design, specification, and installation**




We are a company inspired to make a difference in our customers' businesses. We want to help make your job faster, safer, and more productive. That's why Hilti North America has over 3,600 highly trained team members in sales, engineering, marketing, and other support roles whom all work to help construction professionals solve their biggest challenges.

Hilti offers products, systems, and solutions for every application on the jobsite. Whether our customers work in construction, civil engineering, energy, mechanical, electrical, steel and metal, or interior finishing, Hilti is here to help them build a better future.

With over 60 years of experience in fastening systems, Hilti is your reliable partner for secure anchor solutions. We have now further extended our range of products to include a new generation of cast-in anchor systems for reliable load transfer to concrete structures — the Hilti HAC Anchor Channel.

Hilti's extensive research and testing on anchor channels allowed the publication of the first ICC approval for anchor channels for seismic design categories C, D, E, and F.

Hilti Anchor Channels are a value engineered solution that in addition of preserving the high product performance, they have improved the function and features of the traditional anchor channel system, creating differentiating and innovative solutions that bring added value to the cast-in industry.

Every Hilti product and system is backed with research, training, software, service, and support. It's the right way. And that's the Hilti way.

## Our Purpose

We passionately create enthusiastic customers and build a better future!

**Enthusiastic Customers**
We create success for our customers by identifying their needs and providing innovative and value-adding solutions.

**Build a better future**
We embrace our responsibility towards society and the environment.

## Our Quality System

Hilti is one of a select group of North American companies to receive the ISO 9001 and ISO 14001 Certifications. This recognition of our commitment to quality ensures our customers that Hilti has the systems and procedures in place to maintain our position as the world market leader, and to continually evaluate and improve our performance.

**That's total customer satisfaction.**
For Technical Support, contact

Hilti, Inc. (US) at 1-877-749-6337 or

Hilti (Canada) Corporation at 1-800-363-4458.



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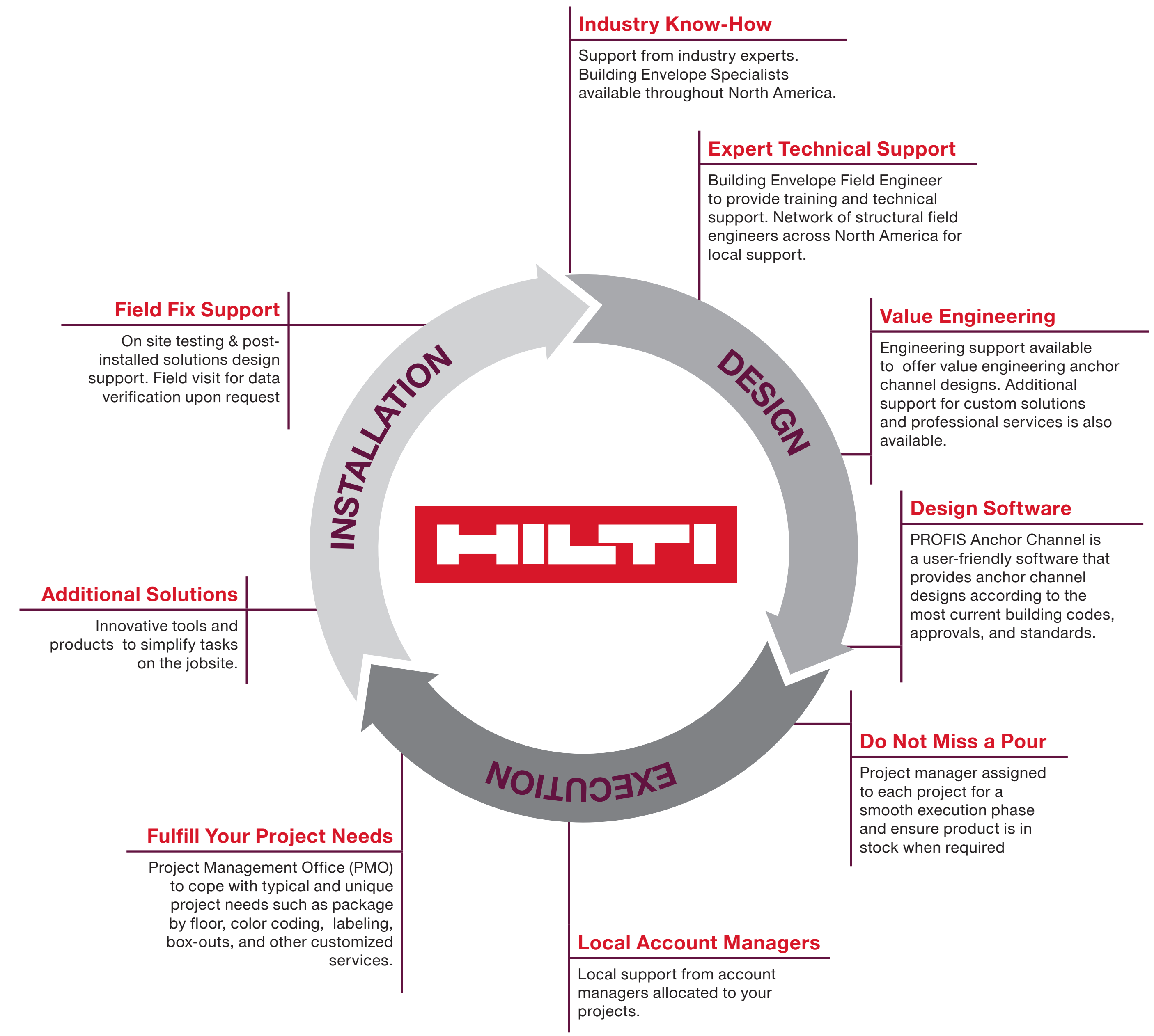
# YOUR PARTNER THROUGHOUT THE LIFE SPAN OF YOUR PROJECT

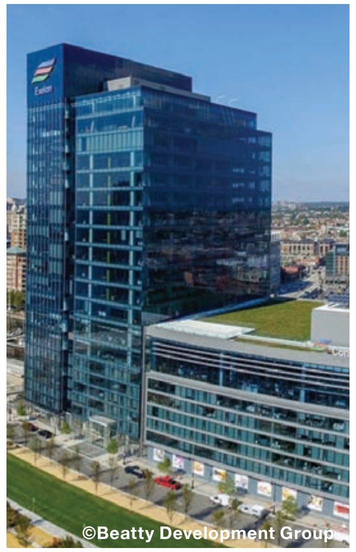



## BACKED UP BY MORE THAN 60 YEARS IN ANCHORING TO CONCRETE EXPERIENCE

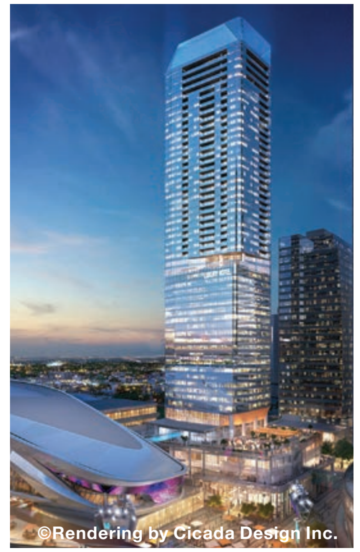
**For additional information: www.hilti.com/hac-anchor-channel**

# HAC SUCCESS STORIES

McKinney and Olive, TX



Exelon Corp, MD

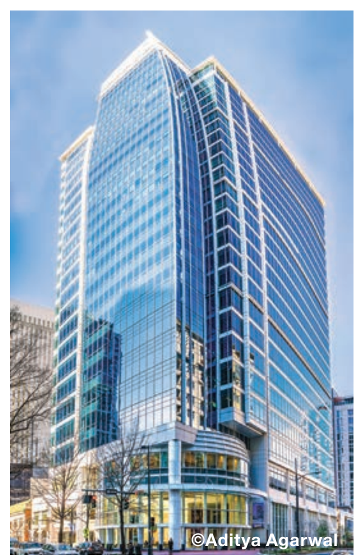


ICE District Block A, CAN

Jasper (45 Lansing), CA

488 University, CAN

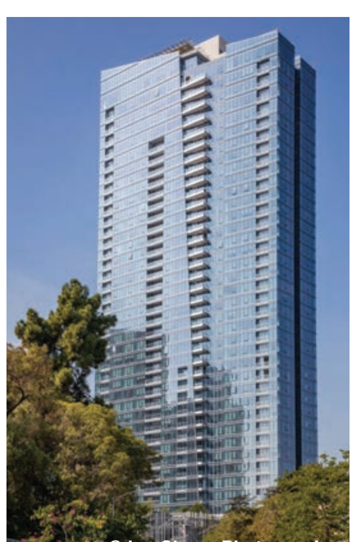
42-12 28th St, NY



300 South Tryon, NC

855 6th Ave., NY

626 1st Ave., NY

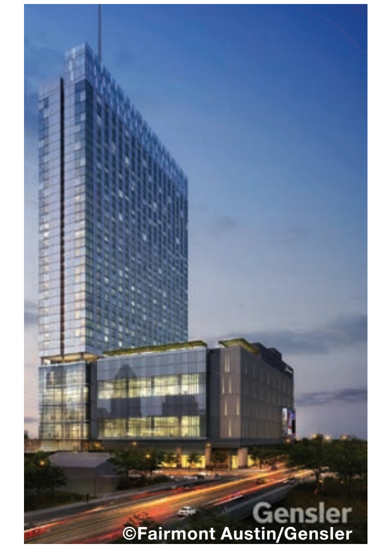


10,000 Santa Monica, CA

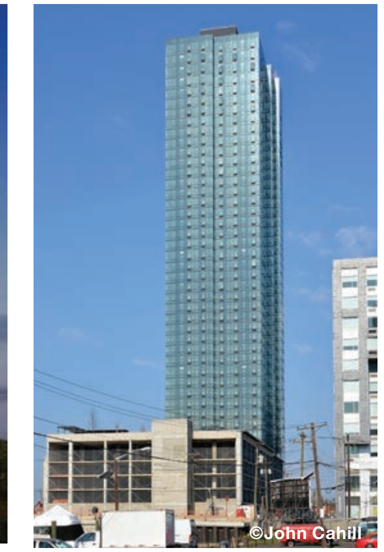
JW Marriot Austin, TX

35 Hudson Yards, NY

One Thousand Museum, FL

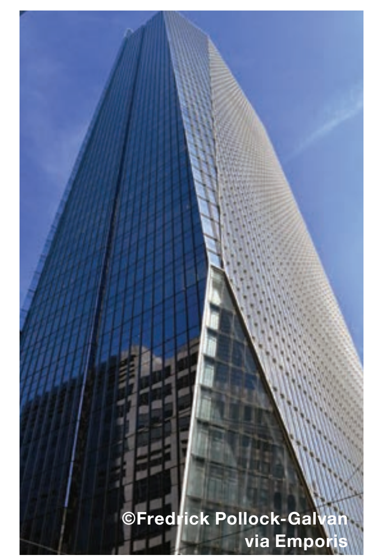


Fairmont Hotel, TX



33 Park Ave., NJ

Bridgestone Tower, TN



609 Main, TX

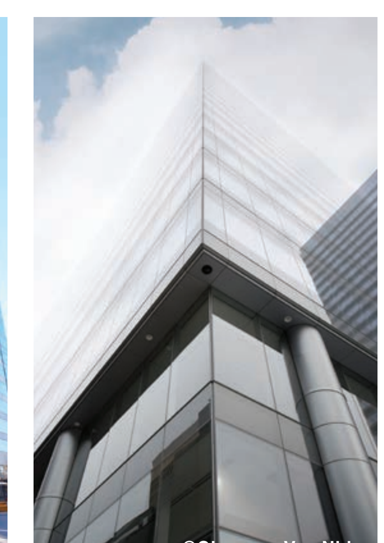
2202 8th Ave., WA

99 Hudson, NJ

Bryant Park, 20 West 40th Street, NY

Building Cure - Seattle Children's Research Institute, WA

601 City Center, CA



Centene Plaza, MI

3rd and Lenora, WA

# HAC SUCCESS STORIES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55 Hudson Yards, NY


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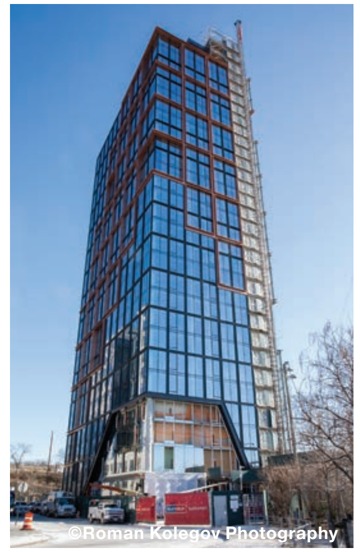
Domino Sugar, NY


©Roman Kolegov Photography
Pier 6, NJ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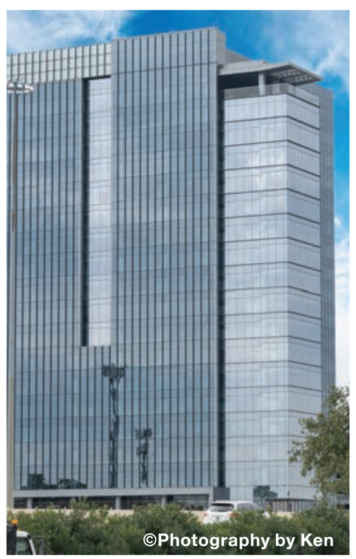
217 West 57th St, NY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Energy Center III, TX


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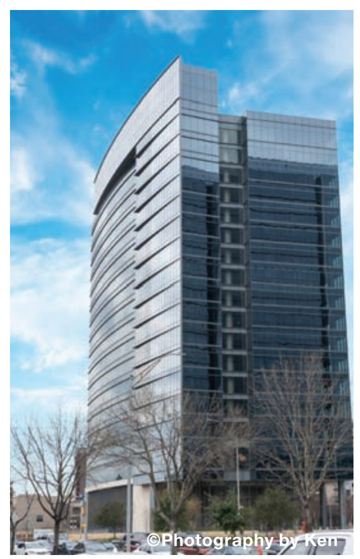
Energy Center IV, TX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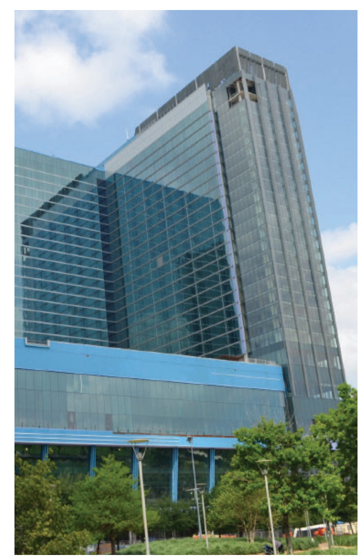
Energy Center V, TX


Marriott Marquis Houston Houston, TX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BOK Park Plaza, OK


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215 Chrystie Street, NY



# HILTI ANCHOR CHANNEL — ONSITE PHOTOS


©Hilti
Curtain wall installation


©Hilti
HAC CRFoS U in composite slab


©Hilti
Box-out solution


©Hilti
Curtain wall bracket


©Hilti
Anchor channel in underside of T-beam


©Hilti
Underside view of face of slab corner configuration


©Hilti
Face of slab corner condition


©Hilti
Installation of curtain wall panels


©Hilti
Anchor channel fixed to form-work in face of slab


©Hilti
Anchor channel in top of slab corner

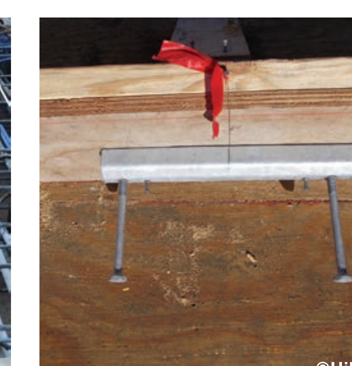

©Hilti
HAC in top of slab with box-out


©Hilti
HAC in face of slab spandrel beam


©Hilti
HAC in top of slab with installation aid


©Hilti
Corner configuration in top of slab


©Hilti
HAC in face of slab condition in PT slab


©Hilti
Anchor channel fixed to formwork in face of slab

# 1. CAST-IN ANCHOR CHANNEL SYSTEMS

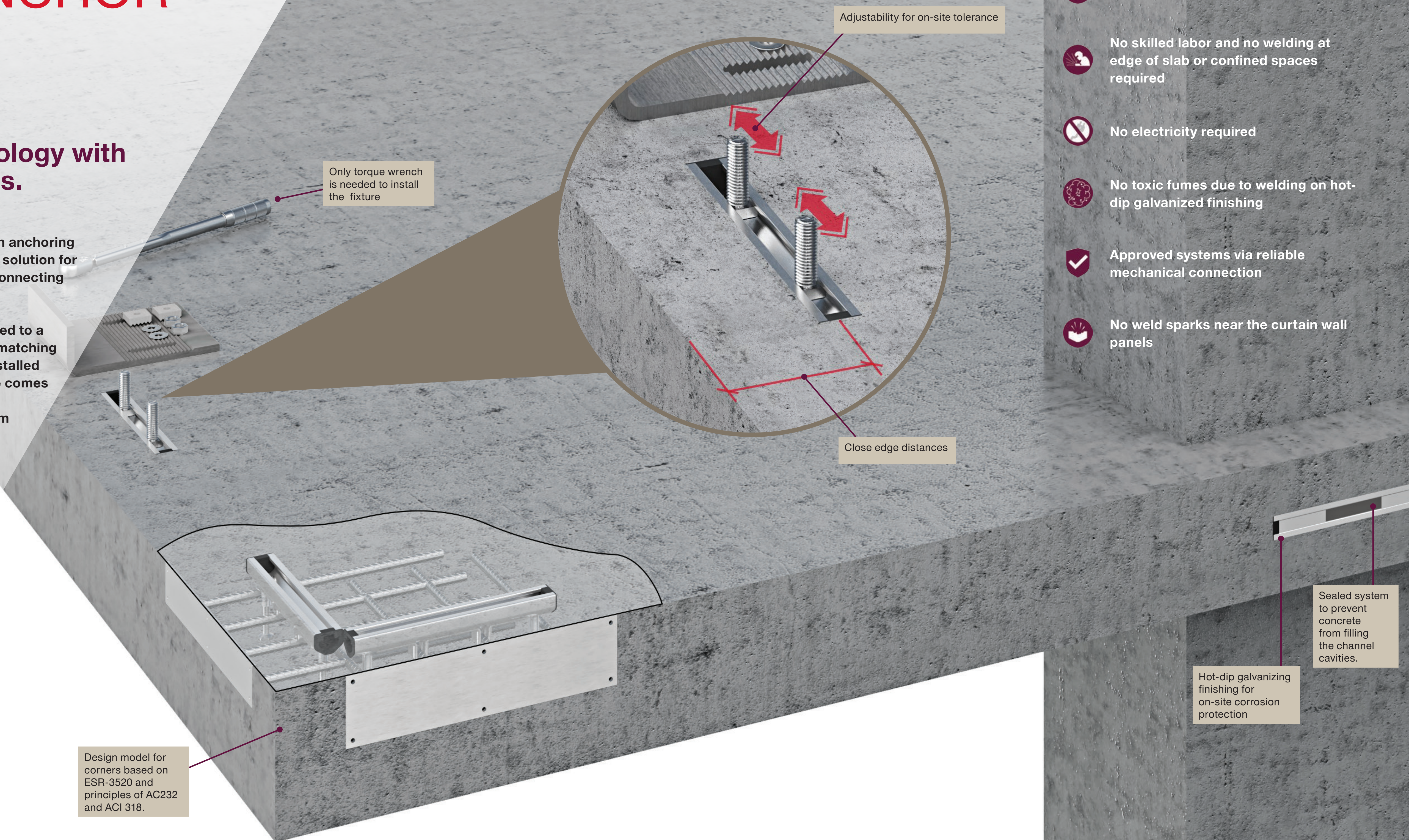
## A proven anchoring technology with approved design standards.

Anchor channel systems are a cost-effective cast-in anchoring to concrete technology. This technology provides a solution for job site tolerances and on-site adjustability when connecting structural and non-structural elements.

The system consists of a group of anchors connected to a channel profile (anchor channel) and a proprietary matching head channel bolt (t-bolt). The anchor channel is installed prior to casting of the concrete. The channel profile comes with a filler foam to prevent the concrete to getting inside the profile. To install the fixture, the filler foam is removed. This leaves the channel cavity exposed and the t-bolts can be installed along the channel profile. The fixture is secured once the washer and nuts are against the fixture and the required installation torque is applied.

Compared to traditional cast-in technologies, anchor channel systems provide added savings by not requiring skilled labor to connect the fixture since welding is not required. Moreover, anchor channels reduce the installation time per connection, improve the productivity of the installer, increase the structural reliability of the connection, and may improve the safety of the installer.

(For additional anchor channel applications, see chapter 3)




- Saves money and time
- Faster installation
- No skilled labor and no welding at edge of slab or confined spaces required
- No electricity required
- No toxic fumes due to welding on hot-dip galvanized finishing
- Approved systems via reliable mechanical connection
- No weld sparks near the curtain wall panels

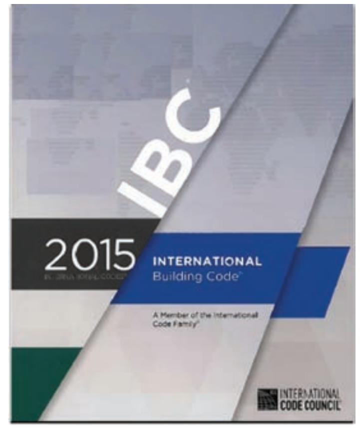
## PLAN AHEAD

Anchor channels are installed before the concrete is poured. Proper planning between different trades is required for a successful project.

Project planning allows for feasible anchoring designs, proper layout, proper fulfillment and execution, and successful installation.

Proactivity goes a long way! By planning ahead, onsite complexities can be minimized thus allowing to take control of the project while it will leave more time to work on the unexpected.

## COMPLY





Traditionally, anchor channel systems have been designed using manufacturer's data and allowable stress design. Anchor channel systems are now easier to show compliance with the International Building Code (IBC) for design with strength design provisions. Providing model Code Compliant designs ensures the use of the product will be accepted by local authorities, jurisdictions, engineer of records, inspectors, etc.

The International Code Council Evaluation Service (ICC-ES) has developed the Acceptance Criteria for Anchor Channels in Concrete Elements (AC232) to show compliance of the anchor channel systems, and to assist in designing these systems using the provisions given in AC232 and in the anchoring-to-concrete provisions provided in the American Concrete Institute (ACI) publication Building Code Requirements for Structural Concrete (ACI 318).

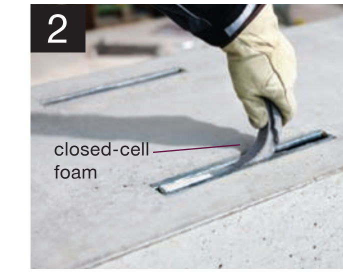
Anchor channel in the slab prior to casting of the concrete.

## SAVE TIME AND MONEY


All Hilti anchor channels come with end caps, tear-out strip, and low density polyethylene (closed-cell) foam to prevent concrete from entering the channel cavity.

### Adjustability without drilling or welding


The tear out band simplifies the foam removal.




The closed-cell foam allows for an easy tear out strip, allowing the entire foam length to be continuously removed.


T-bolts can be installed along the channel length (except outers 1"), thus allowing for the so desired installation tolerance.


Fixture is positioned in the proper position and the hexagonal nut is tightened to the right setting torque.

### 'NO WELDING' ADVANTAGES

- No certified welder needed
- Faster installation
- No toxic fumes (HDG)
- No electricity needed on site
- No welding sparks
- Simpler inspections

### 'NO DRILLING' ADVANTAGES

- Faster installation
- No damage of slab's reinforcement or concrete by multiple drilling attempts
- Anchors with reinforcing bars allowed for superior performance
- No scanning needed
- No dust control requirements

# 1.1 HILTI CAST-IN ANCHOR CHANNEL BENEFITS AND FEATURES

### WELL SEALED SYSTEM

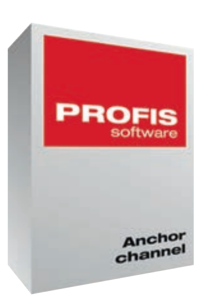
- Well sealed system keeps concrete slurry out of the channel cavity
- Prevents t-bolts from been installed at the outer 1" of the channel profile

### PRODUCTIVITY GAINS ON THE JOB SITE

- Continuous foam reduces the removal time
- Well-sealed system that keeps concrete out of the channel cavity
- Tear out band/strip integrated that eases the foam removal process
- Environmental friendly materials (PE/PP)

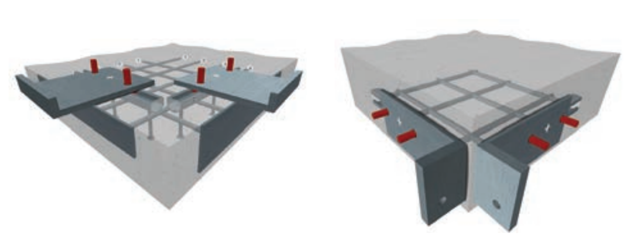
### RELIABILITY: MECHANICAL CONNECTION

- Superior performance/quality control
- Less data/strength fluctuation
- Fully automated assembly



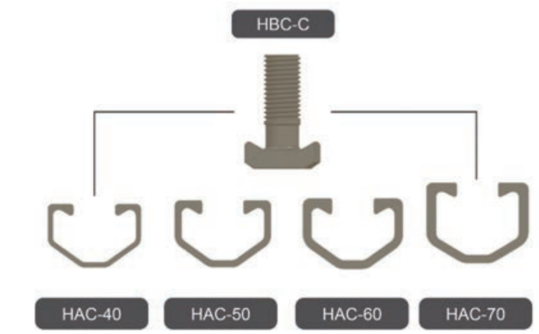

### PROFIS ANCHOR CHANNEL

- Simplifies design
- Based on American Standards
- Optimized and reliable anchor channel design
- Covers all typical applications in a building (i.e. Lightweight concrete, thin members, corners, corner zones, seismic applications)
- No extra cost
- ICC ESR-3520



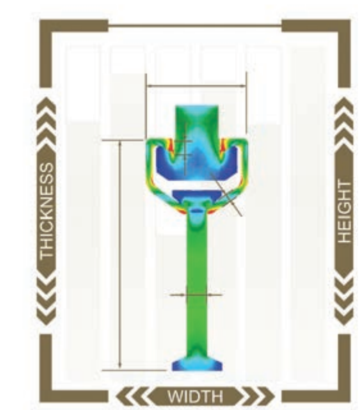
### OPTIMUM CHANNEL PROFILE DESIGN

- Optimum amount of steel allocated to each profile size
- Simplifies logistical management inventory on site: 1 bolt head size that fits all anchor channels
- Feasibility via economies of scale: one bolt size for all applications
- Reduced channel width allows anchor channels to be installed up to a 2" edge distance



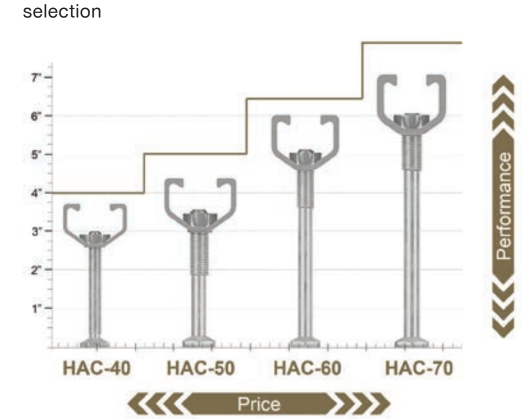

### VALUE ENGINEERED PORTFOLIO

- Synergized anchor channel design
- Optimum anchor channel geometry
- Optimum component size




### VERSATILE PORTFOLIO

- Wider range of anchor channel sizes for optimum anchor selection




1.1 Anchor Channels Benefits and Features
1.2 HAC Overview
1.3 HAC Components
1.4 HAC Selection

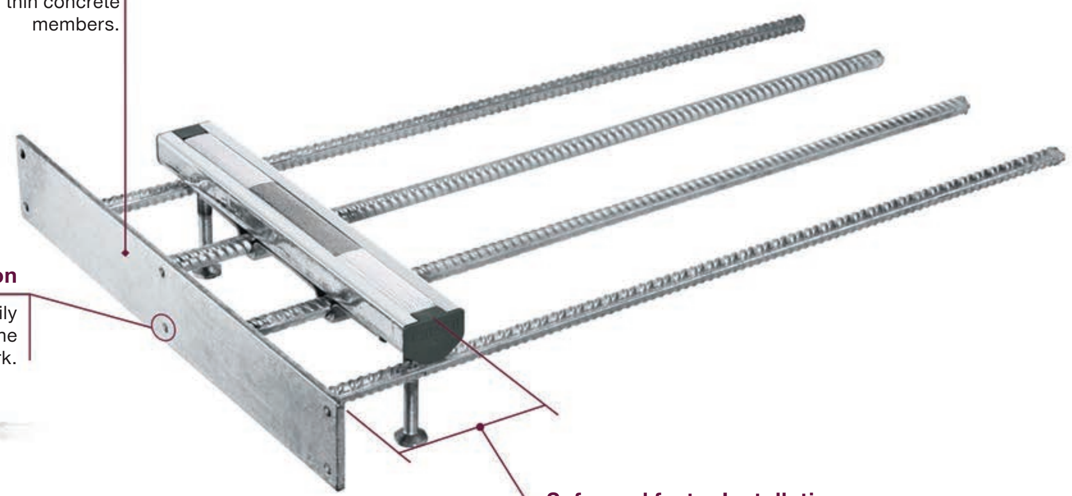
# TAKE YOUR ANCHOR CHANNELS TO A NEW EDGE. ANCHOR CHANNEL SYSTEM FOR SUPERIOR CONCRETE EDGE PERFORMANCE

## HAC EDGE (Patent pending)

Provides up to 5.6X higher concrete breakout strength in shear than traditional anchor channels

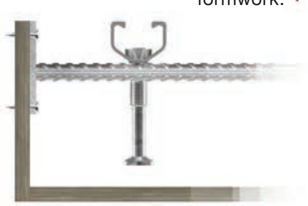
**Rebar Edge Confinement Plate (EDGE plate)**

Superior concrete edge performance in small edge distances and thin concrete members.



**Simplified Installation**

Additional nail holes to easily fix the anchor channel to the formwork.



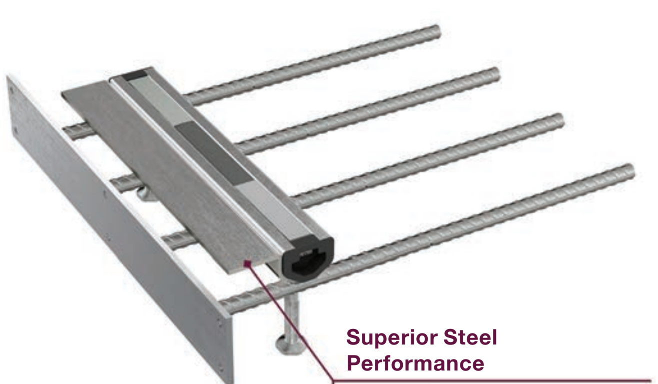
**Safer and faster Installation**

Product comes with the required edge distance for more accurate and faster installation.

State-of-art design model based on ESR-3520 and principles of AC232 and ACI 318

19 out of 20 potential failure modes are calculated in accordance with ESR-3520

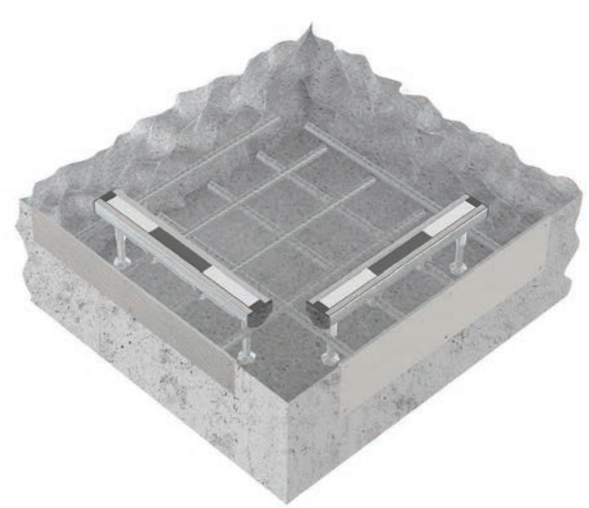
## HAC S EDGE (Patent pending)



**Superior Steel Performance**

"S" bracket structurally connected to HAC for increased channel lip and anchor-channel performance.

## Corner Solutions



State-of-the-art design model for top of slab corners based on principles of AC232. Design valid for HAC, HAC EDGE, and HAC S EDGE

# THE SERRATED HAC-T — THE BEST ANCHOR CHANNEL SYSTEM FOR SEISMIC AND 3D LOADS

## HAC-T

### PERFORMANCE

- High slip resistances at low installation torque.
- Rebar channels available on serrated.

### RELIABILITY

- Optimal t-bolt/channel lip interlocking for consistent performance.
- Redundant system due to multiple teeth engagement between t-bolt and channel lip's serrations.

### FEASIBILITY

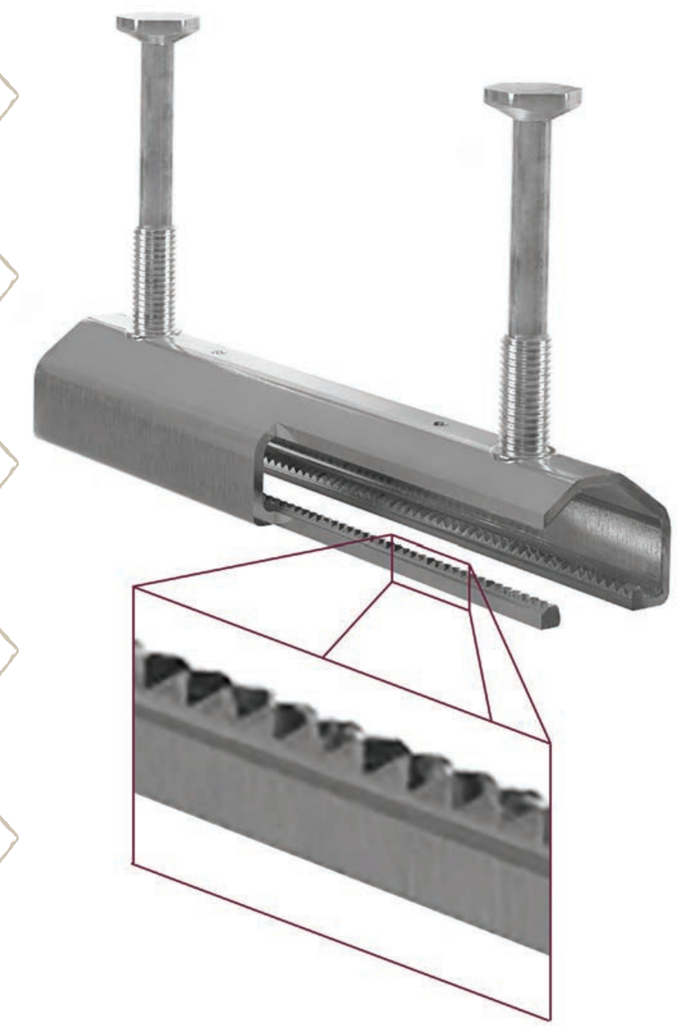
- Innovative manufacturing process that brings serrations at minimal extra cost.
- Price of HAC-T is similar to it's equivalent HAC size with HBC-C-N.

### SAFETY

- Higher installation safety via lower installation torque.
- Lighter torque wrench, less muscle fatigue.

### SIMPLICITY

- Higher slip resistances without continuous inspection requirements.
- One channel bolt size suitable for both channel sizes HAC-T50 and HAC-T70.



Suitable for applications that require repositioning of the T-bolts and transferring of longitudinal forces.

# 1.2 HAC OVERVIEW

## 1.2.1 HILTI ANCHOR CHANNEL PORTFOLIO AT A GLANCE

Hilti's simplified and value engineered cast-in anchor channel system portfolio, in conjunction with PROFIS Anchor Channel, helps designers to easily provide model code compliant and cost-effective anchor channel system solutions.

Hilti Anchor Channel (HAC) design models are based on state-of-the-art compliance with International Council Code Evaluation Service Report 3520 (ICC ESR-3520). Design models of anchor channels not explicitly covered by ICC Acceptance Criteria 232 (AC232) are based on applicable provisions of U.S. Concrete Standard ACI 318 and AC232, and ESR-3520, as applicable. Moreover, all Hilti Anchor Channel have been tested following applicable AC232 testing protocols.

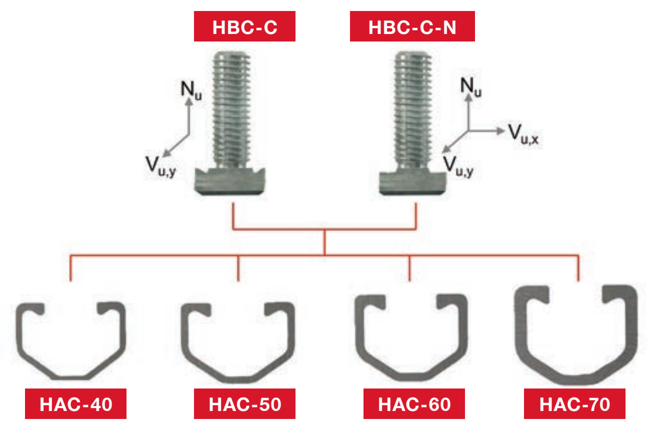
The Hilti Anchor Channel (HAC) portfolio consists of two different V-shape channel profile types; smooth and serrated lips. To feasibly cope with the typical and non-typical conditions encountered in a project, different channel profiles sizes (HAC-40, 50, 60, and 70), channel lengths, and a versatile configuration of anchors have been integrated into the standard HAC portfolio.

The standard HAC portfolio consists of predetermined anchor channel configurations which allow for shorter lead time. The standard portfolio consists of fixed channel lengths, number of anchors per channel, anchor type (rounded headed anchors, reinforcing bar anchors, and/or EDGE plate), anchor diameter, and anchor length.

HAC's standard portfolio covers most of the extreme project conditions. For a broader application coverage range, custom solutions are offered upon request.

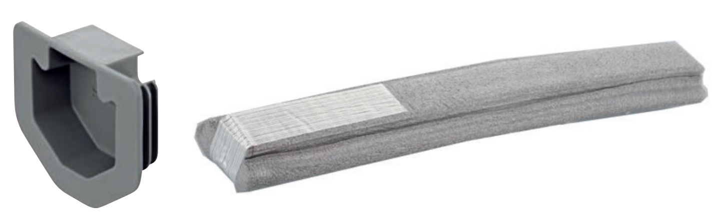
The Hilti Channel Bolts (HBC), commonly known as t-bolts are part of the HAC system. HBC have proprietary bolt head geometry compatible with HAC profiles. HBC are offered in different types, diameters, steel grades, finishing, and lengths. Although serrated t-bolts cannot be used with smooth lip channel profile or vise-versa, t-bolts for each profile type (smooth or serrated) can be used in all corresponding channel profile sizes.

The innovative manufacturing channel technology allows different channel profiles to have a relative constant channel width, permitting one t-bolt head size to be used in all different channel sizes, streamlining product portfolio and simplifying installation on the job site. This means more cost-effective t-bolts via economy of scale.




T-bolts for HAC (smooth lips) and HAC-T (serrated lips) are not interchangeable.

All Hilti channels come with end caps, filler foam, and a tear-out strip for a smooth and clean installation. The product comes with special identification marks to minimize the probability of confusion on the jobsite.



**Hilti Anchor Channels are a value engineered solution that in addition of preserving the high product performance, they have improved the function and features of the traditional anchor channel system, creating differentiated and innovative solutions that bring added value to the cast-in industry.**

## 1.2.2 HILTI ANCHOR CHANNEL PROFILES

Numerical simulations allowed Hilti to design a range of channel profiles with different anchor configurations, resulting in a synergized steel to concrete performance.

Hilti Anchor Channels with smooth lips (HAC) and serrated lips (HAC-T) are covered by ICC ESR-3520. The geometry of HAC versus its matching HAC-T profile (i.e. HAC-50 vs HAC-T50) is identical, with the main difference of the lip type. Generally, HAC and its equivalent HAC-T offer similar performance. The main advantage of HAC-T is that it offers higher slip resistance at a lower installation torque.

HAC profiles (40, 50, 60, and 70) and HAC-T profiles (50 and 70) are the backbones of the Hilti's anchor channel portfolio. Such profiles are utilized in all different anchor channel types. It is only the type of anchor and connection that changes or additional accessories are incorporated. For instance, HAC-50 with rounded head anchors has the same channel profile as HAC-50 with reinforcing bar anchors (HAC-50 CRFoS U).

**HAC**
**(smooth profile)**

HAC-40, HAC-50, HAC-60, & HAC-70

Seismic approved

Optimized design

Filler, tear-out band, and end caps

**HAC-T**
**(serrated profile)**

HAC-T50 and HAC-T70

Seismic approved

Lower installation torque for seismic applications

Optimized design

Filler, tear-out band, and end caps

Note:

HAC-30 has been added to the Hilti Anchor Channel portfolio. Although its channel profile does not have "-T", HAC-30 comes with serrated lips.

## 1.2.3 HILTI ANCHOR CHANNELS TYPES

### HAC and HAC-T

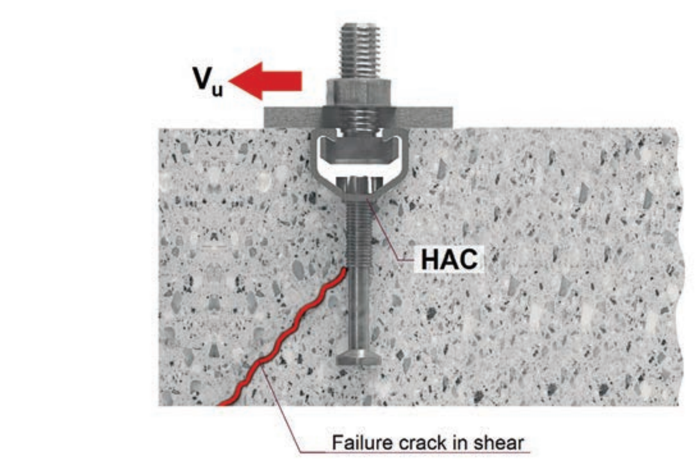
Hilti Anchor Channels with rounded head anchors are characterized by been the most cost-effective anchor channel type. Additionally, due to its lighter weight, they are generally easier to install than anchor channels with reinforcing bars. These are excellent anchor channel systems with optimized steel components. The HAC portfolio allows for a gradual increase in performance. Moreover, they can be installed as close as 2” away from an edge. This anchor channel type is covered by ICC ESR-3520.

HAC and HAC-T have optimized components (i.e. channel profile thickness) that allow the steel performance of the product (i.e. channel lip strength) to be similar to the concrete performance (i.e. concrete breakout strength in tension) when used in typical concrete compressive strength (4000 psi – 5000 psi).

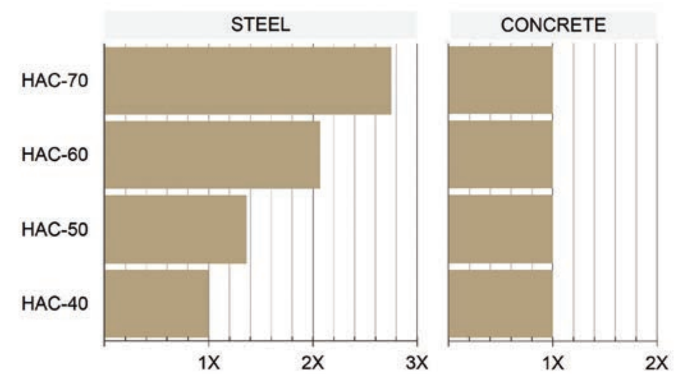
The design of this type of anchor channel is generally limited by the tensile strength and fracture energy of the concrete. Therefore, concrete breakout strength in shear (top of slab applications), concrete breakout strength in tension (face of slab applications), or a combination of both are generally the governing failure modes. Technically speaking, the substrate’s strength tends to be the limiting factor.

The substrate's strength may limit the use of these types of anchor channels in applications with high loads in low to medium concrete compressive strengths, lightweight concrete, thin substrate, close to an edge, and/or close to a corner.

**Shear**



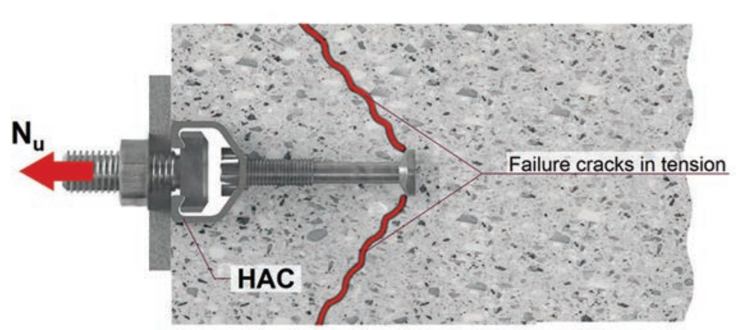

**Performance Index**

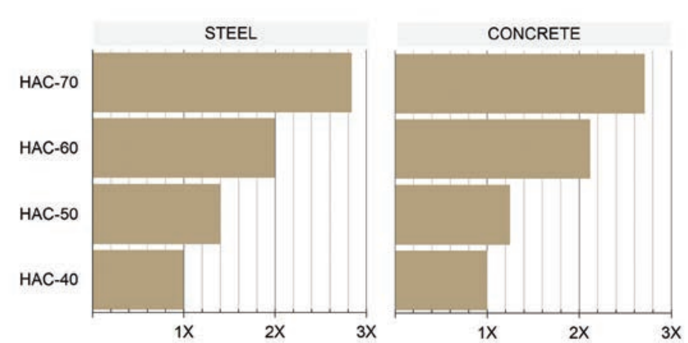



Comparison based on the lowest strength considering the anchor, anchor-channel connection, and channel lip.

Comparison based on a 10" thick slab, edge distance of 4", 4000 psi NWC, 11.8" long HAC with no influence of a corner.

**Tension**




Comparison based on the lowest strength considering the anchor, anchor-channel connection, and channel lip.

Comparison based on t-bolt spacing of 6", 11.8" long HAC, 4000 psi and no influence of a corner or edge.

**State-of-art design based on ICC ESR-3520.**

### HAC CRFoS U

HAC CRFoS U stands for Hilti Anchor Channel Corner Rebar Face of Slab Universal. In contrast to HAC, HAC CRFoS U has reinforcing bars instead of rounded head anchors. By replacing the rounded head anchors with reinforcing bars, the concrete breakout in tension is precluded. This allows the anchor channels to transfer higher tension forces to the concrete member or substrate. The reinforcing bar transfer the loads to the surrounding concrete via interlocking of the reinforcing bar.

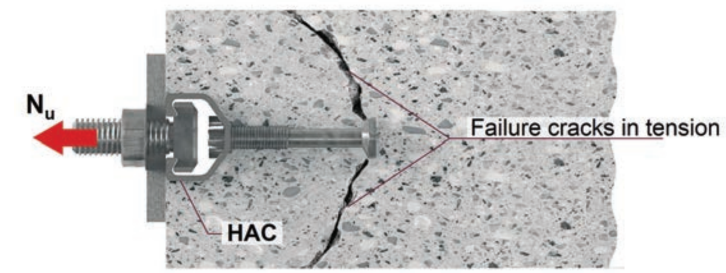
The use of HAC CRFoS U is ideal for applications where the applied tensile force exceeds the concrete breakout strength in tension. Although concrete pry-out is precluded when reinforcing bars are used instead of rounded head anchors, the concrete breakout strength in shear is not impacted by the reinforcing bar anchors.

The design model of HAC CRFoS U is based on AC232 principles. All failure modes are based on AC232 except the pull-out strength of the reinforcing bar, which is calculated in accordance with ACI 318. Steel strengths not covered in ESR-3520 are based on ACI 318 and applicable testing protocols of AC232.

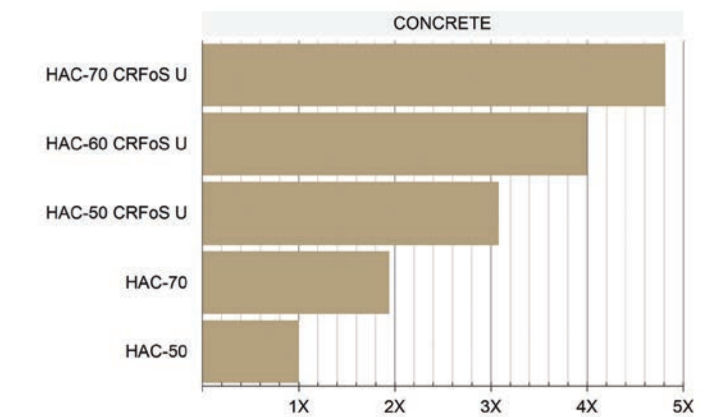
HAC CRFoS U comes with one diameter reinforcing bars offset/bend. This allows to position two CRFoS U in a corner. One channel is rotated 180° to avoid clashing of the reinforcing bar. Moreover, the offset of the reinforcing bar allows for extra rebar cover in composite slab applications where the reinforcing bars may extend into the metal deck zone **The use of HAC CRFoS U is not limited to corner applications.**

HAC CRFoS U is commonly utilized in applications with high tension loads, thin slabs, lightweight concrete, low concrete compressive strength, and corners.

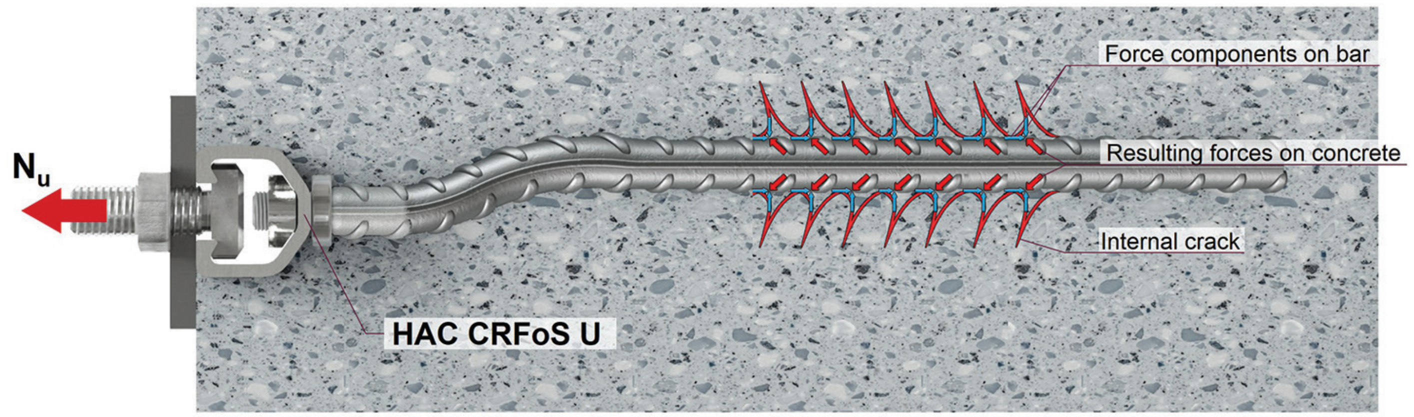
**Tension**




**Performance Index**




Comparison based on a 6" thick slab, edge distance of 3", 4000 psi NWC, 11.8"" in the face of slab with no influence of a corner.




**State-of-art design model based on ICC ESR-3520 and principles of AC232 and ACI 318. 19 out of 20 possible failure modes are calculated in accordance with AC232.**

## HAC EDGE Lite, HAC EDGE, HAC-T EDGE Lite, and HAC-T EDGE

Hilti Anchor Channel with the new rebar edge confinement plate (HAC EDGE) is a solution that offers superior concrete edge breakout performance in shear. HAC EDGE changes the traditional concept of anchor channels with welded reinforcing bars. Instead of relying on structural welds to transfer shear forces from the channel profile to the reinforcing bars, HAC EDGE takes advantage of the compressive strength of the concrete as a way to transfer the forces to the reinforcement attached to the edge plate. The rebar edge confinement plate (EDGE Plate) is not structurally connected to the anchor channel. HAC EDGE optimizes the shear load transfer from the channel profile to the reinforcing bars and overcomes the challenges with traditional anchor channels with welded reinforcing bars.

HAC EDGE is a new anchoring system that brings value innovation. It copes with today's fast track construction demands and requirements of the curtain wall industry such as installation tolerance, high wind loads, thin concrete members, pockets, close edge distances, and lightweight concrete. In such adverse conditions, HAC EDGE provides more than 2 times the capacity of traditional top of slab anchor channels where the reinforcing bars are welded to the back of the channel and outperforms standard anchor channels without reinforcing bars by up to a factor of 5.6.

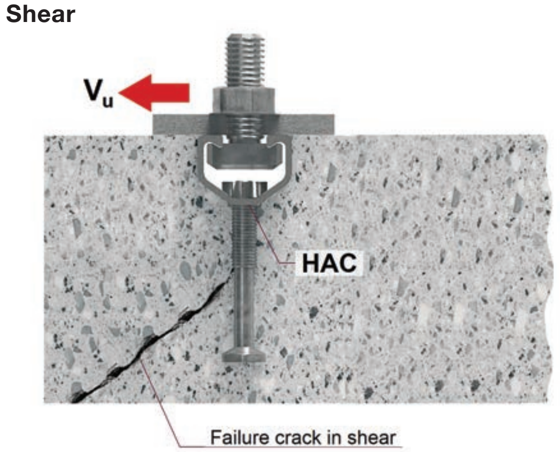
HAC EDGE comes in HAC-50 and HAC-T50. The anchor channel itself is identical to its matching HAC. In order to cope with the market trends such as thin slabs and pockets, anchor channels with reduced anchor depth are offered as standard.

HAC EDGE Lite is the latest addition to the HAC portfolio. It offers a gradual increase in performance and cost between the HAC and HAC EDGE. HAC EDGE Lite is offered in HAC-40, HAC-50, and HAC-T50.

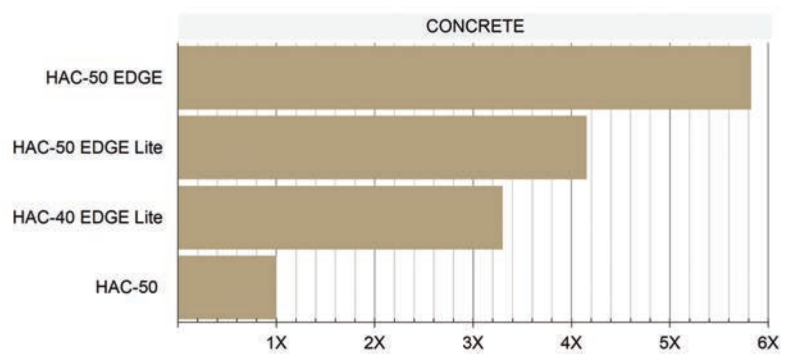
The design model of HAC EDGE is based on ESR-3520, ACI 318, and principles of AC232 and ACI 318. The anchor channel itself is covered by ICC ESR-3520. The verification of the concrete edge due to perpendicular shear loads is based on a Hilti method; see section 9.6.1 for additional design information.

The use of HAC EDGE and HAC EDGE Lite is ideal for applications with high shear loads, thin slabs, small edge distances, lightweight concrete, low concrete compressive strength, and corners.

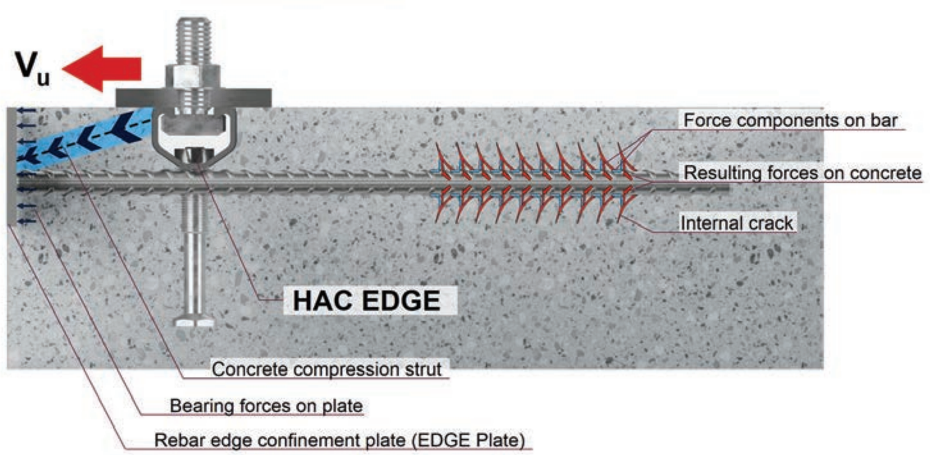
**Shear**




**Performance Index**




Comparison based on a 4" thick slab, edge distance of 4", 4000 psi NWC, 11.8" long HAC with no influence of a corner.




**State-of-art design model based on ICC ESR-3520 and principles of AC232 and ACI 318. 19 out of 20 possible failure modes are calculated in accordance with ESR-3520.**

## HAC S EDGE and HAC-T S EDGE

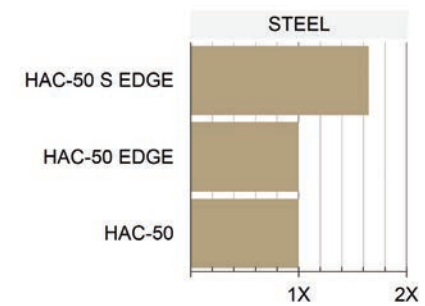
Today's market presents new challenges to contractors and designers. With a better understanding of wind loads, larger panel sizes, unique building geometries, and taller buildings, finding solutions for the very critical conditions creates added challenges. Customized anchor channel and brackets are typically needed to cope with such extreme applications. Oftentimes, longer brackets, numerous t-bolts, or the use of other anchoring technologies is required. Hilti has added HAC S EDGE to the HAC portfolio to standardize this type of applications. Thus allowing installers to keep things on site as simple as possible. The letter "S" denotes superior steel performance.

HAC EDGE overcomes the limitations of the concrete edge breakout capacity in shear. However, for some applications, the steel failure modes of the anchor channel can be the decisive factor. Generally, this is not a problem with HAC since in top of slab applications, the concrete edge tends to govern the design. When HAC EDGE is used, steel can be the limiting factor. Thus the need for higher anchor channel steel strengths.

HAC S EDGE is similar to HAC EDGE, except a strengthening element is added to the front part of the channel. It increases the moment of inertia of the system, the lip strength, and anchor connection in shear of the anchor channel.

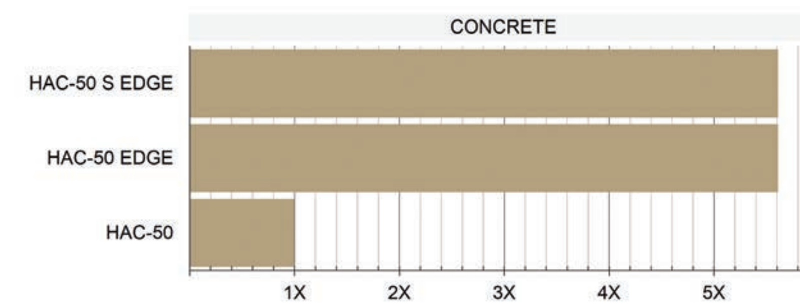
HAC S EDGE is ideal for applications with high shear loads, thin slabs, small edge distances, lightweight concrete, low concrete compressive strength, and corners. In addition, HAC S EDGE present a solution for applications with extremely high torsional moments such as corners.

**Shear**

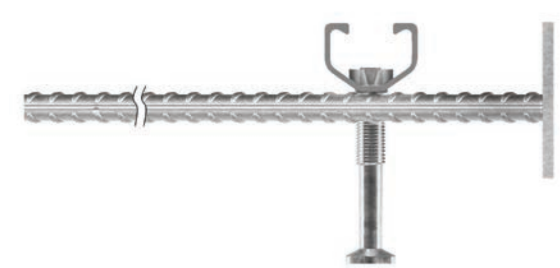



Comparison based on the lowest strength considering the anchor, anchor-channel connection, and channel lip.

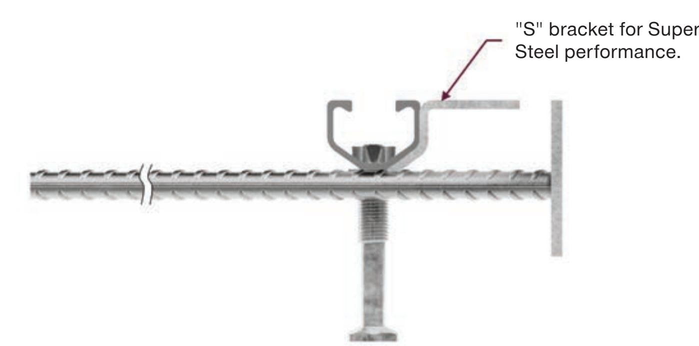
**Performance Index**




Comparison based on a 4" thick slab, edge distance of 4", 4000 psi NWC, 11.8" long HAC with no influence of a corner.



HAC EDGE




HAC S EDGE

### 1.2.4 HILTI CHANNEL BOLTS: HBC-C AND HBC-T

Hilti Channel Bolts (HBC and HBC-T) are part of the cast-in anchor channel system. HBC come in a variety of diameters, grades, and corrosion protection. The T-bolt head shape works with all four different channel HAC sizes (HAC-40, HAC-50, HAC-60, and HAC-70) simplifying logistical management on the jobsite. Moreover, because the size of the head of the bolt does not get bigger as the anchor channel profile gets bigger, optimizing the amount of steel used per bolt, brining economy of scale.

#### HBC-C

Loads in 2D only (tension and perpendicular shear)


HBC-C
(HDG)


HBC-C 50 R
(Stainless Steel)

#### HBC-C-N

For tension, perpendicular and longitudinal shear loads


HBC-C-N
(HDG)

#### HBC-T

For tension, perpendicular and longitudinal shear loads


HBC-T
(HDG)

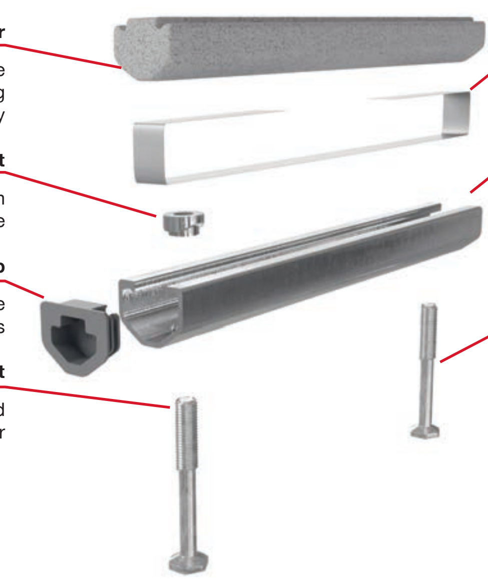
#### HBC-B

For tension, perpendicular and longitudinal shear loads




# 1.3 HAC COMPONENTS

## Hilti Cast-in Anchor Channel: HAC and HAC-T



**Foam Filler**

Environmentally freindly, low density polyethylene foam filling. It prevents fresh concrete from entering the channel cavity

**Rivet**

Carbon steel and hot dip galvanized ≥ 45 μm steel grade

**End cap**

End caps help keep concrete slurry out of the channels

**Loctite-type Agent**

Applied at the threads of the anchor to avoid movement and unscrewing of the anchor

**Textile Tape**

Eases the removal of the foam by allowing the entire foam length to be removed from the channel

**Channel Profile**

Temperature controlled form rolling
Hot-dip galvanized ≥ 55 μm (HAC-30 to HAC-(T)50)
Hot-dip galvanized ≥ 70 μm (HAC-60 to HAC-(T)70)

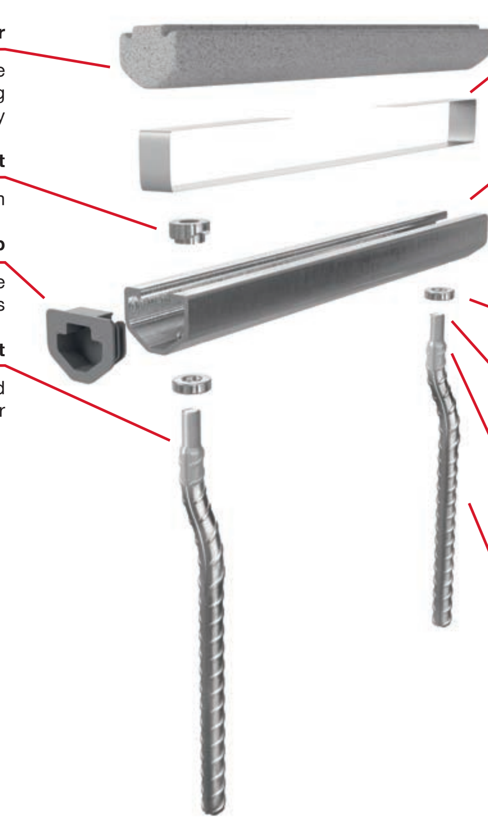
Smooth profile  Serrated profile  Steel grade

**Anchor**

Carbon steel rounded headed anchor, hot-dip galvanized ≥ 45 μm

Steel grade

## Hilti Cast-in Anchor Channel: HAC CRFoS U



**Foam Filler**

Environmentally freindly, low density polyethylene foam filling. It prevents fresh concrete from entering the channel cavity

**Rivet**

Carbon steel and hot dip galvanized ≥ 45 μm

**End cap**

End caps help keep concrete slurry out of the channels

**Loctite-type Agent**

Applied at the threads of the reinforcing bar to avoid movement and unscrewing of the reinforcing bar

**Textile Tape**

Eases the removal of the foam by allowing the entire foam length to be removed from the channel

**Channel Profile**

Temperature controlled form rolling
Hot-dip galvanized ≥ 55 μm (HAC-50)
Hot-dip galvanized ≥ 70 μm (HAC-60 to HAC-70)

Smooth profile  Serated profile

**Jam Nut**

Non-structural stainless steel nut

**Threaded End Reinforcing Bar**

Allows reinforcing bar to be mechanically connected to channel profile

**Zinc Rich Paint**

Zinc rich paint is applies at the thread of the reinforcing bar and adjacent surface, for up to 2" to provide corrosion protection of connection

**Reinforcing Bar**

Reinforcement steel according to DIN 488-1. Bst 500 B
fy = 72.50 ksi

## Hilti Cast-in Anchor Channel: HAC EDGE Lite, HAC EDGE, HAC-T EDGE Lite, and HAC-T EDGE

**Foam Filler**
Environmentally freindly, low density polyethylene foam filling. It prevents fresh concrete from entering the channel cavity

**Rivet**
Carbon steel and hot dip galvanized ≥ 45 µm

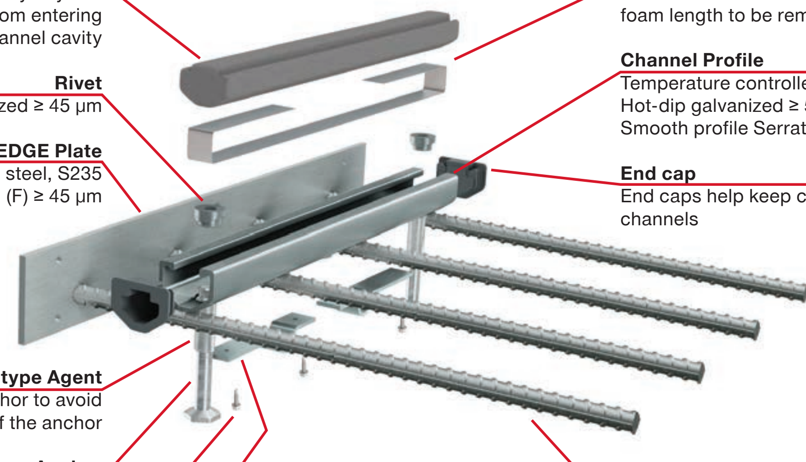
**EDGE Plate**
Carbon steel, S235
Hot dip galvanized (F) ≥ 45 µm

**Loctite-type Agent**
Applied at the threads of the anchor to avoid movement and unscrewing of the anchor

**Anchor**
Carbon steel rounded headed anchor, hot-dip galvanized ≥ 45 µm

**Self drilling screw**
Carbon steel, steel grade 1018 to 1022 according ASTM A510

**Fixture**
Carbon steel, metal sheet DX510+Z



**Textile Tape**
Eases the removal of the foam by allowing the entire foam length to be removed from the channel

**Channel Profile**
Temperature controlled form rolling
Hot-dip galvanized ≥ 55 µm (HAC-40 and HAC-(T)50)
Smooth profile Serrated profile

**End cap**
End caps help keep concrete slurry out of the channels

**Reinforcing Bar**
BSt500 B
galvanized ≥ 45 µm

## Hilti Cast-in Anchor Channel: HAC S EDGE and HAC-T S EDGE

**Foam Filler**
Environmentally freindly, low density polyethylene foam filling. It prevents fresh concrete from entering the channel cavity

**Rivet**
Carbon steel and hot dip galvanized ≥ 45 µm

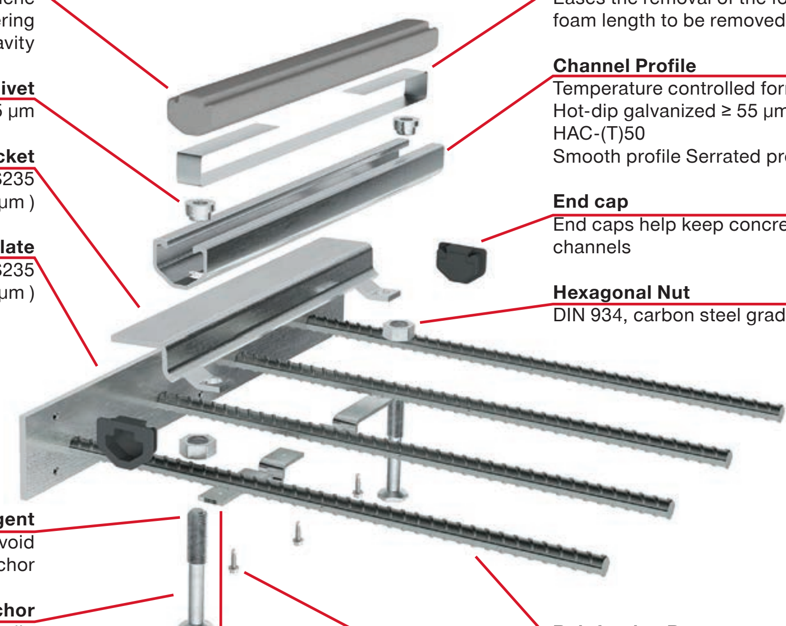
**S Bracket**
Carbon steel, S235
Hot dip galvanized (F) ≥ 45 µm )

**EDGE Plate**
S235
Hot dip galvanized (F) ≥ 45 µm )

**Loctite-type Agent**
Applied at the threads of the anchor to avoid movement and unscrewing of the anchor

**Anchor**
Carbon steel rounded headed anchor, hot-dip galvanized ≥ 45 µm

**Fixture**
Carbon steel, metal sheet DX510+Z



**Textile Tape**
Eases the removal of the foam by allowing the entire foam length to be removed from the channel

**Channel Profile**
Temperature controlled form rolling
Hot-dip galvanized ≥ 55 µm
HAC-(T)50
Smooth profile Serrated profile

**End cap**
End caps help keep concrete slurry out of the channels

**Hexagonal Nut**
DIN 934, carbon steel grade 4.6

**Reinforcing Bar**
BSt500 B
galvanized ≥ 45 µm

**Self drilling screw**
Carbon steel, steel grade 1018 to 1022 according ASTM A510



## Unique markings for reliable identification

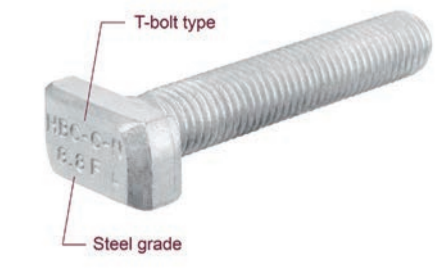
**Markings on Hilti Anchor Channels and HBC Channel Bolts**

Hilti Anchor Channels have distinct markings on the outside and inside surface that allow correct identification before and after casting in concrete. The marking consist of the Hilti logo, the channel type designation, and the type of corrosion protection. The channels bear a unique production number that indicates the production lot as well as the channel type, to aid identification.

Hilti T-bolts bear marks on the head indicating the bolt type, strength class, corrosion class, and also include a manufacturing mark. The outside face of the bolt includes a unique mark for proper bolt identification after installation.

Markings on HAC anchor channels

Markings inside HAC anchor channels



Markings on Hilti HBC bolts

## Traceability

A unique feature offered by our anchor channels is traceability. The lot number and our q-systems allow to trace the product back to the raw material and provide a 3.2 certificate of the raw material of each component if required.

## Labeled anchor channels is our new standard

To simplify the anchor channel identification process and avoid confusion, all Hilti Anchor Channels come labeled.

A fast and accurate channel identification saves times and can help the installer to ensure the anchor channel been installed matches the specified one. Pictures on the right illustrate a Hilti Anchor Channel with a label on the back of the channel profile.

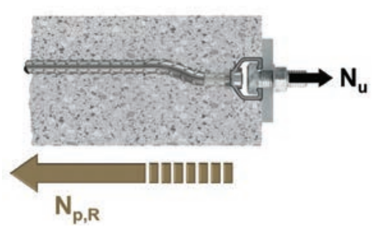
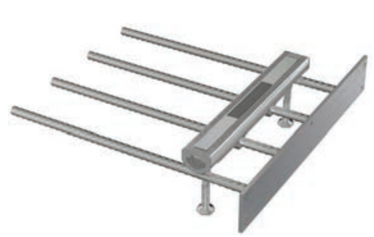
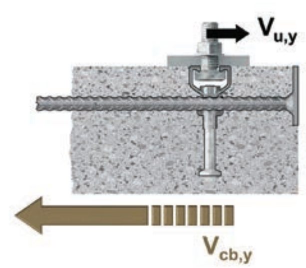
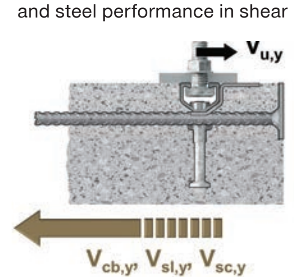
The label provides product name, item number, lot number, country of fabrication, bar code, and approval (if applicable).

Custom labels can be provided upon request.

# 1.4 HAC SELECTION

## 1.4.1 HILTI ANCHOR CHANNEL SELECTION VIA PROJECT NEEDS

Hilti's Anchor Channel portfolio present solutions for today's construction challenges. The Hilti Anchor Channel (HAC) system portfolio includes anchor channels with rounded head anchors (HAC and HAC-T), rebar anchors (HAC CRFoS U), and a combination of rounded head anchors and rebars (HAC-EDGE Lite, HAC-T EDGE Lite, HAC-EDGE, HAC-T EDGE, HAC S EDGE, and HAC-T S EDGE).

| Product | Main Features | Channel Type and Size |
|---|---|---|
| **HAC** | | |
| Hilti Anchor Channel<br> | Product covered by ICC ESR-3520.<br>Most feasible anchor channel solution.<br>Ease of installation | **Smooth lips**<br>HAC-40<br>HAC-50<br>HAC-60<br>HAC-70<br>**Serrated lips**<br>HAC-30<br>HAC-T50<br>HAC-T70 |
| **HAC CRFoS U** | | |
| Hilti Anchor Channel Corner Rebar Face of Slab Universal<br> | Anchor Channel for superior concrete performance in tension<br><br> | **Smooth lips**<br>HAC-50 CRFoS U<br>HAC-60 CRFoS U<br>HAC-70 CRFoS U |
| **HAC EDGE Lite and HAC EDGE** | | |
| Hilti Anchor Channel with concrete edge shear confinement plate<br> | Anchor Channel for superior concrete performance in shear<br><br> | **Smooth lips**<br>HAC-40 EDGELite<br>HAC-50 EDGE Lite<br>HAC-50 EDGE<br>**Serrated lips**<br>HAC-T50 EDGE Lite<br>HAC-T50 EDGE |
| **HAC S EDGE** | | |
| Hilti Anchor Channel with concrete edge shear confinement plate and superior steel performance<br> | Anchor Channel for superior concrete and steel performance in shear<br><br> | **Smooth lips**<br>HAC-50 S EDGE<br>**Serrated lips**<br>HAC-T50 S EDGE |

## 1.4.2 HILTI ANCHOR CHANNEL SELECTION VIA GEOMETRICAL CONSTRAINTS

**HAC**

| Channel | Units | $h_{ef}$ | $h_{min}$ | NWC & SLWC | | ALWC | |
|---|---|---|---|---|---|---|---|
| | | | | $c_{a1,min}$ | $c_{a2,min}$ | $c_{a1,min}$ | $c_{a2,min}$ |
| HAC-30 | in<br>(mm) | 2.68<br>(68) | 3.15<br>(80) | | | | |
| HAC-40 | in<br>(mm) | 3.58<br>(91) | 4.13<br>(105) | 1.97<br>(50) | | | |
| HAC-50<br>HAC-T50 | in<br>(mm) | 3.70<br>(94) | 3.94<br>(100) | | | 2.95<br>(75) | |
| | in<br>(mm) | 4.17<br>(106) | 4.92<br>(125) | | | | |
| HAC-60 | in<br>(mm) | 5.83<br>(148) | 6.61<br>(168) | 2.95<br>(75) | | | |
| HAC-70<br>HAC-T70 | in<br>(mm) | 6.89<br>(175) | 7.72<br>(196) | | | | |

**HAC CRFoS U**

| Channel | Units | $h_{nom}$ | $h_{min}$ | NWC & SLWC | | ALWC | |
|---|---|---|---|---|---|---|---|
| | | | | $c_{a1,min}$ | $c_{a2,min}$ | $c_{a1,min}$ | $c_{a2,min}$ |
| HAC-50 CRFoS U | in<br>(mm) | 14.02<br>(356) | 17.00<br>(431) | 1.97<br>(50) | | | |
| HAC-60 CRFoS U | in<br>(mm) | 15.59<br>(396) | 18.55<br>(471) | 2.95<br>(75) | | 2.95<br>(75) | |
| HAC-70 CRFoS U | in<br>(mm) | 16.54<br>(420) | 19.50<br>(495) | | | | |

**HAC EDGE LITE and HAC EDGE**

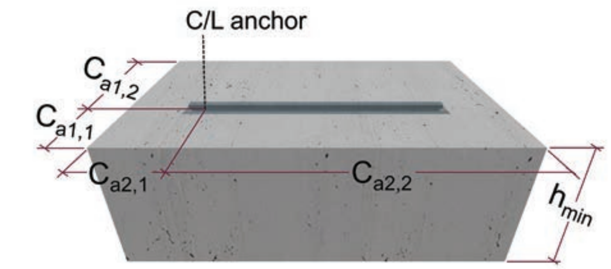
| Channel | Units | $h_{ef}$ | $h_{min}$ | NWC | | SLWC & ALWC | |
|---|---|---|---|---|---|---|---|
| | | | | $c_{a1,min}$ | $c_{a2,min}$ | $c_{a1,min}$ | $c_{a2,min}$ |
| HAC-40 EDGE Lite | in<br>(mm) | 3.58<br>(91) | 3.94<br>(100) | | | | |
| HAC-50 EDGE Lite<br>HAC-T50 EDGE Lite | in<br>(mm) | 3.70<br>(94) | 3.94<br>(100) | | | | |
| | in<br>(mm) | 4.17<br>(106) | 4.92<br>(125) | 1.97<br>(50) | | 3 .94<br>(100) | |
| HAC-50 EDGE<br>HAC-T50 EDGE | in<br>(mm) | 3.70<br>(94) | 3.94<br>(100) | | | | |
| | in<br>(mm) | 4.17<br>(106) | 4.92<br>(125) | | | | |

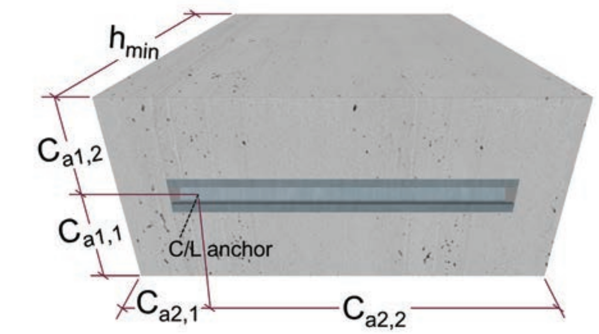
HAC EDGE can be used in 3.125" thick slabs. Please contact Hilti at US+CA.HAC@Hilti.com for information.

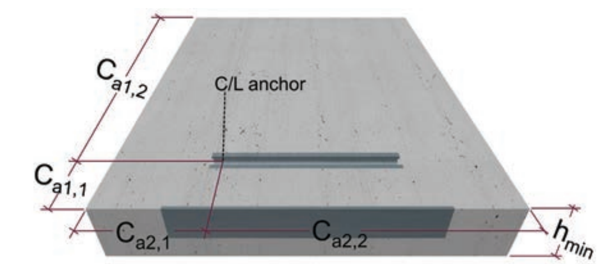
**HAC S EDGE**

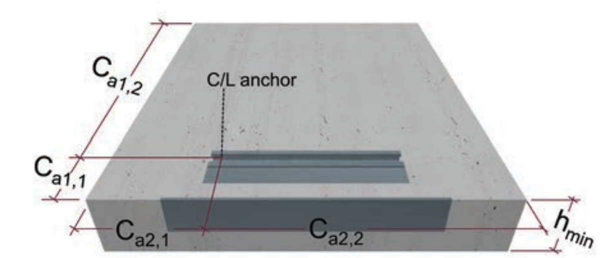
| Channel | Units | $h_{ef}$ | $h_{min}$ | NWC, SLWC, & ALWC | |
|---|---|---|---|---|---|
| | | | | $c_{a1,min}$ | $c_{a2,min}$ |
| HAC-50 S EDGE<br>HAC-T50 S EDGE | in<br>(mm) | 3.70<br>(94) | 3.94<br>(100) | 3.94<br>(100) | |
| | in<br>(mm) | 4.17<br>(106) | 4.92<br>(125) | | |

**NWC:** Normal weight concrete. SLWC: Sand-lightweightc concrete. ALWC: All-lightweight concrete.
$C_{a1,1}$, $C_{a1,2}$, $C_{a2,1}$ and $C_{a2,2}$ are measured from an edge to the center of the anchor.



| | Base material | | | | | | | | | | | Load Features | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Uncracked concrete | Cracked concrete | Lightweight concrete | Concrete over metal deck | Post-tension slabs | Precast concrete panels | Hollow-core concrete | Grout-filled concrete block | Hollow concrete block | Hollow clay brick | Unreinforced Multi-wythe brick | Seismic | Fatigue[1] |
| HAC-30 | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-40 | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-(T)50 | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-60 | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-(T)70 | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-50 CRFoS U | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-60 CRFoS U | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-70 CRFoS U | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-40 EDGE Lite | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-(T)50 EDGE Lite | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-(T)50 EDGE | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-(T)50 EDGE C | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-(T)50 S EDGE C | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HAC-(T)50 S EDGE | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HBC-C | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | | ■ |
| HBC-C-N | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |
| HBC-T HBC-B | ■ | ■ | ■ | ■ | ■ | ■ | ■[2] | | | | | ■ | ■ |

1 Technical data based on CEN/TS.
2 Anchor channel system may be suitable, contingent to minimum edge distance requirements within solid concrete.
HAC-(T) indicates product is available in smooth and serrated channel profile.



| | Approvals | | | | | Codes | Corrosion resistance[1] | | | Anchor Channel Features | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ICC-ES | COLA | UL | Florida Building Code High Velocity Hurricane Zone | FM | California Building Code | Electro / mechanically zinc plated | Hot dip galvanized | Stainless steel | End Caps | End Caps with nail holes | Nail holes | Tear out band with filler foam |
| HAC-30 | ■ | ■ | | | | ■ | | ■ | | ■ | | ■ | ■ |
| HAC-40 | ■ | ■ | | | | ■ | | ■ | | ■ | | ■ | ■ |
| HAC-(T)50 | ■ | ■ | | | | ■ | | ■ | | ■ | ■ | ■ | ■ |
| HAC-60 | ■ | ■ | | | | ■ | | ■ | | ■ | | ■ | ■ |
| HAC-(T)70 | ■ | ■ | | | | ■ | | ■ | | ■ | ■ | ■ | ■ |
| HAC-(50 CRFoS U | | | | | | | | ■[1] | | ■ | ■ | ■ | ■ |
| HAC-60 CRFoS U | | | | | | | | ■[1] | | ■ | | ■ | ■ |
| HAC-70 CRFoS U | | | | | | | | ■[1] | | ■ | ■ | ■ | ■ |
| HAC-40 EDGE Lite | | | | | | | | ■[2] | | ■ | ■ | ■ | ■ |
| HAC-(T)50 EDGE Lite | | | | | | | | ■[2] | | ■ | ■ | ■ | ■ |
| HAC-(T)50 EDGE | | | | | | | | ■[2] | | ■ | ■ | ■ | ■ |
| HAC-(T)50 EDGE C | | | | | | | | ■[2] | | ■ | ■ | ■ | ■ |
| HAC-(T)50 S EDGE C | | | | | | | | ■[2] | | ■ | ■ | ■ | ■ |
| HAC-(T)50 S EDGE | | | | | | | | ■[2] | | ■ | ■ | ■ | ■ |
| HBC-C | ■ | ■ | | | | ■ | | ■ | ■ | N/A | N/A | N/A | N/A |
| HBC-C-N | ■ | ■ | | | | ■ | | ■ | | N/A | N/A | N/A | N/A |
| HBC-T HBC-B | ■ | ■ | | | | ■ | | ■ | | N/A | N/A | N/A | N/A |

1 Refer to updated section, 5.3 for a more detailed discussion on corrosion and corrosion resistance.
Anchor channel is hot dip galvanized only; zinc rich paint is applied at the thread of the rebar and adjacent surface for up to 2" to provide corrosion protection.
2 Anchor channel and Rebar Edge Confinement Plate (EDGE plate) are hot dip galvanized.
HAC-(T) indicates product is available in smooth and serrated channel profile.

# 2. HAC PORTFOLIO

This chapter provides product, geometrical, structural, and general information about the Hilti Anchor Channel Systems. It is intended to provide all relevant information about the product. It provides explanation about the nomenclature of the product, geometrical properties, minimum substrate requirements, and steel strengths. Moreover, this chapter provides item numbers and lead times for standard, non-standard, and information about custom solutions.

# 2.1 HILTI ANCHOR CHANNEL NOMENCLATURE

## Nomenclature of HAC and HAC-T

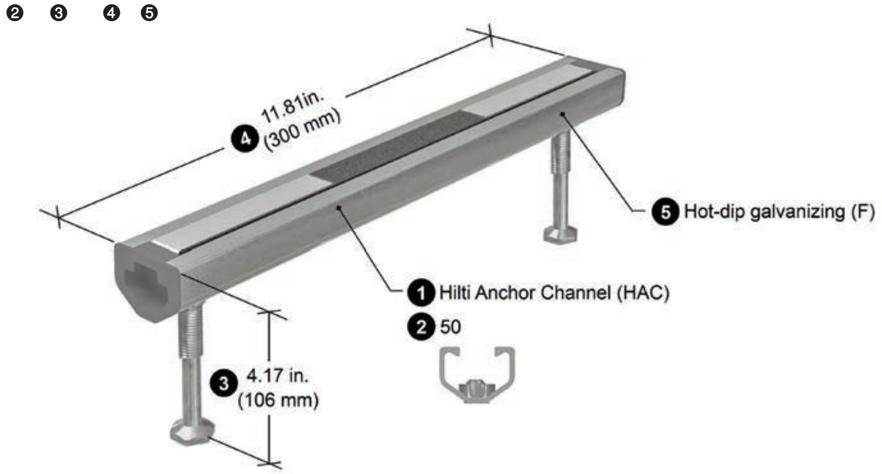
**HAC-Profile $h_{ef}$ /Length Finish**

❶ ❷ ❸ ❹ ❺

| ❶ HAC | ❷ Profile | ❸ $h_{ef}$ | ❹ Length | ❺ Finish |
|---|---|---|---|---|
| Hilti Anchor Channel | Profile type and size | Effective embedment depth in mm | Anchor channel length in mm | Finish or material |
| (E1) HAC | 50 | 106 [4.17 in.] | 300 [11.81 in.] | F (HDG) |
| (E2) HAC | T50 | 106 [4.17 in.] | 350 [13.78 in.] | F (HDG) |

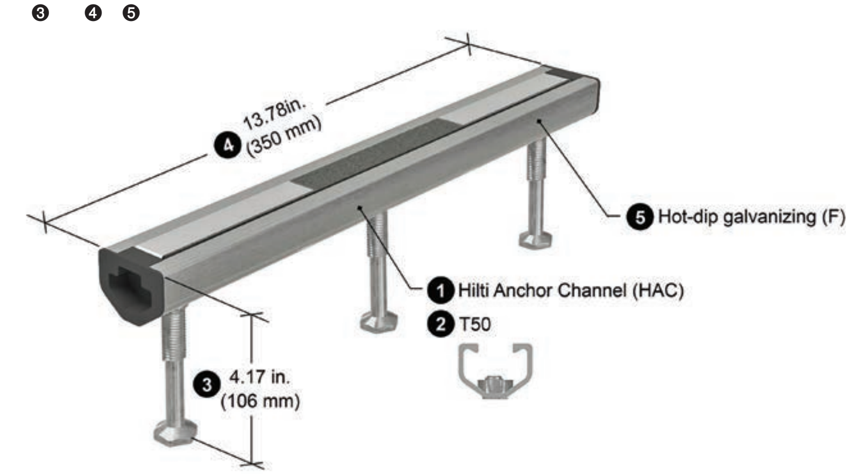
**Example 1 (E1): HAC- 50 106/300 F**

❶ ❷ ❸ ❹ ❺




**Example 2 (E2): HAC- T50 106/350 F**

❶ ❷ ❸ ❹ ❺



## Nomenclature of HAC CRFoS U

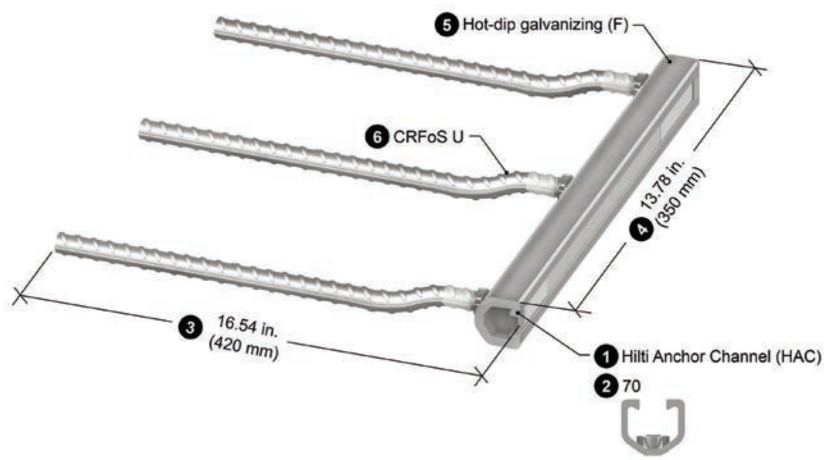
**HAC-profile $h_{nom}$/length Finish CRFoS U**

❶ ❷ ❸ ❹ ❺ ❻

| ❶ HAC | ❷ Profile | ❸ $h_{nom}$ | ❹ Length | ❺ Finish | ❻ CRFoS U |
|---|---|---|---|---|---|
| Hilti Anchor Channel | Profile type and size | Nominal channel height in mm | Anchor channel length in mm | Finish or material | Corner Rebar Face of Slab |
| (E1) HAC | 70 | 420 [16.54 in.] | 350 [13.78 in.] | F (HDG) | CRFoS U |
| (E2) HAC | 70 | 420 [16.54 in.] | 300 [11.81 in.] | F (HDG) | CRFoS U |

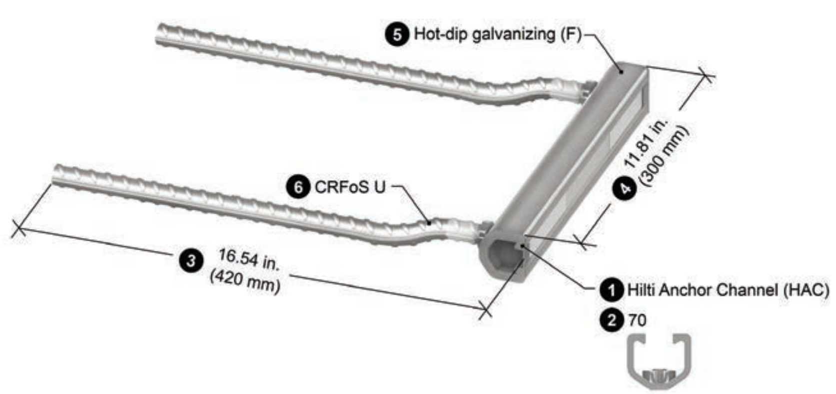
**Example 1 (E1): HAC- 70 420/350 F CRFoS U**

❶ ❷ ❸ ❹ ❺ ❻




**Example 2 (E2): HAC- 70 420/300 F CRFoS U**

❶ ❷ ❸ ❹ ❺ ❻






## Nomenclature of HAC CRFoS U at Corners

**HAC-profile $h_{nom}$/length Finish CRFoS U**

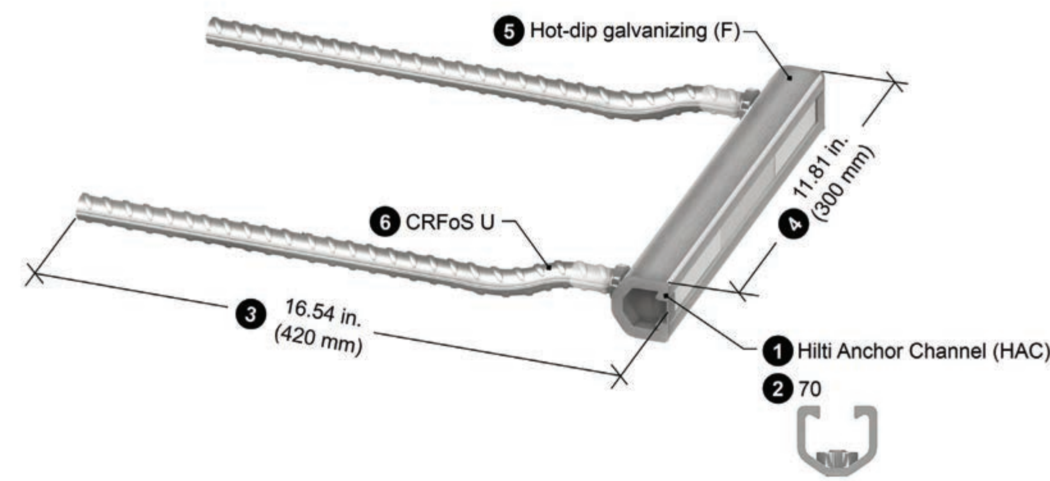
❶ ❷ ❸ ❹ ❺ ❻

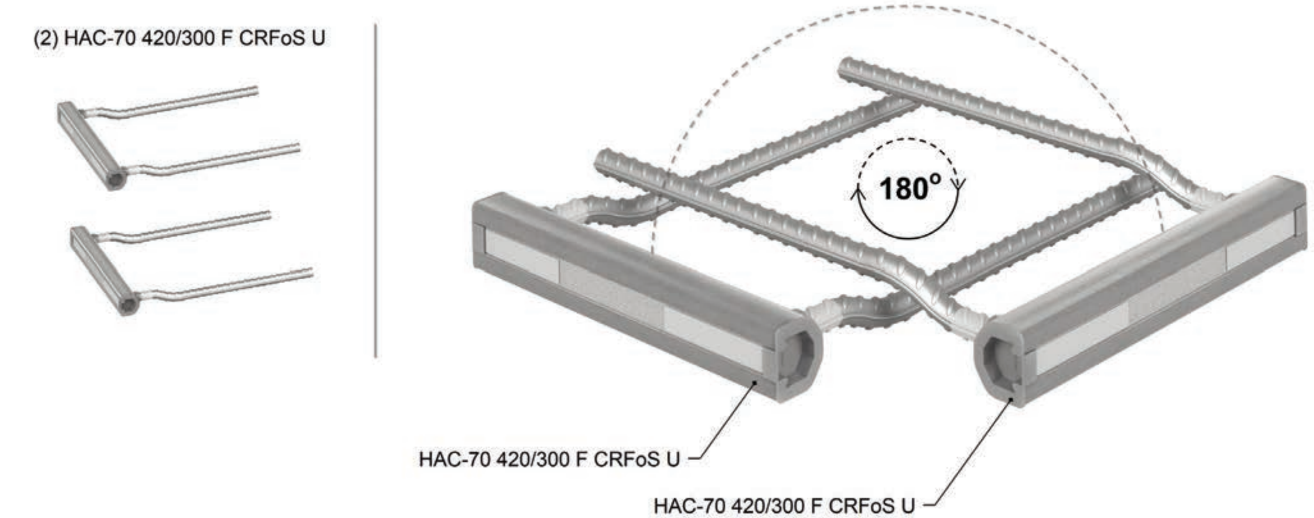
| ❶ HAC | ❷ Profile | ❸ $h_{nom}$ | ❹ Length | ❺ Finish | ❻ CRFoS U |
|---|---|---|---|---|---|
| Hilti Anchor Channel | Profile type and size | Nominal channel height in mm | Anchor channel length in mm | Finish or material | Corner Rebar Face of Slab |
| (E1) HAC | 70 | 420 [16.54 in.] | 300 [11.81 in.] | F (HDG) | CRFoS U |

**Example 1 (E1): HAC- 70 420/300 F CRFoS U**

**(E1): HAC- 70 420/300 F CRFoS U**

❶ ❷ ❸ ❹ ❺ ❻




**Note:** HAC CRFoS U can be used in intermediate and corner conditions. A corner condition requires the use of (2) HAC CRFoS U. For ordering purposes, two (2) units need to be ordered. See section 2.4 for item numbers.

## Nomenclature of HAC EDGE Lite, HAC EDGE, HAC-T EDGE Lite, and HAC-T EDGE

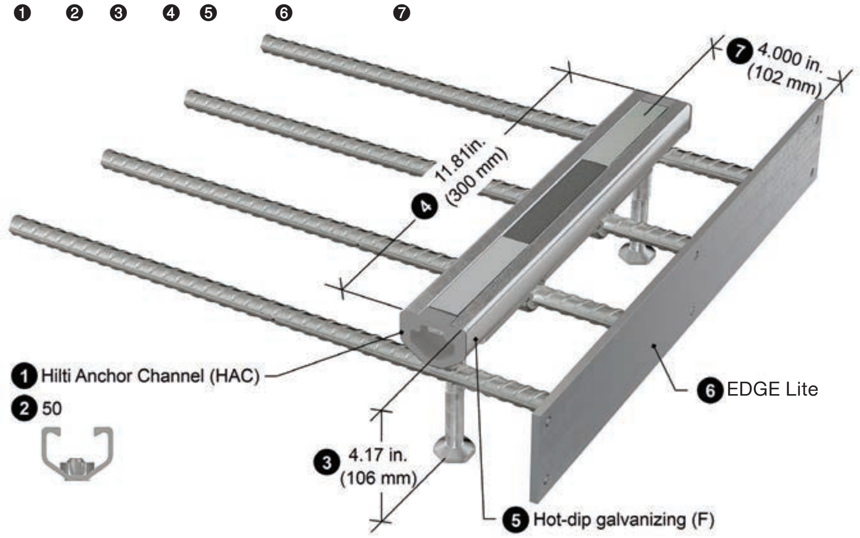
**HAC-profile $h_{ef}$ /length Finish EDGE Edge distance, $c_{a1}$**

❶ ❷ ❸ ❹ ❺ ❻ ❼

| ❶ HAC | ❷ Profile | ❸ $h_{ef}$ | ❹ Length | ❺ Finish | ❻ EDGE EDGE Lite | ❼ Edge Distance , $c_{a1}$ |
|---|---|---|---|---|---|---|
| Hilti Anchor Channel | Profile type and size | Effective embedment depth in mm | Anchor channel length in mm | Finish or material | Rebar edge confinement plate (EDGE Lite or EDGE plate) | Specified edge distance from edge of slab to C/L of HAC in inches |
| (E1) HAC | 50 | 106 [4.17 in.] | 300 [11.81 in.] | F (HDG) | EDGE Lite | 4.000 in. (102 mm) |
| (E2) HAC | T50 | 94 [3.70 in.] | 300 [11.81 in.] | F (HDG) | EDGE | 3.000 in. (76 mm) |

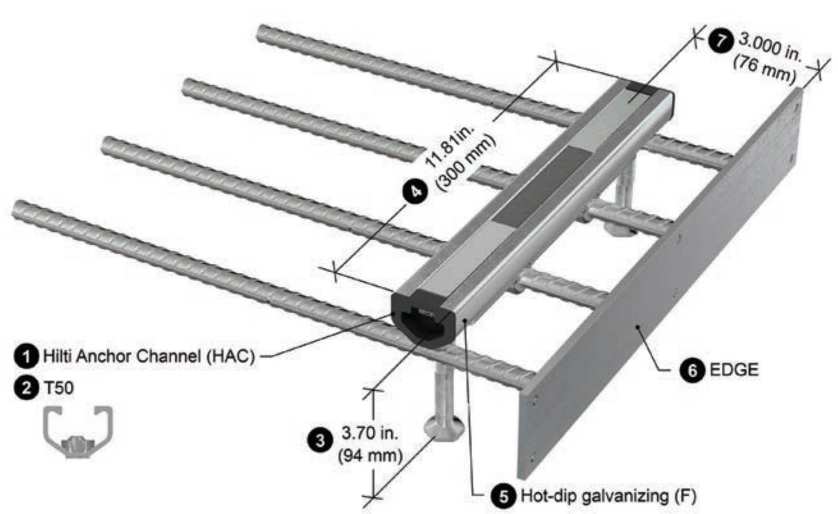
**Example 1 (E1): HAC- 50 106/300 F EDGE Lite 4.000 in.**

❶ ❷ ❸ ❹ ❺ ❻ ❼




**Example 2 (E2): HAC- T50 94/ 300 F EDGE 3.000 in.**

❶ ❷ ❸ ❹ ❺ ❻ ❼




## Nomenclature of HAC EDGE C, HAC-T EDGE C at Corners

**HAC-profile $h_{ef}$ /length Finish EDGE C Edge distance, $c_{a1}$**

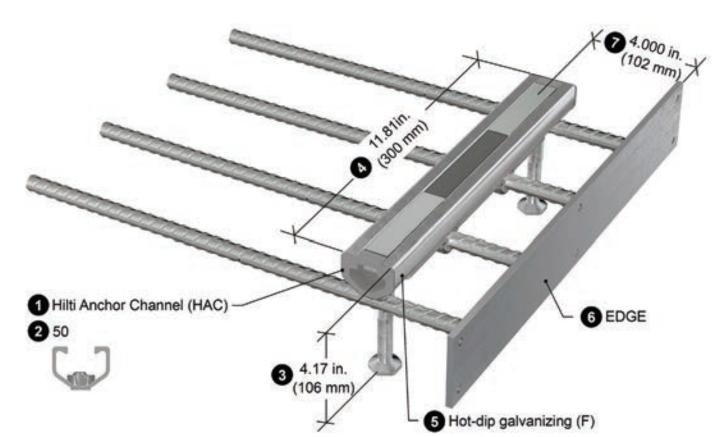
❶ ❷ ❸ ❹ ❺ ❻ ❼

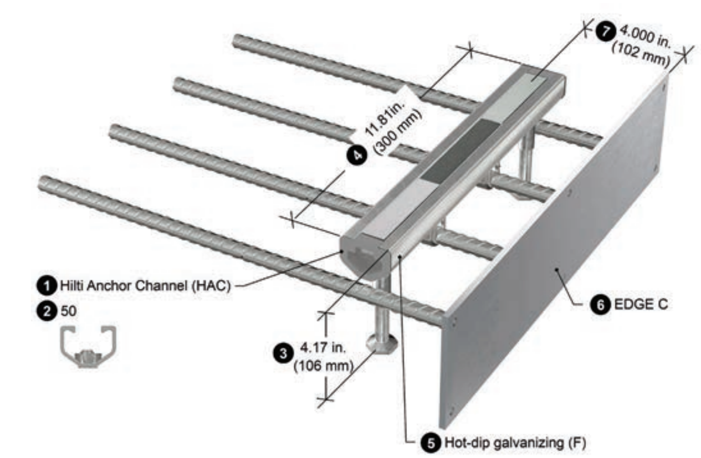
| ❶ HAC | ❷ Profile | ❸ $h_{ef}$ | ❹ Length | ❺ Finish | ❻ EDGE C | ❼ Edge Distance, $c_{a1}$ |
|---|---|---|---|---|---|---|
| Hilti Anchor Channel | Profile type and size | Effective embedment depth in mm | Anchor channel length (mm) | Finish or material | Corner rebar edge confinement plate (EDGE plate) | Specified edge distance from edge of slab to C/L of HAC in inches |
| (E1A) HAC | 50 | 106 [4.17 in.] | 300 [11.81 in.] | F (HDG) | EDGE | 4.000 in. |
| (E1B) HAC | 50 | 106 [4.17 in.] | 300 [11.81 in.] | F (HDG) | EDGE C | 4.000 in. |

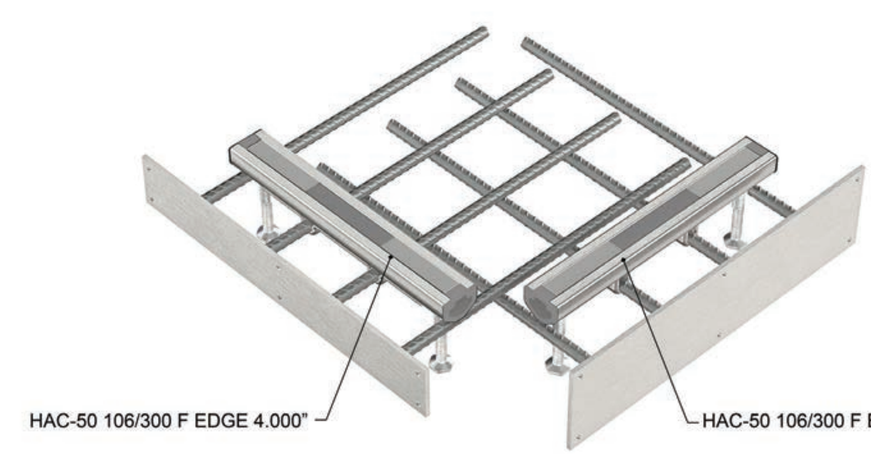
**Example 1 (E1A): HAC- 50 106/300 F EDGE 4.000 in.**

**(E1B): HAC- 50 106/300 F EDGE C 4.000 in.**

❶ ❷ ❸ ❹ ❺ ❻ ❼



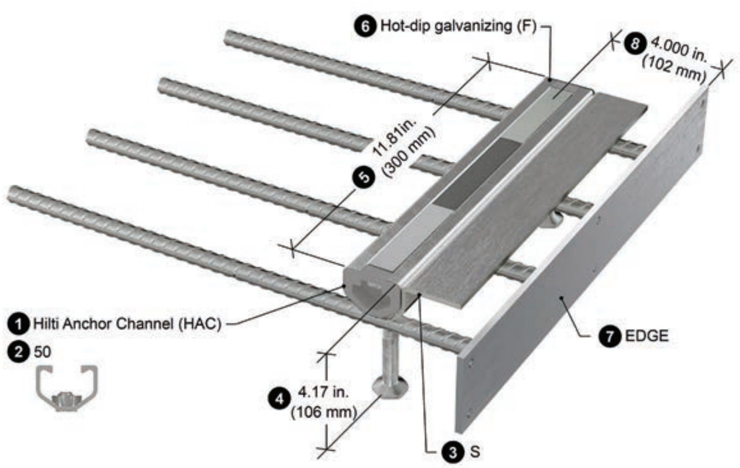
## Nomenclature of HAC S EDGE and HAC-T S EDGE

**HAC-profile S $h_{ef}$ /length Finish EDGE Edge distance, $c_{a1}$**

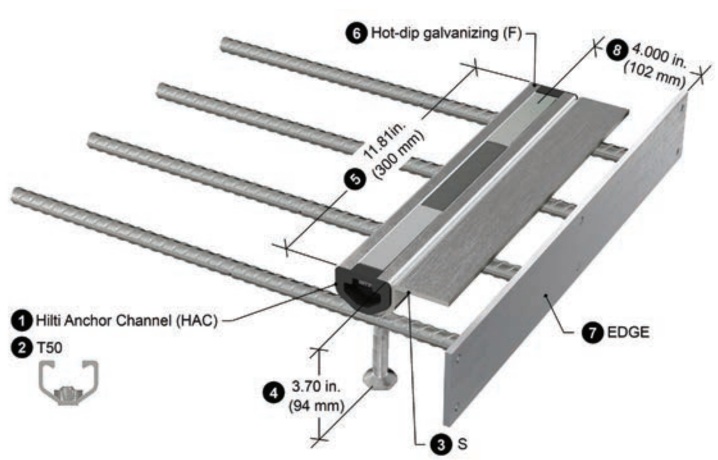
❶ ❷ ❸ ❹ ❺ ❻ ❼ ❽

| ❶ HAC | ❷ Profile | | ❸ S | ❹ $h_{ef}$ | ❺ Length | ❻ Finish | ❼ EDGE | ❽ Edge Distance, $c_{a1}$ |
|---|---|---|---|---|---|---|---|---|
| Hilti Anchor Channel | Profile type and size | | Superior Steel Performance | Effective embedment depth in mm | Anchor channel length (mm) | Finish or material | Rebar edge confinement plate (EDGE plate) | Specified edge distance from edge of slab to C/L of HAC in inches |
| (E1) HAC | 50 | | S | 106 [4.17 in.] | 300 [11.81 in.] | F (HDG) | EDGE | 4.000 in. (102 mm) |
| (E2) HAC | T50 | | S | 94 [3.70 in.] | 300 [11.81 in.] | F (HDG) | EDGE | 4.000 in. (102 mm) |

**Example 1 (E1): HAC- 50 S 106/300 F EDGE 4.000 in.**
❶ ❷ ❸ ❹ ❺ ❻ ❼ ❽




**Example 2 (E2): HAC- T50 S 94/ 300 F EDGE 4.000 in.**
❶ ❷ ❸ ❹ ❺ ❻ ❼ ❽



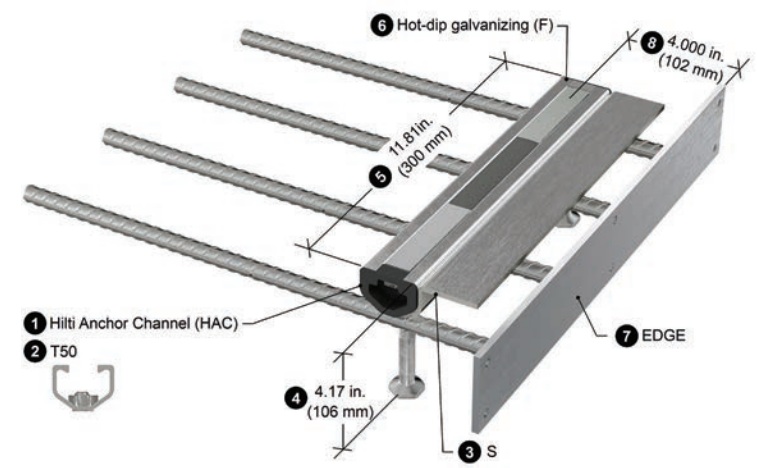

## Nomenclature of HAC S EDGE C and HAC-T S EDGE C at Corners

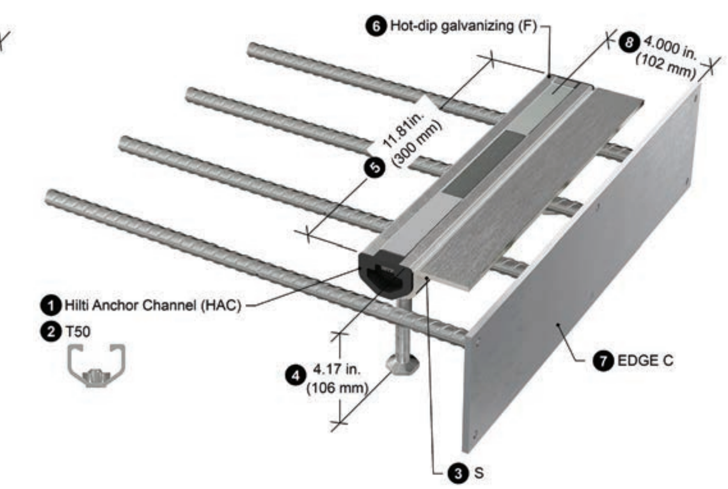
**HAC-profile S $h_{ef}$ /length Finish EDGE C Edge distance, $c_{a1}$**

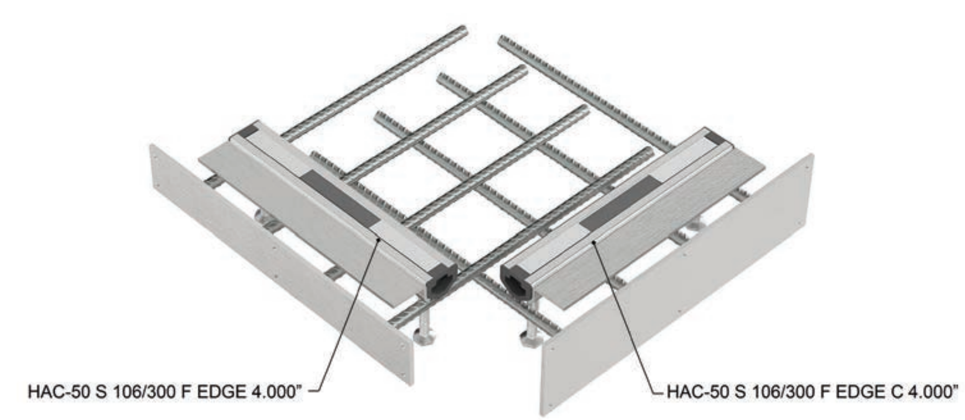
❶ ❷ ❸ ❹ ❺ ❻ ❼ ❽

| ❶ HAC | ❷ Profile | | ❸ S | ❹ $h_{ef}$ | ❺ Length | ❻ Finish | ❼ EDGE C | ❽ Edge Distance, $c_{a1}$ |
|---|---|---|---|---|---|---|---|---|
| Hilti Anchor Channel | Profile type and size | | Superior Steel Performance | Effective embedment depth in mm | Anchor channel length in mm | Finish or material | Corner rebar edge confinement plate (EDGE plate) | Specified edge distance from edge of slab to C/L of HAC in inches |
| (E1A) HAC | 50 | | S | 106 [4.17 in.] | 300 [11.81in.] | F (HDG) | EDGE | 4.000 in. (102 mm) |
| (E1B) HAC | 50 | | S | 106 [4.17 in.] | 300 [11.81in.] | F (HDG) | EDGE C | 4.000 in. (102 mm) |

**Example 1 (E1A): HAC- 50 S 106/300 F EDGE 4.000 in.**
**(E1B): HAC- 50 S 106/300 F EDGE C 4.000 in.**
❶ ❷ ❸ ❹ ❺ ❻ ❼ ❽



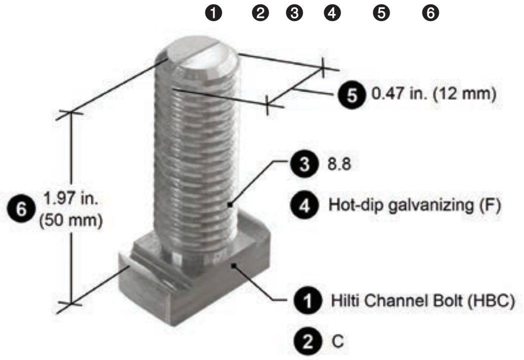
## Nomenclature of Hilti Channel Bolts

**HBC-Type Steel grade Finish, diameter x length**

❶ ❷ ❸ ❹ ❺ ❻

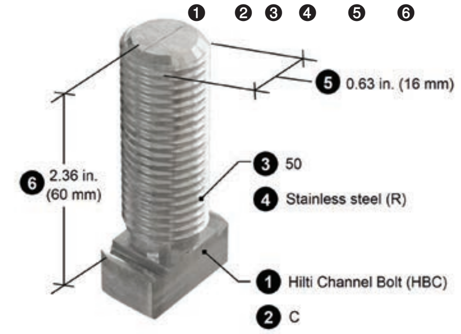
| ❶ HBC | ❷ Type | ❸ Steel grade | ❹ Finish or material | ❺ Diameter | ❻ Length |
|---|---|---|---|---|---|
| Hilti Channel Bolt | Bolt type | | | Bolt diameter in mm | Bolt length in mm |
| (E1) HBC | C | 8.8 | F (HDG) | M12 | 50 [1.97 in.] |
| (E2) HBC | C | 50 | R (stainless steel) | M16 | 60 [2.36 in.] |
| (E3) HBC | C-N | 8.8 | F (HDG) | M16 | 80 [3.15 in.] |
| (E4) HBC | T | 8.8 | F (HDG) | M16 | 60 [2.36 in.] |

**Example 1 (E1): HBC- C 8.8 F M12x 50**
❶ ❷ ❸ ❹ ❺ ❻



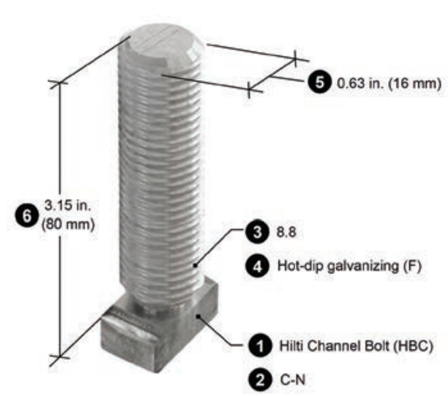

Matching with smooth lip channel profile only

**Example 2 (E2): HBC- C 50 R M16x 60**
❶ ❷ ❸ ❹ ❺ ❻



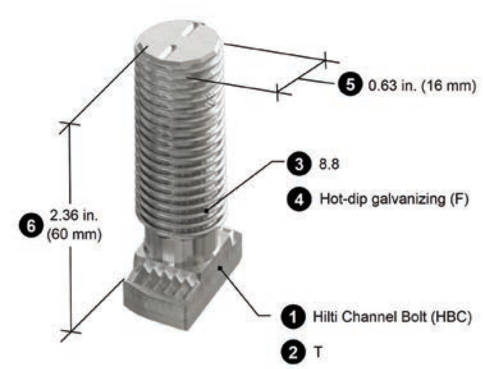

Matching with smooth lip channel profile only

**Example 3 (E3): HBC- C-N 8.8 F M16x 80**
❶ ❷ ❸ ❹ ❺ ❻




Matching with smooth lip channel profile only

**Example 4 (E4): HBC- T 8.8 F M16x 60**
❶ ❷ ❸ ❹ ❺ ❻




Matching with serrated lip channel profile only



# 2.2 HAC GEOMETRIC PARAMETERS

## 2.2.1 HAC

Hilti Anchor Channels (HAC) with smooth channel lips are offered in an array of four channel profile sizes; HAC-40, HAC-50, HAC-60, and HAC-70. Hilti Channel Bolts C (HBC-C) are suitable for all four HAC profiles. Hilti Locking Channel Bolts (HBC-C-N) provide slip resistances via interlocking between t-bolt head and channel lip. Figure 2.2.1.1 illustrates the different channel profile sizes and t-bolt types.

The standard HAC portfolio consists of pre-defined channel lengths, embedment depths, number of anchors, anchor spacing, and defined anchor diameter. Figure 2.2.1.2 illustrates standard HAC-40 to HAC-70 anchor channels. Table 2.2.1.1 provides geometric parameters of HAC portfolio.

Non-standard anchor channels (i.e. custom channel length, custom anchor spacing, etc.) can be provided upon request. Longer lead times can be expected for custom channels. See sections 2.4, 2.5, and 2.6 for standard and custom anchor channels lead times.

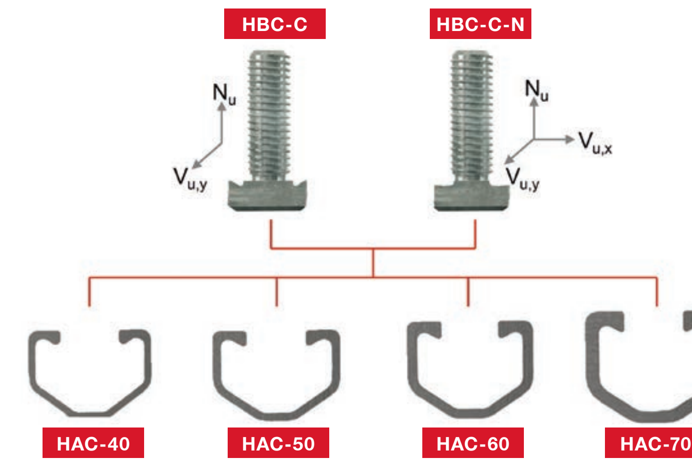



**Figure 2.2.1.1 HAC profiles with matching channel bolts**

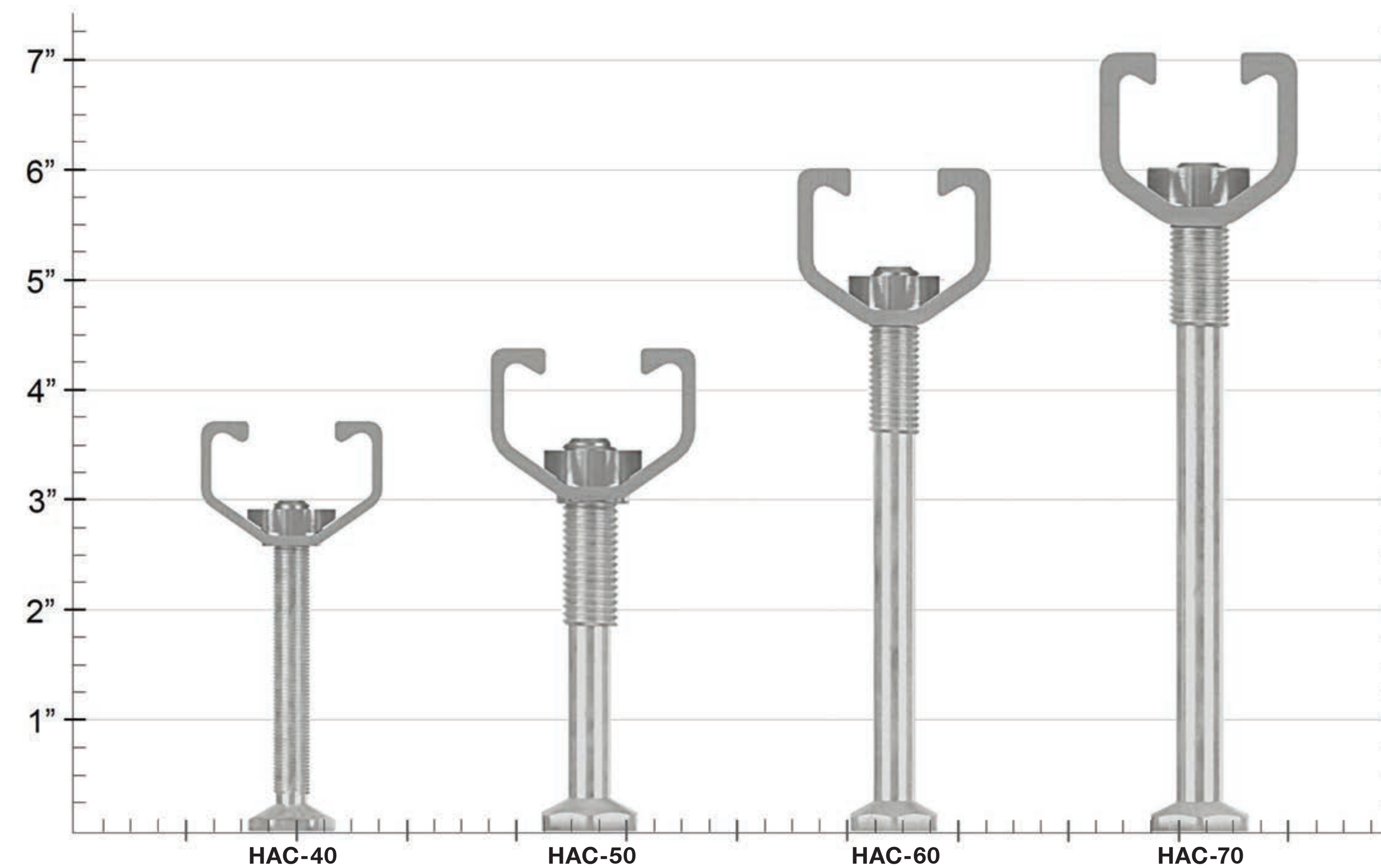



**Figure 2.2.1.2 — Section view of HAC-40, HAC-50, HAC-60, and HAC-70.**

Table 2.2.1.1 provides geometric parameters for HAC. This information is based on ICC ESR-3520 Table 8.1.

**Table 2.2.1.1 – Geometric parameters for HAC**

| Criteria | Symbol | Units | Anchor Channel | | | |
|---|---|---|---|---|---|---|
| | | | HAC-40 | HAC-50 | HAC-60 | HAC-70 |
| Channel profile height | $h_{ch}$ | in (mm) | 1.10 (28.0) | 1.22 (31.0) | 1.40 (35.5) | 1.57 (40.0) |
| Channel profile width | $b_{ch}$ | in (mm) | 1.61 (40.9) | 1.65 (41.9) | 1.71 (43.4) | 1.79 (45.4) |
| Channel profile moment of inertia | $I_y$ | $in^4$ ($mm^4$) | 0.0516 (21,463) | 0.0796 (33,125) | 0.1392 (57,930) | 0.2293 (95,457) |
| Channel profile opening | d | in (mm) | 0.77 (19.50) | 0.77 (19.50) | 0.77 (19.50) | 0.77 (19.50) |
| Channel lip flange thickness | f | in (mm) | 0.18 (4.50) | 0.21 (5.30) | 0.25 (6.30) | 0.30 (7.40) |
| Channel lip thickness (top) | $t_{nom,t}$ | in (mm) | 0.09 (2.25) | 0.11 (2.75) | 0.14 (3.50) | 0.18 (4.50) |
| Channel lip thickness (bottom) | $t_{nom,b}$ | in (mm) | 0.09 (2.25) | 0.11 (2.75) | 0.14 (3.50) | 0.18 (4.50) |
| Min. effective embedment depth[1] | $h_{ef,min}$ | in (mm) | 3.58 (91.00) | 4.17 (106.00) | 5.83 (148.00) | 6.89 (175.00) |
| Thickness of the anchor head | $t_h$ | in (mm) | 0.12 (3.00) | 0.14 (3.50) | 0.18 (4.50) | 0.20 (5.00) |
| Nominal embedment depth[2] | $h_{nom}$ | in (mm) | 3.70 (94.00) | 4.31 (109.50) | 6.00 (152.50) | 7.09 (180) |
| Minimum end spacing | $x_{min}$ | in (mm) | 0.98 (25) | 0.98 (25) | 0.98 (25) | 0.98 (25) |
| Anchor shaft diameter | $d_2$ | in (mm) | 0.28 (7.19) | 0.36 (9.03) | 0.36 (9.03) | 0.43 (10.86) |
| Head diameter[3] | $d_1$ | in (mm) | 0.69 (17.50) | 0.77 (19.50) | 0.77 (19.50) | 0.91 (23.00) |
| Anchor length | $l_A$ | in (mm) | 2.62 (66.50) | 3.09 (78.50) | 4.61 (117.00) | 5.51 (140.00) |
| Minimum anchor spacing | $s_{min}$ | in (mm) | 3.94 (100) | 3.94 (100) | 3.94 (100) | 3.94 (100) |
| Maximum anchor spacing | $s_{max}$ | in (mm) | 9.84 (250) | 9.84 (250) | 9.84 (250) | 9.84 (250) |
| Net bearing area of the anchor head | $A_{brg}$ | $in^2$ ($mm^2$) | 0.324 (209) | 0.400 (258) | 0.400 (258) | 0.552 (356) |
| Matching channel bolt | $x_{nail}$ | | HBC-C, HBC-C 50R, HBC-C-N | | | |
| Minimum channel bolt spacing | $s_{chb}$ | | 3 x bolt diameter | | | |
| Nail hole location[4] | | in (mm) | 1" offset from anchor (25.4 offset from anchor) | | | |

1 Longer anchors can be offered upon request; longer lead time is expected.
2 Manufacture tolerance of up to +3 mm (0.118 in.).
3 The head diameter is the inner diameter of the hexagonal shaped head, and does not fully reflect the cross sectional area of the anchor head.
4 Nail hole diameter is 4 mm (0.16 in.)

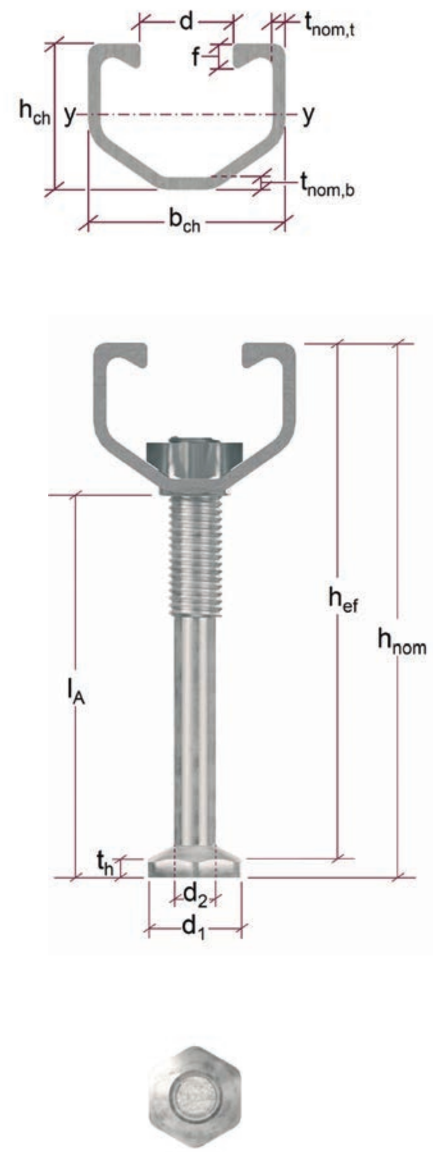



**Figure 2.2.1.3 a — HAC dimensions.**

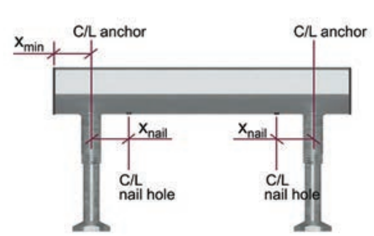



**Figure 2.2.1.3 b — HAC end and nail hole distance.**

## Minimum substrate requirements

The minimum edge distance and member thickness for anchor channels are established via testing. It is the interaction between minimum member thickness and minimum edge distance that determines the minimum edge distance. If the anchor channel is installed closer than the minimum edge distance, cracking of the concrete may occur while applying the required installation torque to the t-bolts. Testing to determine the minimum edge distance considers unfavorable site conditions. The test is based on having the anchor channel recessed 1/8" in unreinforced concrete. Splitting/cracking may occur. Therefore, minimum substrate requirements vary depending on the anchor channel size. HAC substrate requirements are provided in Table 2.2.1.2 and 2.2.1.3.

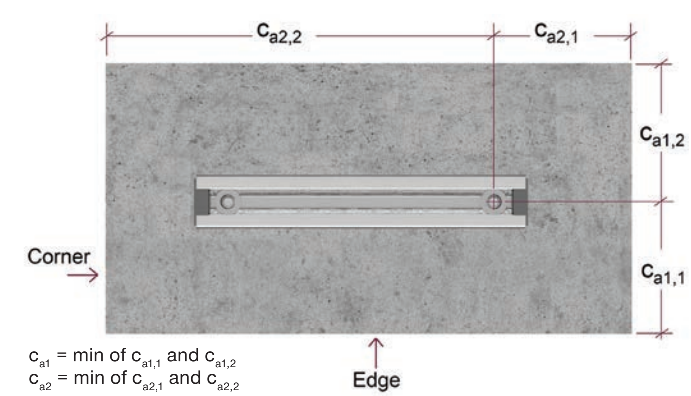
**Table 2.2.1.2 — Minimum substrate dimensions for HAC in normal weight and sand-lightweight concrete**

| Anchor channel | Units | $c_{a1}$ | $c_{a2}$ | *$h_{min}$ |
|---|---|---|---|---|
| HAC-40 | in (mm) | 1.97 (50) | 1.97 (50) | 4.13 (105) |
| HAC-50 | in (mm) | 1.97 (50) | 1.97 (50) | 4.92 (125) |
| HAC-60 | in (mm) | 2.95 (75) | 2.95 (75) | 6.61 (168) |
| HAC-70 | in (mm) | 2.95 (75) | 2.95 (75) | 7.72 (196) |

**Table 2.2.1.3 — Minimum substrate dimensions for HAC in all lightweight concrete**

| Anchor channel | Units | $c_{a1}$ | $c_{a2}$ | *$h_{min}$ |
|---|---|---|---|---|
| HAC-40 | in (mm) | 2.95 (75) | 2.95 (75) | 4.13 (105) |
| HAC-50 | in (mm) | 2.95 (75) | 2.95 (75) | 4.92 (125) |
| HAC-60 | in (mm) | 2.95 (75) | 2.95 (75) | 6.61 (168) |
| HAC-70 | in (mm) | 2.95 (75) | 2.95 (75) | 7.72 (196) |

* Minimum slab thickness, $h_{min}$ may be reduced if anchor cover requirements can be omitted (i.e. interior applications with metal deck underneath the channel). To avoid splitting of the concrete, the minimum edge and corner distance shall be increased by a factor of 2.




Corner and edge distances are measured to the center of the anchor

**Figure 2.2.1.4 — Minimum HAC edge and corner distances, plan view.**


**Figure 2.2.1.5 – Minimum HAC member thickness, isometric view.**

## Edge distance facts:

- Any edge which the distance perpendicular to the long axis of the anchor channels is considered an edge.
- For determination of the minimum edge distance of
- concrete breakout strength in tension, $c_{a1}$ = min of $c_{a1,1}$ and $c_{a1,2}$
- For analysis purposes of concrete edge breakout strength in shear, $c_{a1}$ is always measured in the direction of the applied shear load.
- Edge distances are always measured from the center of the anchor under consideration.

## Corner distance facts:

- Any edge which the distance parallel to the long axis of the anchor channels is considered a corner
- For determination of the minimum corner distance, $c_{a2}$ = min of $c_{a2,1}$ and $c_{a2,2}$
- Corner distances are always measured from the center of the anchor under consideration

# 2.2.2 HAC IN FACE OF SLAB CORNERS

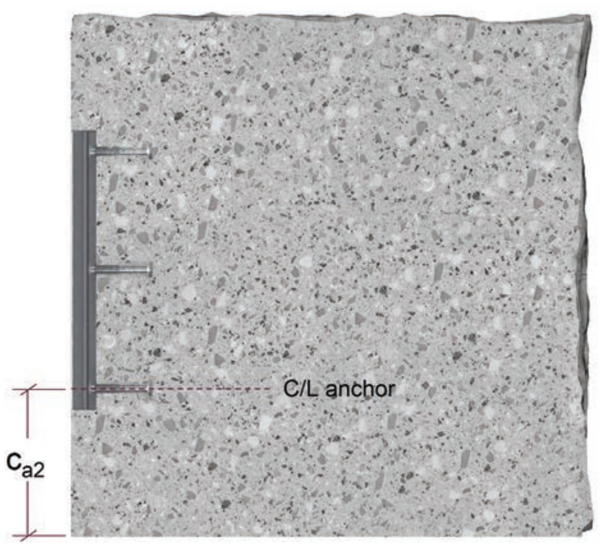
## Single HAC in face of slab corners

AC232 provides design guidelines to account for the influence of corners where only one anchor channel is present. The design of this type of applications is covered in ESR-3520. Table 2.2.2.1 provides the minimum edge and corner distances for HAC.

**Table 2.2.2.1 — Minimum substrate edge and corner distances for single HAC in a corner in normal weight, sand-lightweight and all light-weight concrete**

| Anchor channel | Units | Minimum $c_{a1}$ | Minimum $c_{a2}$ |
|---|---|---|---|
| HAC-40 | In (mm) | *1.97 (50) | *1.97 (50) |
| HAC-50 | In (mm) | *1.97 (50) | *1.97 (50) |
| HAC-60 | In (mm) | 2.95 (75) | 2.95 (75) |
| HAC-70 | In (mm) | 2.95 (75) | 2.95 (75) |

*For all-lightweight concrete, $c_{a1}$ and $c_{a2}$= 2.95" (75 mm)




Corner distance $c_{a2}$ is measured to the center of the anchor.

**Figure 2.2.2.1– Minimum corner distance for single HAC in face of slab, plan view.**

## Pair of HAC in a corner

AC232 does not include provisions to account for the influence of an adjacent channel in a face of slab corner. Technically, HAC can be used in both sides of the corner, if there is no overlapping of the anchors.

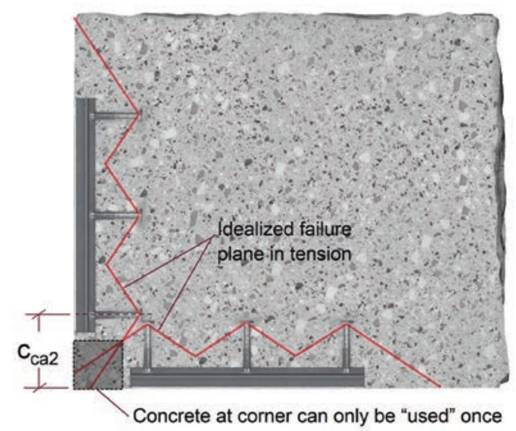
Additional measurements shall be taken in consideration to account for the negative influence of the adjacent anchor channel, if both channels are to be loaded simultaneously. See chapter 9, Anchor Channel Design for additional design information. Although this solution is technically feasible, installing HAC at 4 to 7 inches away from the corner typically results in unpractical bracket sizes, large eccentricities, large forces, and consequently, inadequate concrete strengths.

Table 2.2.2.2 and figure 2.2.2.3 provide information about the minimum corner distance for pair of HAC. See chapter 9, Anchor Channel Design for additional design information.

**Table 2.2.2.2 — Minimum substrate edge and corner distances for pair of HAC in corners in normal weight, sand-lightweight and all light-weight concrete**

| Anchor channel | Units | Minimum $c_{a1}$ | Minimum $c_{ca2}$ |
|---|---|---|---|
| HAC-40 | In (mm) | *1.97 (50) | 3.70 (94.00) |
| HAC-50 | In (mm) | *1.97 (50) | 4.31 (109.50) |
| HAC-60 | In (mm) | 2.95 (75) | 6.01 (152.50) |
| HAC-70 | In (mm) | 2.95 (75) | 7.09 (180.00) |

*For all-lightweight concrete, $c_{a1}$ = 2.95" (75 mm)




Corner distance $c_{ca2}$ is measured to the center of the anchor.

**Figure 2.2.2.2 — Minimum corner distances for pair of HAC, plan view.**

For face of slab applications, it is not recommended to install HAC in both sides of the corner if overlapping of the rounded head anchors occurs and simultaneous loading will be experienced. The overlapping of the anchors of the corner channels creates a weakened failure plane, making the corner susceptible to premature cracking and reduced concrete strengths.

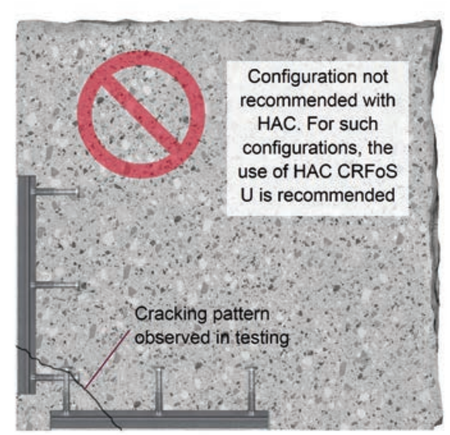



**Figure 2.2.3.3 — Premature concrete cracking due to simultaneous loading of pair HAC at corner with overlapped anchors, plan view.**



# 2.2.3 HAC IN TOP AND BOTTOM OF SLAB CORNERS

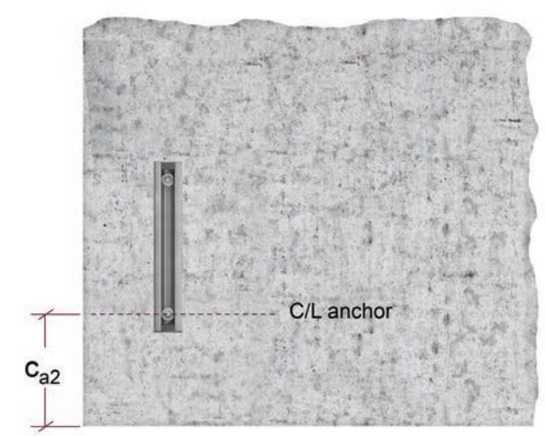
## Single HAC in top of slab corner

AC232 provides design guidelines to account for the influence of corners where only one anchor channel is present. The design of this type of application is covered in ESR-3520. Table 2.2.3.1 provides the minimum edge and corner distances for HAC. HAC requirements for top and bottom of slab corners are equal.

**Table 2.2.3.1 — Minimum substrate edge and corner distances for single HAC in a corner in normal weight, sand-lightweight and All light-weight concrete**

| Anchor channel | Units | Minimum $c_{a1}$ | Minimum $c_{a2}$ |
|---|---|---|---|
| HAC-40 | In (mm) | *1.97 (50) | *1.97 (50) |
| HAC-50 | In (mm) | *1.97 (50) | *1.97 (50) |
| HAC-60 | In (mm) | 2.95 (75) | 2.95 (75) |
| HAC-70 | In (mm) | 2.95 (75) | 2.95 (75) |

*For all-lightweight concrete, $c_{a1}$= $c_{a2}$ = 2.95" (75 mm)




Corner distance $c_{a2}$ is measured to the center of the anchor.

**Figure 2.2.3.1– Minimum corner distance for single HAC in top of slab, plan view.**

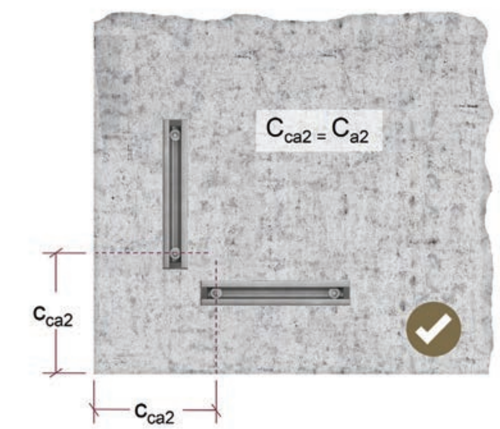
## Pair of HAC in top of slab corners

AC232 does not include provisions to account for the influence of an adjacent and/or corner channel. Technically, HAC can be used in both sides of the corner.

Additional measurements shall be taken into consideration to account for the negative influence of the adjacent anchor channel, if both channels are to be loaded simultaneously. See chapter 9, Special Anchor Channel Design for additional design information.

The minimum corner distances for pair of HAC in top of slab corners ($c_{ca2}$) are consistent with table 2.2.3.1. These minimum distances are based on installation requirements. Both HAC at corners cannot be installed at the minimum corner distance due to physical constraints (clashing of HAC will occur). However, two HAC can be installed next to each other in a corner configuration where the anchor channels are installed perpendicular to each other; see Figure 2.2.3.2.

Figure 2.2.3.2 illustrates a pair of HAC in a corner. Corner distances greater than the minimum corner distance may be required based on the structural adequacy of the concrete at the corner.




Corner distance $c_{ca2}$ is measured to the center of the anchor.

**Figure 2.2.3.2– Minimum corner distance for pair of HAC in top of slab, plan view.**

## Design of Top of Slab Corners

Hilti has developed a model to account for the influence of adjacent and corner channels. The model follows the fundamentals of AC232 and allows to analyze more complex but typical applications encountered in a project such as the conditions shown in Figure 2.2.3.3. See chapter 9, Special Anchor Channel Design for additional design information.

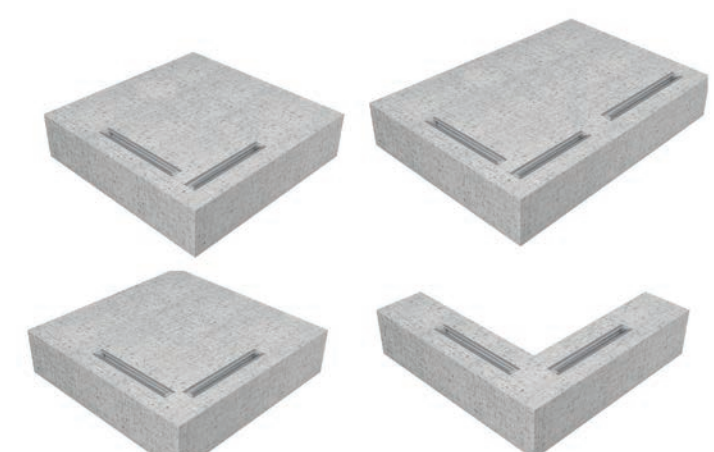


**Figure 2.2.3.3 Corner configuration of pair of HAC in top of slab.**

## 2.2.4 HAC CRFoS U

Hilti Anchor Channel Rebar Face of Slab with smooth channel lips (HAC CRFoS U) are offered in three channel profile sizes; HAC-50, HAC-60, and HAC-70. Hilti Channel Bolts C (HBC-C) are suitable for all HAC CRFoS U.

The standard portfolio consists of HAC-50, HAC-60, and HAC-70 channels profiles with pre-defined channel length, rebar lengths, number of anchors, and defined rebar diameter. Non-standard anchor channels (i.e. custom channel length, rebar length, number of rebars etc.) can be provided upon request. Refer to sections 2.4 and 2.5 for additional information about standard items and lead times.

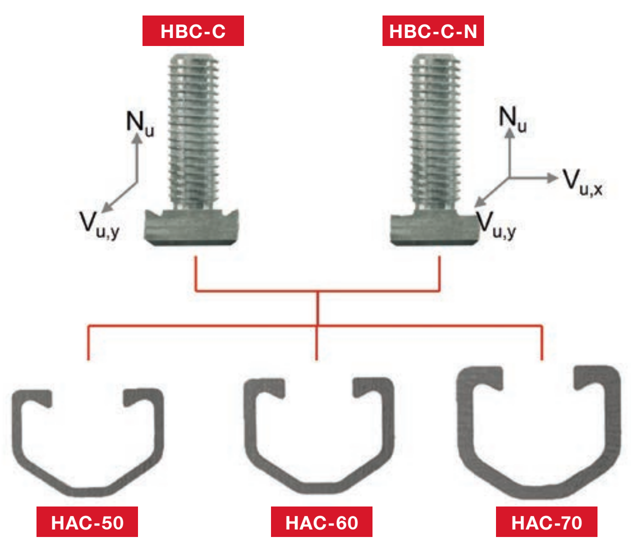



**Figure 2.2.4.1 - HAC CRFoS profiles with matching channel bolts.**

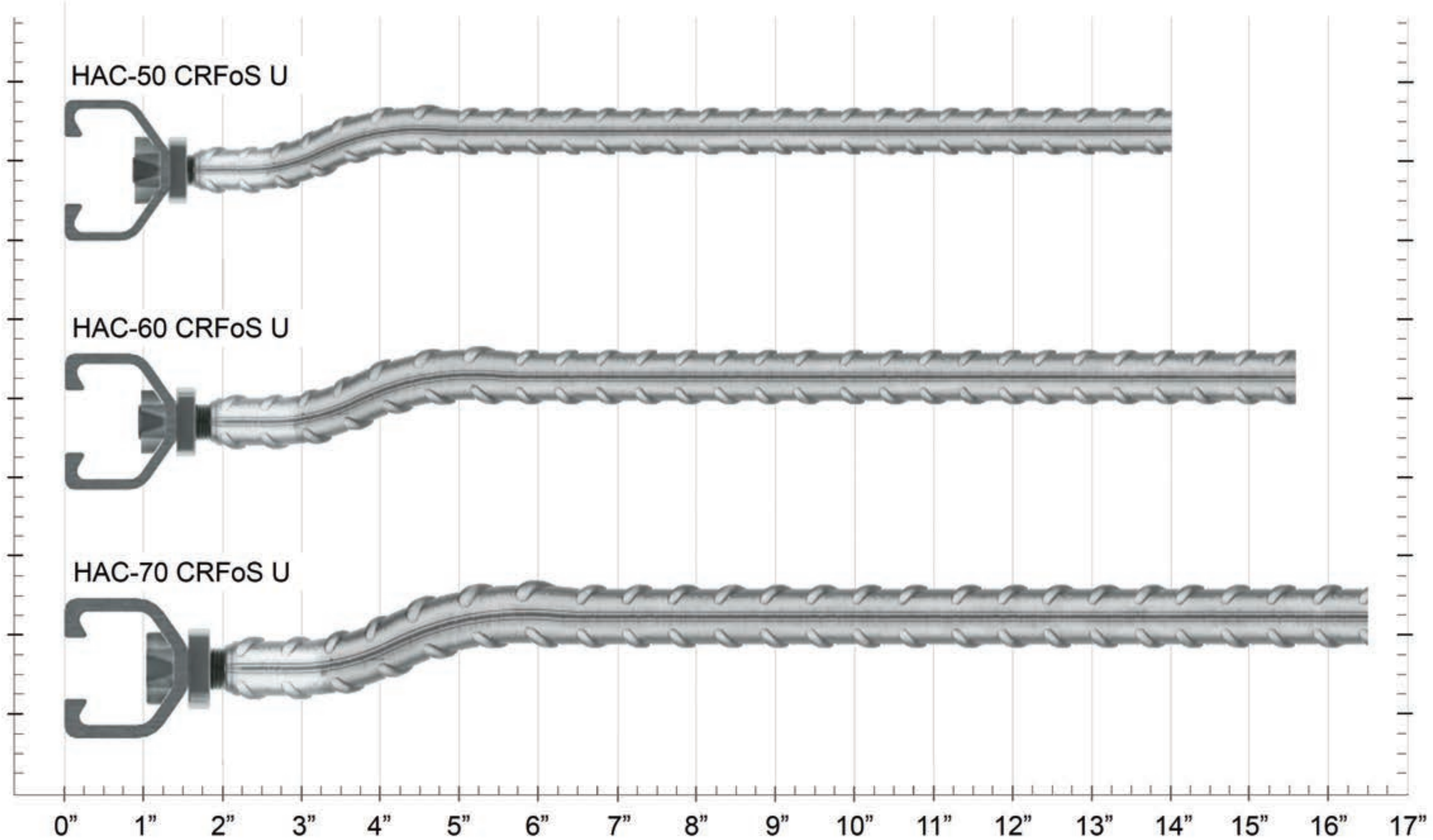



**Figure 2.2.4.2 - Section view of HAC-50 CRFoS U, HAC-60 CRFoS U, and HAC-70 CRFoS U.**

**Table 2.2.4.1 — Geometric parameters for HAC CRFoS U**

| Criteria | Symbol | units | Anchor Channel | | |
|---|---|---|---|---|---|
| | | | HAC-50 CRFoS U | HAC-60 CRFoS U | HAC-70 CRFoS U |
| Channel profile height | $h_{ch}$ | in (mm) | 1.22 (31) | 1.40 (35.5) | 1.57 (40) |
| Channel profile width | $b_{ch}$ | in (mm) | 1.65 (41.9) | 1.71 (43.4) | 1.79 (45.4) |
| Channel profile moment of inertia | $I_y$ | $in^4$ ($mm^4$) | 0.0796 (33,125) | 0.1392 (57,930) | 0.2293 (95,457) |
| Channel profile opening | d | in (mm) | 0.77 (19.50) | 0.77 (19.50) | 0.77 (19.50) |
| Channel lip flange thickness | f | in (mm) | 0.21 (5.30) | 0.25 (6.30) | 0.3 (7.40) |
| Channel lip thickness (top) | $t_{nom,t}$ | in (mm) | 0.11 (2.75) | 0.14 (3.50) | 0.18 (4.50) |
| Channel lip thickness (bottom) | $t_{nom,b}$ | in (mm) | 0.11 (2.75) | 0.14 (3.50) | 0.18 (4.50) |
| *Rebar length | $\ell_d$ | in (mm) | 12.80 (325) | 14.17 (360) | 14.96 (380) |
| Rebar kink/offset height | $k_h$ | in (mm) | 0.47 (12) | 0.55 (14) | 0.63 (16) |
| Nominal anchor channel depth | $h_{nom}$ | in (mm) | 14.02 (356) | 15.60 (396) | 16.54 (420) |
| Minimum end spacing | $x_{min}$ | in (mm) | 0.98 (25) | 0.98 (25) | 0.98 (25) |
| Rebar diameter | $d_b$ | in (mm) | 0.47 (12) | 0.55 (14) | 0.63 (16) |
| Minimum rebar spacing | $s_{min}$ | in (mm) | 3.94 (100) | 3.94 (100) | 3.94 (100) |
| Maximum rebar spacing | $s_{max}$ | in (mm) | 9.84 (250) | 9.84 (250) | 9.84 (250) |
| Bar effective cross-sectional area | $A_{se}$ | $in^2$ ($mm^2$) | 0.18 (113.10) | 0.24 (153.93) | 0.31 (201.06) |
| Matching channel bolt | | | HBC-C, HBC-C 50R, and HBC-C-N | | |
| Minimum channel bolt spacing | $s_{chb}$ | | 3 x bolt diameter | | |
| Nail hole location[1] | $x_{nail}$ | in (mm) | 1" offset from rebar (25.4 offset from rebar) | | |

*Custom rebar lengths can be offered upon request. Longer rebars may require longer lead times. Refer to sections 2.4 and 2.6 for information about lead times of custom channels.

1 Nail hole diameter is 4 mm (0.16 in.)

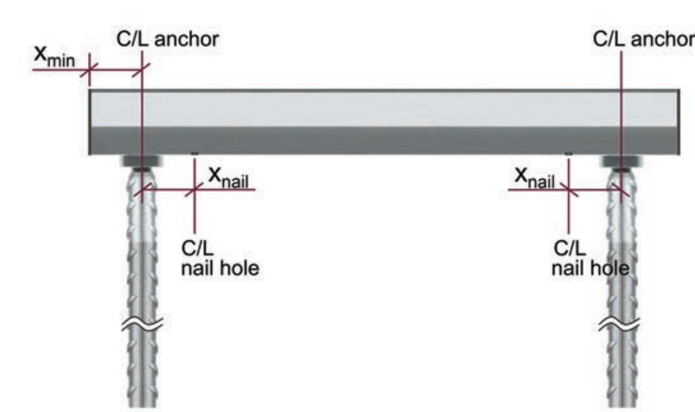



**Figure 2.2.4.3 a — HAC CRFoS U end and nail hole distance.**

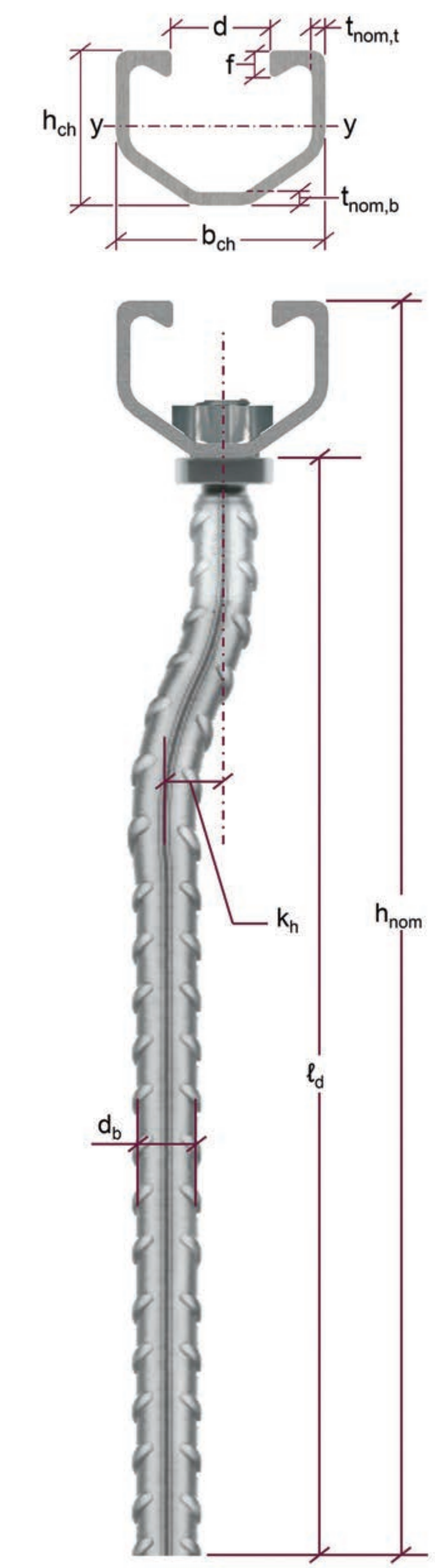



**Figure 2.2.4.3 b — HAC CRFoS U dimensions.**

## Minimum substrate requirements for HAC CRFoS U

Similarly to HAC, the minimum edge distances for HAC CRFoS U are established via testing. Although HAC CRFoS U are not implicitly covered by AC232, ESR-3520 provides the minimum edge and corner distance for the minimum member thickness. The minimum member thickness for HAC CRFoS U is larger than the minimum member thickness for HAC. However, the channel profile is the same for HAC and HAC CRFoS U. Therefore, it is conservative to use the minimum HAC edge and corner distances for HAC CRFoS U.

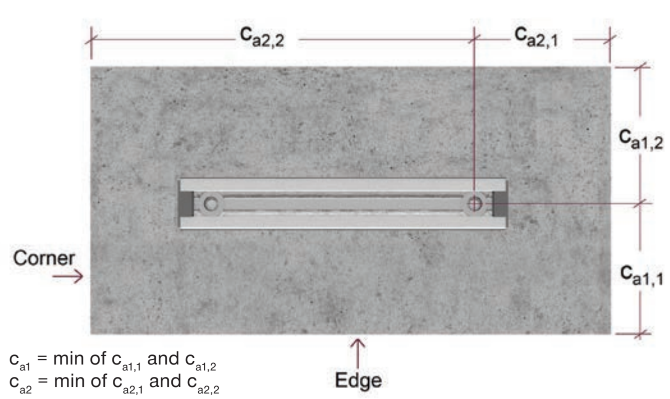
**Table 2.2.4.2 — Minimum edge and corner distances for HAC CRFoS U in normal weight and sand-lightweight concrete**

| Anchor channel | Units | $c_{a1}$ | $c_{a2}$ | *$h_{min}$ |
|---|---|---|---|---|
| HAC-50 CRFoS U | in<br>(mm) | 1.97<br>(50) | 1.97<br>(50) | 14.00<br>(356) |
| HAC-60 CRFoS U | in<br>(mm) | 2.95<br>(75) | 2.95<br>(75) | 14.25<br>(362) |
| HAC-70 CRFoS U | in<br>(mm) | 2.95<br>(75) | 2.95<br>(75) | 14.25<br>(362) |

**Table 2.2.5.2 — Minimum edge and corner distances for HAC CRFoS U in all-lightweight concrete**

| Anchor channel | Units | $c_{a1}$ | $c_{a2}$ | *$h_{min}$ |
|---|---|---|---|---|
| HAC-50 CRFoS U | in<br>(mm) | 2.95<br>(75) | 2.95<br>(75) | 14.00<br>(356) |
| HAC-60 CRFoS U | in<br>(mm) | 2.95<br>(75) | 2.95<br>(75) | 14.25<br>(362) |
| HAC-70 CRFoS U | in<br>(mm) | 2.95<br>(75) | 2.95<br>(75) | 14.25<br>(362) |

*Minimum slab thickness, hmin may be reduced.




Corner and edge distances are measured to the center of the anchor.

**Figure 2.2.4.4 — Minimum HAC CRFoS U edge and corner distances, elevation view.**


**Figure 2.2.4.5 — Minimum HAC CRFoS U member thickness, isometric view.**

## Minimum edge distance for anchor channels in composite slabs

The minimum edge and corner distances for HAC CRFoS U are consistent with the minimum requirements of its matching HAC profile size. Moreover, the AC232 test series 6 - splitting failure due to installation requires a 1/8 inch (3 mm) gap between channel lip and fixture to ensure introduction of a tension load into the anchor during torquing. This takes into considerations unfavorable anchor channel installation. However, this can be prevented in composite slabs where the anchor channel profile bears on the pour stop and the channel lips and fixture are flush with the pour stop.

For composite slabs where the anchor channel is fixed to the pour stop and the channel cannot be recessed in the slab, smaller edge distances may be allowed. Additional measurement may be required if the rebar is embedded in the metal deck zone. See section 9 for additional information.

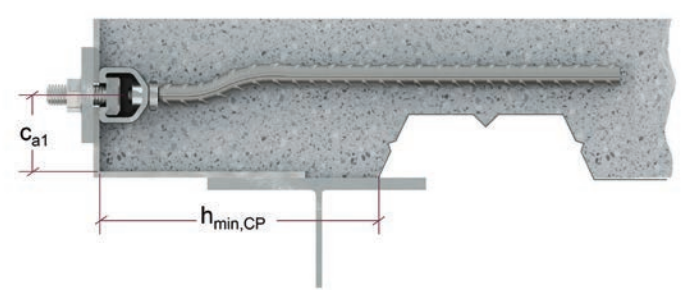



**Figure 2.2.4.6 — HAC CRFoS U in composite slab.**

**Table 2.2.4.4 — Minimum distance from face of slab to metal deck, $h_{min,CP}$**

| Anchor channel | Units | *$h_{min,CP}$ |
|---|---|---|
| HAC-50 CRFoS U | in<br>(mm) | 4.92<br>(125) |
| HAC-60 CRFoS U | in<br>(mm) | 6.61<br>(168) |
| HAC-70 CRFoS U | in<br>(mm) | 7.72<br>(196) |

* min. distance where no concrete edge breakout in shear capacity is reduced $h_{min,CP}$, contact Hilti.



# 2.2.5 HAC CRFoS U IN FACE OF SLAB CORNERS

HAC CRFoS U are ideal for face of slab corner applications. The Hilti face of slab corner solution utilizes two independent anchor channels. The use of two independent anchor channels eases the installation in congested conditions. This minimizes clashes of the anchors with the rebar cage, preventing damage of the anchors during installation. Moreover, two independent anchor channels allows de-coupling of the loads applied on each corner channel, preventing the anchors from experiencing undesired loads.

The use of anchor channels with rebar anchors (HAC CRFoS U) allows the anchor channels to be installed as close as 2-1/8" (from end of channel profile) away from the corner, without penalizing the concrete tensile strengths in tension, as is the case for HAC.

HAC CRFoS U comes with specially bent rebars. Thus, allowing both corner channels to be installed at the same elevation without clashing of the rebars of both corner channels.

Due to the HAC CRFoS U configuration, the anchor channel used at both corners is the same type. At corners, one HAC CRFoS U is rotated 180 degrees. Therefore, one channel has the bent rebars going up while the other are going down.

Anchor channel steel strengths are provided in sections 2.3.3 and 2.3.4. For design of channels at corners, refer to chapter 9.

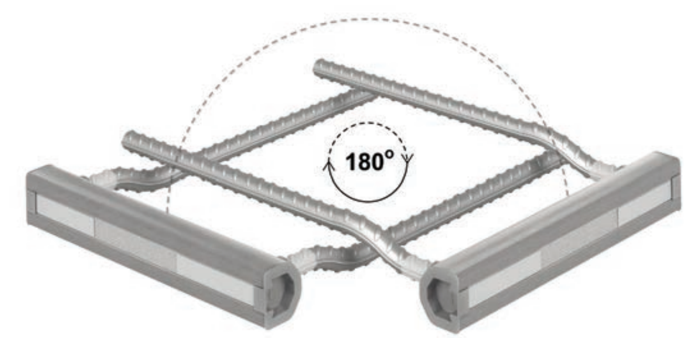
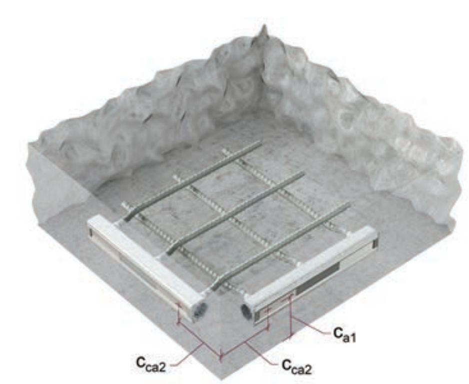



**Figure 2.2.5.1 — HAC CRFoS U at corners.**



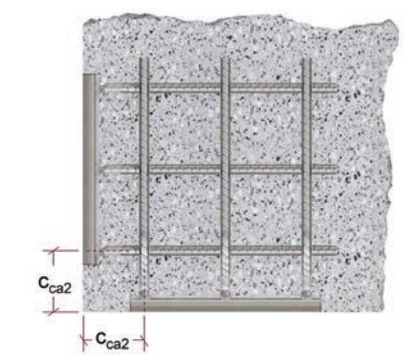

Corner distance $c_{ca2}$ is measured to the center of the anchor.

**Figure 2.2.5.2 — Minimum corner distance for pair of HAC CRFoS U in a corner.**

**Table 2.2.5.3 — Minimum substrate edge and corner distances for pair of HAC CRFoS U in corners in normal weight, sand-lightweight and all light-weight concrete**

| Anchor channel | Units | Minimum $c_{a1}$ | Minimum $c_{ca2}$ |
|---|---|---|---|
| HAC-50 CRFoS U | in<br>(mm) | *1.97<br>(50) | 3.15<br>(80) |
| HAC-60 CRFoS U | in<br>(mm) | 2.95<br>(75) | 3.62<br>(92) |
| HAC-70 CRFoS U | in<br>(mm) | 2.95<br>(75) | 3.94<br>(100) |

*For all-lightweight concrete, $c_{a1}$ = 2.95" (75 mm)




Corner distance $c_{ca2}$ is measured to the center of the anchor.

**Figure 2.2.5.3 — Minimum corner distance for pair of HAC CRFoS U in a corner, plan view.**

## What drives the minimum corner distance?

The minimum corner distance ($C_{ca,2}$) is based on the minimum physical distance required to avoid clashing of the rebars of the two corner anchor channels, installed at the same elevation.

## HAC CRFoS U at non-90° corners

HAC CRFoS U are suitable for non-90° corners. The use of two independent anchor channels simplifies the portfolio by no requiring custom made channels. See chapter 9 for design information.

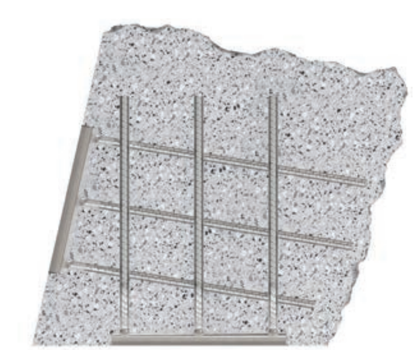


**Figure 2.2.5.4 — Pair of HAC CRFoS U in an acute corner, plan view.**

# 2.2.6 HAC CRFoS U IN TOP OR BOTTOM OF SLAB APPLICATIONS

## HAC CRFoS U in intermediate applications

The use of HAC CRFoS U is not limited to face of slab applications. HAC CRFoS U is ideal for applications with high tension forces. In top of slab applications, HAC CRFoS U presents a great solution for applications (intermediate and corners) with high tension forces and HAC is not adequate. The minimum member thickness, corner and edge distances are provided in tables 2.2.5.1 and 2.2.5.2. The minimum rebar length should be established in accordance with applicable provisions of AC232 and ACI 318.

## HAC CRFoS U in corner applications

The requirements for HAC CRFoS U in top of slab applications are similar to the HAC requirements discussed in section 2.2.3. See section 9 for additional design information.

## HAC CRFoS U in top or bottom of slab applications

A good example for a top of "slab" applications where HAC CRFoS U may be the only solution is handrails in top of curb. Although the shear forces are typically low, the high tension forces on the t-bolts due to the cantilever effect of the rails tends to create unsatisfactory concrete breakout in tension utilizations. Figure 2.2.6.1 illustrates such scenario. The curb needs to be tall enough to meet the minimum member thickness. Standard hooks and headed rebars may be used if the minimum member thickness is not met.

Another example is a kicker in a spandrel beam (corner or intermediate) where the anchor is installed at a large edge distance but the bracket eccentricity generates overly high tension forces on the t-bolts.

HAC CRFoS U transfers higher tension forces than HAC. HAC CRFoS U does not increase the concrete breakout strength in shear. See section 9 for additional design information.

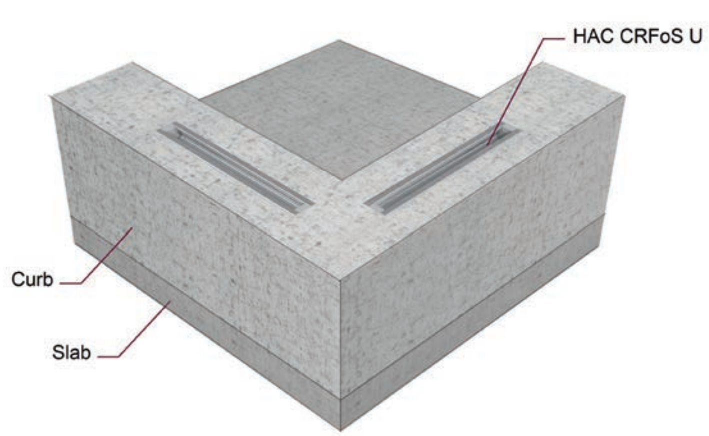



Figure 2.2.6.1 — Pair of HAC CRFoS U in a top of curb corner, isometric view.

The concrete breakout strength in shear is not negatively impacted by the rebars. The concrete breakout strength in shear for HAC and its matching HAC CRFoS U is asssumed to be equal and the same design standards are applied.

In bottom of slab applications, the concrete breakout strength in shear can be increased by increasing the edge distance. However, if the tension is too high as it can be the case with kicker, the interaction (or tension alone) of concrete in tension and shear can yield unsatisfactory utilizations. HAC CRFoS U can solve this limitation, if the member thickness is sufficient.

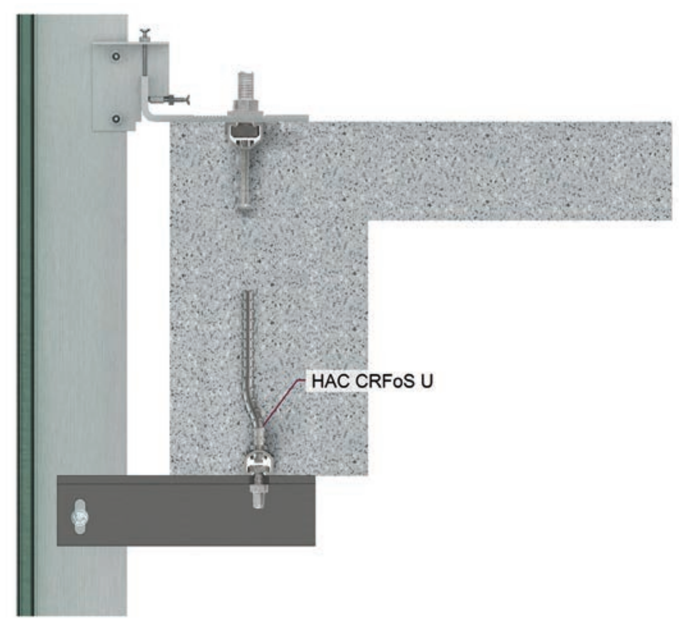



Figure 2.2.6.2 — HAC CRFoS U in bottom of slab application, section view.

# 2.2.7 HAC EDGE LITE, HAC EDGE, AND HAC S EDGE

Hilti Anchor Channels with smooth channel lips and rebar edge confinement plate (HAC EDGE Lite and HAC EDGE) are offered in HAC-40 (HAC EDGE Lite only) and HAC-50 profiles. HAC EDGE with superior steel performance (HAC S EDGE) are offered in HAC-50 profiles. The anchor channel is identical to its matching HAC, except the rebar edge confinement plate (EDGE Lite or EDGE Plate) is incorporated for superior concrete performance in shear.

The standard portfolio consists of HAC-40 with a nominal anchor height of 3.70" (94.00 mm) and HAC-50 with two defined nominal anchor heights; 4.31" (109.50 mm) and 3.84" (97.50 mm). Moreover, defined channel length, EDGE Lite and EDGE Plate geometry, rebar lengths, anchor and rebar diameter, and number of rebar are also defined. The number of anchors per channels is pre-defined and may be modified and ordered upon request. Refer to section 2.4 and 2.5 for additional information about standard items and lead times. For custom solutions, refer to section 2.6.

The concrete edge shear confinement plate (EDGE Plate) is fixed to the form work or pour stop. The EDGE Plate comes with installation holes. As an added value, the product comes with the specified edge distance ($c_{a1}$).

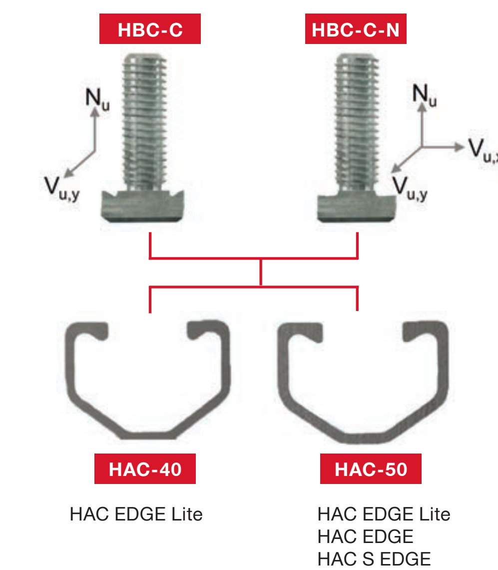
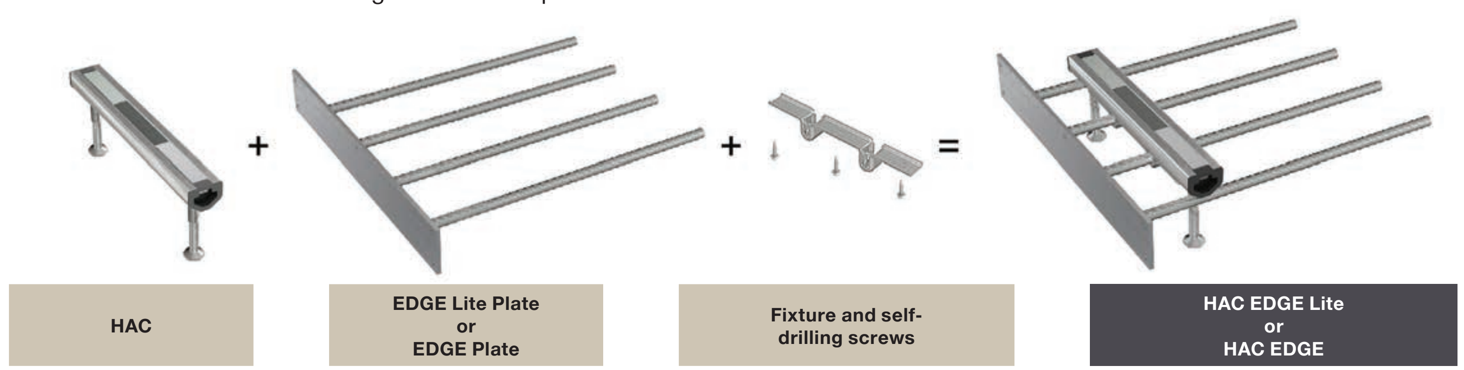



Figure 2.2.7.1 — HAC EDGE Lite, HAC EDGE, and HAC S EDGE profiles with matching bolts

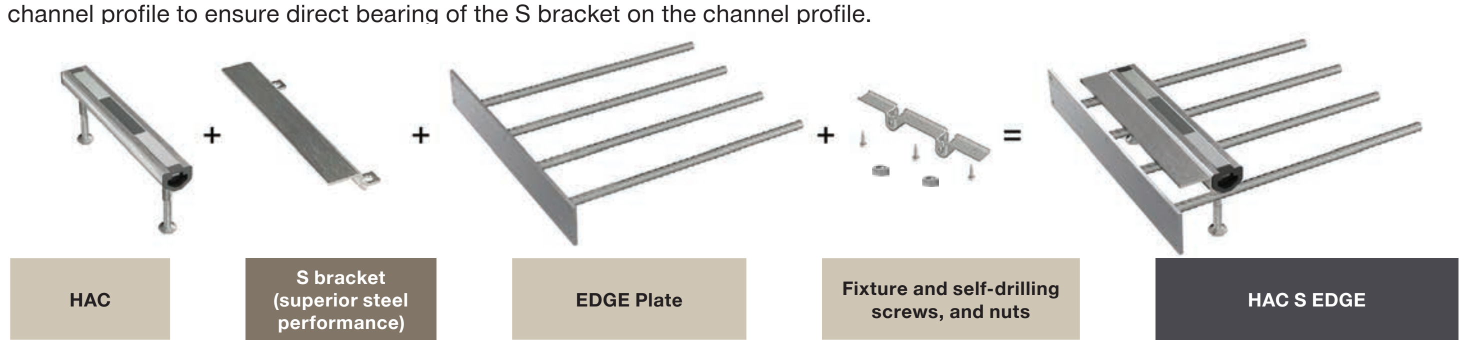
## HAC EDGE Lite and HAC EDGE

These anchor channel systems consist of HAC and the new rebar edge confinement plate (EDGE plate). The EDGE plate is not structurally attached to the anchor channel. This allows to decouple the tension and shear forces. The HAC-50 EDGE C comes with an offset rebar and increased height of the front plate.




## HAC S EDGE

This anchor channel is equal to its matching HAC EDGE, except the "S" bracket is added. The "S" bracket offers superior steel performance. The S bracket is structurally attached to the anchor channel. The S-bracket has a similar geometry to the connected channel profile to ensure direct bearing of the S bracket on the channel profile.



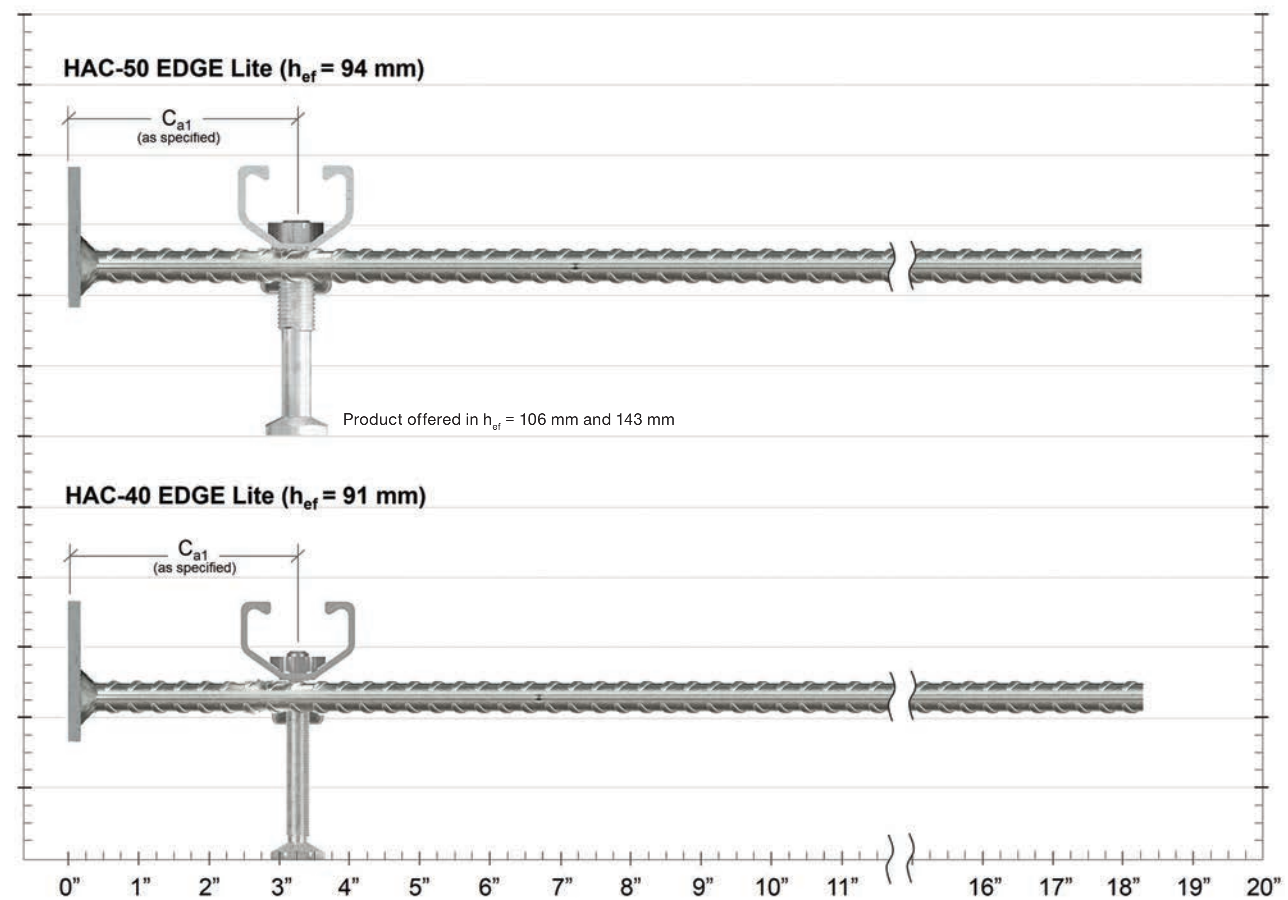



**Figure 2.2.7.2 — Section view of HAC-40 EDGE Lite and HAC-50 EDGE Lite.**

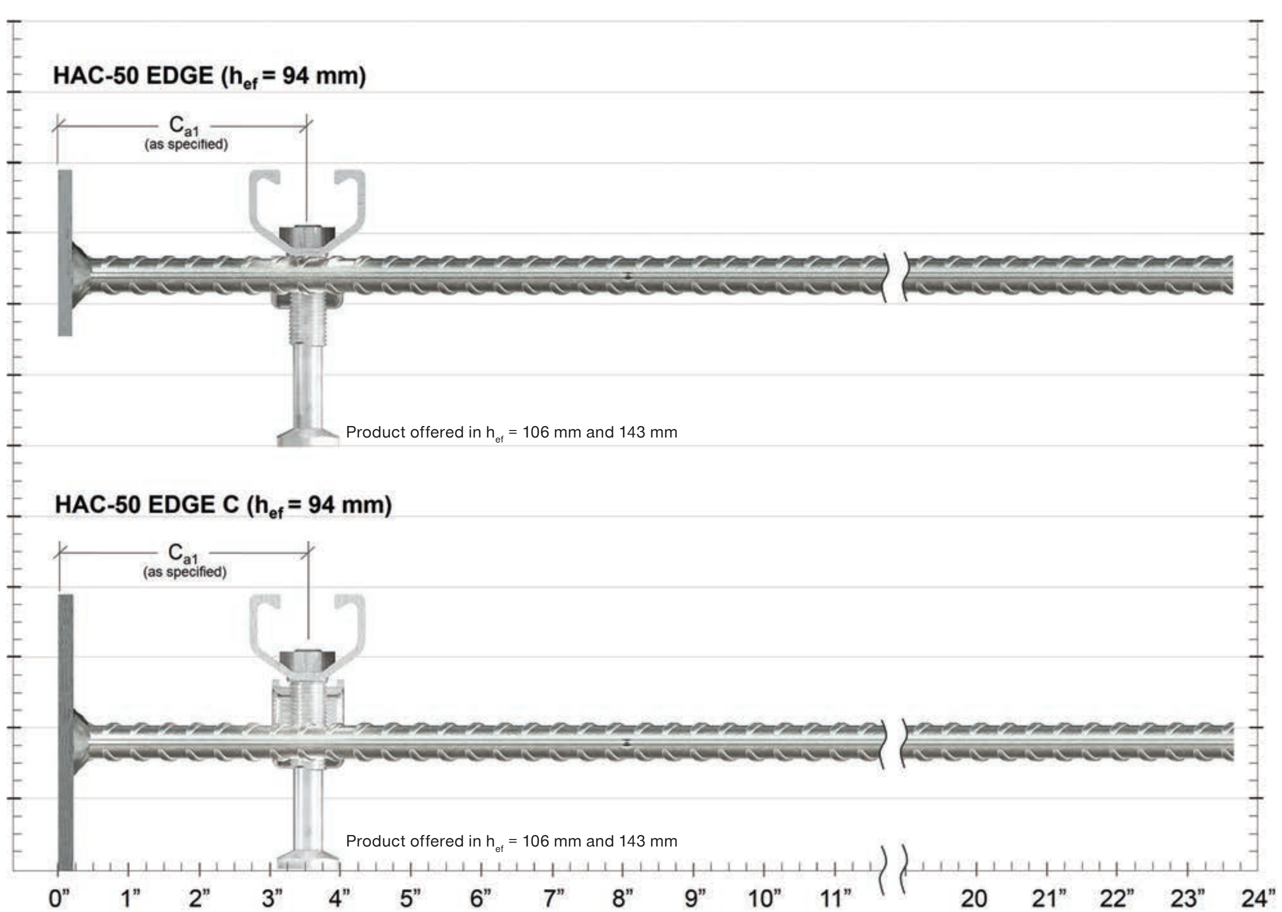



**Figure 2.2.7.3 — Section view of HAC-50 EDGE and HAC-50 EDGE C.**

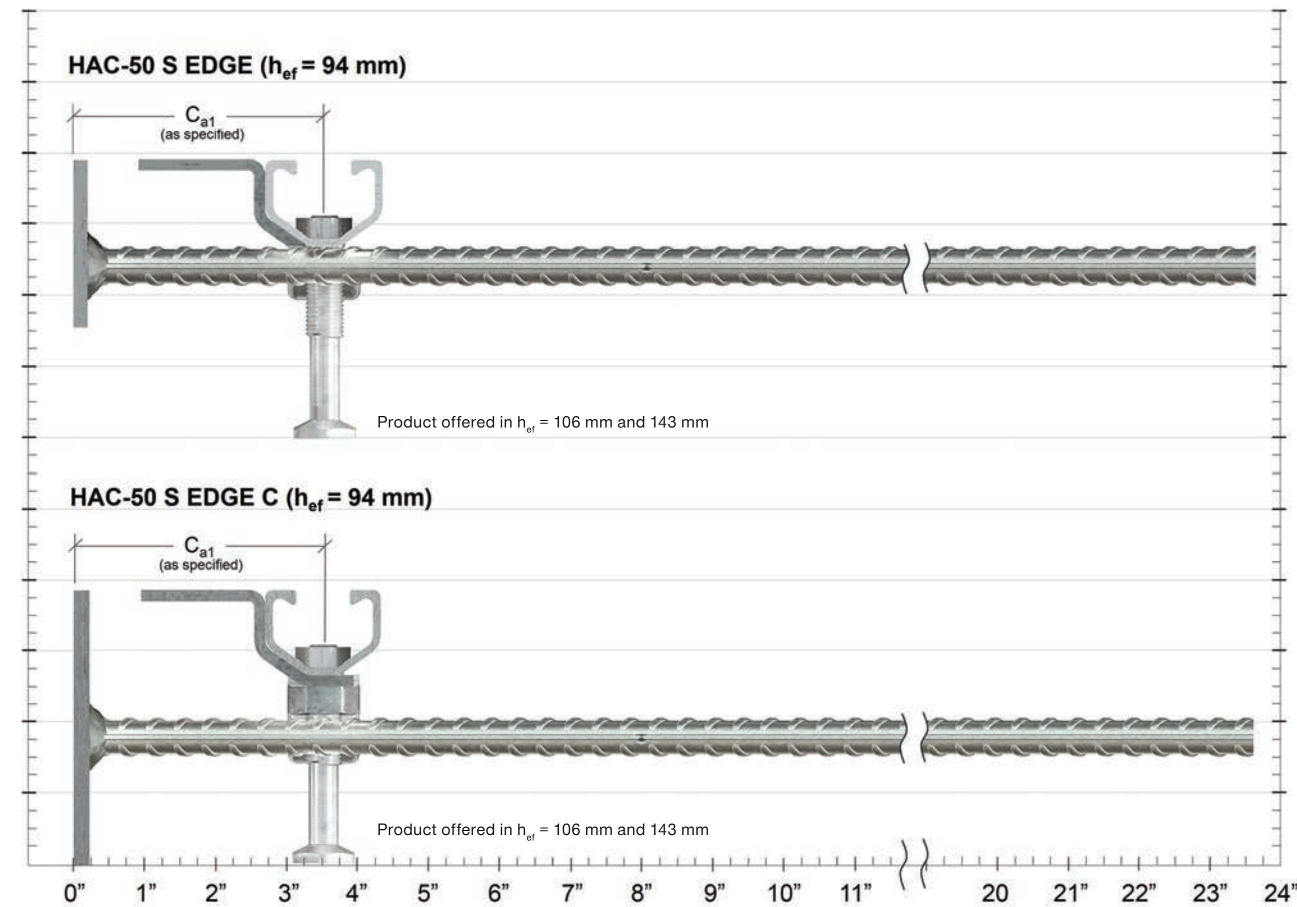



**Figure 2.2.7.4 — Section view of HAC-50 S EDGE and HAC-50 S EDGE C.**

HAC EDGE Lite, HAC EDGE, and HAC S EDGE utilize HAC-50 with rounded head anchors. HAC EDGE Lite is also offered in HAC-40. These are the same anchor channel covered by ICC ESR-3520. The HAC-50 with reduced embedment depth ($h_{ef}$ < 4.17" (106 mm)) is not covered by ESR-3520. Additional components are added to improve the concrete capacity in perpendicular shear and to provide superior steel performance in perpendicular shear.

Table 2.2.7.1 provides geometric parameters for the anchor channels that compose the HAC EDGE product line. Tables 2.2.7.2 and 2.2.7.3 provide geometric information about EDGE Lite and EDGE plate.

**Table 2.2.7.1 – Geometric parameters for HAC EDGE Lite, HAC EDGE, and HAC S EDGE[2]**

| Criteria | Symbol | Units | Anchor Channel | | |
|---|---|---|---|---|---|
| | | | HAC-40 EDGE Lite | HAC-50 EDGE Lite HAC-50 EDGE HAC-50 S EDGE | |
| Min. effective embedment depth | $h_{ef,min}$ | in (mm) | 3.58 (91.0) | 4.17 (106) | *3.70 (94) |
| Thickness of the anchor head | $t_h$ | in (mm) | 0.12 (3.00) | 0.14 (3.50) | |
| Nominal embedment depth | $h_{nom}$ | in (mm) | 3.70 (94.00) | 4.31 (109.5) | 3.84 (97.5) |
| Channel profile height | $h_{ch}$ | in (mm) | 1.10 (28.0) | 1.22 (31.0) | |
| Channel profile width | $b_{ch}$ | in (mm) | 1.61 (40.9) | 1.65 (41.9) | |
| Channel profile moment of inertia | $I_y$ | $in^4$ ($mm^4$) | 0.0516 (21,463) | 0.0796 (33,125) | |
| Channel profile opening | d | in (mm) | 0.77 (19.50) | 0.77 (19.50) | |
| Channel lip flange thickness | f | in (mm) | 0.18 (4.50) | 0.21 (5.30) | |
| Channel lip thickness (top) | $t_{nom,t}$ | in (mm) | 0.09 (2.25) | 0.11 (2.75) | |
| Channel lip thickness (bottom) | $t_{nom,b}$ | in (mm) | 0.09 (2.25) | 0.11 (2.75) | |
| Minimum end spacing | $x_{min}$ | in (mm) | 0.98 (25) | 0.98 (25) | |
| Anchor shaft diameter | $d_2$ | in (mm) | 0.28 (7.19) | 0.36 (9.03) | |
| Head diameter[1] | $d_1$ | in (mm) | 0.69 (17.50) | 0.77 (19.50) | |
| Anchor length | $l_A$ | in (mm) | 2.60 (66) | 3.09 (78.50) | 2.62 (66.5) |
| Minimum anchor spacing | $s_{min}$ | in (mm) | 3.94 (100) | 3.94 (100) | |
| Maximum anchor spacing | $s_{max}$ | in (mm) | 9.84 (250) | 9.84 (250) | |
| Net bearing area of the anchor head | $A_{brg}$ | $in^2$ ($mm^2$) | 0.324 (209) | 0.400 (258) | |
| Matching channel bolt | | | HBC-C, HBC-C 50R, HBC-C-N | | |
| Minimum channel bolt spacing | $s_{chb}$ | | 3 x bolt diameter | | |
| Nail hole location[3] | $x_{nail}$ | in (mm) | 1" offset from anchor (25.4 offset from anchor) | | |

1 The head diameter is the inner diameter of the hexagonal shaped head, and does not fully reflect the cross sectional area of the anchor head.
2 HAC EDGE C and HAC S EDGE C are the matching corner channel and have the same anchor channel as the intermediate HAC EDGE and HAC S EDGE. Although the shear confinement plate has different geometry, the anchor channel is the same.
* Effective embedment depth not covered by ICC ESR-3520.
3 Nail hole diameter is 4 mm (0.16 in.)

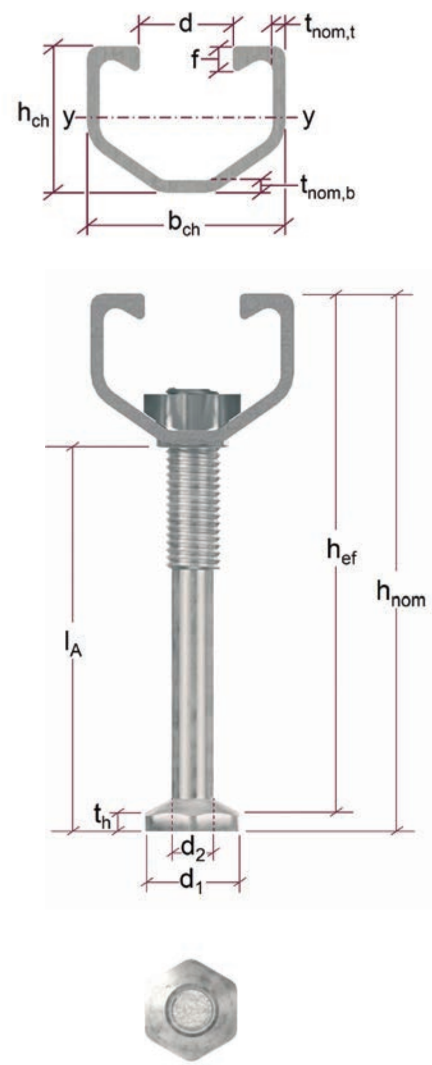



**Figure 2.2.7.5 a — Dimensions of the anchor channel of HAC EDGE Lite, HAC EDGE, and HAC S EDGE.**

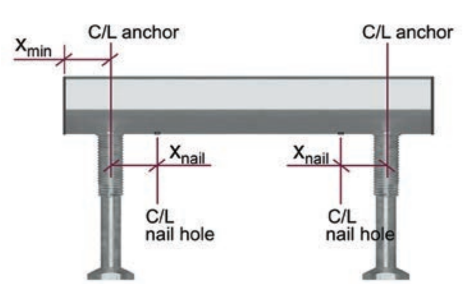



**Figure 2.2.7.5 b — HAC end and nail hole distance.**



**Table 2.2.7.2 — Geometric parameters of HAC EDGE Lite and HAC EDGE**

| Criteria | Symbol | Units | Anchor Channel | | | |
|---|---|---|---|---|---|---|
| | | | HAC-40 | HAC-50 | | |
| | | | EDGE Lite | EDGE Lite | EDGE | EDGE C |
| Thickness of the EDGE Lite or EDGE plate | $t_{pl}$ | in (mm) | 0.16 (4.00) | 0.16 (4.00) | 0.20 (5.00) | 0.24 (6.00) |
| Height of the EDGE Lite or EDGE plate | $h_{pl}$ | in (mm) | 1.97 (50) | 1.97 (50) | 2.36 (60) | 3.94 (100) |
| Projection of the EDGE Lite or EDGE plate | $x_{pl}$ | in (mm) | 0.99 (25) | 0.99 (25) | 1.97 (50) | |
| Length of the EDGE Lite or EDGE plate | $l_{pl}$ | in (mm) | Channel length + 2($x_{pl}$) | | | |
| Overall length of the EDGE Lite or EDGE plate rebars | $l_R$ | in (mm) | 18.11 (460) | | 23.62 (600) | |
| Rebar nominal diameter | $d_b$ | in (mm) | 0.31 (8) | 0.39 (10) | 0.47 (12) | |
| Bar effective cross-sectional area | $A_{se}$ | $in^2$ ($mm^2$) | 0.08 (50.27) | 0.12 (78.54) | 0.18 (113.1) | |
| Minimum rebar spacing | $s_{min,R}$ | in (mm) | 3.74 (95) | 3.74 (95) | 3.74 (95) | |
| Maximum rebar spacing | $s_{max,R}$ | in (mm) | 3.74 (95) | 3.74 (95) | 5.71 (145) | |
| C/C distance between the outer rebar and the outer anchor | $x_R$ | in (mm) | 0.295 (7.50) | 0.295 (7.50) | 0.295 (7.50) | |
| Distance from the end of the EDGE Lite or EDGE plate to the center of the installation hole[1] | $d_i$ | in (mm) | 0.40 (10) | | | |
| Edge distance (from outside face of EDGE Lite or EDGE plate to center of HAC anchor) | $c_{a1}$ | in (mm) | As specified | | | |
| Development length of rebars | $l_d$ | in (mm) | $l_R$ - $c_{a1}$ + $t_{pl}$ | | | |

1 Nail hole diameter is equal to 6 mm (0.25 in.)

**Figure 2.2.7.6 — Isometric view of HAC EDGE Lite and HAC EDGE.**

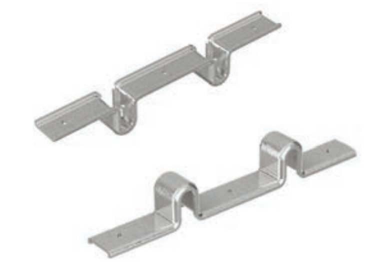


**Figure 2.2.7.7 — Isometric view of fixture that attaches the EDGE Lite or EDGE plate to HAC.**

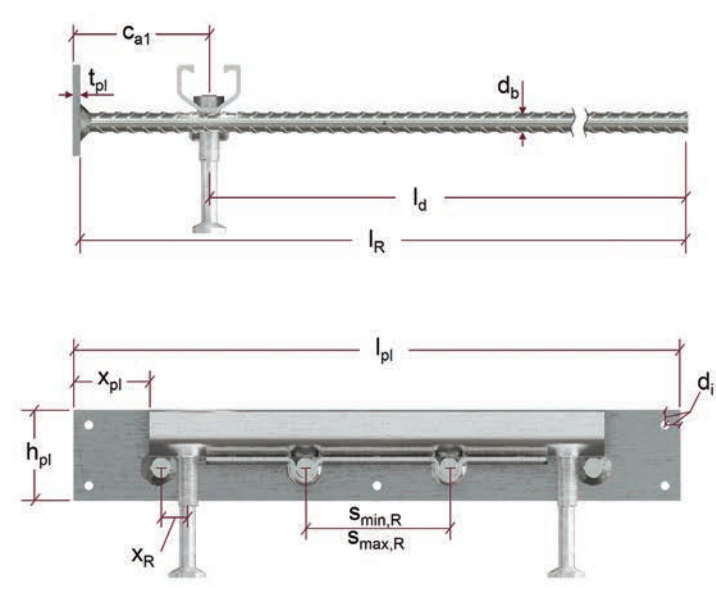
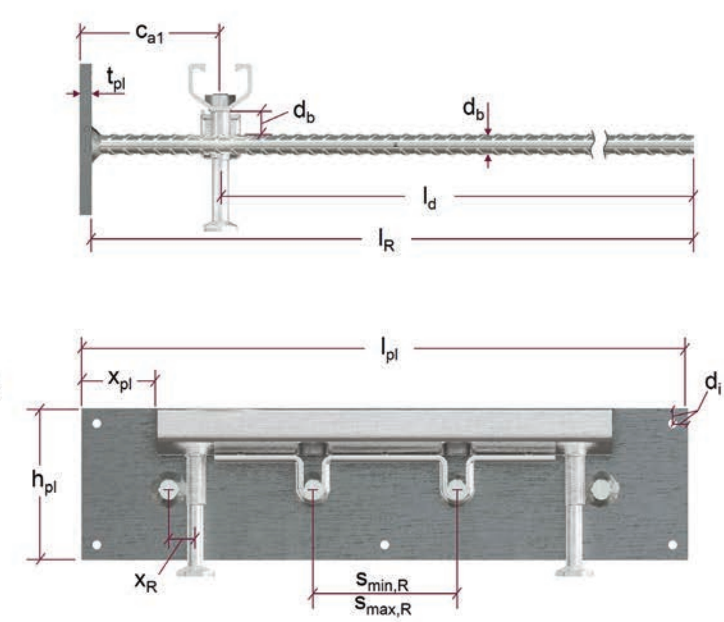



**Figure 2.2.7.8 — HAC EDGE Lite and HAC EDGE dimensions, section and elevation view.**




**HAC EDGE C has rebars that are located one rebar diameter below the bottom base of the anchor channel profile to avoid clashing with the rebars of the opposite corner channel (HAC EDGE). The plate is taller and thicker.**

**Figure 2.2.7.9 - HAC EDGE C dimensions, section and elevation view.**

**Table 2.2.7.3 — Geometric parameters for HAC S EDGE concrete edge shear confinement plate**

| Criteria | Symbol | Units | Anchor Channel HAC-50 S EDGE | Anchor Channel HAC-50 S EDGE C |
|---|---|---|---|---|
| Thickness of the EDGE plate | $t_{pl}$ | in (mm) | 0.20 (5.00) | 0.24 (6.00) |
| Height of the EDGE Plate | $h_{pl}$ | in (mm) | 2.36 (60) | 3.94 (100) |
| Projection of the EDGE plate | $x_{pl}$ | in (mm) | 1.97 (50) | |
| Length of the EDGE plate | $l_{pl}$ | in (mm) | Channel length + 2($x_{pl}$) | |
| Overall length of the EDGE plate rebars | $l_R$ | in (mm) | 23.62 (600) | |
| Rebar nominal diameter | $d_b$ | in (mm) | 0.47 (12) | |
| Bar effective cross-sectional area | $A_{se}$ | $in^2$ ($mm^2$) | 0.18 (113.1) | |
| Minimum rebar spacing | $s_{min,R}$ | in (mm) | 3.74 (95) | |
| Maximum rebar spacing | $s_{max,R}$ | in (mm) | 5.71 (145) | |
| C/C distance between the outer rebar and the outer anchor | $x_R$ | in (mm) | 0.295 (7.50) | |
| Distance from the end of the EDGE Lite or EDGE plate to the center of the installation hole[1] | $d_i$ | in (mm) | 0.40 (10) | |
| Edge distance (from outside face of EDGE Lite or EDGE plate to center of HAC anchor) | $c_{a1}$ | in (mm) | As specified | |
| Development length of rebars | $l_d$ | in (mm) | $l_R$ - $c_{a1}$ + $t_{pl}$ | |

1 Nail hole diameter is equal to 6 mm (0.25 in.)

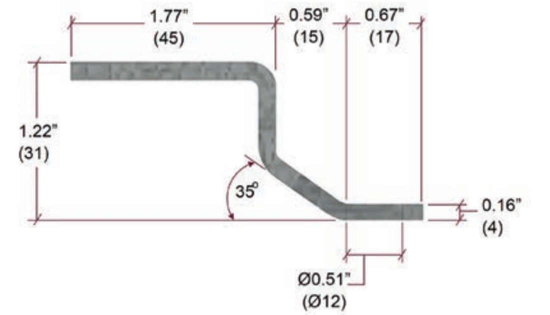



Figure 2.2.7.10 — Geometry of S bracket, section view.


Figure 2.2.7.11 — Isometric view of HAC-50 S.

Figure 2.2.7.12 — Isometric view of HAC-50 S EDGE.

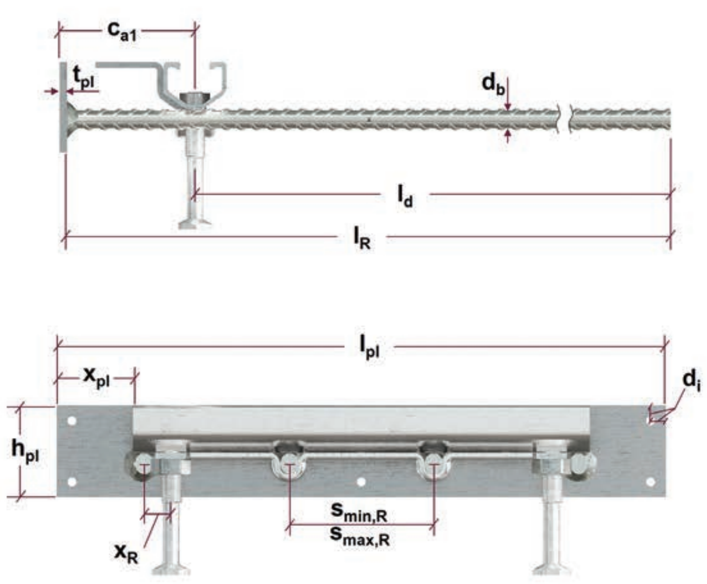
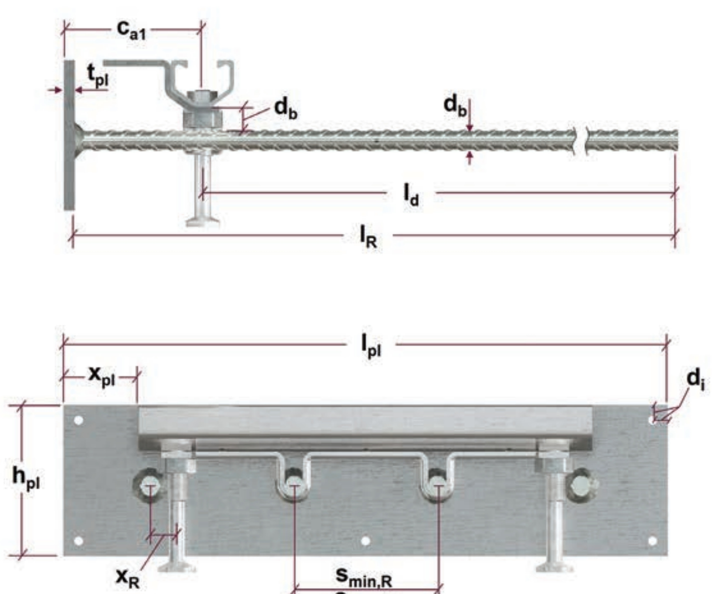



Figure 2.2.7.13 — HAC S EDGE dimensions, section and elevation view.




HAC S EDGE C has rebars that are located one rebar diameter below the bottom base of the anchor channel profile to avoid clashing with the rebars of the opposite corner channel (HAC S EDGE). The plate is taller and thicker.

Figure 2.2.7.14 — HAC S EDGE C dimensions, section and elevation view.

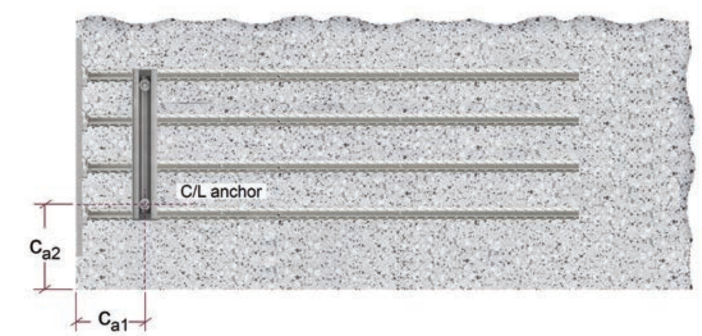


## Minimum substrate requirements for HAC EDGE Lite, HAC EDGE, and HAC S EDGE

Similarly to HAC, the minimum edge distances for HAC EDGE are established via testing. Although the HAC EDGE product line are not implicitly covered in AC232, AC232 provides testing protocols for anchor channels to establish the minimum edge and corner distance for the minimum member thickness. The following substrate requirements have been established in accordance with testing protocols of AC232.

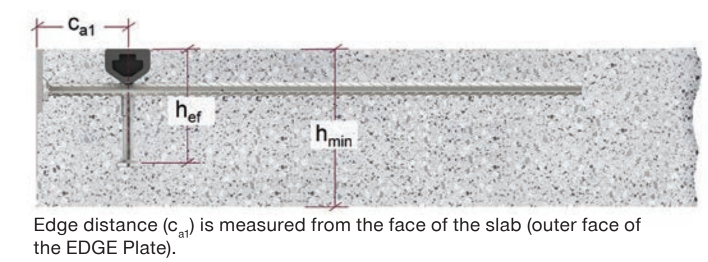
**Table 2.2.7.4 — Minimum substrate dimensions for HAC EDGE Lite, HAC EDGE, and HAC S EDGE**

| Anchor channel | Units | $h_{ef}$ | $*h_{min}$ | Normal weight concrete $c_{a1}$ | Normal weight concrete $c_{a2}$ | Sand lightweight and all lightweight concrete $c_{a1}$ | Sand lightweight and all lightweight concrete $c_{a2}$ |
|---|---|---|---|---|---|---|---|
| HAC-40 EDGE Lite | in (mm) | 3.58 (91) | 3.94 (100) | 1.97 (50) | 3.94 (100) | 3.94 (100) | |
| HAC-50 EDGE Lite | in (mm) | 3.70 (94) | | | | | |
| | in (mm) | 4.17 (106) | 4.92 (125) | | | | |
| HAC-50 EDGE | in (mm) | 3.70 (94) | 3.94 (100) | | | | |
| HAC-50 EDGE C | in (mm) | 4.17 (106) | 4.92 (125) | | | | |
| HAC-50 S EDGE | in (mm) | 3.70 (94) | 3.94 (100) | 3.94 (100) | | | |
| HAC-50 S EDGE C | in (mm) | 4.17 (106) | 4.92 (125) | | | | |




Corner and edge distances are measured to the center of the anchor.

Figure 2.2.7.15 — Minimum edge and corner distances for HAC EDGE Lite, HAC EDGE, and HAC S EDGE, plan view




Edge distance ($c_{a1}$) is measured from the face of the slab (outer face of the EDGE Plate).

Figure 2.2.7.16 — Minimum member thickness for HAC EDGE Lite, HAC EDGE, and HAC S EDGE, isometric section view.

## Minimum edge distance for anchor channels in composite slabs

The minimum edge and corner distances for HAC EDGE are consistent with the minimum requirements of HAC. In response to the market trends such as composite slabs with pockets, Hilti has added HAC EDGE with shorter anchor lengths.

For composite slabs where there is a pour stop along the perimeter of the edge of slab preventing oxygen from reaching out to the bottom of the slab and concrete cover of the anchor is not required, the minimum member thickness can be reduced.

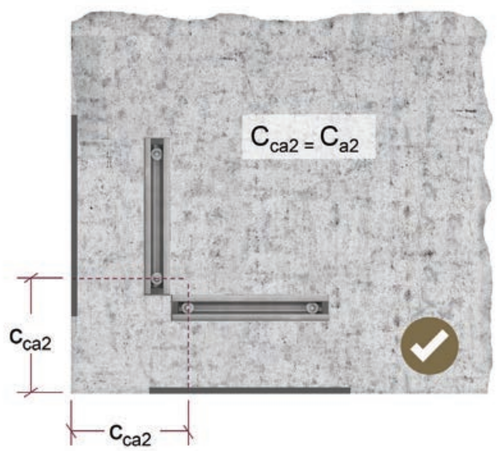
Chapters 8 and 9 provide design information for HAC EDGE in composite slabs and how to account for the potential negative influence of the metal deck.

Figure 2.2.7.17 — HAC EDGE in a composite slab, section view.

# 2.2.8 HAC EDGE AND HAC S EDGE IN TOP OR BOTTOM OF SLAB CORNERS

## Pair of HAC EDGE or HAC S EDGE in top of slab corner

HAC EDGE and HAC S EDGE are ideal for top of slab corner applications. Two independent anchor channels at the corner allows de-coupling the loads at both channels, preventing anchors and rebars from taking undesired loads. Furthermore, using two independent channels eases the installation in congested areas, preventing damage of the anchors during installation.




Corner distance $c_{ca2}$ is measured to the center of the anchor.

**Figure 2.2.8.1 — Corner configuration of pair of HAC EDGE in top of slab, plan view.**

The new Hilti design method for corners follows the principles of AC232 and allows the anchor channels to be installed as close as physically possible to the corner, as long as the minimum corner and edge distances are not exceeded. The use of HAC EDGE allows the concrete to take higher shear forces, making it the perfect solution for corner applications.

HAC EDGE at corner requires the use of HAC EDGE and HAC EDGE C. The EDGE C plate of HAC EDGE C comes with rebars that are located 1 rebar diameter below the bottom of the channel profile to prevent clashing of the rebars with the HAC EDGE.

HAC EDGE C and HAC EDGE C steel strengths are provided in section 2.3. For design of channels at corners, refer to Chapter 9.

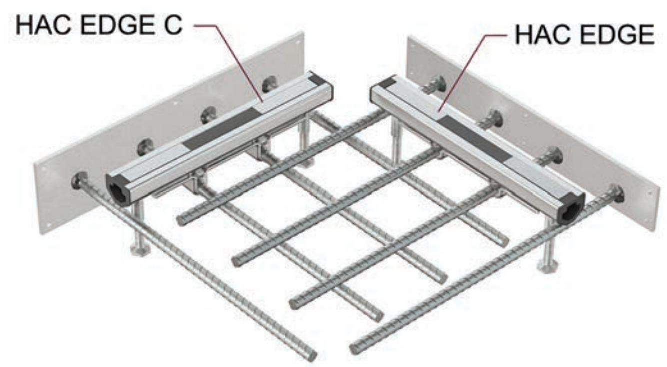



**Figure 2.2.8.2 — Isometric view of HAC EDGE and HAC EDGE C.**

## HAC EDGE and HAC S EDGE at non-90° corners

HAC EDGE C and HAC S EDGE C are suitable for non-90° corners. The use of two independent anchor channels simplifies the portfolio by no requiring custom made channels. See Chapter 9 for design information.

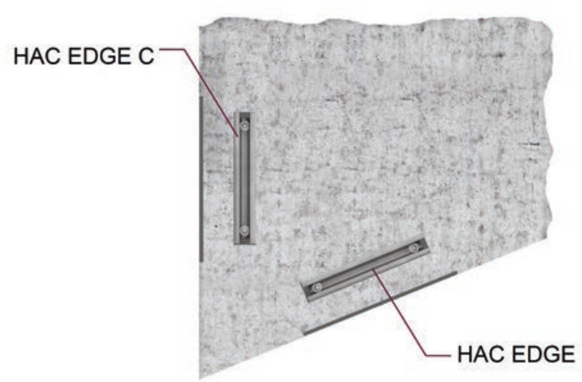



**Figure 2.2.8.3 — HAC EDGE and HAC EDGE C in an acute corner, plan view.**

**Table 2.2.8.1 — Minimum substrate edge and corner distance for pair of HAC EDGE and HAC S EDGE at a corner**

<table>
<tr><th colspan="4"></th><th colspan="2">Normal weight concrete</th><th colspan="2">Sand lightweight and all lightweight concrete</th></tr>
<tr><th>Anchor channel</th><th>Units</th><th>$h_{ef}$</th><th>$*h_{min}$</th><th>$c_{a1}$</th><th>$c_{a2}$</th><th>$c_{a1}$</th><th>$c_{a2}$</th></tr>
<tr><td>HAC-50 EDGE</td><td>in<br>(mm)</td><td>3.70<br>(94)</td><td>3.94<br>(100)</td><td rowspan="2">1.97<br>(50)</td><td rowspan="4">3.94<br>(100)</td><td colspan="2" rowspan="4">3.94<br>(100)</td></tr>
<tr><td>HAC-50 EDGE C</td><td>in<br>(mm)</td><td>4.17<br>(106)</td><td>4.92<br>(125)</td></tr>
<tr><td>HAC-50 S EDGE</td><td>in<br>(mm)</td><td>3.70<br>(94)</td><td>3.94<br>(100)</td><td rowspan="2">3.94<br>(100)</td></tr>
<tr><td>HAC-50 S EDGE C</td><td>in<br>(mm)</td><td>4.17<br>(106)</td><td>4.92<br>(125)</td></tr>
</table>



# 2.2.9 HILTI CHANNEL BOLTS

The Hilti Channel Bolts (HBC) are part of the anchor channel system. HBC are threaded fasteners commonly known as T-bolts. HBC are the link between the fixture and anchor channel. The HBC have a proprietary head geometry, therefore, and HBC are only compatible with Hilti Anchor Channels. The head of the HBC can be inserted along the channel cavity. The fixture is connected to the anchor channel by channel bolts with a nut and washer. Thus, allowing for the so desired jobsite tolerance.

The head of the t-bolt is first installed parallel to the channel profile. Once it is positioned in place, the bolt is turned 90° clockwise. The head of the bolt has been engineered in a way that the t-bolt cannot rotate more than 90° clockwise. This ensures the bolt is properly positioned before the required installation torque is applied.

HBC come with a special marking to ease the identification before and after installation takes place. All HBC are covered by ESR-3520.

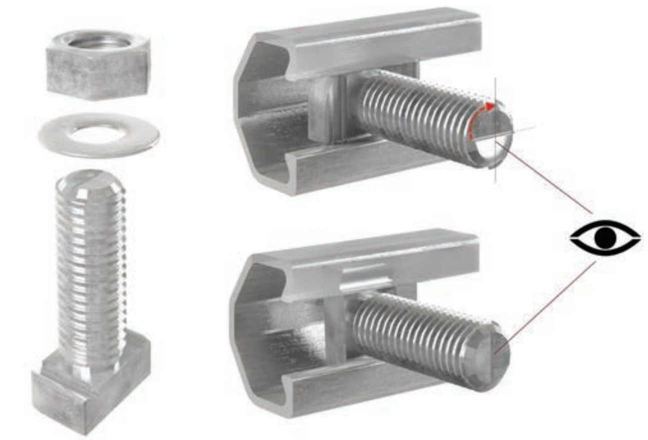


**Figure 2.2.9.1 — HBC-C, washer, and nut (left). HBC-C outside face inspection marking and installation (right).**

# 2.2.10 HILTI CHANNEL BOLTS: HBC-C

Hilti Channel Bolts — C (HBC-C) are suitable for channel profiles HAC-40, HAC-50, HAC-60, & HAC-70. HBC-C come in bolt diameters M12, M16, and M20, steel grades 8.8 and 50, finishing and materials HDG and SS, respectively

HBC-C can be used to transfer tensile loads, shear loads perpendicular to the longitudinal channel axis, or any combination of these loads. Transferring of the loads takes place via interlock between the HBC and the channel lips.

**Table 2.2.10.1 — Hilti Channel Bolts (HBC-C) material information**

| Channel bolt | Units | Carbon steel[1] | Stainless steel[1] |
|---|---|---|---|
| Property class | - | 8.8 | A4-50 |
| $f_u$ | ksi<br>(N/mm²) | 116.0<br>(800) | 72.5<br>(500) |
| $f_y$ | ksi<br>(N/mm²) | 92.82<br>(640) | 30.4<br>(210) |
| Coating | | F[2] | - |

1 Materials according to Annex 3, Table 1
2 Hot-dop galvanized


**Figure 2.2.10.1 — T-bolt marking.**



HBC-C 8.8 F M12 HBC-C 50 R M12

**Figure 2.2.10.2 — Hot dip galvanized t-bolt (left) and stainless steel t-bolt (right).**

Special markings on the outer surface of the t-bolt aids the installer to ensure the t-bolt is properly positioned before the installation torque is applied. Moreover, it allows the installer and inspector to identify the type of bolt, after the fixture is installed. Once the fixture is installed, the head of the t-bolt is no longer visible and the only visible part of the t-bolt is its outer face.

## Hilti Channel Bolt Length (HBC-C)

**Table 2.2.10.2 — Hilti Channel Bolts dimensions**

| Channel Bolt | Anchor Channel Profile | Units | Dimensions | | | | Channel bolt length |
|---|---|---|---|---|---|---|---|
| | | | Diameter ø | $b_1$ | $b_2$ | k | L |
| HBC-C | HAC-40<br>HAC-50<br>HAC-50 S<br>HAC-60<br>HAC-70 | mm<br>(in) | M12 | 14<br>(0.55) | 33<br>(1.30) | 10.4<br>(0.41) | 40-200<br>(1.57-7.87) |
| | | mm<br>(in) | M16 | 18.5<br>(0.73) | | 11.4<br>(0.45) | 40-200<br>(1.57-7.87) |
| | | mm<br>(in) | M20 | | | 13.9<br>(0.55) | 60-200<br>(2.36-7.87) |

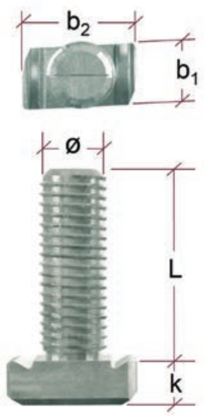



**Table 2.2.10.3 — Channel lip thickness**

| Anchor Channel profile | Channel lip thickness, $L_{th}$ |
|---|---|
| HAC-40 | 7/64 in<br>(2.6 mm) |
| HAC-50<br>HAC-50 S | 1/8 in<br>(3.10 mm) |
| HAC-60 | 5/32 in<br>(4.1 mm) |
| HAC-70 | 13/64 in<br>(5.2 mm) |

## Minimum t-bolt overhang

According to AISC Steel Construction Manual, 13th Edition, Section 14-10 “Adequate thread engagement for anchor rods is identical to the condition described in the RCSC Specification as adequate for steel to steel structural joints using high strength bolts: having the end of the [anchor rod] flush with or outside the face of the nut”.

There is no maximum thread protrusion limitation from the standpoint of the function of the bolt.

If needed, the excess at the end of the bolt can be cut-off. The nut shall be fully engaged. The outside face of the head of the t-bolt has special markings to identify the t-bolt type and proper head orientation of the t-bolt. If the t-bolt is to be cut or grind, inspect and ensure the orientation and t-bolt type is as specified prior to any work on the t-bolt. If the marking on the t-bolt are removed, proper inspection is not possible. Proper corrosion protection shall be required.

Although there is minimum t-bolt overhang (Lo) can be zero, for tolerance purposes it is recommended to have a minimum t-bolt overhang. Table 2.2.10.4 provides the minimum t-bolt overhang length.

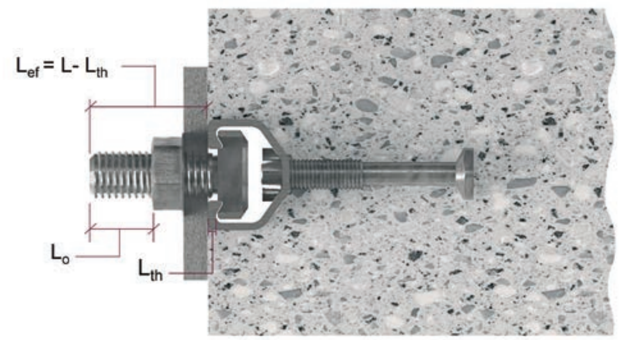



Figure 2.2.10.3 – Overhang of Hilti Channel Bolts (HBC-C).

**Table 2.2.10.4 — Recommended t-bolt overhang, $L_o$**

| Hilti locking channel bolt diameter (mm) | Minimum nominal overhang, $L_o$ |
|---|---|
| M12 | 1/8 in<br>(3 mm) |
| M16 | 13/64 in<br>(5 mm) |
| M20 | 9/32 in<br>(7 mm |

## Installation torque of HBC-C

**Table 2.2.10.5 — Installation torque for Hilti Channel Bolts (HBC-C)**

| Bolt type | Units | Installation torque $T_{inst}$ (Installation type A)[1] | | | | Installation torque $T_{inst}$ (Installation type B)[2] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | HAC-40 | HAC-50 | HAC-60 | HAC-70 | HAC-40 | HAC-50 | HAC-60 | HAC-70 |
| HBC-C M12 8.8 | ft-lb<br>(Nm) | 19<br>(25) | | | | 55<br>(75) | | | |
| HBC-C M16 8.8 | ft-lb<br>(Nm) | 44<br>(60) | | | | 136<br>(185) | | | |
| HBC-C M16 50 R | ft-lb<br>(Nm) | 44<br>(60) | | | | 44<br>(60) | | | |
| HBC-C M20 8.8 | ft-lb<br>(Nm) | 52<br>(70) | 78<br>(105) | 89<br>(120) | | 236<br>(320) | | | |

1 Installation type A: The fixture is in contact with the channel profile and the concrete surface
2 Installation type B: The fixture is fastened to the anchor channel by suitable steel part (e.g. square plate washer), fixture is in contact with the channel profile only



# 2.2.11 HILTI LOCKING CHANNEL BOLTS: HBC-C-N

Hilti Locking Channel Bolts (HBC-C-N) are suitable for channel profiles HAC-40, HAC-50, HAC-60, & HAC-70. HBC-C-N come in bolt diameters M12, M16, and M20, steel grade 8.8, and HDG finishing. All HBC-C-N are covered by ESR-3520.

HBC-C-N can be used to transfer tensile loads, shear loads perpendicular to the longitudinal channel axis, longitudinal shear forces, or any combination of these loads. Transferring the loads takes place via interlock between the head of the HBC-C-N and the channel lips.

## Longitudinal load transfer mechanism

The inside head of the HBC-C-N has 4 hardened notches. After the required installation torque is applied, the head of the t-bolt “bites” into the channel lips, creating four (4) - 2 mm deep “notches” in the channel lip. Hence, a positive connection between channel lip and t-bolt head is created. The longitudinal shear resistance of the HBC-C-N and HAC is achieved via mechanical interlock between the channel lips and head of the notched bolt. The load transfer mechanism ensures full load capacity, even if the nut experiences up to 50 percent relaxation.

The notches created in the channel lips reduce the moment of inertia of the channel profile. Therefore, the flexural strength of the anchor channel in tension is reduced by 10-15 percent, depending on the anchor channel profile size. Corrosion of the notches is not a concern due to the tight sealing that occurs during the installation torque.

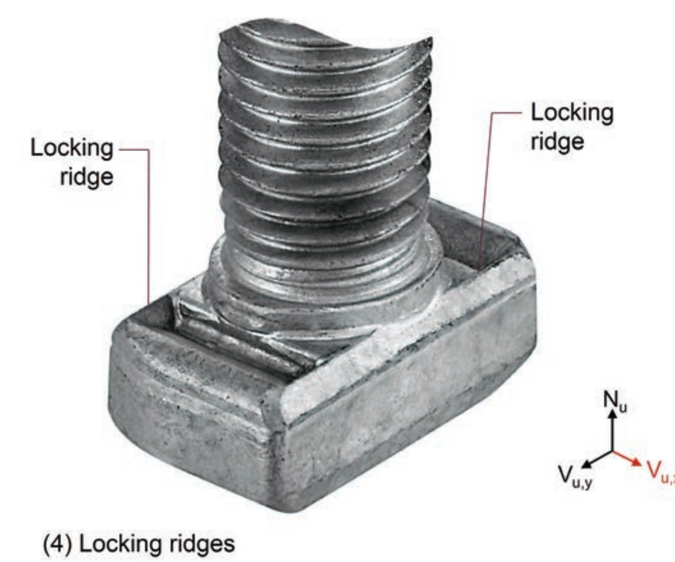



Figure 2.2.11.1 — Head of Hilti Locking Channel Bolt (HBC-C-N).

## Can longitudinal shear loads be resisted via friction?

Although longitudinal shear forces may be justified via friction, AC232 requires a positive connection between T-bolt and channel lip. Due to different installation uncertainties, long-term relaxation, and performance variance, Hilti does not recommend the use of friction as a means of transferring longitudinal loads, especially seismic loads.

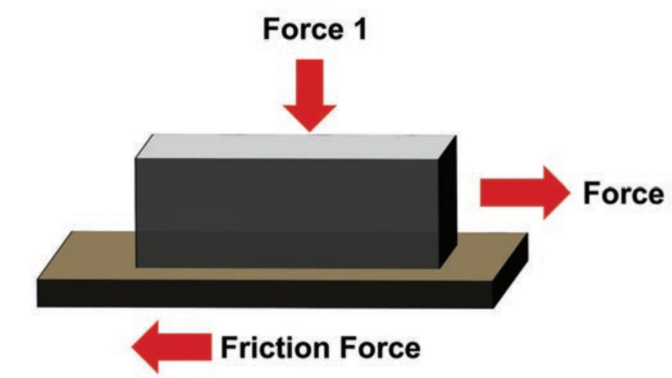



Figure 2.2.11.2 — Friction.

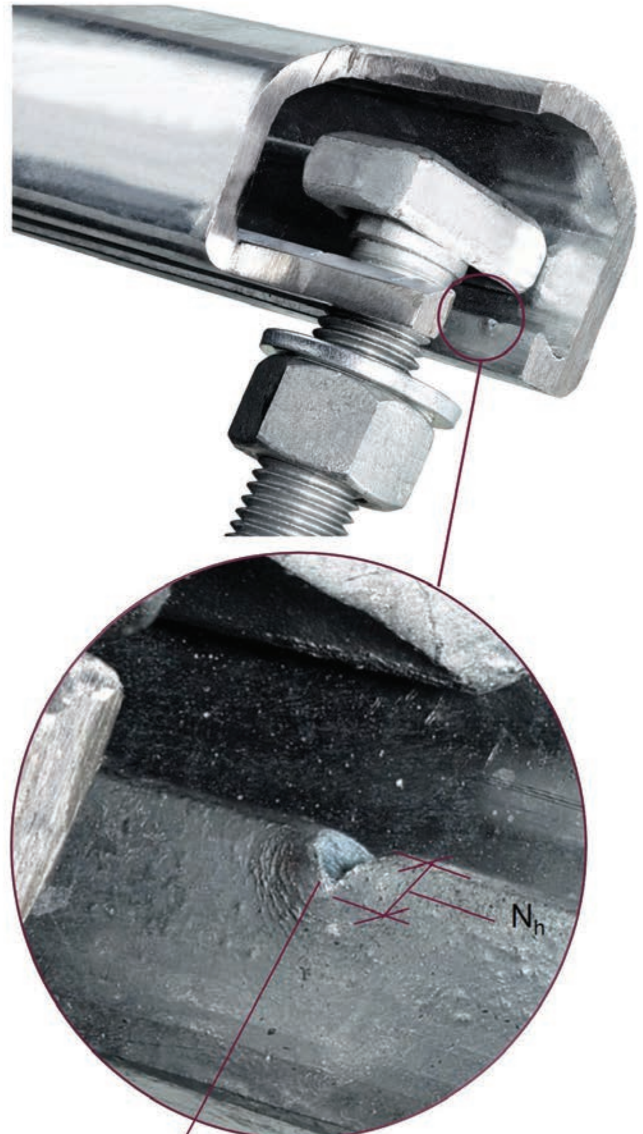
## Special channel bolt markings

Special markings on the t-bolt aid the installer to ensure the bolt is properly positioned before the installation torque is applied. Moreover, it allows the installer and inspector to identify the type of bolt, after the fixture is installed.


Figure 2.2.11.3 — T-bolt marking.

## Mechanical interlock between channel lip and locking channel bolts via channel lip notches


Figure 2.2.11.4 – Notches in channel lips due to HBC-C-N.




Notch in channel lip created by HBC-C-N after installation torque; 4 total.

**Table 2.2.11.1 — Depth of notches created by Hilti Locking Channel Bolts (HBC-C-N)**

| Channel Bolt | Diameter (mm) | $N_h$ |
|---|---|---|
| | 12 | 2 mm |
| | 16 | 2 mm |
| | 20 | 2 mm |

The extra 2 mm shall be considered when determining the protruding length ( $l_{ef}$) of the Hilti Locking Channel Bolt

## Hilti Locking Channel bolt grade

**Table 2.2.11.2 — Hilti Locking Channel Bolts (HBC-C-N) material information**

| Channel bolt | Units | Carbon steel[1] |
|---|---|---|
| Property class | - | 8.8 |
| $f_u$ | ksi (N/mm²) | 116.0 (800) |
| $f_y$ | ksi (N/mm²) | 92.82 (640) |
| Coating | | F[2] |

1 Materials according to Annex 3, Table 1
2 Hot-dop galvanized

## Hilti Locking Channel Bolt Length

**Table 2.2.11.3 — Hilti Locking Channel Bolts dimensions**

| Channel Bolt | Anchor Channel Profile | units | Dimensions | | | | Channel bolt length |
|---|---|---|---|---|---|---|---|
| | | | Diameter ø | $b_1$ | $b_2$ | k | L |
| HBC-C-N | HAC-40 HAC-50 HAC-50 S HAC-60 HAC-70 | mm (in) | M12 | 18.5 (0.73) | 33 (1.30) | 11.4 (0.45) | 40 (1.57-7.87) |
| | | mm (in) | M16 | | | | 40-300 (1.57-7.87) |
| | | mm (in) | M20 | | | 13.9 (0.55) | 60-300 (2.36-7.87) |

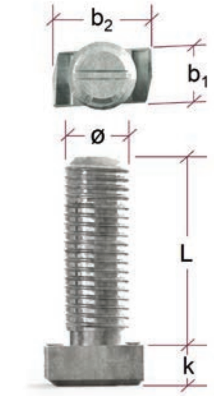
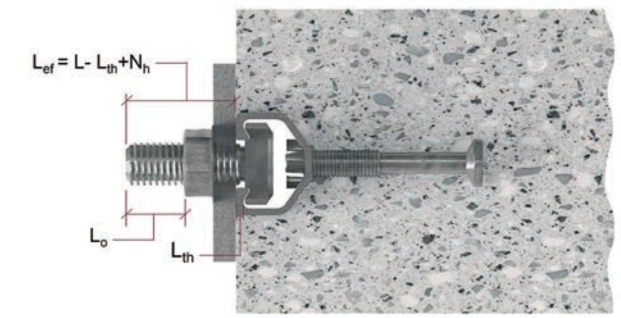



**Table 2.2.11.4 — Channel lip thickness**

| Anchor Channel profile | Channel lip thickness, $L_{th}$ |
|---|---|
| HAC-40 | 7/64 in (2.6 mm) |
| HAC-50 HAC-50 S | 1/8 in (3.10 mm) |
| HAC-60 | 5/32 in (4.1 mm) |
| HAC-70 | 13/64 in (5.2 mm) |




$N_h$ occurs after the installation torque is applied to the HBC-C-N t-bolt and the 2 mm deep notches are created in the lips of the anchor channel.

**Figure 2.2.11.5 — Overhang of Hilti Locking Channel Bolt (HBC-C-N).**

## Minimum bolt overhang

According to AISC Steel Construction Manual, 13th Edition, Section 14-10: "Adequate thread engagement for anchor rods is identical to the condition described in the RCSC Specification as adequate for steel to steel structural joints using high strength bolts: having the end of the [anchor rod] flush with or outside the face of the nut".

There is no maximum thread protrusion limitation from the standpoint of the function of the bolt.

If needed, the excess at the end of the bolt can be cut-off. The nut shall be fully engaged. The outside face of the head of the t-bolt has special markings to identify the t-bolt type and proper head orientation of the t-bolt. If the t-bolt is to be cut or grind, inspect and ensure the orientation and t-bolt type is as specified.

**Table 2.2.11.5 — Recommended t-bolt overhang, $L_o$**

| Hilti locking channel bolt diameter (mm) | Minimum nominal overhang, $L_o$ |
|---|---|
| M12 | 1/8 in (3 mm) |
| M16 | 13/64 in (5 mm) |
| M20 | 9/32 in (7 mm) |

Although there is minimum t-bolt overhang (Lo) can be zero, for tolerance purposes it is recommended to have a minimum t-bolt overhang. Table 2.2.11.5 provides the minimum t-bolt overhang length.

## Installation Torque

**Table 8-2 — Installation torque for Hilti Locking Channel Bolts (HBC-C-N)**

| Bolt type | Units | Installation torque $T_{inst}$ (Installation type A)[1] | | | | Installation torque $T_{inst}$ (Installation type B)[2] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | HAC-40 | HAC-50 HAC-50 S | HAC-60 | HAC-70 | HAC-40 | HAC-50 HAC-50 S | HAC-60 | HAC-70 |
| HBC-C-N M12 8.8 | ft-lb (Nm) | 55 (75) | | | | | | | |
| HBC-C M16 8.8 | ft-lb (Nm) | 136 (185) | | | | | | | |
| HBC-C-N M20 8.8 | ft-lb (Nm) | 236 (320) | | | | | | | |

1 Installation type A: The fixture is in contact with the channel profile and the concrete surface
2 Installation type B: The fixture is fastened to the anchor channel by suitable steel part (e.g. square plate washer), fixture is in contact with the channel profile only

# 2.2.12 HILTI CHANNEL BOLTS HARDWARE

## Hexagonal head nut

Anchor channel systems consist of a group of anchors, channel profile, and matching t-bolt. The t-bolt hardware consists of a hex head nut and a flat washer.

**Table 2.2.12.1 — Material specifications of HBC-C and HBC-C-N Nuts**

| Material specifications | |
|---|---|
| **Material** | ASTM A 563 Grade A; Stainless Steel 316 |
| **Dimensions** | ASME/ANSI B18.2.2 - 1986 |
| **Finish** | ASTM B 633-98, SC 1 Type I |
| **Thread** | Class 2A fit; Class 2B thrd; ASME B1.1 |

**Figure 2.2.12.1 — Isometric view of HBC-C and HBC-C-N nut.**

**Table 2.2.12.2 — HBC-C and HBC-C-N nut dimensions**

| Criteria | | units | M12 | M16 | M20 |
|---|---|---|---|---|---|
| $p_a$ (pitch size) | | mm | 1.75 | 2.00 | 2.50 |
| c | max. | mm | 0.60 | 0.80 | 0.80 |
| | min. | mm | 0.15 | 0.20 | 0.20 |
| $d_a$ | max. | mm | 13.00 | 17.30 | 21.60 |
| | min. | mm | 12.00 | 16.00 | 20.00 |
| $d_w$ | min. | mm | 16.60 | 22.50 | 27.70 |
| e | min. | mm | 20.03 | 26.75 | 32.95 |
| m | max. | mm | 10.80 | 14.80 | 18.00 |
| | min. | mm | 10.37 | 14.10 | 16.90 |
| $m_w$ | min. | mm | 8.30 | 11.30 | 13.50 |
| s | max. | mm | 18.00 | 24.00 | 30.00 |
| | min. | mm | 17.73 | 23.67 | 29.16 |

Different surfaces and materials might have a significant influence on the ratio between torque moment and pre-tension. Therefore, it is important to use the washer as per product approval or recommended by Hilti.

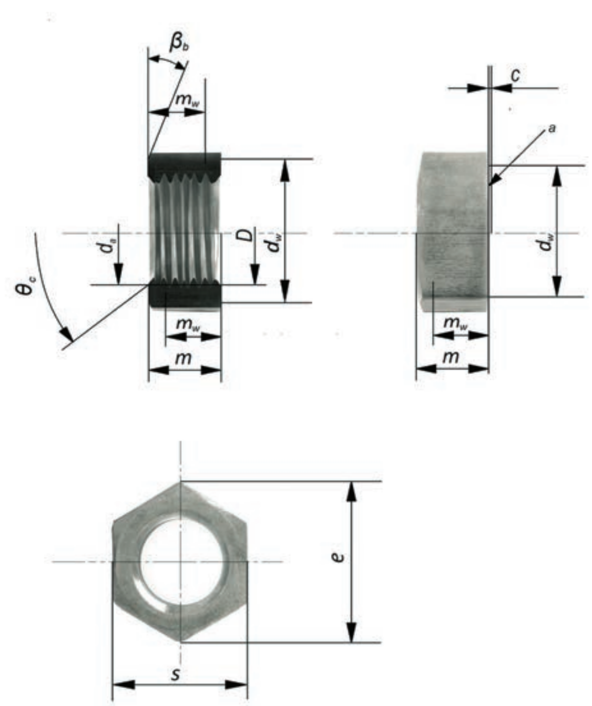



**Figure 2.2.12.2 — HBC-C and HBC-C-N nut dimensions.**

## Flat washers

Flat washers ensure compression forces (due to installation torque) from the nut are distributed over a larger surface, preventing localized damage of the base surface. Moreover, it ensures the nut presses against a smooth surface, reducing the probability of relaxation of the nut, as is the case when the nut bears against uneven surfaces.

**Table 2.2.12.3 — Material specification of HBC-C and HBC-C-N washers**

| Material specifications | |
|---|---|
| **Material** | Carbon steel, Hardness A, 200 HV |
| **Specifications** | ISO 7089 and ISO 7093-1 |
| **Finish** | ASTM B 633-98, SC 1 Type I |

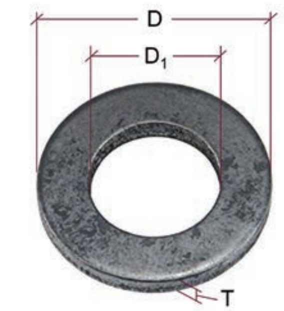



**Figure 2.2.12.3 — HBC-C and HBC-C-N washer dimensions.**

# 2.2.13 SERRATED ANCHOR CHANNELS: HAC-T AND HAC-30

Hilti Anchor Channel with serrated channel lips (HAC-30 and HAC-T) is a cast-in solution for applications that require on-site adjustability and slip resistances along the long axis of the anchor channel resulting from loads such as seismic wind, live, gravity or other.

HAC-30 profile is cold formed and although its name does not include "-T", the profile comes with serrated lips. HAC-30 is for low range loads.

The innovative manufacturing technology allows HAC-T to offer slip resistances that require up to 58 percent lower installation torques than existing technologies without compromising the price point or performance of the anchorage. Because of the lower installation torque, the installation time per connection can be reduced and muscle fatigue may be avoided. HAC-30 and HAC-T are fully covered by the International Council Code Evaluation Service Report 3520 (ESR-3520).

Hilti Anchor Channels with serrated channel lips (HAC-T) are offered in two channel profile sizes; HAC-T50 and HAC-T70. Hilti Serrated Channel Bolts (HBC-T) are suitable for all HAC-T profiles. HAC-T50 and HAC-T70 profiles are utilized in all different types of anchor channels.

Hilti Serrated Anchor Channel (HAC-T) come with a serrated channel profile and rounded head anchors. Pre-formed serrations allows the channel to resist longitudinal shear loads via a positive connection with lower installation torque.

The standard portfolio consists of HAC30, HAC-T50, and HAC-T70 channels profiles with pre-defined channel length, rebar lengths, number of anchors, and defined rebar diameter. Non-standard anchor channels (i.e. custom channel length, rebar length, number of rebars etc.) can be provided upon request. Refer to section 2.4, 2.5, and 2.6 for additional information about standard items lead times, and custom anchor channels.

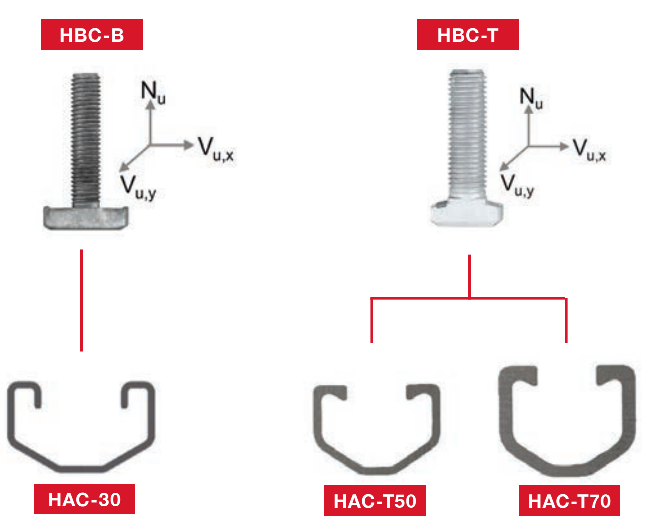


Figure 2.2.13.1 — HAC-30 (left) and HAC-T (right) profiles with matching channel bolts.


Figure 2.2.13.1 — Hilti Serrated Anchor Channel (HAC-T)

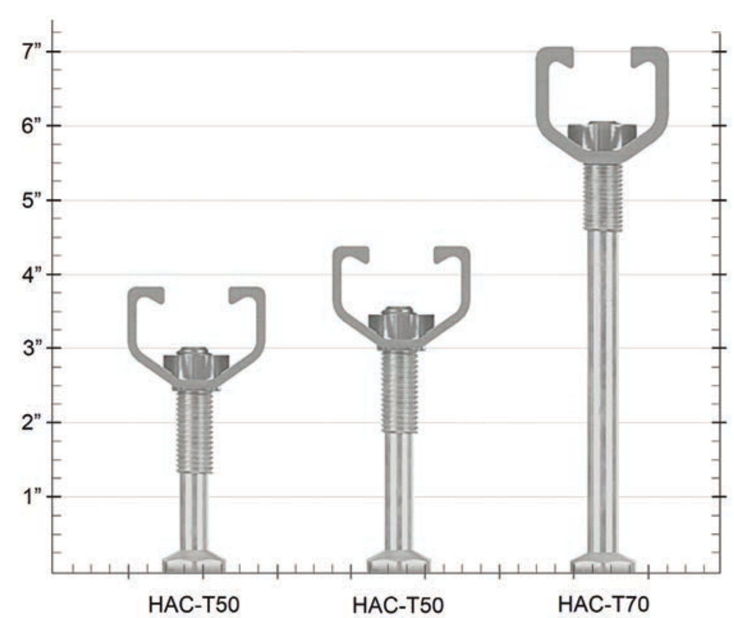


Figure 2.2.13.3 — Section view of HAC-T50 and HAC-T70

**Table 2.2.13.1 — Geometric parameters of serrated anchor channels**

| Criteria | Symbol | units | Anchor channel size: HAC-30 | HAC-T50 | | HAC-T70 |
|---|---|---|---|---|---|---|
| Channel profile height | $h_{ch}$ | in (mm) | 1.01 (25.6) | 1.22 (31) | | 1.57 (40) |
| Channel profile width | $b_{ch}$ | in (mm) | 1.63 (41.3) | 1.65 (41.9) | | 1.79 (45.4) |
| Channel profile moment of inertia | $I_y$ | $in^4$ ($mm^4$) | 0.0369 (15,349) | 0.0770 (32,049) | | 0.2215 (92,192) |
| Channel profile opening | d | in (mm) | 0.88 (22.30) | 0.77 (19.50) | | 0.77 (19.50) |
| Channel lip flange thickness | f | in (mm) | 0.30 (7.50) | 0.21 (5.30) | | 0.3 (7.40) |
| Channel lip thickness (top) | $t_{nom,t}$ | in (mm) | 0.079 (2.00) | 0.11 (2.75) | | 0.18 (4.50) |
| Channel lip thickness (bottom) | $t_{nom,b}$ | in (mm) | 0.079 (2.00) | 0.11 (2.75) | | 0.18 (4.50) |
| Serration height | $S_h$ | in (mm) | 0.057 (1.45) | 0.057 (1.45) | | |
| Serration spacing | $s_s$ | in (mm) | 0.118 (3.00) | 0.118 (3.00) | | |
| Min. effective embedment depth[1] | $h_{ef,min}$ | in (mm) | 2.68 (68) | 3.70 (94) | 4.17 (106) | 6.89 (175) |
| Thickness of the anchor head | $t_h$ | in (mm) | 0.08 (2.0) | 0.14 (3.5) | | 0.20 (5.0) |
| Nominal embedment depth[2] | $h_{nom}$ | in (mm) | 2.76 (70) | 3.84 (97.50) | 4.31 (109.5) | 7.09 (180) |
| Minimum end spacing | $x_{min}$ | in (mm) | 0.98 (25) | 0.98 (25) | | 0.98 (25) |
| Anchor shaft diameter | $d_2$ | in (mm) | 0.21 (5.35) | 0.36 (9.03) | | 0.43 (10.86) |
| Head diameter[3] | $d_1$ | in (mm) | 0.45 (11.5) | 0.77 (19.50) | | 0.91 (23.00) |
| Anchor length | $l_A$ | in (mm) | 1.75 (44.40) | 2.62 (66.50) | 3.09 (78.5) | 5.51 (140.00) |
| Minimum anchor spacing | $s_{min}$ | in (mm) | 1.97 | 3.94 (100) | | 3.94 (100) |
| Maximum anchor spacing | $s_{max}$ | in (mm) | 9.84 (250) | 9.84 (250) | | 9.84 (250) |
| Net bearing area of the anchor head | $A_{brg}$ | $in^2$ ($mm^2$) | 0.138 (89) | 0.4 (258) | | 0.552 (356) |
| Matching channel bolt | | | HBC-B | HBC-T | | |
| Minimum channel bolt spacing | $s_{chb}$ | | 3 x bolt diameter | | | |
| Nail hole location[3] | | in (mm) | 1" offset from anchor (25.4 offset from anchor) | | | |

1 Manufacturing tolerance of up to +3 mm (0.118 in.).
2 The head diameter is the inner diameter of the hexagonal shaped head, and does not fully reflect the cross sectional area of the anchor head.
3 Nail hole diameter is 4 mm (0.16 in.)

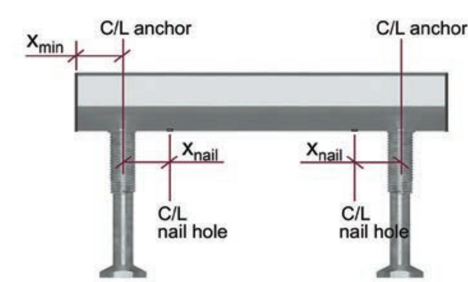


Figure 2.2.13.5 a — HAC end and nail hole distance.

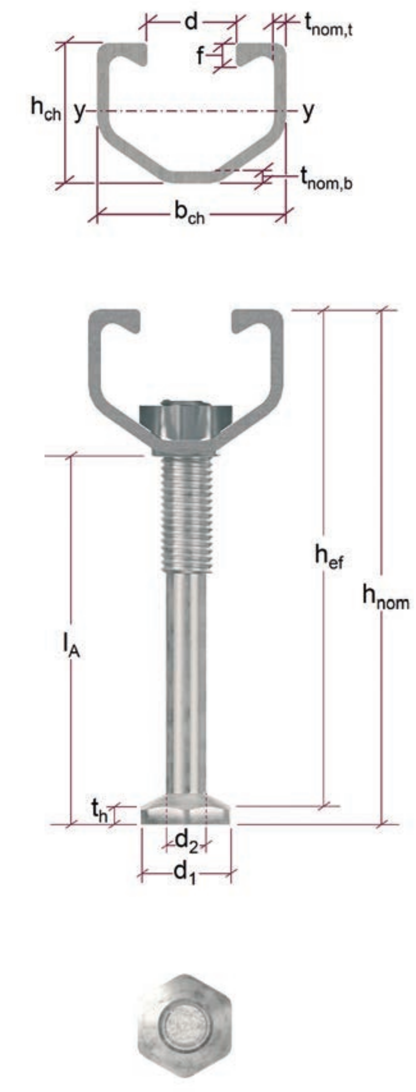


Figure 2.2.13.4 — HAC-T dimensions.

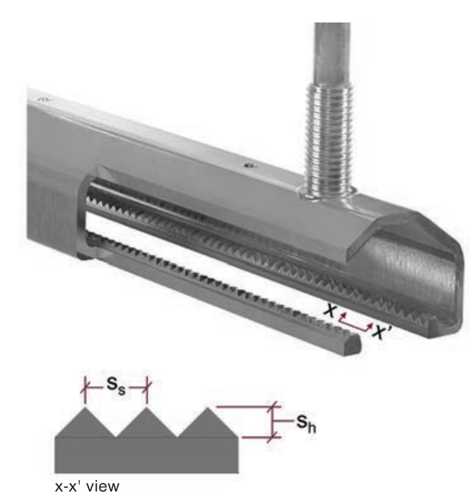


Figure 2.2.13.5 b — HAC-T serrations dimensions.

## Minimum substrate requirements for HAC-T and HAC-30

The minimum edge distance and member thickness for anchor channels are established via testing. It is the interaction between minimum member thickness and minimum edge distance that determines the minimum edge distance. If the anchor channel is installed closer than the minimum edge distance, cracking of the concrete may occur while applying the required installation torque to the t-bolts. Testing to determine the minimum edge distance considers unfavorable site conditions. The test is based on having the anchor channel recessed 1/8" in unreinforced concrete. Splitting/cracking may occur. Therefore, minimum substrate requirements vary depending on the anchor channel size. HAC-T substrate requirements are provided in Table 2.2.13.2 and 2.2.13.3.

**Table 2.2.13.2 — Minimum substrate dimensions for HAC-T and HAC-30 in normal weight and sand-lightweight concrete**

| Anchor channel | Units | $h_{ef}$ | $c_{a1}$ | $c_{a2}$ | $*h_{min}$ |
|---|---|---|---|---|---|
| HAC-30 | in (mm) | 2.68 (68) | 1.97 (50) | 1.97 (50) | 3.15 (80) |
| HAC-T50 | in (mm) | 3.70 (94) | 3.94 (100) | 3.94 (100) | 3.94 (100) |
| | in (mm) | 4.17 (106) | 1.97 (50) | 1.97 (50) | 4.92 (125) |
| HAC-T70 | in (mm) | 6.89 ( 175) | 2.95 (75) | 2.95 (75) | 7.72 (196) |

**Table 2.2.13.3 — Minimum substrate dimensions for HAC-T and HAC-30 in all lightweight concrete**

| Anchor channel | Units | $h_{ef}$ | $c_{a1}$ | $c_{a2}$ | $h_{min}$ |
|---|---|---|---|---|---|
| HAC-30 | in (mm) | 2.68 (68) | 2.95 (75) | 2.95 (75) | 3.15 (80) |
| HAC-T50 | in (mm) | 3.70 (94) | 3.94 (100) | 3.94 (100) | 3.94 (100) |
| | in (mm) | 4.17 (106) | 2.95 (75) | 2.95 (75) | 4.92 (125) |
| HAC-T70 | in (mm) | 6.89 ( 175) | 2.95 (75) | 2.95 (75) | 7.72 (196) |

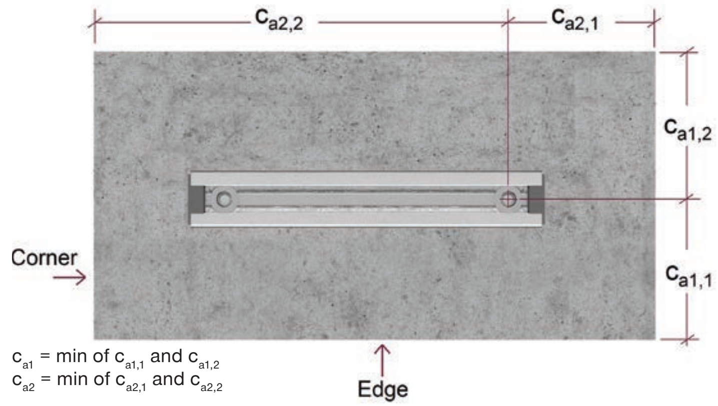
* Minimum slab thickness, $h_{min}$ may be reduced if anchor cover requirements can be omitted (i.e. interior applications with metal deck underneath the channel). To avoid splitting of the concrete, the minimum edge and corner distance shall be increased by a factor of 2.

## Edge distance facts:

- Any edge perpendicular to the long axis of the anchor channels is considered an edge.
- For determination of the minimum edge distance, $c_{a1}$ = min of $c_{a1,1}$ and $c_{a1,2}$
- For analysis purposes, $c_{a1}$ is always measured in the direction of the applied shear load.
- Edge distances are always measured from the center of the anchor under consideration.

## Corner distance facts:

- Any edge parallel to the long axis of the anchor channels is considered a corner
- For determination of the minimum corner distance, $c_{a2}$ = min of $c_{a2,1}$ and $c_{a2,2}$
- Corner distances are always measured from the center of the anchor under consideration




Corner and edge distances are measured to the center of the anchor.

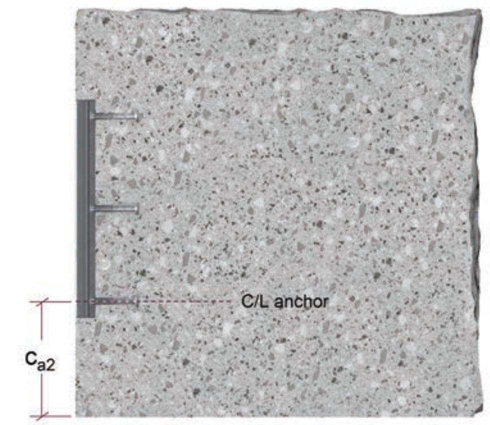
**Figure 2.2.13.6 — Minimum HAC-T and HAC-30 edge and corner distances, plan view.**


**Figure 2.2.13.7 — Minimum HAC-T and HAC-30 member thickness, isometric view.**

# 2.2.14 HAC-T AND HAC-30 IN FACE OF SLAB CORNERS

## Single HAC-T or HAC-30 in face of slab corners

AC232 provides design guidelines to account for the influence of corners where only one anchor channel is present. The design of this type of applications is covered in ESR-3520. Table 2.2.13.1 provides the minimum edge and corner distances for HAC-T and HAC-30.




Corner distance $c_{a2}$ is measured to the center of the anchor.

**Figure 2.2.14.1 — Minimum corner distances for single HAC-T, plan view.**

**Table 2.2.14.1 — Minimum substrate edge and corner distances for single HAC-T or HAC-30 in a corner in normal weight, sand-lightweight and all light-weight concrete**

| Anchor channel | Units | $h_{ef}$ | Minimum $c_{a1}$ | Minimum $c_{a2}$ |
|---|---|---|---|---|
| HAC-30 | in (mm) | 2.68 (68) | *1.97 (50) | *1.97 (50) |
| HAC-T50 | in (mm) | 3.70 (94) | 3.94 (100) | 3.94 (100) |
| | in (mm) | 4.17 (106) | *1.97 (50) | *1.97 (50) |
| HAC-T70 | in (mm) | 6.89 ( 175) | 2.95 (75) | 2.95 (75) |

*For all-lightweight concrete, $c_{a1}$ = $c_{a2}$ = 2.95" (75 mm)

## Pair of HAC-T or HAC-30 in a corner

AC232 does not include provisions to account for the influence of an adjacent channel in a face of slab corner. Technically, HAC-T or HAC-30 can be used in both sides of the corner, if there is no overlapping of the anchors.

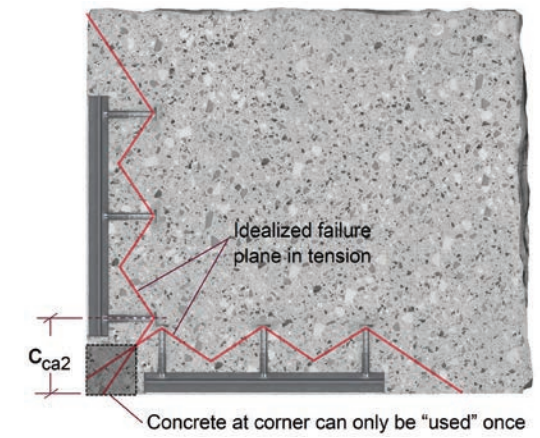
Additional measurements shall be taken in consideration to account for the negative influence of the adjacent anchor channel, if both channels are to be loaded simultaneously. See chapter 9, Anchor Channel Design for additional design information. Although this solution is technically feasible, installing anchor channels at 4 to 7 inches away from the corner typically results in unpractical bracket sizes, large eccentricities, large forces, and consequently, inadequate concrete strengths.

Tables 2.2.14.2 and figure 2.2.14.2 provide information about the minimum corner distance for pair of HAC. See chapter 9, Anchor Channel Design for additional design information.

**Table 2.2.14.2 — Minimum substrate edge and corner distances for pair of HAC-T or HAC-30 in corners in normal weight, sand-lightweight and all light-weight concrete**

| Anchor channel | Units | $h_{ef}$ | Minimum $c_{a1}$ | Minimum $c_{ca2}$ |
|---|---|---|---|---|
| HAC-30 | in (mm) | 2.68 (68) | *1.97 (70) | 2.76 (70) |
| HAC-T50 | in (mm) | 3.70 (94) | 3.94 (100) | 3.70 (97.50) |
| | in (mm) | 4.17 (106) | *1.97 (50) | 4.31 (109.50) |
| HAC-T70 | in (mm) | 6.89 ( 175) | 2.95 (75) | 7.09 (180.00) |

*For all-lightweight concrete, $c_{a1}$ = 2.95" (75 mm)




Corner distance $c_{ca2}$ is measured to the center of the anchor.

**Figure 2.2.14.2 — Minimum corner distances for pair of HAC-T, plan view.**

For face of slab applications, it is not recommended to install HAC-T or HAC-30 in both sides of the corner if there is overlapping of the rounded head anchors and they will experience simultaneous loading.

The overlapping of the two anchor of the corner channels creates a weakened failure plane, making the corner susceptible to undesired cracking and therefore, reduced concrete strengths.

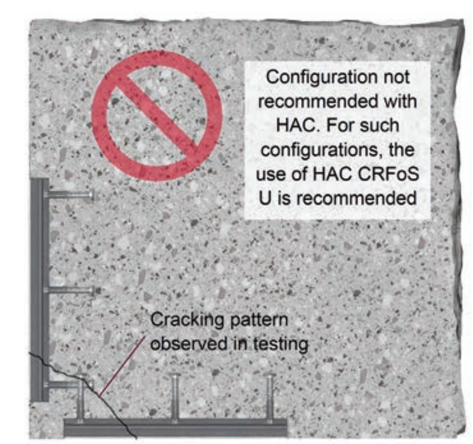



**Figure 2.2.14.3 — Premature concrete cracking due to simultaneous loading of pair HAC-T at corner with overlapped anchors, plan view.**

# 2.2.15 HAC-T AND HAC-30 IN TOP OR BOTTOM OF SLAB CORNERS

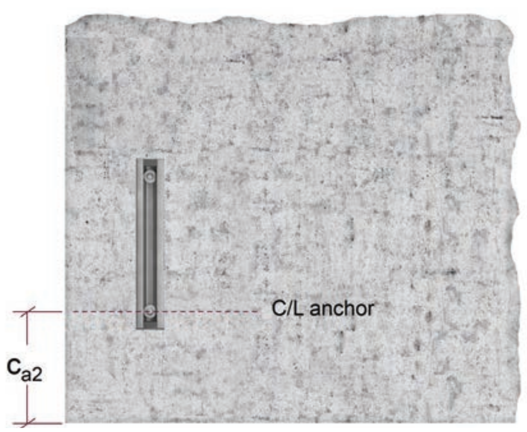
## Single HAC-T or HAC-30 in top of slab corner

AC232 provides design guidelines to account for the influence of corners where only one anchor channel is present. The design of this type of application is covered in ESR-3520. Table 2.2.15.1 provides the minimum edge and corner distances for and HAC-30. HAC-T and HAC-30 requirements for top and bottom of slab corners are equal.

**Table 2.2.15.1 — Minimum substrate edge and corner distances for single HAC-T in a corner in normal weight, sand-lightweight and All light-weight concrete**

| Anchor channel | Units | $h_{ef}$ | Minimum $c_{a1}$ | Minimum $c_{a2}$ |
|---|---|---|---|---|
| HAC-30 | In (mm) | 2.68 (68) | *1.97 (70) | *1.97 (50) |
| HAC-T50 | In (mm) | 3.70 (94) | 3.94 (100) | 3.94 (100) |
| | In (mm) | 4.17 (106) | *1.97 (50) | *1.97 (50) |
| HAC-T70 | In (mm) | 6.89 ( 175) | 2.95 (75) | 2.95 (75) |

*For all-lightweight concrete, $c_{a1} = c_{a2}$ = 2.95" (75 mm)




Corner distance $c_{a2}$ is measured to the center of the anchor.

**Figure 2.2.15.1 — Minimum corner distance for single HAC-T and HAC-30 in top of slab, plan view.**

## Pair of HAC-T or HAC-30 in top of slab corners

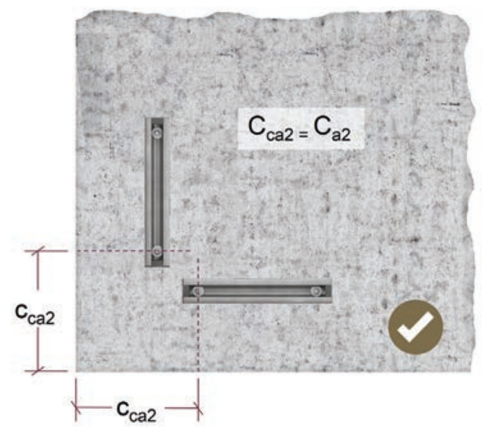
AC232 does not include provisions to account for the influence of an adjacent and/or corner channel. Technically, HAC-T can be used in both sides of the corner.

Additional measurements shall be taken into consideration to account for the negative influence of the adjacent anchor channel, if both channels are to be loaded simultaneously. See chapter 9, Special Anchor Channel Design for additional design information.

The minimum corner distances for pair of HAC-T in top of slab corners ($c_{a2}$) are consistent with table 2.2.15.1. These minimum distances are based on installation requirements. Both HAC-T at corners cannot be installed at the minimum corner distance due to physical constraints (clashing of HAC-T will occur).

However, two HAC can be installed next to each other in a corner configuration where the anchor channels are installed perpendicular to each other.

Figure 2.2.15.2 illustrates a pair of HAC-T in a corner. Corner distances greater than the minimum corner distance may be required based on the structural adequacy of the concrete at the corner.




Corner distance $c_{ca2}$ is measured to the center of the anchor.

**Figure 2.2.15.2 — Minimum corner distance for pair of HAC-T or HAC-30 in top of slab, plan view.**

## Design of top of slab corners

Hilti has developed a model to account for the influence of adjacent and corner channels. The model follows the fundamentals of AC232 and allows analysis of more complex but typical applications encountered in a project such as the conditions shown in Figure 2.2.15.3. See chapter 9, Special Anchor Channel Design for additional design information.

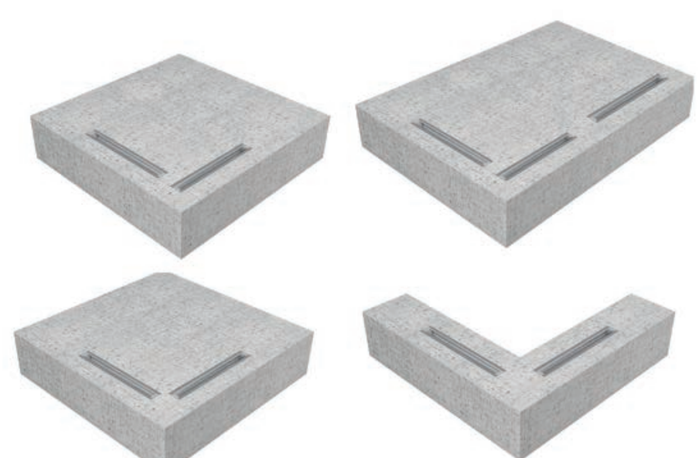


**Figure 2.2.15.3 — Corner configuration of pair of HAC-T or HAC-30 in top of slab.**



# 2.2.16 HAC-T EDGE LITE, HAC-T EDGE, AND HAC-T S EDGE

Hilti Anchor Channels with serrated channel lips and rebar edge confinement plate (HAC-T EDGE Lite and HAC EDGE) and HAC-T EDGE with superior steel performance (HAC-T S EDGE) are offered in HAC-T50 profiles. The anchor channel is identical to its matching HAC-T, except the rebar edge confinement plate (EDGE Lite or EDGE plate) is incorporated for superior concrete performance in shear.

The standard portfolio consists of HAC-T50 with two defined nominal anchor heights; 4.31" (109.50 mm) and 3.84" (97.50 mm). Moreover, defined channel length, EDGE Plate geometry, rebar lengths, anchor and rebar diameter, and number of rebar are also defined. The number of anchors per channels is pre-defined and can be modified and ordered upon request. Refer to section 2.4 for additional information about standard items and lead times.

The concrete edge shear confinement plate (EDGE plate) is fixed to the form work or pour stop. The EDGE plate comes with installation holes. As an added value, the product comes with the specified edge distance ($c_{a1}$).

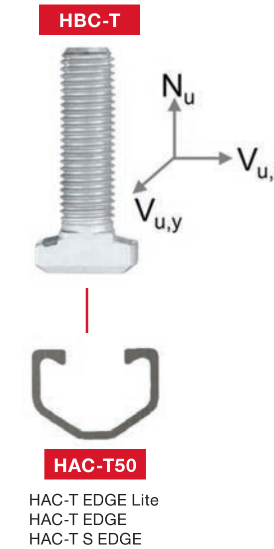
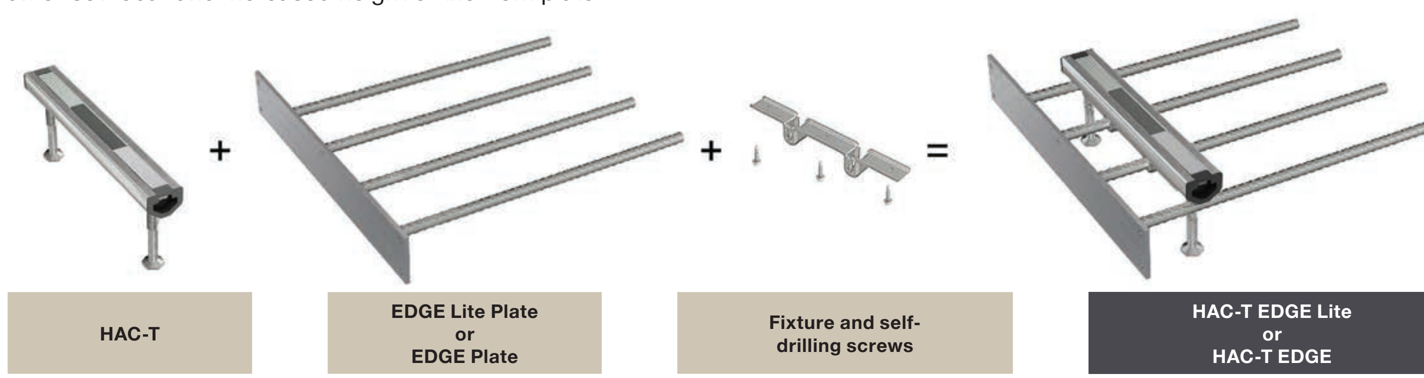



**Figure 2.2.16.1 — HAC-T EDGE Lite, HAC-T EDGE, and HAC-T S EDGE profiles with matching bolts.**

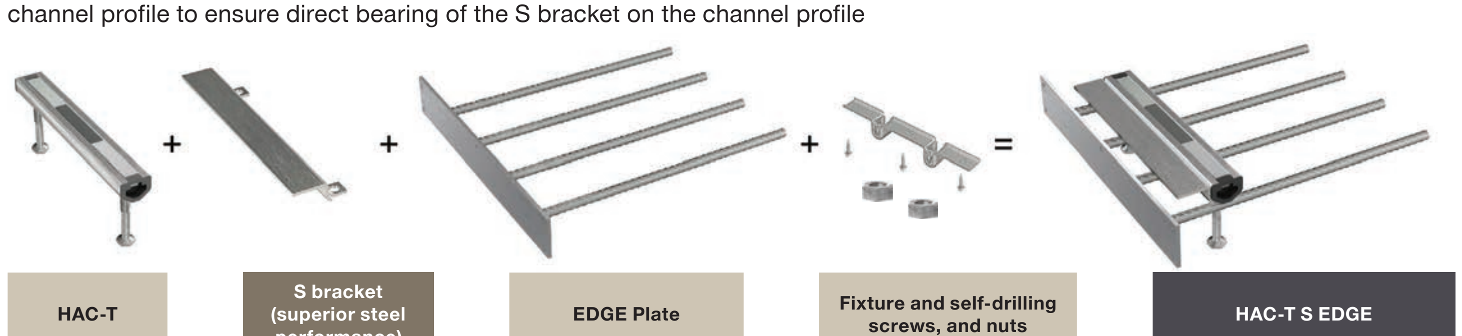
## HAC-T EDGE Lite and HAC EDGE

These anchor channel systems consist of HAC-T and the new rebar edge confinement plate (EDGE plate). The EDGE plate is not structurally attached to the anchor channel. This allows decoupling of the tension and shear forces. HAC-T50 EDGE C comes with an offset rebar and increased height of the front plate.




## HAC-T S EDGE

This anchor channel is equal to its matching HAC-T EDGE, except the "S" bracket is added. The "S" bracket offers superior steel performance. The S bracket is structurally attached to the anchor channel. The S-bracket has a similar geometry to the connected channel profile to ensure direct bearing of the S bracket on the channel profile



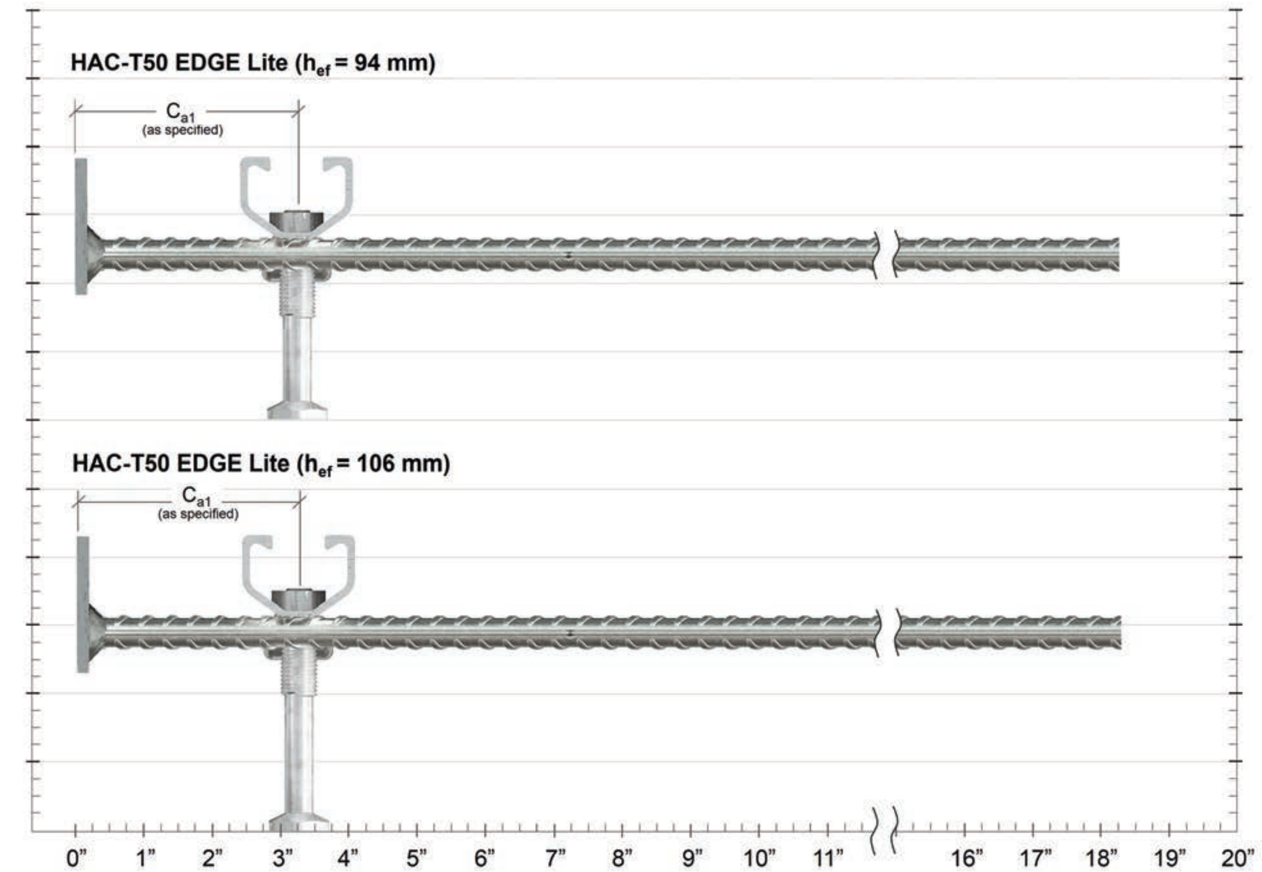



Figure 2.2.16.2 - Section view of HAC-T50 EDGE Lite.

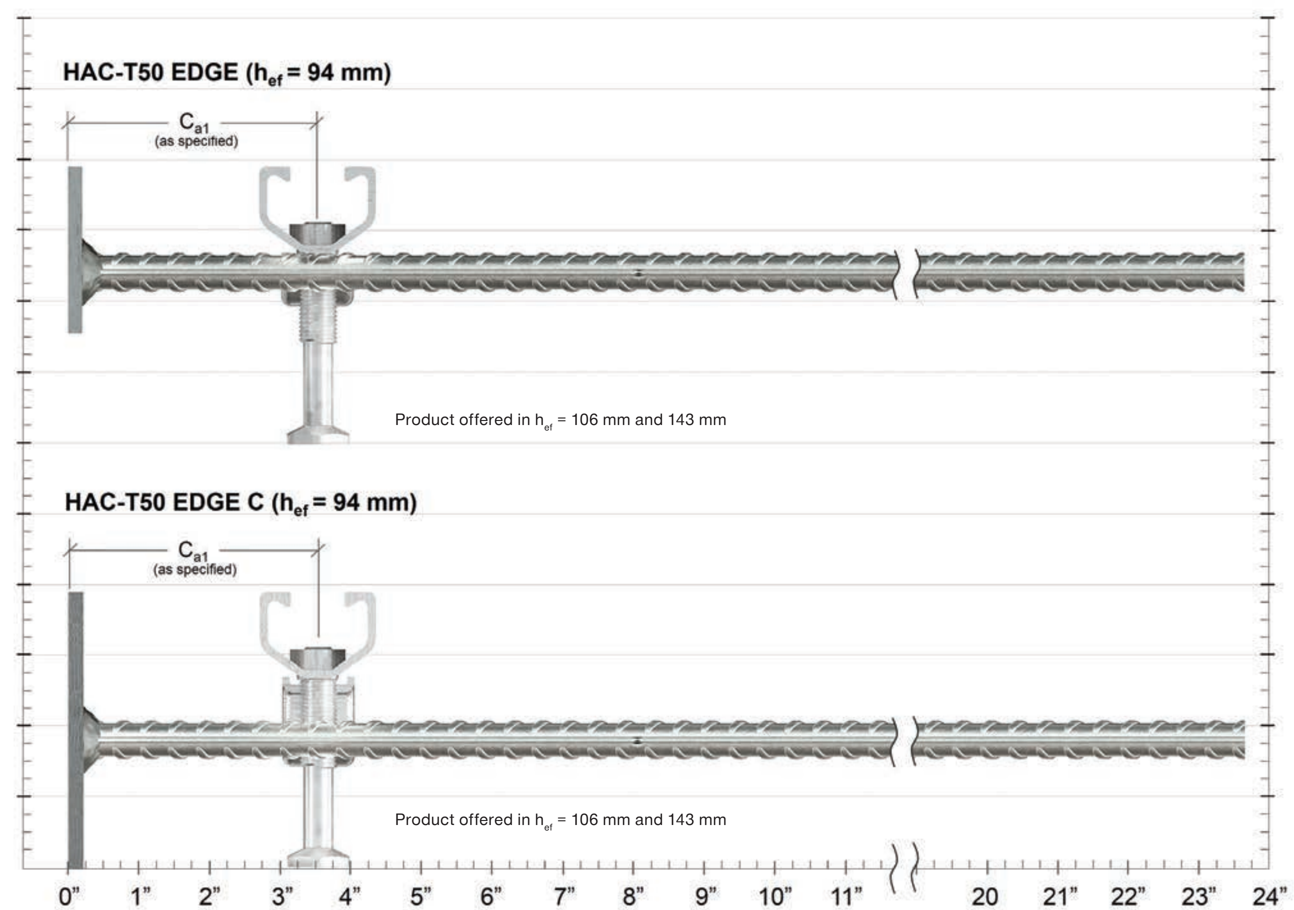



Figure 2.2.16.3 - Section view of HAC-T50 EDGE and HAC-T50 EDGE C.

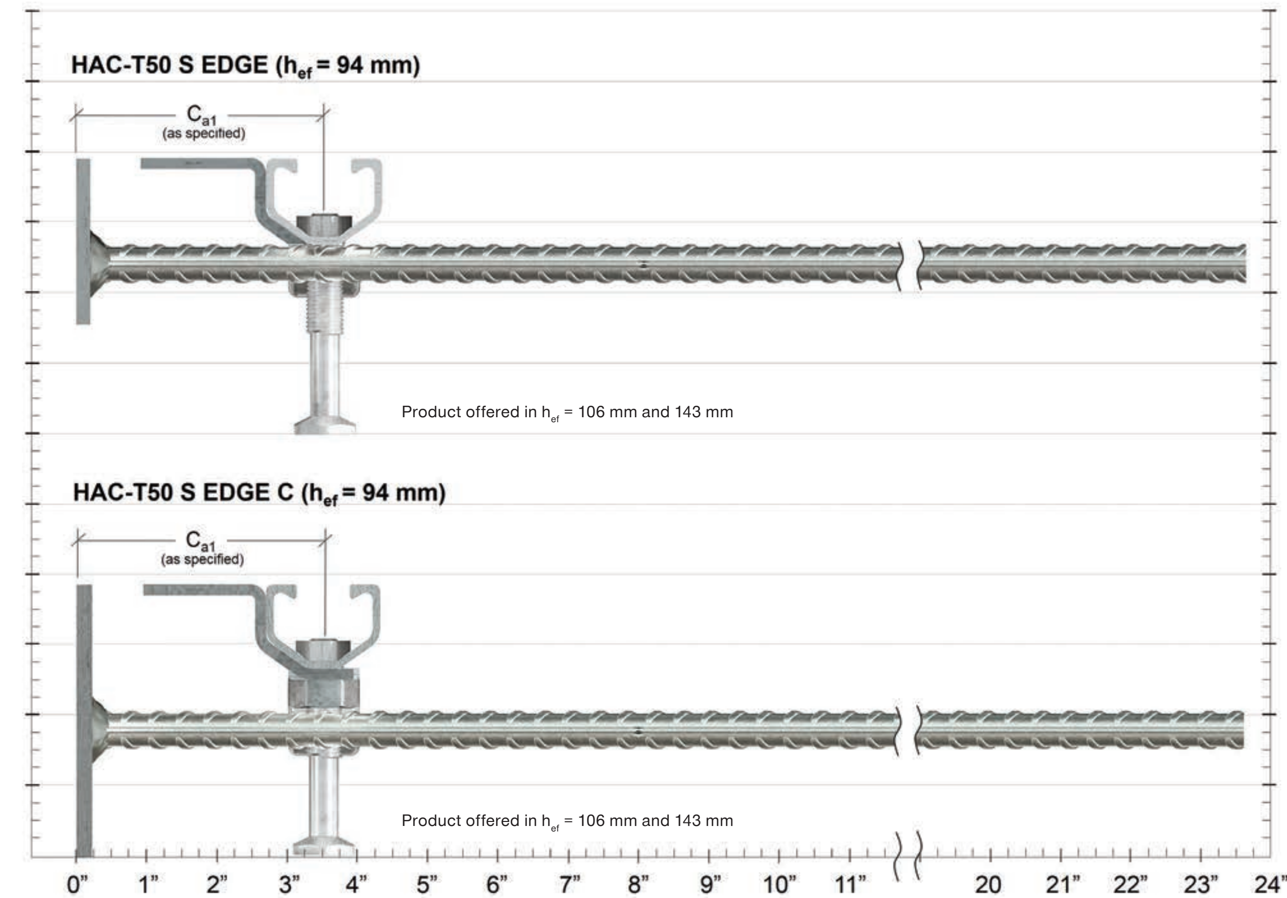



Figure 2.2.16.4 - Section view of HAC-T50 S EDGE and HAC-T50 S EDGE C.

HAC-T50 EDGE Lite, HAC-T50 EDGE, and HAC-T50 S EDGE utilize HAC-T50 with rounded head anchors. HAC-T50 is covered by ICC ESR-3520. HAC-T50 with reduced embedment depth [$h_{ef}$ = 3.70" (94 mm)] is not covered by ESR-3520.

Table 2.2.16.1 provides geometric parameters for the anchor channels that compose the HAC-T EDGE product line. Tables 2.2.16.2 and 2.2.16.3 provide geometric information about the EDGE Lite, EDGE, and EDGE S plate. These components increase the perpendicular concrete edge breakout strength.

The S brackets improves the shear steel performance (perpendicular shear) of HAC. Dimensions of the S bracket are given in Figures 2.2.16.8 and 2.2.16.9.

**Table 2.2.16.1 — Geometric parameters for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T S EDGE[2]**

| Criteria | Symbol | Units | Anchor Channel: HAC-T50 EDGE Lite / HAC-T50 EDGE / HAC-T50 S EDGE | |
|---|---|---|---|---|
| Min. effective embedment depth | $h_{ef,min}$ | in (mm) | 4.17 (106) | *3.70 (94) |
| Thickness of the anchor head | $t_h$ | in (mm) | 0.14 (3.50) | |
| Nominal embedment depth | $h_{nom}$ | in (mm) | 4.31 (109.2) | 3.84 (97.5) |
| Channel profile height | $h_{ch}$ | in (mm) | 1.22 (31.0) | |
| Channel profile width | $b_{ch}$ | in (mm) | 1.65 (41.9) | |
| Channel profile moment of inertia | $I_y$ | $in^4$ ($mm^4$) | 0.0796 (33,125) | |
| Channel profile opening | d | in (mm) | 0.77 (19.50) | |
| Channel lip flange thickness | f | in (mm) | 0.21 (5.30) | |
| Channel lip thickness (top) | $t_{nom,t}$ | in (mm) | 0.11 (2.75) | |
| Channel lip thickness (bottom) | $t_{nom,b}$ | in (mm) | 0.11 (2.75) | |
| Minimum end spacing | $x_{min}$ | in (mm) | 0.98 (25) | |
| Anchor shaft diameter | $d_2$ | in (mm) | 0.36 (9.03) | |
| Head diameter[1] | $d_1$ | in (mm) | 0.77 (19.50) | |
| Anchor length | $l_A$ | in (mm) | 3.09 (78.50) | 2.62 (66.5) |
| Minimum anchor spacing | $s_{min}$ | in (mm) | 3.94 (100) | |
| Maximum anchor spacing | $s_{max}$ | in (mm) | 9.84 (250) | |
| Net bearing area of the anchor head | $A_{brg}$ | $in^2$ ($mm^2$) | 0.400 (258) | |
| Matching channel bolt | | | HBC-T | |
| Minimum channel bolt spacing | $s_{chb}$ | | 3 x bolt diameter | |
| Nail hole location[3] | $x_{nail}$ | in (mm) | 1" offset from anchor (25.4 offset from anchor) | |

1 The head diameter is the inner diameter of the hexagonal shaped head, and does not fully reflect the cross sectional area of the anchor head.
2 HAC-T EDGE C is the matching corner channel and has the same anchor channel as the intermediate HAC EDGE. The shear confinement plate has different geometry.
* Effective embedment depth not covered by ICC ESR-3520.
3 Nail hole diameter is 4 mm (0.16 in.)

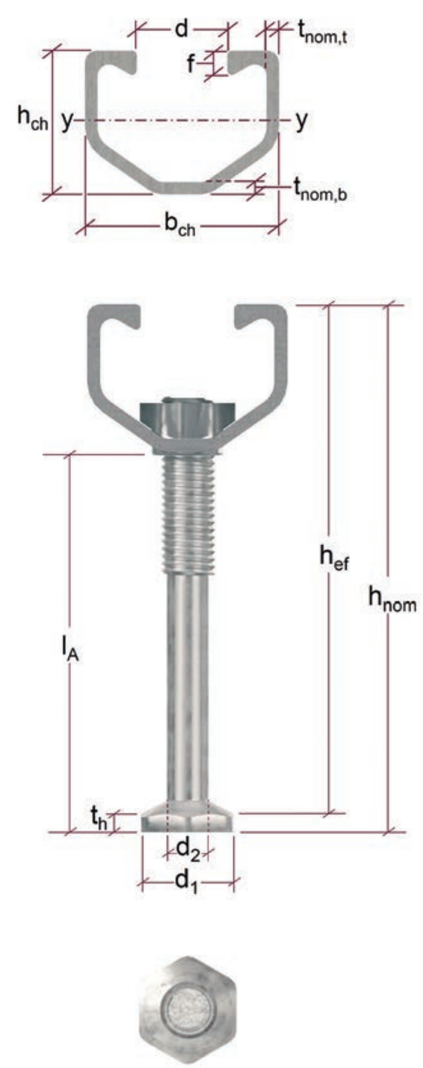



**Figure 2.2.16.5 a — Dimensions of the anchor channel of HAC-T EDGE Lite, HAC-T EDGE, and HAC-T S EDGE.**

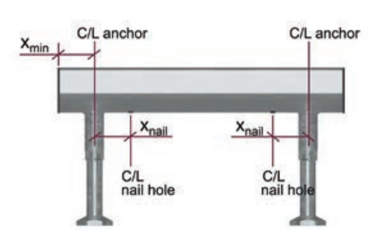



**Figure 2.2.16.5 b — HAC end and nail hole distance.**

**Table 2.2.16.2 — Geometric parameters of HAC-T EDGE Lite and HAC-T EDGE**

| Criteria | Symbol | Units | Anchor Channel HAC-T50 EDGE Lite | Anchor Channel HAC-T50 EDGE | Anchor Channel HAC-T50 EDGE C |
|---|---|---|---|---|---|
| Thickness of the EDGE Lite or EDGE plate | $t_{pl}$ | in (mm) | 0.16 (4.00) | 0.20 (5.00) | 0.24 (6.00) |
| Height of the EDGE Lite or EDGE plate | $h_{pl}$ | in (mm) | 1.97 (50) | 2.36 (60) | 3.94 (100) |
| Projection of the EDGE Lite or EDGE plate | $x_{pl}$ | in (mm) | 0.99 (25) | 1.97 (50) | |
| Length of the EDGE Lite or EDGE plate | $l_{pl}$ | in (mm) | Channel length + $2(x_{pl})$ | | |
| Overall length of the EDGE Lite or EDGE plate rebars | $l_R$ | in (mm) | 18.11 (460) | 23.62 (600) | |
| Rebar nominal diameter | $d_b$ | in (mm) | 0.39 (10) | 0.47 (12) | |
| Bar effective cross-sectional area | $A_{se}$ | $in^2$ ($mm^2$) | 0.12 (78.54) | 0.18 (113.1) | |
| Minimum rebar spacing | $s_{min,R}$ | in (mm) | 3.74 (95) | 3.74 (95) | |
| Maximum rebar spacing | $s_{max,R}$ | in (mm) | 3.75 (95) | 5.71 (145) | |
| C/C distance between the outer rebar and the outer anchor | $x_R$ | in (mm) | 0.295 (7.50) | 0.295 (7.50) | |
| Distance from the end of the EDGE Lite or EDGE plate to the center of the installation hole[1] | $d_i$ | in (mm) | 0.40 (10) | | |
| Edge distance (from outside face of EDGE Lite or EDGE plate to center of HAC anchor | $c_{a1}$ | in (mm) | As specified | | |
| Development length of rebars | $l_d$ | in (mm) | $l_R - c_{a1} + t_{pl}$ | | |

1 Nail hole diameter is equal to 6 mm (0.25 in.)

**Figure 2.2.16.6 — Isometric view of HAC-T EDGE Lite and HAC-T EDGE.**

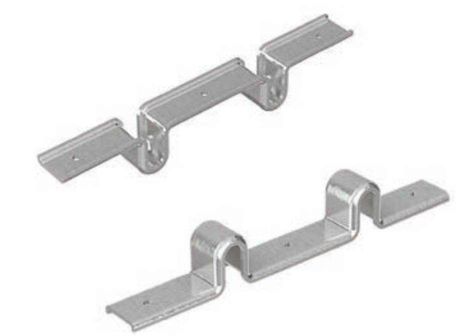


**Figure 2.2.16.7 — Isometric view of fixture that attaches the EDGE Lite or EDGE plate to HAC-T.**

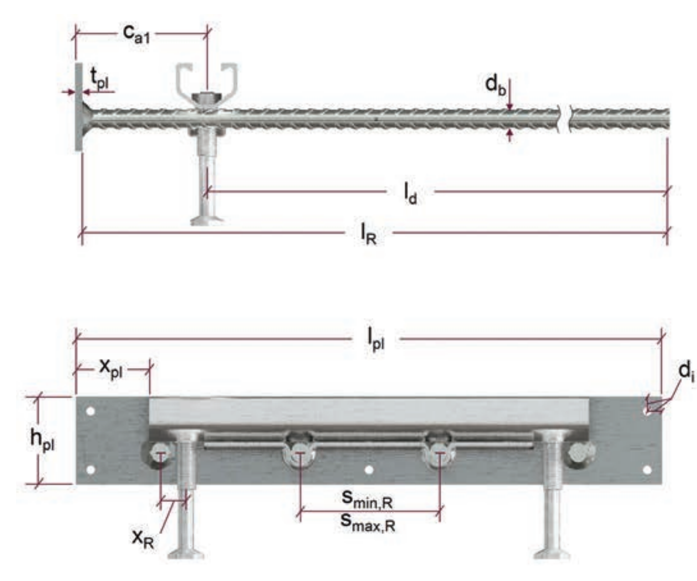
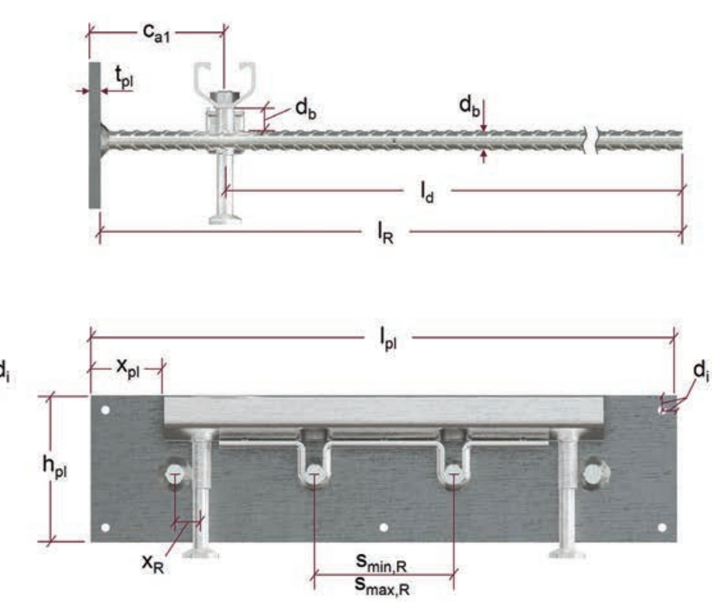



**Figure 2.2.16.8 — HAC-T EDGE Lite and HAC-T EDGE dimensions, section and elevation view.**




HAC-T EDGE C has reinforcing bars that are located one reinforcing bar diameter below the bottom base of the anchor channel profile to avoid clashing with the reinforcing bars of the opposite corner channel (HAC-T EDGE). The plate is taller and thicker.

**Figure 2.2.16.9 — HAC-T EDGE C dimensions, section and elevation view.**

**Table 2.2.16.3 — Geometric parameters for HAC-T S EDGE rebar edge confinement plate (EDGE Plate)**

| Criteria | Symbol | Units | Anchor Channel HAC-T50 S EDGE | Anchor Channel HAC-T50 S EDGE C |
|---|---|---|---|---|
| Thickness of the EDGE plate | $t_{pl}$ | in (mm) | 0.20 (5.00) | 0.24 (6.00) |
| Height of the EDGE plate | $h_{pl}$ | in (mm) | 2.36 (60) | 3.94 (100) |
| Projection of the EDGE plate | $x_{pl}$ | in (mm) | 1.97 (50) | |
| Length of the EDGE plate | $l_{pl}$ | in (mm) | Channel length + 2($x_{pl}$) | |
| Overall length of the EDGE plate rebars | $l_R$ | in (mm) | 23.62 (600) | |
| Rebar nominal diameter | $d_b$ | in (mm) | 0.47 (12) | |
| Bar effective cross-sectional area | $A_{se}$ | in² (mm²) | 0.18 (113.1) | |
| Minimum rebar spacing | $s_{min,R}$ | in (mm) | 3.74 (95) | |
| Maximum rebar spacing | $s_{max,R}$ | in (mm) | 5.71 (145) | |
| C/C distance between the outer rebar and the outer anchor | $x_R$ | in (mm) | 0.295 (7.50) | |
| Distance from the end of the EDGE plate to the center of the installation hole[1] | $d_i$ | in (mm) | 0.40 (10) | |
| Edge distance (from outside face of EDGE plate to center of HAC anchor | $c_{a1}$ | in (mm) | As specified | |
| Development length of rebars | $l_d$ | in (mm) | $l_R - c_{a1} + t_{pl}$ | |

1 Nail hole diameter is equal to 6 mm (0.25 in.)

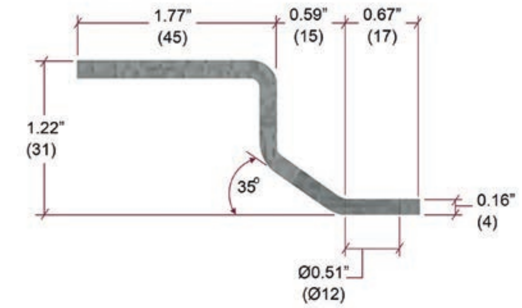


**Figure 2.2.16.10 — Geometry of S bracket, section view.**

**Figure 2.2.16.11 — Isometric view of HAC-T50 S.**


**Figure 2.2.16.12 — Isometric view of HAC-T50 S EDGE.**

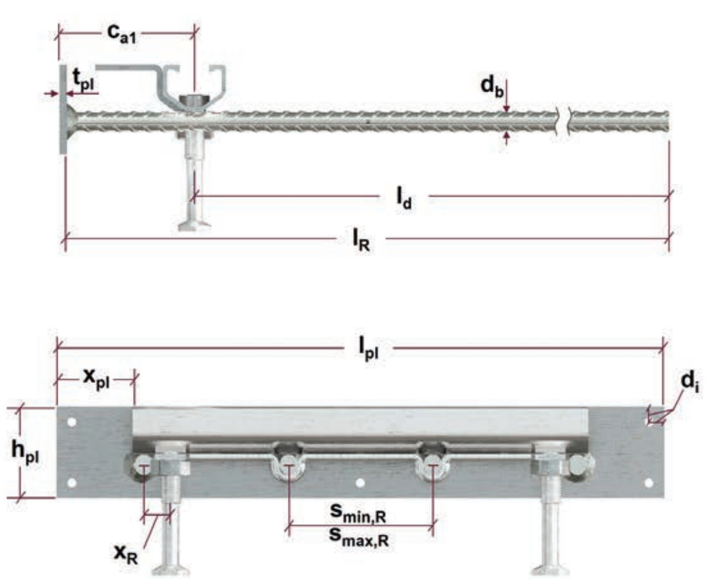
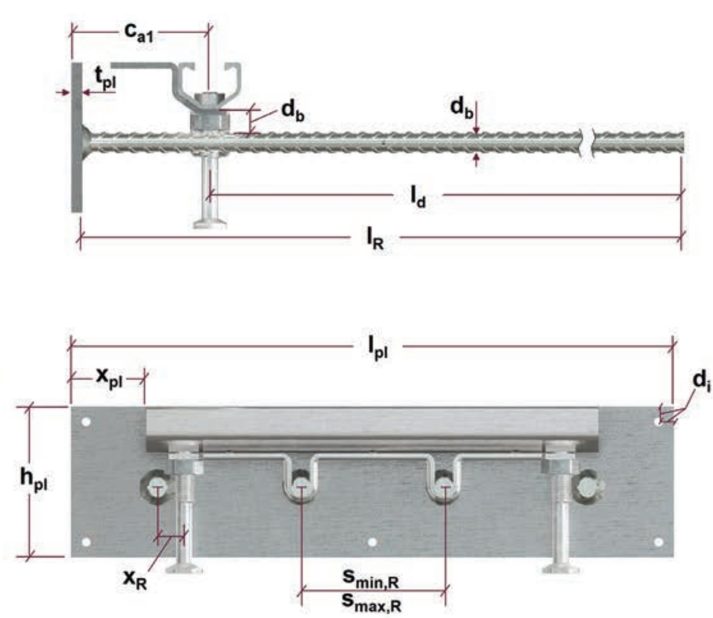


**Figure 2.2.16.13 — HAC-T S EDGE dimensions, section and elevation view.**



HAC-T S EDGE C has reinforcing bars that are located one reinforcing bar diameter below the bottom base of the anchor channel profile to avoid clashing with the reinforcing bars of the opposite corner channel (HAC-T S EDGE). The plate is taller and thicker.

**Figure 2.2.16.14 — HAC-T S EDGE C dimensions, section and elevation view.**

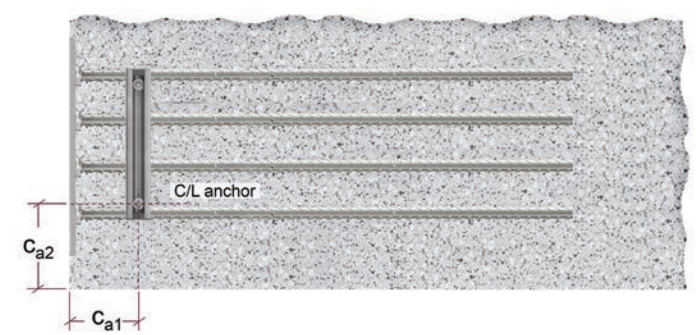
## Min. substrate requirements for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T S EDGE

Similarly to HAC, the minimum edge distances for HAC EDGE are established via testing. Although the HAC EDGE product line are not implicitly covered in AC232, AC232 provides testing protocols for anchor channels to establish the minimum edge and corner distance for the minimum member thickness. The following substrate requirements have been established in accordance with testing protocols of AC232..

**Table 2.2.16.4 — Minimum substrate dimensions for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T S EDGE**

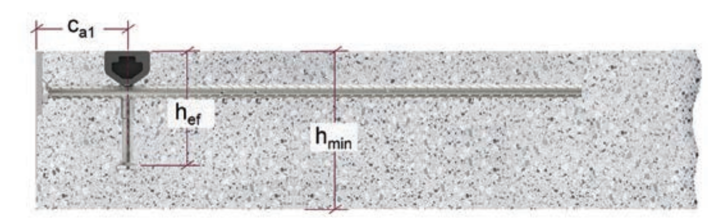
| Anchor channel | Units | $h_{ef}$ | *$h_{min}$ | Normal weight concrete $c_{a1}$ | Normal weight concrete $c_{a2}$ | Sand lightweight and all lightweight concrete $c_{a1}$ | Sand lightweight and all lightweight concrete $c_{a2}$ |
|---|---|---|---|---|---|---|---|
| HAC-T50 EDGE Lite | in (mm) | 3.70 (94) | 3.94 (100) | 1.97 (50) | 3.94 (100) | 3.94 (100) | |
| | in (mm) | 4.17 (106) | 4.92 (125) | | | | |
| HAC-T50 EDGE HAC-T50 EDGE C | in (mm) | 3.70 (94) | 3.94 (100) | | | | |
| | in (mm) | 4.17 (106) | 4.92 (125) | 3.94 (100) | | | |
| HAC-T50 S EDGE HAC-T50 S EDGE C | in (mm) | 3.70 (94) | 3.94 (100) | | | | |
| | in (mm) | 4.17 (106) | 4.92 (125) | | | | |

HAC-T50 EDGE (C) Indicates HAC-T50 EDGE and HAC-T50 EDGE C
HAC-T50 S EDGE (C) Indicates HAC-T50 S EDGE and HAC-T50 S EDGE C



Corner and edge distances are measured to the center of the anchor.

**Figure 2.2.16.15 — Minimum edge and corner distances for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T S EDGE, plan view.**



Edge distance ($c_{a1}$) is measured from the face of the slab (outer face of the EDGE Plate).

**Figure 2.2.16.16 — Minimum member thickness for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T S EDGE, section view.**

## Minimum edge distance for anchor channels in composite slabs

The minimum edge and corner distances for HAC-T EDGE are consistent with the minimum requirements of HAC. However, as a response to the market trends, composite slabs with pockets, Hilti has added HAC EDGE-T with shorter anchor lengths.

For composite slabs where there is a pour stop along the perimeter of the edge of slab prevent, prevent oxygen from reaching out to the bottom of the slab, the minimum member thickness can be reduced.

Chapters 8 and 9 provide design information for HAC-T EDGE in composite slabs and how to account for the potential negative influence of the metal deck.

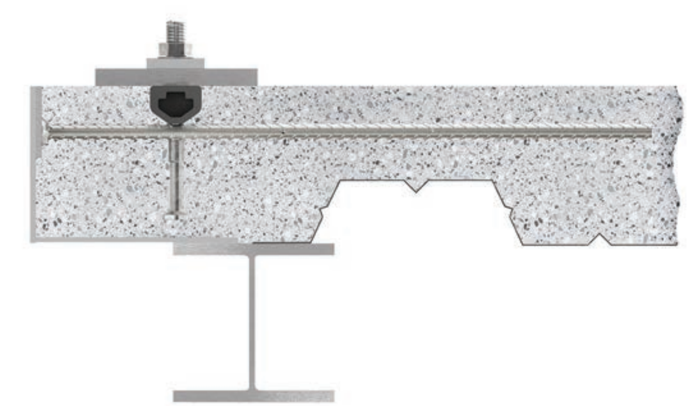
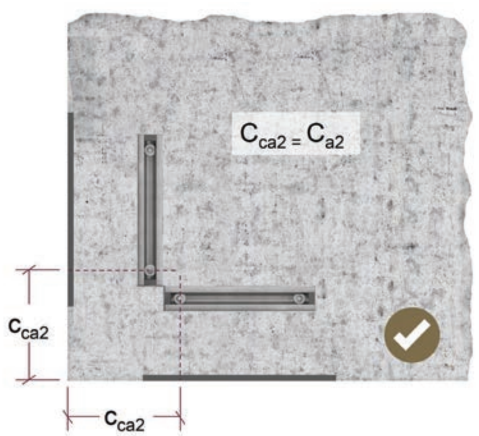


**Figure 2.2.16.17 — HAC-T EDGE in a composite slab, section view.**

# 2.2.17 HAC-T EDGE AND HAC-T S EDGE IN TOP OR BOTTOM OF SLAB CORNERS

## Pair of HAC-T EDGE and HAC-T S EDGE in top of slab corners

HAC-T EDGE and HAC-T S EDGE are ideal for top of slab corner applications. Two independent anchor channels at the corner allows de-coupling the loads at both channels, preventing anchors and rebars from taking undesired loads. Furthermore, using two independent channels eases the installation in congested areas, preventing damage of the anchors during installation.




Corner distance $c_{ca2}$ is measured to the center of the anchor.

**Figure 2.2.17.1 — Corner configuration of pair of HAC in top of slab.**

The new Hilti design method for corners follows the principles of AC232 and allows the anchor channels to be installed as close as physically possible to the corner, as long as the minimum corner and edge distances are not exceeded. The use of HAC EDGE allows the concrete to take higher shear forces, making it the perfect solution for corner applications.

HAC-T EDGE at corner requires the use of HAC-T EDGE and HAC-T EDGE C. The EDGE C plate of HAC-T EDGE C comes with rebars that are located 1 rebar diameter below the bottom of the channel profile to prevent clashing of the rebars with the HAC-T EDGE.

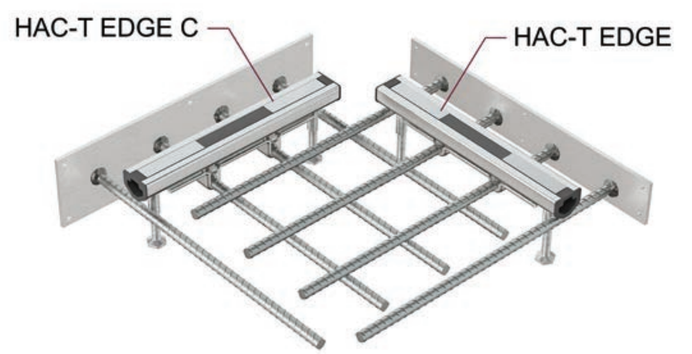



**Figure 2.2.17.2 — HAC-T EDGE and HAC-T EDGE C.**

HAC-T EDGE and HAC-T S EDGE steel strengths are provided in section 2.3. For design of channels at corners, refer to chapter 9.

## HAC T EDGE and HAC-T S EDGE at non-90° corners

HAC-T EDGE C and HAC-T S EDGE C are suitable for non-90° corners. The use of two independent anchor channels simplifies the portfolio by no requiring custom made channels. See chapter 9 for design information.

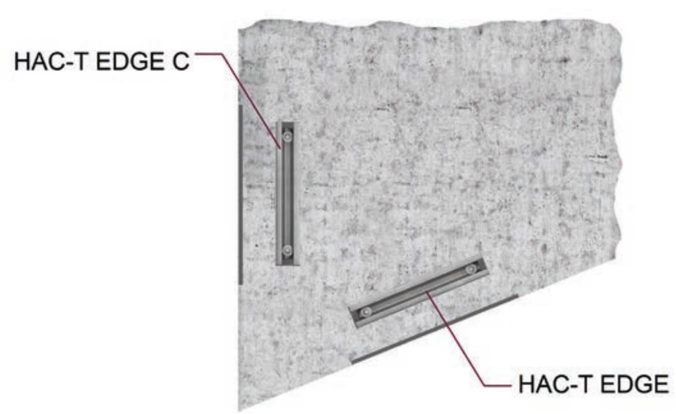



**Figure 2.2.17.3 — HAC-T EDGE and HAC-T EDGE C in an acute corner, plan view.**

**Table 2.2.17.1 — Minimum substrate edge and corner for pair of HAC-T EDGE and HAC-T S EDGE at a corner.**

| | | | | Normal weight concrete | | Sand lightweight concrete | |
|---|---|---|---|---|---|---|---|
| Anchor channel | Units | $h_{ef}$ | $*h_{min}$ | $c_{a1}$ | $c_{a2}$ | $c_{a1}$ | $c_{a2}$ |
| HAC-50 EDGE<br>HAC-50 EDGE C | in | 3.70 | 3.94 | 1.97 | 3.94 | 3.94 | |
| | (mm) | (94) | (100) | (50) | (100) | (100) | |
| | in | 4.17 | 4.92 | | | | |
| | (mm) | (106) | (125) | | | | |
| HAC-50 S EDGE<br>HAC-50 S EDGE C | in | 3.70 | 3.94 | 3.94 | | | |
| | (mm) | (94) | (100) | (100) | | | |
| | in | 4.17 | 4.92 | | | | |
| | (mm) | (106) | (125) | | | | |



# 2.2.18 HILTI SERRATED CHANNEL BOLTS

The Hilti Serrated Channel Bolts (HBC-T and HBC-B) are part of the anchor channel system. HBC are threaded fasteners commonly known as T-bolts. HBC are the link between the fixture and anchor channel. The HBC have a proprietary head geometry and are compatible with Hilti channels only. The head of the HBC-T or HBC-B can be inserted along the channel cavity. The fixture is connected to the anchor channel by channel bolts with a nut and washer. Thus, allowing for the so needed jobsite tolerance.

The head of the t-bolt is first installed parallel to the channel profile. Once it is positioned in place, the bolt is turned 90° clockwise. The head of the bolt has been engineered in a way that the t-bolt cannot rotate more than 90° clockwise. This ensures that the bolt is properly positioned before the installation torque is applied.

HBC-T and HBC-B come with a special marking to ease the identification before and after installation. All Hilti serrated channel bolts are covered by ESR-3520.

**Figure 2.2.18.1 — Hilti Serrated Channel Bolt with nut and washer; HBC-T (left) and HBC-B (right)**

# 2.2.19 HILTI SERRATED CHANNEL BOLTS: HBC-T AND HBC-B

Hilti serrated channel bolts (HBC-T) are only suitable for channel profiles HAC-T50 & HAC-T70. HBC-T come in bolt diameters M12, M16, and M20, steel grades 8.8 and HDG finishing. Hilti serrated channel bolts (HBC-B) are only suitable for channel profiles HAC-30.

HBC-T and HBC-B can be used to transfer tensile loads, shear loads perpendicular to the longitudinal channel axis, longitudinal shear forces, or any combination of these loads. Transferring of the loads takes place via interlock of the serrations of the HBC-T and serrated lips of HAC-T or HBC-B and serrated lips of HAC-30.

**Table 2.2.19.1 — Hilti Serrated Channel Bolts (HBC-T) material information**

| Channel bolt | Units | Carbon steel[1] |
|---|---|---|
| Property class | - | 8.8 |
| fu | ksi<br>(N/mm²) | 116.0<br>(800) |
| fy | ksi<br>(N/mm²) | 92.82<br>(640) |
| Coating | | F[2] |

1 Materials according to Annex 3, Table 1
2 Hot-dop galvanized

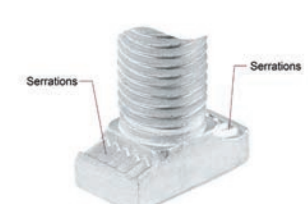



**Figure 2.2.19.2 — Head of Hilti Serrated Channel Bolt (HBC-T).**

Special markings on the t-bolt aid the installer to ensure the bolt is properly positioned before the installation torque is applied. Moreover, it allows the installer and inspector to identify the type of bolt after the fixture is installed.


**Figure 2.2.19.3 — Hilti Serrated Channel Bolt, HBC-B M12, HBC-T M16 and HBC-T M20**

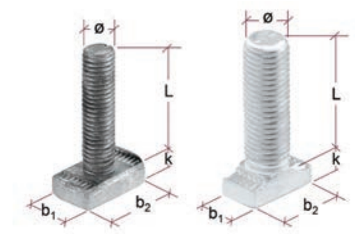
**HBC-T and HAC-T are subjected to a special corrosion protection process which reduces the amount of zinc that is accumulated in the serrations. Thus the difference in color between the HBC-B and HBC-T and the higher slip resistance of the of the HBC-T and HAC-T.**

**NOTE:**
**HBC-B can only be used with HAC-30.**
**HBC-T can only be used with HAC-T.**

### Hilti Serrated Channel Bolt length (HBC-T and HBC-B)

**Table 2.2.19.2 — Hilti Serrated Channel Bolts dimensions**

| Channel Bolt | Anchor Channel Profile | Units | Dimensions | | | | Channel bolt length |
|---|---|---|---|---|---|---|---|
| | | | Diameter ø | $b_1$ | $b_2$ | k | L |
| HBC-T | HAC-T50<br>HAC-T70 | mm<br>(in) | M12 | 18.5<br>(0.55) | 33<br>(1.30) | 12.0<br>(0.47) | 40-200<br>(1.57-7.87) |
| | | mm<br>(in) | M16 | | | | 40-200<br>(1.57-7.87) |
| | | mm<br>(in) | M20 | | | | 60-200<br>(2.36-7.87) |
| HBC-B | HAC-30 | mm<br>(in) | M10<br>M12 | 19.0<br>(0.75) | 34.0<br>(1.34) | 9.2<br>(0.36) | 40-200<br>(1.57-7.87) |



HBC-B (compatible with HAC-30) HBC-T (compatible with HAC-T)

**Table 2.2.19.3 — Channel lip thickness**

| Anchor Channel profile | Channel lip thickness, $l_{th}$ |
|---|---|
| HAC-T50 | 1/8 in<br>(3.10 mm) |
| HAC-T70 | 13/64 in<br>(5.2 mm) |
| HAC-30 | 19/64 in<br>(7.5 mm) |

### Minimum t-bolt overhang

According to AISC Steel Construction Manual, 13th Edition, Section 14-10: “Adequate thread engagement for anchor rods is identical to the condition described in the RCSC Specification as adequate for steel to steel structural joints using high strength bolts: having the end of the [anchor rod] flush with or outside the face of the nut”.

There is no maximum thread protrusion limitation from the standpoint of the function of the bolt.

If needed, the excess at the end of the bolt can be cut-off. The nut shall be fully engaged. The outside face of the head of the t-bolt has special markings to identify the t-bolt type and proper head orientation of the t-bolt. If the t-bolt is to be cut or grind, inspect and ensure the orientation and t-bolt type is as specified prior to any work on the t-bolt. If the marking on the t-bolt are removed, proper inspection is not possible. Proper corrosion protection shall be required.

### Onsite adjustability

Serrations of channel lip allow incremental longitudinal displacement of 1/8” (3 mm). If the bracket needs to be slightly adjusted, while a force is applied (i.e. hung panel), the HBC-T will not slide. The HBC-T need not to be loaded in order to reposition the bracket. Therefore, it is not acceptable to adjust the location of the t-bolts via hammering of the bracket, if the weight of the panel is applied on the bracket

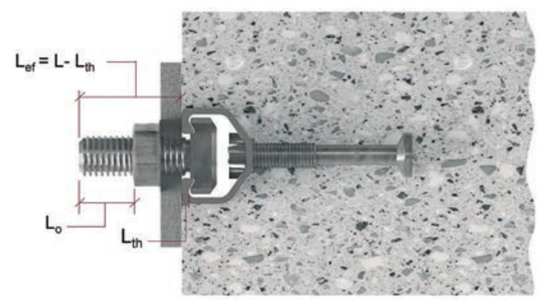


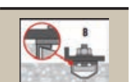

**Figure 2.2.19.4 — Overhang of Hilti Channel Bolts (HBC-T).**

**Table 2.2.19.4 – Recommended t-bolt overhang, $L_o$**

| Hilti locking channel bolt diameter (mm) | Minimum nominal overhang, $L_o$ |
|---|---|
| M12 | 1/8 in<br>(3 mm) |
| M16 | 13/64 in<br>(5 mm) |
| M20 | 9/32 in<br>(7 mm) |

### Installation Torque

**Table 2-2.19.5 — Installation torque for Hilti Serrated Channel Bolts (HBC-T and HBC-B)**

| Bolt type | Units | Installation torque Tinst (Installation type A)[1]  | | | | Installation torque Tinst (Installation type B)[2]  | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | HAC-30 F | HAC-T50 F | HAC-T50 S | HAC-T70 | HAC-30 F | HAC-T50 F | HAC-T50 S | HAC-T70 |
| HBC-B M10 4.6 | ft-lb (Nm) | 11 (15) | N/A | | | 11 (15) | N/A | | |
| HBC-B M12 4.6 | ft-lb (Nm) | 19 (25) | N/A | | | 19 (25) | N/A | | |
| HBC-T M12 8.8 | ft-lb (Nm) | N/A | 55 (75) | | | N/A | 55 (75) | | |
| HBC-T M16 8.8 | ft-lb (Nm) | N/A | 74 (100) | | | N/A | 136 (185) | | |
| HBC-T M20 8.8 | ft-lb (Nm) | N/A | 89 (120) | | | N/A | 236 (320) | | |

1 Installation type A: The fixture is in contact with the channel profile and the concrete surface
2 Installation type B: The fixture is fastened to the anchor channel by suitable steel part (e.g. square plate washer), fixture is in contact with the channel profile only



# 2.2.20 HILTI CHANNEL BOLTS HARDWARE

### Hexagonal head nut

Anchor channel systems consist of a group of anchors, channel profile, and matching t-bolt. The t-bolt hardware consists of a hex head nut and a flat washer.

**Table 2.2.20.1 — Material specifications of HBC-T nuts**

| Material specifications | |
|---|---|
| Material | ASTM A 563 Grade A; Stainless Steel 316 |
| Dimensions | ASME/ANSI B18.2.2-1986 |
| Finish | ASTM B 633-98, SC 1 Type I |
| Thread | Class 2A fit; Class 2B thrd; ASME B1.1 |

**Figure 2.2.20.1 — Isometric view if HBC-T nut.**

**Table 2.2.20.2— Dimensions of HBC-T Nuts**

| Criteria | | units | M12 | M16 | M20 |
|---|---|---|---|---|---|
| $p_a$ (pitch size) | | mm | 1.75 | 2.00 | 2.50 |
| c | max. | mm | 0.60 | 0.80 | 0.80 |
| | min. | mm | 0.15 | 0.20 | 0.20 |
| $d_a$ | max. | mm | 13.00 | 17.30 | 21.60 |
| | min. | mm | 12.00 | 16.00 | 20.00 |
| $d_w$ | min. | mm | 16.60 | 22.50 | 27.70 |
| e | min. | mm | 20.03 | 26.75 | 32.95 |
| m | max. | mm | 10.80 | 14.80 | 18.00 |
| | min. | mm | 10.37 | 14.10 | 16.90 |
| $m_w$ | min. | mm | 8.30 | 11.30 | 13.50 |
| s | max. | mm | 18.00 | 24.00 | 30.00 |
| | min. | mm | 17.73 | 23.67 | 29.16 |

Different surfaces and materials might have a significant influence on the ratio between torque moment and pre-tension. Therefore, it is important to use the washer as per product approval or recommended by Hilti.

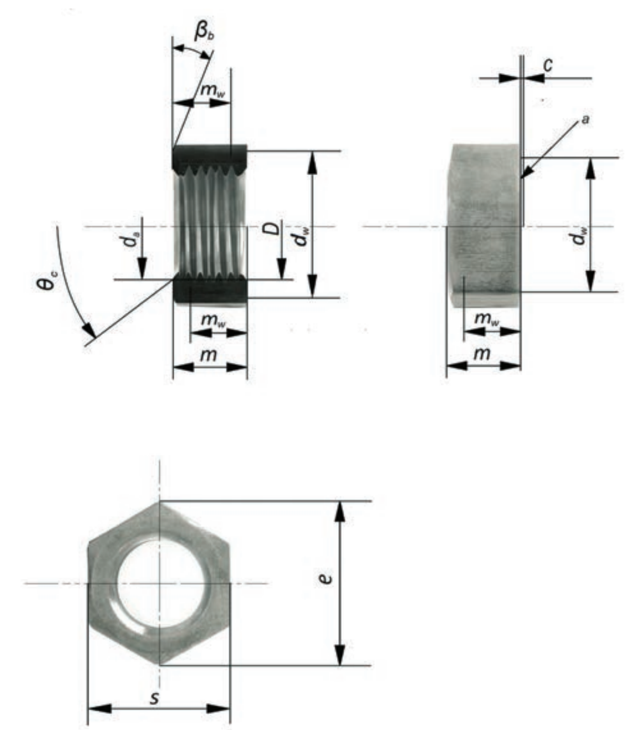



**Figure 2.2.20.2 — HBC-T nut dimensions.**

### Flat washers

Ensures compression forces (due to installation torque) from the nut are distributed over a larger surface, preventing localized damage of the base surface. Moreover, it ensures the nut presses against a smooth surface, reducing the probability of relaxation of the nut, as is the case when the nut bears against uneven surfaces.

**Table 2.2.20.3 — Material specification of HBC-T washers**

| Material specifications | |
|---|---|
| **Material** | Carbon steel, Hardness A, 200 HV |
| **Specifications** | ISO 7089 and ISO 7093-1 |
| **Finish** | Hot dip galvanized according to ISO 10684 |


**Figure 2.2.20.3 — HBC-T washer dimensions.**

**Table 2.2.20.4 — HBC-T washer dimensions**

| Order Designation | Suitable for channel bolt | Units | Inner diameter, $D_1$ | Outer, diameter D | Thickness, T |
|---|---|---|---|---|---|
| **Flat washer A 13/24-F** | M12 | mm (in) | 13 (0.51) | 24 (0.94) | 2.5 (0.10) |
| **Flat washer A 17/30-F** | M16 | mm (in) | 17 (0.67) | 30 (1.18) | 3 (0.12) |
| **Flat washer A 21/37-F** | M20 | mm (in) | 22 (0.87) | 37 (1.46) | 3 (0.12 |



# 2.3 STRUCTURAL STEEL PERFORMANCE OF HILTI ANCHOR CHANNEL SYSTEMS

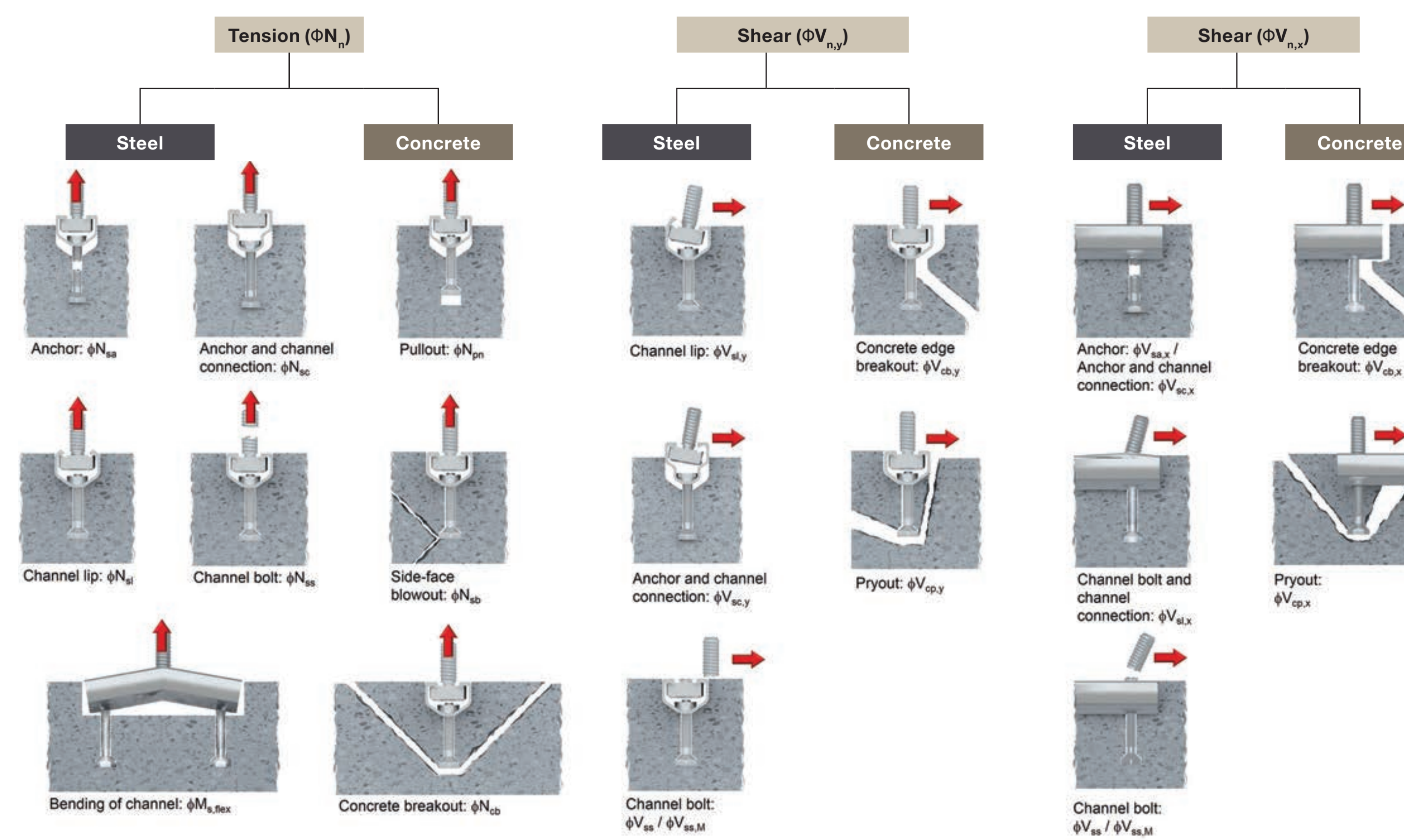
The design of cast-in anchor channels requires the verification of up to 25 different failure modes. As is the case with any other type of anchor, its design requires the verification of the adequacy of the steel, concrete at the anchorage zone, and/or anchor reinforcement. In addition, up to 5 interaction equations are required to complete the design of the anchor channel. Figure 2.3.1.1 illustrates the possible failure modes of a cast-in anchor channel system with rounded head anchors (HAC and HAC-T). Some of the failure modes illustrated on Figure 2.3.1.1 are not applicable to HAC CRFoS U while there are additional failure modes to HAC EDGE. For instance, pry-out is not applicable to HAC CRFoS U.

This chapter provides information about the structural performance of the Hilti cast-in anchor channel system. Therefore, information about the steel strengths of the anchor channels for all possible steel failure modes are covered in this section.

Acceptance Criteria 232 (AC232) is a comprehensive document of technical guidelines and testing protocols for cast-in anchor channels systems. AC232 was established through public hearings with industry experts and building officials' committee approval. The published steel strength values in this brochure are based on the International Code Council — Evaluation Service Report 3520 (ICC ESR-3520) when applicable. Steel strengths of anchor channels outside the scope of AC232 and ESR-3520 (i.e. HAC CRFoS U) have been derived in accordance with applicable testing protocols of AC232.

For additional design information such as interaction equations, impact of bolt spacing to anchor channel lip strength, etc., see anchor channel theory, see chapter 7. The provided steel strengths shall be applied in conjunction with the design guidelines provided in chapter 7. Moreover, refer to chapter 5 for information about the evaluation of the concrete at the anchorage zone and anchor reinforcement. Due of the number of factors that can influence the concrete performance, design guidelines are provided for its verification.

### Possible failure modes of anchor channel per AC232




Anchor reinforcement verifications are not included.
Anchor channel design shall satisfy interaction equations for combined shear and tension loading.

**Figure 2.3.1.1 — Possible failure modes of an anchor channel.**

## 2.3.1 HAC STRUCTURAL STEEL PERFORMANCE — TENSION

**Table 2.3.1.1 — Tension steel strength design information for Hilti Anchor Channels (HAC) with Hilti Channel Bolts (HBC-C and HBC-C-N)**

| Criteria | | Symbol | Units | HAC-40 F | HAC-50 F | HAC-60 F | HAC-70 F |
|---|---|---|---|---|---|---|---|
|  | Nominal tensile steel strength for local failure of channel lips | $N_{sl}$ | lb (kN) | 5,620 (25.0) | 7,865 (35.0) | 11,240 (50.0) | 15,960 (71.0) |
| | Nominal tensile steel strength for local failure of channel lips for seismic design | $N_{sl,seis}$ | lb (kN) | 5,620 (25.0) | 7,865 (35.0) | 7,865 (35.0) | 15,960 (71.0) |
| | Strength reduction factor for local failure of channel lips[1] | ϕ | - | 0.75 | | | |
|  | Nominal tensile steel strength of a single anchor | $N_{sa}$ | lb (kN) | 7,080 (31.5) | 11,240 (50.0) | 11,240 (50.0) | 16,320 (72.60) |
| | Nominal tensile steel strength of a single anchor for seismic design | $N_{sa,seis}$ | lb (kN) | 7,080 (31.5) | 11,240 (50.0) | 11,240 (50.0) | 16,320 (72.60) |
| | Strength reduction factor for anchor failure[1] | ϕ | - | 0.65 | 0.75 | | |
|  | Nominal tensile steel strength of connection between anchor and channel | $N_{sc}$ | lb (kN) | 5,620 (25.0) | 7,865 (35.0) | 11,240 (50.0) | 15,960 (71.0) |
| | Nominal tensile steel strength of connection between anchor and channel for seismic design | $N_{sc,seis}$ | lb (kN) | 5,620 (25.0) | 7,865 (35.0) | 7,865 (35.0) | 15,960 (71.0) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 | | | |
|  | Nominal bending strength of the anchor channel with HBC-C | $M_{s,flex}$ | lb-in (N*m) | 10,050 (1,136) | 14,125 (1,596) | 19,355 (2,187) | 28,000 (3,164) |
| | Nominal bending strength of the anchor channel with HBC-C-N | | lb-in (N*m) | 8,673 (980) | 11,903 (1,345) | 19,081 (2,156) | 26,594 (3,005) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C | $M_{s,flex,seis}$ | lb-in (N*m) | 10,050 (1,136) | 14,125 (1,596) | 14,125 (1,596) | 28,000 (3,164) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C-N | | lb-in (N*m) | 8,673 (980) | 11,903 (1,345) | 11,903 (1,345) | 26,594 (3,005) |
| | Strength reduction factor for bending failure[1] | ϕ | - | 0.85 | | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

**Table 2.3.1.2 — Tension concrete strength design information for Hilti Anchor Channels (HAC)**

| Criteria | Symbol | Units | HAC-40 F | HAC-50 F | HAC-60 F | HAC-70 F |
|---|---|---|---|---|---|---|
| Edge distance required to develop full concrete capacity in absence of anchor reinforcement | $c_{ac}$ | in (mm) | 10.75 (273) | 12.52 (318) | 17.48 (444) | 20.67 (525) |
| Strength reduction factor for tension, concrete failure modes[1] | ϕ | - | Condition A: 0.75<br>Condition B: 0.70 | | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.



## 2.3.2 HAC STRUCTURAL STEEL PERFORMANCE — SHEAR

**Table 2.3.2.1 — Shear steel strength design information for Hilti Anchor Channels (HAC) with Hilti Channel Bolts (HBC-C and HBC-C-N)**

| Criteria | | Symbol | Units | HAC-40 F | HAC-50 F | HAC-60 F | HAC-70 F |
|---|---|---|---|---|---|---|---|
|  | Nominal shear steel strength for local failure of channel lips | $V_{sl,y}$ | lb (kN) | 7,835 (34.8) | 10,675 (47.4) | 16,205 (72.0) | 21,550 (95.8) |
| | Nominal shear steel strength for local failure of the channel lips for seismic design | $V_{sl,y,seis}$ | lb (kN) | 7,835 (34.8) | 10,675 (47.4) | 10,675 (47.4) | 21,550 (95.8) |
| | Strength reduction factor for local failure of channel lips[1] | ϕ | - | 0.75 | | | |
|  | Nominal shear steel strength of a single anchor | $V_{sa,y}$ | lb (kN) | 8,903 (39.6) | 12,050 (53.6) | 17,378 (77.3) | 25,790 (114.7) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,y,seis}$ | lb (kN) | 8,903 (39.6) | 10,675 (47.4) | 10,675 (47.4) | 21,550 (95.8) |
| | Strength reduction factor anchor failure[1] | ϕ | - | 0.65 | 0.75 | | |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,y}$ | lb (kN) | 8,903 (39.6) | 12,050 (53.6) | 17,378 (77.3) | 25,790 (114.7) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,y,seis}$ | lb (kN) | 8,903 (39.6) | 10,675 (47.4) | 10,675 (47.4) | 21,550 (95.8) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 | | | |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,x}$ | lb (kN) | 3,552 (15.8) | 5,240 (23.3) | 6,722 (29.9) | 9,590 (42.6) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,x,seis}$ | lb (kN) | 3,552 (15.8) | 5,240 (23.3) | 5,240 (23.3) | 9,590 (42.6) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 | | | |
|  | Nominal shear steel strength of a single anchor | $V_{sa,x}$ | lb (kN) | 4,249 (18.9) | 6,740 (30.0) | 6,740 (30.0) | 9,800 (43.6) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,x,seis}$ | lb (kN) | 4,249 (18.9) | 6,740 (30.0) | 6,740 (30.0) | 9,800 (43.6) |
| | Strength reduction factor anchor failure[1] | ϕ | - | 0.75 | | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

**Table 2.3.2.2 — Shear concrete strength design information for Hilti Anchor Channels (HAC) with Hilti Channel Bolts (HBC-C and HBC-C-N)**

| Criteria | Symbol | Units | HAC-40 F | HAC-50 F | HAC-60 F | HAC-70 F |
|---|---|---|---|---|---|---|
| Factor to account for the influence of channel size and anchor diameter on concrete edge breakout strength in shear | $\alpha_{ch,V}$ | $lb^{1/2}/in^{1/3}$ ($N^{1/2}/mm^{1/3}$) | 10.50 (7.50) | | | |
| Coefficient for pryout strength | $k_{cp}$ | - | 2 | | | |
| Strength reduction factor for shear, concrete failure modes[1] | ϕ | - | Condition A: 0.75<br>Condition B: 0.70 | | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

**Table 2.3.2.3 — Steel strength design information for shear acting in longitudinal direction of the channel axis for Hilti Anchor Channels (HAC) with Hilti Locking Channel Bolts (HBC-C-N)**

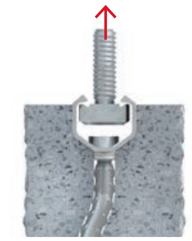
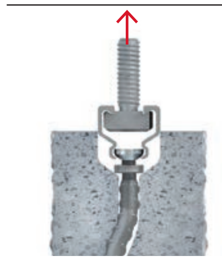
| | Criteria | Symbol | Channel bolt type HBC-C-N | Units | HAC-40 F | HAC-50 F | HAC-60 F | HAC-70 F |
|---|---|---|---|---|---|---|---|---|
|  | Nominal shear steel strength of connection between channel lips and channel bolts | $V_{sl,x}$ | M12[2] | lb (kN) | 1,920 (8.5) | | | |
| | | | M16 | lb (kN) | 4,420 (19.7) | | | |
| | | | M20 | lb (kN) | N/A | 5,425 (24.1) | | |
|  | Nominal shear steel strength of connection between channel lips and channel bolts for seismic design | $V_{sl,x,seis}$ | M12[2] | lb (kN) | 1,920 (8.5) | | | |
| | | | M16 | lb (kN) | 4,420 (19.7) | | | |
| | | | M20 | lb (kN) | N/A | 5,425 (24.1) | | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (periodic inspection) | ϕ | M12 | - | 0.55 | | | |
| | | | M16 | | | | | |
| | | | M20 | | | | | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (continuous inspection) | ϕ | M12 | - | 0.55 | | | |
| | | | M16 | | 0.65 | | | |
| | | | M20 | | | | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.
2 In case of continuous inspection the value for $V_{sl,x}$ for the size M12 can be taken for all channel sizes HAC-40 F through HAC-70 F as $V_{sl,x}$ = 2,021 lb (9.0 kN).



## 2.3.3 HAC CRFoS U STRUCTURAL STEEL PERFORMANCE — TENSION

**Table 2.3.3.1 — Tension steel strength design information for HAC CRFoS U with Hilti Channel Bolts (HBC-C and HBC-C-N)**

| | Criteria | Symbol | Units | HAC-50 F CRFoS U | HAC-60 F CRFoS U | HAC-70 F CRFoS U |
|---|---|---|---|---|---|---|
|  | Nominal tensile steel strength for local failure of channel lips | $N_{sl}$ | lb (kN) | 7,531 (33.5) | 10,723 (47.7) | 14,365 (63.9) |
| | Nominal tensile steel strength for local failure of channel lips for seismic design | $N_{sl,seis}$ | lb (kN) | 7,531 (33.5) | 10,723 (47.7) | 14,365 (63.9) |
| | Strength reduction factor for local failure of channel lips | ϕ | - | 0.75 | | |
|  | Nominal tensile steel strength of a single anchor | $N_{sa}$ | lb (kN) | 7,531 (33.5) | 11,510 (51.2) | 14,275 (63.5) |
| | Nominal tensile steel strength of a single anchor for seismic design | $N_{sa,seis}$ | lb (kN) | 7,531 (33.5) | 11,510 (51.2) | 14,275 (63.5) |
| | Strength reduction factor for anchor failure | ϕ | - | 0.75 | | |
|  | Nominal tensile steel strength of connection between anchor and channel | $N_{sc}$ | lb (kN) | 7,531 (33.5) | 10,723 (47.7) | 14,275 (63.5) |
| | Nominal tensile steel strength of connection between anchor and channel for seismic design | $N_{sc,seis}$ | lb (kN) | 7,531 (33.5) | 10,723 (47.7) | 14,275 (63.5) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 | | |
|  | Nominal bending strength of the anchor channel with HBC-C | $M_{s,flex}$ | lb-in (N*m) | 14,125 (1,596) | 19,355 (2,187) | 28,000 (3,164) |
| | Nominal bending strength of the anchor channel with HBC-C-N | | lb-in (N*m) | 11,903 (1,345) | 19,081 (2,156) | 26,594 (3,005) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C | $M_{s,flex,seis}$ | lb-in (N*m) | 14,125 (1,596) | 19,355 (2,187) | 28,000 (3,164) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C-N | | lb-in (N*m) | 11,903 (1,345) | 19,081 (2,156) | 26,594 (3,005) |
| | Strength reduction factor for bending failure | ϕ | - | 0.85 | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

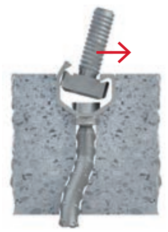
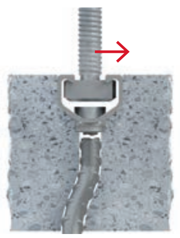
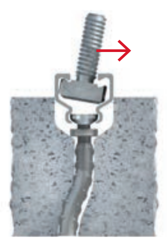
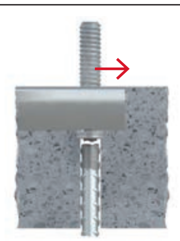
**Table 3.2.1.2 — Tension concrete strength design information for Hilti Anchor Channels HAC CRFoS U**

| Criteria | Symbol | Units | HAC-50 F CRFoS U | HAC-60 F CRFoS U | HAC-70 F CRFoS U |
|---|---|---|---|---|---|
| Edge distance required to develop full concrete capacity in absence of anchor reinforcement | $c_{ac}$ | in (mm) | 12.52 (318) | 17.48 (444) | 20.67 (525) |
| Strength reduction factor for tension, concrete failure modes[1] | ϕ | - | Condition A: 0.75<br>Condition B: 0.70 | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

## 2.3.4 HAC CRFoS U STRUCTURAL STEEL PERFORMANCE — SHEAR

**Table 2.3.4.1 — Shear steel strength design information for HAC CRFoS U with Hilti Channel Bolts (HBC-C and HBC-C-N)**

| | Criteria | Symbol | Units | HAC-50 F CRFoS U | HAC-60 F CRFoS U | HAC-70 F CRFoS U |
|---|---|---|---|---|---|---|
|  | Nominal shear steel strength for local failure of channel lips | $V_{sl,y}$ | lb (kN) | 10,675 (47.4) | 16,205 (72.0) | 21,550 (95.8) |
| | Nominal shear steel strength for local failure of the channel lips for seismic design | $V_{sl,y,seis}$ | lb (kN) | 10,675 (47.4) | 16,205 (72.0) | 21,550 (95.8) |
| | Strength reduction factor for local failure of channel lips[1] | $\phi$ | - | 0.75 | | |
|  | Nominal shear steel strength of a single anchor | $V_{sa,y}$ | lb (kN) | 12,050 (53.6) | 17,378 (77.3) | 24,414 (108.6) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,y,seis}$ | lb (kN) | 12,050 (53.6) | 17,378 (77.3) | 24,414 (108.6) |
| | Strength reduction factor anchor failure[1] | $\phi$ | - | 0.75 | | |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,y}$ | lb (kN) | 12,050 (53.6) | 17,378 (77.3) | 24,414 (108.6) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,y,seis}$ | lb (kN) | 12,050 (53.6) | 17,378 (77.3) | 24,414 (108.6) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | $\phi$ | - | 0.75 | | |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,x}$ | lb (kN) | 4,519 (20.1) | 6,430 (28.6) | 8,565 (38.1) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,x,seis}$ | lb (kN) | 4,519 (20.1) | 6,430 (28.6) | 8,565 (38.1) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | $\phi$ | - | 0.75 | | |
|  | Nominal shear steel strength of a single anchor | $V_{sa,x}$ | lb (kN) | 4,519 (20.1) | 6,902 (30.7) | 8,565 (38.1) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,x,seis}$ | lb (kN) | 4,519 (20.1) | 6,902 (30.7) | 8,565 (38.1) |
| | Strength reduction factor anchor failure[1] | $\phi$ | - | 0.75 | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed



**Table 2.3.4.2 — Shear concrete strength design information for HAC CRFoS U with Hilti Channel Bolts (HBC-C and HBC-C-N)**

| Criteria | Symbol | Units | HAC-50 F CRFoS U | HAC-60 F CRFoS U | HAC-70 F CRFoS U |
|---|---|---|---|---|---|
| Factor to account for the influence of channel size and anchor diameter on concrete edge breakout strength in shear | $\alpha_{ch,V}$ | $lb^{1/2}/in^{1/3}$ ($N^{1/2}/mm^{1/3}$) | 10.50 (7.50) | | |
| Coefficient for pryout strength | $k_{cp}$ | - | 2 | | |
| Strength reduction factor for shear, concrete failure modes[1] | $\phi$ | - | Condition A: 0.75<br>Condition B: 0.70 | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the f factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

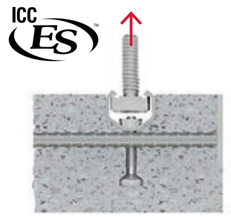
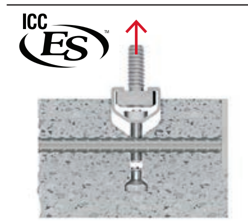
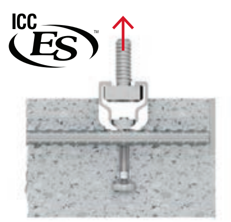
**Table 2.3.4.3 — Steel strength design information for shear acting in longitudinal direction of the channel axis for HAC CRFoS U with Hilti Locking Channel Bolts (HBC-C-N)**

| | Criteria | Symbol | Channel bolt type HBC-C-N | Units | HAC-50 F CRFoS U | HAC-60 F CRFoS U | HAC-70 F CRFoS U |
|---|---|---|---|---|---|---|---|
|  | Nominal shear steel strength of connection between channel lips and channel bolts | $V_{sl,x}$ | M12[2] | lb (kN) | 1,920 (8.5) | | |
| | | | M16 | lb (kN) | 4,420 (19.7) | | |
| | | | M20 | lb (kN) | 5,425 (24.1) | | |
|  | Nominal shear steel strength of connection between channel lips and channel bolts for seismic design | $V_{sl,x,seis}$ | M12[2] | lb (kN) | 1,920 (8.5) | | |
| | | | M16 | lb (kN) | 4,420 (19.7) | | |
| | | | M20 | lb (kN) | 5,425 (24.1) | | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (periodic inspection) | $\phi$ | M12 | - | 0.55 | | |
| | | | M16 | | | | |
| | | | M20 | | | | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (continuous inspection) | $\phi$ | M12 | - | 0.55 | | |
| | | | M16 | | 0.65 | | |
| | | | M20 | | | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.
2 In case of continuous inspection the value for $V_{sl,x}$ for the size M12 can be taken for all channel sizes HAC-40 F through HAC-70 F as $V_{sl,x}$ = 2,021 lb (9.0 kN).

# 2.3.5 HAC EDGE LITE, HAC EDGE, AND HAC EDGE C STRUCTURAL STEEL PERFORMANCE — TENSION

**Table 2.3.5.1 — Tension steel strength design information for HAC EDGE Lite, HAC EDGE, and HAC EDGE C with Hilti Channel Bolts (HBC-C and HBC-C-N)**

| | Criteria | Symbol | Units | HAC-40 EDGE Lite | HAC-50 EDGE Lite<br>HAC-50 EDGE<br>HAC-50 EDGE C |
|---|---|---|---|---|---|
|  | Nominal tensile steel strength for local failure of channel lips | $N_{sl}$ | lb<br>(kN) | 5,620<br>(25.0) | 7,865<br>(35.0) |
| | Nominal tensile steel strength for local failure of channel lips for seismic design | $N_{sl,seis}$ | lb<br>(kN) | 5,620<br>(25.0) | 7,865<br>(35.0) |
| | Strength reduction factor for local failure of channel lips | φ | - | 0.75 | |
|  | Nominal tensile steel strength of a single anchor | $N_{sa}$ | lb<br>(kN) | 7,080<br>(31.50) | 11,240<br>(50.0) |
| | Nominal tensile steel strength of a single anchor for seismic design | $N_{sa,seis}$ | lb<br>(kN) | 7,080<br>(31.50) | 11,240<br>(50.0) |
| | Strength reduction factor for anchor failure | φ | - | 0.65 | 0.75 |
|  | Nominal tensile steel strength of connection between anchor and channel | $N_{sc}$ | lb<br>(kN) | 5,620<br>(25.0) | 7,865<br>(35.0) |
| | Nominal tensile steel strength of connection between anchor and channel for seismic design | $N_{sc,seis}$ | lb<br>(kN) | 5,620<br>(25.0) | 7,865<br>(35.0) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | φ | - | 0.75 | |
|  | Nominal bending strength of the anchor channel with HBC-C | $M_{s,flex}$ | lb-in<br>(N*m) | 10,050<br>(1,136) | 14,125<br>(1,596) |
| | Nominal bending strength of the anchor channel with HBC-C-N | | lb-in<br>(N*m) | 8,673<br>(980) | 11,903<br>(1,345) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C | $M_{s,flex,seis}$ | lb-in<br>(N*m) | 10,050<br>(1,136) | 14,125<br>(1,596) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C-N | | lb-in<br>(N*m) | 8,673<br>(980) | 11,903<br>(1,345) |
| | Strength reduction factor for bending failure | φ | - | 0.85 | |

1 The tabulated value of φ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the φ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

**Table 2.3.5.2 — Tension concrete strength design information for HAC EDGE Lite and HAC EDGE**

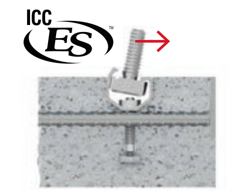
| Criteria | Symbol | Units | HAC-40 F<br>$h_{ef}$ = 91 mm | HAC-50 F<br>$h_{ef}$ = 94 mm | HAC-50 F<br>$h_{ef}$ = 106 mm |
|---|---|---|---|---|---|
| Edge distance required to develop full concrete capacity in absence of anchor reinforcement | $c_{ac}$ | in<br>(mm) | 10.75<br>(273) | TBD<br>(TBD) | 12.52<br>(318) |
| Strength reduction factor for tension, concrete failure modes[1] | φ | - | Condition A: 0.75<br>Condition B: 0.70 | | |

1 The tabulated value of φ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the φ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.



# 2.3.6 HAC EDGE LITE, HAC EDGE, AND HAC EDGE C STRUCTURAL STEEL PERFORMANCE — SHEAR

**Table 2.3.6.1 — Shear steel strength design information for HAC EDGE Lite, HAC EDGE, and HAC EDGE C Hilti Channel Bolts (HBC-C and HBC-C-N)**

| | Criteria | Symbol | Units | HAC-40 EDGE Lite | HAC-50 EDGE Lite<br>HAC-50 EDGE<br>HAC-50 EDGE C |
|---|---|---|---|---|---|
|  | Nominal shear steel strength for local failure of channel lips | $V_{sl,y}$ | lb<br>(kN) | 7,835<br>(34.8) | 10,675<br>(47.4) |
| | Nominal shear steel strength for local failure of the channel lips for seismic design | $V_{sl,y,seis}$ | lb<br>(kN) | 7,835<br>(34.8) | 10,675<br>(47.4) |
| | Strength reduction factor for local failure of channel lips[1] | φ | - | 0.75 | |
|  | Nominal shear steel strength of a single anchor | $V_{sa,y}$ | lb<br>(kN) | 8,903<br>(39.6) | 12,050<br>(53.6) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,y,seis}$ | lb<br>(kN) | 8,903<br>(39.6) | 10,675<br>(47.4) |
| | Strength reduction factor anchor failure[1] | φ | - | 0.65 | **0.75** |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,y}$ | lb<br>(kN) | 8,903<br>(39.6) | 12,050<br>(53.6) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,y,seis}$ | lb<br>(kN) | 8,903<br>(39.6) | 10,675<br>(47.4) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | φ | - | 0.75 | |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,x}$ | lb<br>(kN) | 3,552<br>(15.8) | 5,240<br>(23.3) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,x,seis}$ | lb<br>(kN) | 3,552<br>(15.8) | 5,240<br>(23.3) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | φ | - | 0.75 | |
|  | Nominal shear steel strength of a single anchor | $V_{sa,x}$ | lb<br>(kN) | 4,249<br>(18.9) | 6,740<br>(30.0) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,x,seis}$ | lb<br>(kN) | 4,249<br>(18.9) | 6,740<br>(30.0) |
| | Strength reduction factor anchor failure[1] | φ | - | 0.75 | |

1 The tabulated value of φ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the φ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are allowed.

**Table 2.3.6.2 — Shear concrete strength design information for for HAC EDGE Lite and HAC EDGE with Hilti Channel Bolts (HBC-C and HBC-C-N) when shear load acts away from the EDGE Plate.**

| Criteria | Symbol | Units | HAC-40 F | HAC-50 F |
|---|---|---|---|---|
| Factor to account for the influence of channel size and anchor diameter on concrete edge breakout strength in shear[2] | $\alpha_{ch,V}$ | $lb^{1/2}/in^{1/3}$<br>$(N^{1/2}/mm^{1/3})$ | 10.50<br>(7.50) | |
| Coefficient for pryout strength | $k_{cp}$ | - | 2 | |
| Strength reduction factor for shear, concrete failure modes[1] | φ | - | Condition A: N/A<br>Condition B: 0.70 | |

1 The tabulated value of φ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the φ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.
2 This factor will be applicable for shear acting in opposite direction edge plate (i.e away from edge plate). In case of shear acting in direction towards edge plate refer to Table 2.3.7.2 for design information.

**Table 2.3.6.3 — Steel strength design information for shear acting in longitudinal direction of the channel axis for HAC EDGE Lite, HAC EDGE, and HAC EDGE C with Hilti Locking Channel Bolts (HBC-C-N)**

| Criteria | | Symbol | Channel bolt type HBC-C-N | Units | HAC-40 EDGE Lite | HAC-50 EDGE Lite HAC-50 EDGE HAC-50 EDGE C |
|---|---|---|---|---|---|---|
| ICC ES  | Nominal shear steel strength of connection between channel lips and channel bolts | $V_{sl,x}$ | M12[2] | lb (kN) | 1,920 (8.5) | |
| | | | M16 | lb (kN) | 4,420 (19.7) | |
| | | | M20 | lb (kN) | 5,425 (24.1) | |
| ICC ES  | Nominal shear steel strength of connection between channel lips and channel bolts for seismic design | $V_{sl,x,seis}$ | M12[2] | lb (kN) | 1,920 (8.5) | |
| | | | M16 | lb (kN) | 4,420 (19.7) | |
| | | | M20 | lb (kN) | 5,425 (24.1) | |
| $\phi$ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (periodic inspection) | $\phi$ | M12 | - | 0.55 | |
| | | | M16 | | | |
| | | | M20 | | | |
| $\phi$ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (continuous inspection) | $\phi$ | M12 | - | 0.55 | |
| | | | M16 | | 0.65 | |
| | | | M20 | | | |

1 The tabulated value of φ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.
2 In case of continuous inspection the value for $V_{sl,x}$ for the size M12 can be taken for all channel sizes HAC-40 F through HAC-70 F as $V_{sl,x}$ = 2,021 lb (9.0 kN).

## 2.3.7 EDGE LITE, HAC EDGE, AND HAC EDGE C PLATE STEEL STRENGTH INFORMATION

**Table 2.3.7.1 — Steel strength design information for HAC EDGE Lite, HAC EDGE, and HAC EDGE C rebar edge confinement plate (EDGE Lite, EDGE, and EDGE C plate)**

| Criteria | Symbol | Units | Anchor Channel | | | |
|---|---|---|---|---|---|---|
| | | | HAC-40 | HAC-50 | | |
| | | | EDGE Lite | EDGE Lite | EDGE | EDGE C |
| Modulus of elasticity of the EDGE lite and EDGE plate | E | ksi (MPa) | 30,458 (210,000) | | | |
| Minimum specified ultimate strength | $f_{uta}$ | psi (MPa) | 79,750 (550) | | | |
| Minimum specified yield strength | $f_{ya}$ | psi (MPa) | 72,500 (500) | | | |
| Nominal rebar steel strength | $N_{s,r}$ | lb (kN) | 5,650 (25.13) | 8,828 (39.27) | 12,713 (56.55) | |
| Nominal rebar-shear confinement plate connection strength | $N_{s,c}$ | lb (kN) | | | | |
| Strength reduction factor for rebar tensile steel strength | φ | - | 0.75 | | | |

## 2.3.8 DESIGN INFORMATION FOR HAC EDGE LITE , HAC EDGE AND HAC EDGE C CONCRETE BREAKOUT IN PERPENDICULAR SHEAR

**Table 2.3.8.1 — Shear concrete strength design information for HAC EDGE Lite, HAC EDGE, and HAC EDGE C with Hilti Channel Bolts (HBC-C and HBC-C-N) when shear load acts towards the EDGE Plate.**

| Criteria | Symbol | Units | Anchor Channel | | | |
|---|---|---|---|---|---|---|
| | | | HAC-40 EDGE Lite | HAC-50 EDGE Lite | HAC-50 EDGE | HAC-50 EDGE C |
| Factor to account for the influence of plate size and rebar diameter on concrete edge breakout strength in shear for the EDGE Lite and EDGE plate | $k_{EDGE}$ / $k_{EDGE\ C}$ | Imperial units | 575 | 700 | 880 | 720 |
| | | SI units | (270) | (330) | (415) | (340) |
| Exponent for the edge distance in the basic value of the concrete edge breakout | $x_1$ | - | 0.97 | | | |
| Exponent for the concrete strength in the basic value of the concrete edge breakout | $x_2$ | - | 0.18 | | | |
| Exponent for the modification factor to account for influence of member thickness on concrete edge breakout strength for anchors channels loaded in shear | $x_3$ | - | 0.25 | | | |
| Exponent for the modification factor for corner effects on concrete edge breakout strength for anchor channels loaded in shear | $x_4$ | - | 0.11 | | | |
| Modification factor for the critical anchor spacing in combination with the EDGE Lite and EDGE plate | $\alpha_{1,V}$ | - | 0.60 | | | |
| Coefficient for pry out strength | $k_{cp}$ | - | 2.0 | | | |
| Modification factor for HAC EDGE Lite and HAC EDGE to control splitting | $\psi_{cp}$ | - | 1.0 | | | |
| Modification factor to account for influence of cracked or uncracked concrete for concrete edge breakout strength | $\psi_{c,V}$ | - | 1.0 | | | |
| Strength reduction factor for shear, concrete failure modes[1] | φ | - | 0.70 | | | |

1 The tabulated value of φ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided.

See chapter 9 for additional design information for HAC EDGE Lite, HAC EDGE, and HAC EDGE C

## 2.3.9 HAC S EDGE AND HAC S EDGE C STRUCTURAL STEEL PERFORMANCE — TENSION

**Table 2.3.9.1 — Tension steel strength design information for HAC S EDGE and HAC S EDGE C with Hilti Channel Bolts (HBC-C and HBC-C-N).**

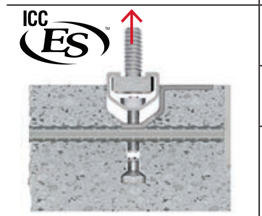
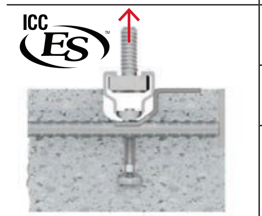
| Criteria | | Symbol | Units | HAC-50 S EDGE HAC-50 S EDGE C |
|---|---|---|---|---|
|  | Nominal tensile steel strength for local failure of channel lips | $N_{sl}$ | lb (kN) | 7,865 (35.0) |
| | Nominal tensile steel strength for local failure of channel lips for seismic design | $N_{sl,seis}$ | lb (kN) | 7,865 (35.0) |
| | Strength reduction factor for local failure of channel lips | ϕ | - | 0.75 |
|  | Nominal tensile steel strength of a single anchor | $N_{sa}$ | lb (kN) | 11,240 (50.0) |
| | Nominal tensile steel strength of a single anchor for seismic design | $N_{sa,seis}$ | lb (kN) | 11,240 (50.0) |
| | Strength reduction factor for anchor failure | ϕ | - | 0.75 |
|  | Nominal tensile steel strength of connection between anchor and channel | $N_{sc}$ | lb (kN) | 7,865 (35.0) |
| | Nominal tensile steel strength of connection between anchor and channel for seismic design | $N_{sc,seis}$ | lb (kN) | 7,865 (35.0) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 |
|  | Nominal bending strength of the anchor channel with HBC-C | $M_{s,flex}$ | lb-in (N*m) | 14,125 (1,596) |
| | Nominal bending strength of the anchor channel with HBC-C-N | | lb-in (N*m) | 11,903 (1,345) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C | $M_{s,flex,seis}$ | lb-in (N*m) | 14,125 (1,596) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C-N | | lb-in (N*m) | 11,903 (1,345) |
| | Strength reduction factor for bending failure | ϕ | - | 0.85 |

**Table 2.3.9.2 — Tension concrete strength design information for HAC S EDGE and HAC S EDGE C**

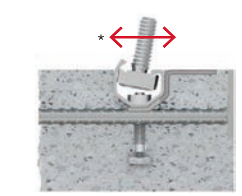
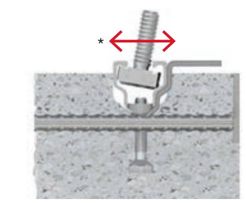
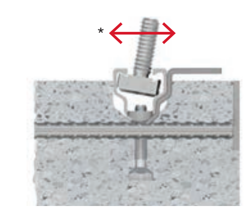
| Criteria | Symbol | Units | HAC-50 S $h_{ef}$ = 94 mm | HAC-50 S $h_{ef}$ = 106 mm |
|---|---|---|---|---|
| Edge distance required to develop full concrete capacity in absence of anchor reinforcement | $c_{ac}$ | in (mm) | TBD (TBD) | 12.52 (318) |
| Strength reduction factor for tension, concrete failure modes[1] | ϕ | - | Condition A: N/A Condition B: 0.70 | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.



## 2.3.10 HAC S EDGE AND HAC S EDGE C STRUCTURAL STEEL STEEL PERFORMANCE — SHEAR

**Table 2.3.10.1 — Shear steel strength design information for HAC S EDGE and HAC S EDGE C with Hilti Channel Bolts (HBC-C and HBC-C-N).**

| Criteria | | Symbol | Units | HAC-50 S EDGE HAC-50 S EDGE C |
|---|---|---|---|---|
|  | *Nominal shear steel strength for local failure of channel lips in opposite direction of the S bracket | $V_{sl,y}$ | lb (kN) | 10,675 (47.4) |
| | Nominal shear steel strength for local failure of the channel lips in direction of the S bracket | $V_{sl,y,clip}$ | lb (kN) | 17,707 (78.7) |
| | Nominal shear steel strength for local failure of the channel lips for seismic design in both directions | $V_{sl,y,seis}$ | lb (kN) | 10,675 (47.4) |
| | Strength reduction factor for local failure of channel lips[1] | ϕ | - | 0.75 |
|  | *Nominal shear steel strength of a single anchor in opposite direction of the S bracket | $V_{sa,y}$ | lb (kN) | 12,050 (53.6) |
| | Nominal shear steel strength of a single anchor in direction of the S bracket | $V_{sa,y,clip}$ | lb (kN) | 13,865 (61.7) |
| | Nominal shear steel strength of a single anchor for seismic design in both directions | $V_{sa,y,seis}$ | lb (kN) | 10,675 (47.4) |
| | Strength reduction factor anchor failure[1] | ϕ | - | 0.75 |
|  | *Nominal shear steel strength of connection between anchor and channel in opposite direction of the S bracket | $V_{sc,y}$ | lb (kN) | 12,050 (53.6) |
| | Nominal shear steel strength of connection between anchor and channel in direction of the S bracket | $V_{sc,y,clip}$ | lb (kN) | 13,865 (61.7) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design in both directions | $V_{sc,y,seis}$ | lb (kN) | 10,675 (47.4) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,x}$ | lb (kN) | 5,240 (23.3) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,x,seis}$ | lb (kN) | 5,240 (23.3) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 |
|  | Nominal shear steel strength of a single anchor | $V_{sa,x}$ | lb (kN) | 6,740 (30.0) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,x,seis}$ | lb (kN) | 6,740 (30.0) |
| | Strength reduction factor anchor failure[1] | ϕ | - | 0.75 |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

**Table 2.3.10.2 — Shear concrete strength design information for for HAC S EDGE and HAC S EDGE C with Hilti Channel Bolts (HBC-C and HBC-C-N) when shear load acts away from the EDGE Plate.**

| Criteria | Symbol | Units | HAC-50 S $h_{ef}$ = 106 mm |
|---|---|---|---|
| Factor to account for the influence of channel size and anchor diameter on concrete edge breakout strength in shear[2] | $\alpha_{ch,V}$ | $lb^{1/2}/in^{1/3}$ ($N^{1/2}/mm^{1/3}$) | 10.50 (7.50) |
| Coefficient for pryout strength | $k_{cp}$ | - | 2 |
| Strength reduction factor for shear, concrete failure modes[1] | ϕ | - | Condition A: N/A Condition B: 0.70 |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.
2 This factor will be applicable for shear acting in opposite direction edge plate (i.e away from edge plate). In case of shear acting in direction towards edge plate refer to Table 2.3.12.1 for design information.

**Table 2.3.10.3 — Steel strength design information for shear acting in longitudinal direction of the channel axis for HAC S EDGE and HAC S EDGE C with Hilti Locking Channel Bolts (HBC-C-N)**

| | Criteria | Symbol | | Units | HAC-40 EDGE Lite | HAC-50 S EDGE<br>HAC-50 S EDGE C |
|---|---|---|---|---|---|---|
|  | Nominal shear steel strength of connection between channel lips and channel bolts | $V_{sl,x}$ | M12[2] | lb<br>(kN) | 1,920<br>(8.5) | |
| | | | M16 | lb<br>(kN) | 4,420<br>(19.7) | |
| | | | M20 | lb<br>(kN) | 5,425<br>(24.1) | |
|  | Nominal shear steel strength of connection between channel lips and channel bolts for seismic design | $V_{sl,x,seis}$ | M12[2] | lb<br>(kN) | 1,920<br>(8.5) | |
| | | | M16 | lb<br>(kN) | 4,420<br>(19.7) | |
| | | | M20 | lb<br>(kN) | 5,425<br>(24.1) | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (periodic inspection | ϕ | M12 | - | 0.55 | |
| | | | M16 | | | |
| | | | M20 | | | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (continuous inspection) | ϕ | M12 | - | 0.55 | |
| | | | M16 | | 0.65 | |
| | | | M20 | | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.
2 In case of continuous inspection the value for $V_{sl,x}$ for the size M12 can be taken for all channel sizes HAC-40 F through HAC-70 F as $V_{sl,x}$ = 2,021 lb (9.0 kN).

## 2.3.11 HAC S EDGE AND HAC S EDGE C PLATE STEEL STRENGTH INFORMATION

**Table 2.3.11.1 — Steel strength design information for HAC S EDGE and HAC S EDGE C rebar edge confinement plate (EDGE and EDGE C plate)**

| Criteria | Symbol | Units | Anchor Channel HAC-50 S EDGE | Anchor Channel HAC-50 S EDGE C |
|---|---|---|---|---|
| Modulus of elasticity of the EDGE plate | E | ksi<br>(MPa) | 30,458<br>(210,000) | |
| Minimum specified ultimate strength | $f_{uta}$ | psi<br>(MPa) | 79,750<br>(550) | |
| Minimum specified yield strength | $f_{ya}$ | psi<br>(MPa) | 72,500<br>(500) | |
| Nominal rebar steel strength | $N_{s,r}$ | lb<br>(kN) | 12,713<br>(56.55) | |
| Nominal connection strength of rebar-EDGE plate | $N_{s,c}$ | lb<br>(kN) | | |
| Strength reduction factor for Rebar steel tensile strength | ϕ | - | 0.75 | |

## 2.3.12 DESIGN INFORMATION FOR HAC S EDGE AND HAC S EDGE C CONCRETE BREAKOUT IN PERPENDICULAR SHEAR

**Table 2.3.12.1 — Shear concrete strength design information for HAC S EDGE and HAC S EDGE C with Hilti Channel Bolts (HBC-C and HBC-C-N) when shear load acts towards the EDGE Plate.**

| Criteria | Symbol | Units | Anchor Channel HAC-50 S EDGE | Anchor Channel HAC-50 S EDGE C |
|---|---|---|---|---|
| Factor to account for the influence of plate size and rebar diameter on concrete edge breakout strength in shear for the EDGE plate | $k_{EDGE}$ / $k_{EDGE\ C}$ | Imperial units<br>SI units | 880<br>(415) | 720<br>(340) |
| Exponent for the edge distance in the basic value of the concrete edge breakout | $x_1$ | - | 0.97 | |
| Exponent for the concrete strength in the basic value of the concrete edge breakout | $x_2$ | - | 0.18 | |
| Exponent for the modification factor to account for influence of member thickness on concrete edge breakout strength for anchors channels loaded in shear | $x_3$ | - | 0.25 | |
| Exponent for the modification factor for corner effects on concrete edge breakout strength for anchor channels loaded in shear | $x_4$ | - | 0.11 | |
| Modification factor for the critical anchor spacing in combination with the EDGE plate | $\alpha_{1,V}$ | - | 0.60 | |
| Coefficient for pry out strength | $k_{cp}$ | - | 2.0 | |
| Modification factor for HAC EDGE to control splitting | $\psi_{cp}$ | - | 1.0 | |
| Modification factor to account for influence of cracked or uncracked concrete for concrete edge breakout strength | $\psi_{c,V}$ | - | 1.0 | |
| Strength reduction factor for shear, concrete failure modes[1] | ϕ | - | 0.70 | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided.

See chapter 9 for additional design information for HAC S EDGE and HAC S EDGE C

## 2.3.13 HBC-C AND HBC-C-N STEEL PERFORMANCE — TENSION

**Table 2.3.13.1 — Tension steel strengths design information for Hilti Channel Bolts (HBC-C and HBC-C-N).**

| Criteria | | Symbol | Bolt type | Units | M12 | M16 | M20 |
|---|---|---|---|---|---|---|---|
|  | Nominal tensile strength of a channel bolt | $N_{ss}$ | HBC-C 50R | lb (kN) | - - | 14,080 (62.6) | - - |
| | | | HBC-C 8.8 | lb (kN) | 15,160 (67.4) | 28,235 (125.6) | 39,190 (174.3) |
| | | | HBC-C-N 8.8 | lb (kN) | 15,160 (67.4) | 28,235 (125.6) | 45,524 (202.5) |
|  | Nominal tensile strength of a channel bolt for a seismic design | $N_{ss,seis}$ | HBC-C 8.8 | lb (kN) | 15,160 (67.4) | 28,235 (125.6) | 39,190 (174.3) |
| | | | HBC-C-N 8.8 | lb (kN) | 15,160 (67.4) | 28,235 (125.6) | 45,524 (202.5) |
| ϕ | Strength reduction factor for tension, steel failure modes[1] | ϕ | - | - | 0.65 | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.

## 2.3.14 HBC-C AND HBC-C-N STEEL PERFORMANCE — SHEAR

**Table 2.3.14.1 — Shear steel strengths design information for Hilti Channel Bolts (HBC-C and HBC-C-N).**

| Criteria | | Symbol | Bolt type | Units | M12 | M16 | M20 |
|---|---|---|---|---|---|---|---|
|  | Nominal shear strength of a channel bolt | $V_{ss}$ | HBC-C 50R | lb (kN) | - - | 8,450 (37.5) | - - |
| | | | HBC-C 8.8 | lb (kN) | 9,095 (40.4) | 16,940 (75.3) | 27,427 (122.0) |
| | | | HBC-C-N 8.8 | lb (kN) | 9,095 (40.4) | 16,940 (75.3) | 27,427 (122.0) |
|  | Nominal shear strength of a channel bolt for seismic design | $V_{ss,seis}$ | HBC-C-N 8.8 | lb (kN) | 9,095 (40.4) | 16,940 (75.3) | 27,427 (122.0) |
|  | Nominal flexural strength of the channel bolt | $M^{o}_{ss}$ | HBC-C 50R | lb-in (N*m) | - - | 1,180 (132.80) | - - |
| | | | HBC-C 8.8 | lb-in (N*m) | 930 (104.8) | 2,355 (266.3) | 4,768 (538.7) |
| | | | HBC-C-N 8.8 | lb-in (N*m) | 930 (104.8) | 2,355 (266.3) | 4,768 (538.7) |
|  | Nominal flexural strength of the channel bolt for seismic design | $M^{o}_{ss,seis}$ | HBC-C-N 8.8 | lb-in (N*m) | 930 (104.8) | 2,355 (266.3) | 4,768 (538.7) |
| ϕ | Strength reduction factor for shear, steel failure modes[1] | ϕ | - | - | 0.60 | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.



## 2.3.15 HAC-30 AND HAC-T STRUCTURAL STEEL PERFORMANCE — TENSION

**Table 2.3.15.1 — Tension steel strength design information for HAC-T with Hilti Serrated Channel Bolts (HBC-T)**

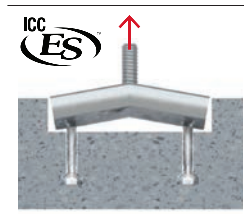
| Criteria | | Symbol | Units | HAC-30 (compatible with HBC-B) | HAC-T50 (compatible with HBC-T) | HAC-T70 (compatible with HBC-T) |
|---|---|---|---|---|---|---|
|  | Nominal tensile steel strength for local failure of channel lips | $N_{sl}$ | lb (kN) | 3,935 (17.5) | 7,865 (35.0) | 15,960 (71.0) |
| | Nominal tensile steel strength for local failure of channel lips for seismic design | $N_{sl,seis}$ | lb (kN) | 3,935 (17.5) | 7,865 (35.0) | 15,960 (71.0) |
| | Strength reduction factor for local failure of channel lips | ϕ | - | 0.75 | | |
|  | Nominal tensile steel strength of a single anchor | $N_{sa}$ | lb (kN) | 3,890 (17.3) | 11,240 (50.0) | 16,320 (72.6) |
| | Nominal tensile steel strength of a single anchor for seismic design | $N_{sa,seis}$ | lb (kN) | 3,890 (17.3) | 11,240 (50.0) | 16,320 (72.6) |
| | Strength reduction factor for anchor failure | ϕ | - | 0.75 | | |
|  | Nominal tensile steel strength of connection between anchor and channel | $N_{sc}$ | lb (kN) | 3,935 (17.5) | 7,865 (35.0) | 15,960 (71.0) |
| | Nominal tensile steel strength of connection between anchor and channel for seismic design | $N_{sc,seis}$ | lb (kN) | 3,935 (17.5) | 7,865 (35.0) | 15,960 (71.0) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 | | |
|  | Nominal bending strength of the anchor channel with HBC-T | $M_{s,flex}$ | lb-in (N*m) | 5,955 (673) | 14,125 (1,596) | 26,331 (2,975) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-T | $M_{s,flex,seis}$ | lb-in (N*m) | 5,955 (673) | 14,125 (1,596) | 26,331 (2,975) |
| | Strength reduction factor for bending failure | ϕ | - | 0.85 | | |

**Table 2.3.15.2 — Tension concrete strength design information for HAC-T and HAC-30.**

| Criteria | Symbol | Units | HAC-30 | HAC-T50 $h_{ef}$ = 94 mm | HAC-T50 $h_{ef}$ = 106 mm | HAC-T70 |
|---|---|---|---|---|---|---|
| Edge distance required to develop full concrete capacity in absence of anchor reinforcement | $c_{ac}$ | in (mm) | 8.03 (204) | | 12.52 (318) | 20.67 (525) |
| Strength reduction factor for tension, concrete failure modes[1] | ϕ | - | Condition A: 0.75 Condition B: 0.70 | Condition A: 0.75 Condition B: 0.70 | Condition A: 0.75 Condition B: 0.70 | Condition A: 0.75 Condition B: 0.70 |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

# 2.3.16 HAC-30 AND HAC-T STRUCTURAL STEEL PERFORMANCE — SHEAR

**Table 2.3.161 – Shear steel strength design information for HAC-T with Hilti Serrated Channel Bolts (HBC-T) HAC-30 with Hilti Channel Bolts (HBC-B).**

| | Criteria | Symbol | Units | HAC-30 (compatible with HBC-B) | HAC-T50 (compatible with HBC-T) | HAC-T70 (compatible with HBC-T) |
|---|---|---|---|---|---|---|
|  | Nominal shear steel strength for local failure of channel lips | $V_{sl,y}$ | lb (kN) | 5,620 (25.0) | 10,675 (47.4) | 21,550 (95.8) |
| | Nominal shear steel strength for local failure of the channel lips for seismic design | $V_{sl,y,seis}$ | lb (kN) | 5,620 (25.0) | 10,675 (47.4) | 21,550 (95.8) |
| | Strength reduction factor for local failure of channel lips[1] | ϕ | - | | 0.75 | |
|  | Nominal shear steel strength of a single anchor | $V_{sa,y}$ | lb (kN) | 5,620 (25.0) | 12,050 (53.6) | 25,790 (114.7) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,y,seis}$ | lb (kN) | 5,620 (25.0) | 10,675 (47.4) | 21,550 (95.8) |
| | Strength reduction factor anchor failure[1] | ϕ | - | | 0.75 | |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,y}$ | lb (kN) | 5,620 (25.0) | 12,050 (53.6) | 25,790 (114.7) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,y,seis}$ | lb (kN) | 5,620 (25.0) | 10,675 (47.4) | 21,550 (95.8) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | | 0.75 | |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,x}$ | lb (kN) | 2,360 (10.5) | 5,240 (23.3) | 9,590 (42.6) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,x,seis}$ | lb (kN) | 2,360 (10.5) | 5,240 (23.3) | 9,590 (42.6) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | | 0.75 | |
|  | Nominal shear steel strength of a single anchor | $V_{sa,x}$ | lb (kN) | 2,340 (10.4) | 6,740 (30.0) | 9,800 (43.6) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,x,seis}$ | lb (kN) | 2,340 (10.4) | 6,740 (30.0) | 9,800 (43.6) |
| | Strength reduction factor anchor failure[1] | ϕ | - | | 0.75 | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

**Table 2.3.16.2 — Shear concrete strength design information for HAC-T with Hilti Serrated Channel Bolts (HBC-T) and HAC-30 with Hilti Channel Bolts (HBC-B).**

| Criteria | Symbol | Units | HAC-30 F HAC-T50 F HAC-T70 F |
|---|---|---|---|
| Factor to account for the influence of channel size and anchor diameter on concrete edge breakout strength in shear | $\alpha_{ch,V}$ | $lb^{1/2}/in^{1/3}$ ($N^{1/2}/mm^{1/3}$) | 10.50 (7.50) |
| Coefficient for pryout strength | $k_{cp}$ | - | 2 |
| Strength reduction factor for shear, concrete failure modes[1] | ϕ | - | Condition A: 0.75<br>Condition B: 0.70 |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

**Table 2.3.16.3 — Steel strength design information for shear acting in longitudinal direction of the channel axis for HAC-T with Hilti Serrated Channel Bolts (HBC-T) and HAC-30 with Hilti Channel Bolts (HBC-B).**

| | Criteria | Symbol | *Channel bolt type | | Units | HAC-30 F (compatible with HBC-B) | HAC-T50 F (compatible with HBC-T) | HAC-T70 F (compatible with HBC-T) |
|---|---|---|---|---|---|---|---|---|
| | | | HBC-B (compatible with HAC-30) | HBC-T (compatible with HBC-T) | | | | |
|  | Nominal shear steel strength of connection between channel lips and channel bolts | $V_{sl,x}$ | M12 | | lb (kN) | 790 (3.5) | 3,395 (15.1) | |
| | | | M16 | | lb (kN) | - | 4,519 (20.1) | |
| | | | M20 | | lb (kN) | - | 4,519 (20.1) | |
|  | Nominal shear steel strength of connection between channel lips and channel bolts for seismic design | $V_{sl,x,seis}$ | M12 | | lb (kN) | 790 (3.5) | 3,395 (15.1) | |
| | | | M16 | | lb (kN) | - | 4,519 (20.1) | |
| | | | M20 | | lb (kN) | - | 4,519 (20.1) | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (periodic inspection) | ϕ | M12 | | - | 0.55 | 0.65 | |
| | | | M16 | | | | | |
| | | | M20 | | | | | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (continuous inspection) | ϕ | M12 | | - | 0.55 | 0.75 | |
| | | | M16 | | | | | |
| | | | M20 | | | | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.
* Note: HBC-T are only compatible with HAC-T. HBC-B are only compatible with HAC-30.

# 2.3.17 HAC-T EDGE LITE, HAC-T EDGE, AND HAC-T EDGE C STRUCTURAL STEEL PERFORMANCE — TENSION

**Table 2.3.17.1 — Tension steel strength design information for HAC-T EDGE Lite, HAC-T EDGE and HAC-T EDGE C with Hilti Serrated Channel Bolts (HBC-T)**

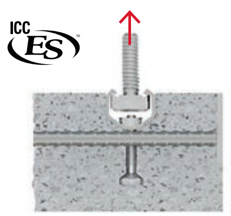
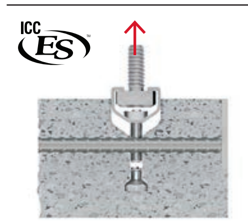
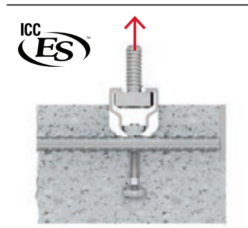
| | Criteria | Symbol | Units | HAC-T50 EDGE Lite<br>HAC-T50 EDGE<br>HAC-T50 EDGE C |
|---|---|---|---|---|
|  | Nominal tensile steel strength for local failure of channel lips | $N_{sl}$ | lb<br>(kN) | 7,865<br>(35.0) |
| | Nominal tensile steel strength for local failure of channel lips for seismic design | $N_{sl,seis}$ | lb<br>(kN) | 7,865<br>(35.0) |
| | Strength reduction factor for local failure of channel lips[1] | ϕ | - | 0.75 |
|  | Nominal tensile steel strength of a single anchor | $N_{sa}$ | lb<br>(kN) | 11,240<br>(50.0) |
| | Nominal tensile steel strength of a single anchor for seismic design | $N_{sa,seis}$ | lb<br>(kN) | 11,240<br>(50.0) |
| | Strength reduction factor for anchor failure[1] | ϕ | - | 0.75 |
|  | Nominal tensile steel strength of connection between anchor and channel | $N_{sc}$ | lb<br>(kN) | 7,865<br>(35.0) |
| | Nominal tensile steel strength of connection between anchor and channel for seismic design | $N_{sc,seis}$ | lb<br>(kN) | 7,865<br>(35.0) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | 0 | 0.75 |
|  | Nominal bending strength of the anchor channel with HBC-T | $M_{s,flex}$ | lb-in<br>(N*m) | 14,125<br>(1,596) |
| | Nominal bending strength of the anchor channel with HBC-T | $M_{s,flex,seis}$ | lb-in<br>(N*m) | 14,125<br>(1,596) |
| | Strength reduction factor for bending failure[1] | ϕ | - | 0.85 |

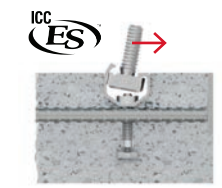
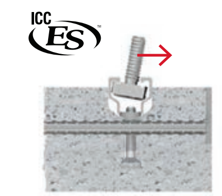
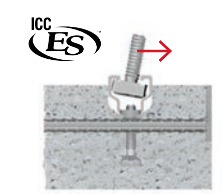
**Table 2.3.17.2 — Tension concrete strength design information for HAC-T EDGE Lite, HAC-T EDGE and HAC-T EDGE C**

| Criteria | Symbol | Units | HAC-T50<br>$h_{ef}$ = 94 mm | HAC-T50<br>$h_{ef}$ = 106 mm |
|---|---|---|---|---|
| Edge distance required to develop full concrete capacity in absence of anchor reinforcement | $c_{ac}$ | in<br>(mm) | 12.52<br>(318) | 20.67<br>(525) |
| Strength reduction factor for tension, concrete failure modes[1] | ϕ | - | Condition A: 0.75<br>Condition B: 0.70 | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

# 2.3.18 HAC-T EDGE LITE, HAC EDGE, AND HAC-T EDGE C STRUCTURAL STEEL PERFORMANCE — SHEAR

**Table 2.3.18.1 — Shear steel strength design information for HAC-T EDGE Lite, HAC-T EDGE and HAC-T EDGE C with Hilti Serrated Channel Bolts (HBC-T)**

| | Criteria | Symbol | Units | HAC-T50 EDGE Lite<br>HAC-T50 EDGE<br>HAC-T50 EDGE C |
|---|---|---|---|---|
|  | Nominal shear steel strength for local failure of channel lips | $V_{sl,y}$ | lb<br>(kN) | 10,675<br>(47.4) |
| | Nominal shear steel strength for local failure of the channel lips for seismic design | $V_{sl,y,seis}$ | lb<br>(kN) | 10,675<br>(47.4) |
| | Strength reduction factor for local failure of channel lips[1] | ϕ | - | 0.75 |
|  | Nominal shear steel strength of a single anchor | $V_{sa,y}$ | lb<br>(kN) | 12,050<br>(53.6) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,y,seis}$ | lb<br>(kN) | 10,675<br>(47.4) |
| | Strength reduction factor anchor failure[1] | ϕ | - | 0.75 |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,y}$ | lb<br>(kN) | 12,050<br>(53.6) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,y,seis}$ | lb<br>(kN) | 10,675<br>(47.4) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,x}$ | lb<br>(kN) | 5,240<br>(23.3) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,x,seis}$ | lb<br>(kN) | 5,240<br>(23.3) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | ϕ | - | 0.75 |
|  | Nominal shear steel strength of a single anchor | $V_{sa,x}$ | lb<br>(kN) | 6,740<br>(30.0) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,x,seis}$ | lb<br>(kN) | 6,740<br>(30.0) |
| | Strength reduction factor anchor failure[1] | ϕ | - | 0.75 |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.

**Table 2.3.18.2 — Shear concrete strength design information for HAC-T EDGE Lite and HAC-T EDGE with Hilti Serrated Channel Bolts (HBC-T) when shear load acts away from the EDGE Plate.**

| Criteria | Symbol | Units | HAC-70 F |
|---|---|---|---|
| Factor to account for the influence of channel size and anchor diameter on concrete edge breakout strength in shear | $\alpha_{ch,V}$ | $lb^{1/2}/in^{1/3}$<br>$(N^{1/2}/mm^{1/3})$ | 10.50<br>(7.50) |
| Coefficient for pryout strength | $k_{cp}$ | - | 2 |
| Strength reduction factor for shear, concrete failure modes[1] | ϕ | - | Condition A: 0.75<br>Condition B: 0.70 |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the ϕ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.
2 This factor will be applicable for shear acting in opposite direction edge plate (i.e away from edge plate). In case of shear acting in direction towards edge plate refer to Table 2.3.7.2 for design information.

**Table 2.3.18.3 — Steel strength design information for shear acting in longitudinal direction of the channel axis for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T EDGE C with Hilti Serrated Channel Bolts (HBC-T)**

| | Criteria | Symbol | Channel bolt type HBC-T | Units | HAC-T50 EDGE Lite<br>HAC-T50 EDGE<br>HAC-T50 EDGE C |
|---|---|---|---|---|---|
|  | Nominal shear steel strength of connection between channel lips and channel bolts | $V_{sl,x}$ | M12 | lb (kN) | 3,395 (15.1) |
| | | | M16 | lb (kN) | 4,519 (20.1) |
| | | | M20 | lb (kN) | 4,519 (20.1) |
|  | Nominal shear steel strength of connection between channel lips and channel bolts for seismic design | $V_{sl,x,seis}$ | M12 | lb (kN) | 3,395 (15.1) |
| | | | M16 | lb (kN) | 4,519 (20.1) |
| | | | M20 | lb (kN) | 4,519 (20.1) |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (periodic inspection) | ϕ | M12 | - | 0.65 |
| | | | M16 | | |
| | | | M20 | | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (continuous inspection) | ϕ | M12 | - | 0.75 |
| | | | M16 | | |
| | | | M20 | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.



## 2.3.19 HAC-T EDGE LITE, HAC-T EDGE, AND HAC-T EDGE C PLATE STEEL STRENGTH INFORMATION

**Table 2.3.19.1 — Steel strength design information for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T EDGE C rebar edge confinement plate (EDGE Lite, EDGE, and EDGE C plate)**

| Criteria | Symbol | Units | Anchor Channel | | |
|---|---|---|---|---|---|
| | | | HAC-T50 | HAC-T50 | |
| | | | EDGE Lite | EDGE | EDGE C |
| Modulus of elasticity of the EDGE lite and EDGE plate | E | ksi (MPa) | 30,458 (210,000) | | |
| Minimum specified ultimate strength | $f_{uta}$ | psi (MPa) | 79,750 (550) | | |
| Minimum specified yield strength | $f_{ya}$ | psi (MPa) | 72,500 (500) | | |
| Nominal rebar steel strength | $N_{s,r}$ | lb (kN) | 12,713 (56.55) | | |
| Nominal connection strength of rebar-EDGE Lite or EDGE plate | $N_{s,c}$ | lb (kN) | | | |
| Strength reduction factor for rebar tensile steel strength | ϕ | - | 0.75 | | |

## 2.3.20 DESIGN INFORMATION FOR HAC-T EDGE LITE, HAC-T EDGE, AND HAC-T EDGE C CONCRETE BREAKOUT IN PERPENDICULAR SHEAR

**Table 2.3.20.1 — Shear concrete strength design information for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T EDGE C with Hilti Serrated Channel Bolts (HBC-T) when shear load acts towards the EDGE Plate.**

| Criteria | Symbol | Units | Anchor Channel | | |
|---|---|---|---|---|---|
| | | | HAC-T50 EDGE Lite | HAC-T50 EDGE | HAC-T50 EDGE C |
| Factor to account for the influence of plate size and rebar diameter on concrete edge breakout strength in shear for the EDGE Lite and EDGE plate | $k_{EDGE}$ / $k_{EDGE\ C}$ | Imperial units | 700 | 880 | 720 |
| | | SI units | (330) | (415) | (340) |
| Exponent for the edge distance in the basic value of the concrete edge breakout | $x_1$ | - | 0.97 | | |
| Exponent for the concrete strength in the basic value of the concrete edge breakout | $x_2$ | - | 0.18 | | |
| Exponent for the modification factor to account for influence of member thickness on concrete edge breakout strength for anchors channels loaded in shear | $x_3$ | - | 0.25 | | |
| Exponent for the modification factor for corner effects on concrete edge breakout strength for anchor channels loaded in shear | $x_4$ | - | 0.11 | | |
| Modification factor for the critical anchor spacing in combination with the EDGE Lite and EDGE plate | $\alpha_{1,V}$ | - | 0.60 | | |
| Coefficient for pry out strength | $k_{cp}$ | - | 2.0 | | |
| Modification factor for HAC-T EDGE Lite and HAC-T EDGE to control splitting | $\psi_{cp}$ | - | 1.0 | | |
| Modification factor to account for influence of cracked or uncracked concrete for concrete edge breakout strength | $\psi_{c,V}$ | - | 1.0 | | |
| Strength reduction factor for shear, concrete failure modes[1] | ϕ | - | 0.70 | | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided.

See chapter 9 for additional design information for HAC-T EDGE Lite, HAC-T EDGE, and HAC-T EDGE C

## 2.3.21 HAC-T S EDGE AND HAC-T S EDGE C STRUCTURAL STEEL PERFORMANCE — TENSION

**Table 2.3.21.1 — Tension steel strength design information for HAC-T S EDGE and HAC-T S EDGE C with Hilti Serrated Channel Bolts (HBC-T)**

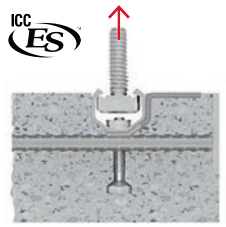
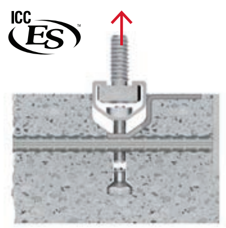
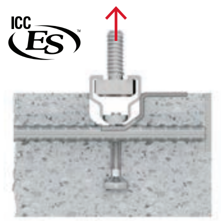
| Criteria | | Symbol | Units | HAC-T50 S EDGE<br>HAC-T50 S EDGE C |
|---|---|---|---|---|
|  | Nominal tensile steel strength for local failure of channel lips | $N_{sl}$ | lb<br>(kN) | 7,865<br>(35.0) |
| | Nominal tensile steel strength for local failure of channel lips for seismic design | $N_{sl,seis}$ | lb<br>(kN) | 7,865<br>(35.0) |
| | Strength reduction factor for local failure of channel lips[1] | φ | - | 0.75 |
|  | Nominal tensile steel strength of a single anchor | $N_{sa}$ | lb<br>(kN) | 11,240<br>(50.0) |
| | Nominal tensile steel strength of a single anchor for seismic design | $N_{sa,seis}$ | lb<br>(kN) | 11,240<br>(50.0) |
| | Strength reduction factor for anchor failure[1] | φ | - | 0.75 |
|  | Nominal tensile steel strength of connection between anchor and channel | $N_{sc}$ | lb<br>(kN) | 7,865<br>(35.0) |
| | Nominal tensile steel strength of connection between anchor and channel for seismic design | $N_{sc,seis}$ | lb<br>(kN) | 7,865<br>(35.0) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | φ | 0 | 0.75 |
|  | Nominal bending strength of the anchor channel with HBC-C | $M_{s,flex}$ | lb-in<br>(N*m) | 14,125<br>(1,596) |
| | Nominal bending strength of the anchor channel with HBC-C-N | | lb-in<br>(N*m) | 11,903<br>(1,345) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C | $M_{s,flex,seis}$ | lb-in<br>(N*m) | 14,125<br>(1,596) |
| | Nominal bending strength of the anchor channel for seismic design with HBC-C-N | | lb-in<br>(N*m) | 11,903<br>(1,345) |
| | Strength reduction factor for bending failure | φ | - | 0.85 |

**Table 2.3.21.2 — Tension concrete strength design information for HAC-T S EDGE and HAC-T S EDGE C**

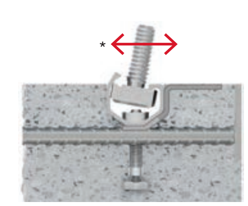
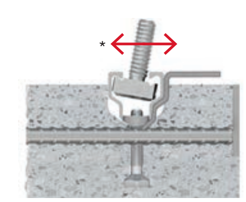
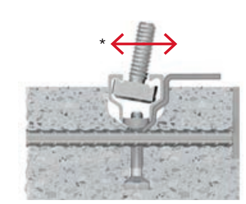
| Criteria | Symbol | Units | HAC-50 S $h_{ef}$ = 94 mm | HAC-50 S $h_{ef}$ = 106 mm |
|---|---|---|---|---|
| Edge distance required to develop full concrete capacity in absence of anchor reinforcement | $c_{ac}$ | in<br>(mm) | TBD<br>(TBD) | 12.52<br>(318) |
| Strength reduction factor for tension, concrete failure modes[1] | φ | - | Condition A: 0.75<br>Condition B: 0.70 | |

1 The tabulated value of φ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the φ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.



## 2.3.22 HAC-T S EDGE AND HAC-T S EDGE C STRUCTURAL STEEL STEEL PERFORMANCE — SHEAR

**Table 2.3.22.1 — Shear steel strength design information for HAC-T S EDGE and HAC-T S EDGE C with Hilti Serrated Channel Bolts (HBC-T)**

| Criteria | | Symbol | Units | HAC-T50 S EDGE<br>HAC-T50 S EDGE C |
|---|---|---|---|---|
|  | *Nominal shear steel strength for local failure of channel lips in opposite direction of the S bracket | $V_{sl,y}$ | lb<br>(kN) | 10,675<br>(47.4) |
| | Nominal shear steel strength for local failure of the channel lips in direction of the S bracket | $V_{sl,y,clip}$ | lb<br>(kN) | 17,707<br>(78.7) |
| | Nominal shear steel strength for local failure of the channel lips for seismic design in both directions | $V_{sl,y,seis}$ | lb<br>(kN) | 10,675<br>(47.4) |
| | Strength reduction factor for local failure of channel lips[1] | φ | - | 0.75 |
|  | *Nominal shear steel strength of a single anchor in opposite direction of the S bracket | $V_{sa,y}$ | lb<br>(kN) | 12,050<br>(53.6) |
| | Nominal shear steel strength of a single anchor in direction of the S bracket | $V_{sl,y,clip}$ | lb<br>(kN) | 13,865<br>(61.7) |
| | Nominal shear steel strength of a single anchor for seismic design in both directions | $V_{sa,y,seis}$ | lb<br>(kN) | 10,675<br>(47.4) |
| | Strength reduction factor anchor failure[1] | φ | - | 0.75 |
|  | *Nominal shear steel strength of connection between anchor and channel in opposite direction of the S bracket | $V_{sc,y}$ | lb<br>(kN) | 12,050<br>(53.6) |
| | Nominal shear steel strength of connection between anchor and channel in direction of the S bracket | $V_{sl,y,clip}$ | lb<br>(kN) | 13,865<br>(61.7) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design in both directions | $V_{sc,y,seis}$ | lb<br>(kN) | 10,675<br>(47.4) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | φ | - | 0.75 |
|  | Nominal shear steel strength of connection between anchor and channel | $V_{sc,x}$ | lb<br>(kN) | 5,240<br>(23.3) |
| | Nominal shear steel strength of connection between anchor and channel for seismic design | $V_{sc,x,seis}$ | lb<br>(kN) | 5,240<br>(23.3) |
| | Strength reduction factor for failure of connection between anchor and channel[1] | φ | - | 0.75 |
|  | Nominal shear steel strength of a single anchor | $V_{sa,x}$ | lb<br>(kN) | 6,740<br>(30.0) |
| | Nominal shear steel strength of a single anchor for seismic design | $V_{sa,x,seis}$ | lb<br>(kN) | 6,740<br>(30.0) |
| | Strength reduction factor anchor failure[1] | φ | - | 0.75 |

1 The tabulated value of φ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the φ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are allowed.

**Table 2.3.22.2 — Shear concrete strength design information for HAC-T S EDGE and HAC-T S EDGE C with Hilti Serrated Channel Bolts (HBC-T) when shear load acts away from the EDGE Plate.**

| Criteria | Symbol | Units | HAC-T50 S EDGE<br>HAC-T50 S EDGE C |
|---|---|---|---|
| Factor to account for the influence of channel size and anchor diameter on concrete edge breakout strength in shear | $\alpha_{ch,V}$ | $lb^{1/2}/in^{1/3}$<br>($N^{1/2}/mm^{1/3}$) | 10.50<br>(7.50) |
| Coefficient for pryout strength | $k_{cp}$ | - | 2 |
| Strength reduction factor for shear, concrete failure modes[1] | φ | - | Condition A: N/A<br>Condition B: 0.70 |

1 The tabulated value of φ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided. For installations where complying supplementary reinforcement can be verified, the φ factors described in ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition A are allowed.
2 This factor will be applicable for shear acting in opposite direction edge plate (i.e away from edge plate). In case of shear acting in direction towards edge plate refer to Table 2.3.26.1 for design information.

**Table 2.3.22.3 — Steel strength design information for shear acting in longitudinal direction of the channel axis for HAC-T S EDGE and HAC-T S EDGE C with Hilti Serrated Channel Bolts (HBC-T)**

| Criteria | | Symbol | Channel bolt type HBC-T | Units | HAC-40 EDGE Lite | HAC-T50 S EDGE HAC-T50 S EDGE C |
|---|---|---|---|---|---|---|
|  | Nominal shear steel strength of connection between channel lips and channel bolts | $V_{sl,x}$ | M12[2] | lb (kN) | 3,395 (15.1) | |
| | | | M16 | lb (kN) | 4,519 (20.1) | |
| | | | M20 | lb (kN) | 4,519 (20.1) | |
|  | Nominal shear steel strength of connection between channel lips and channel bolts for seismic design | $V_{sl,x,seis}$ | M12[2] | lb (kN) | 3,395 (15.1) | |
| | | | M16 | lb (kN) | 4,519 (20.1) | |
| | | | M20 | lb (kN) | 4,519 (20.1) | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (periodic inspection) | ϕ | M12 | - | 0.65 | |
| | | | M16 | | | |
| | | | M20 | | | |
| ϕ | Strength reduction factor for failure of connection between channel lips and channel bolts[1] (continuous inspection) | ϕ | M12 | - | 0.75 | |
| | | | M16 | | | |
| | | | M20 | | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.



## 2.3.23 HAC-T S EDGE AND HAC-T S EDGE C PLATE STEEL STRENGTH INFORMATION

**Table 2.3.23.1 — Steel strength design information for HAC-T S EDGE and HAC-T EDGE C rebar edge confinement plate (EDGE and EDGE C plate)**

| Criteria | Symbol | Units | Anchor Channel HAC-T50 S EDGE | Anchor Channel HAC-T50 S EDGE C |
|---|---|---|---|---|
| Modulus of elasticity of the EDGE plate | E | ksi (MPa) | 30,458 (210,000) | |
| Minimum specified ultimate strength | $f_{uta}$ | psi (MPa) | 79,750 (550) | |
| Minimum specified yield strength | $f_{ya}$ | psi (MPa) | 72,500 (500) | |
| Nominal rebar steel strength | $N_{s,r}$ | lb (kN) | 12,713 (56.55) | |
| Nominal connection strength of rebar-EDGE Lite or EDGE plate | $N_{s,c}$ | lb (kN) | | |
| Strength reduction factor for rebar tensile steel strength | ϕ | - | 0.75 | |

## 2.3.24 DESIGN INFORMATION FOR HAC-T S EDGE AND HAC-T S EDGE C CONCRETE BREAKOUT IN PERPENDICULAR SHEAR

**Table 2.3.24.1 —Shear concrete strength design information for HAC-T S EDGE and HAC-T S EDGE C with Hilti Serrated Channel Bolts (HBC-T) when shear load acts towards the EDGE Plate.**

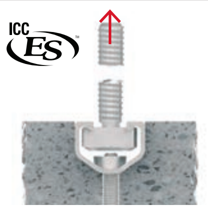
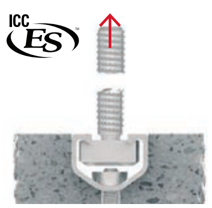
| Criteria | Symbol | Units | Anchor Channel HAC-T50 S EDGE | Anchor Channel HAC-T50 S EDGE C |
|---|---|---|---|---|
| Factor to account for the influence of plate size and rebar diameter on concrete edge breakout strength in shear for the EDGE plate | $k_{EDGE}$ / $k_{EDGE\ C}$ | Imperial units / SI units | 880 (415) | 720 (340) |
| Exponent for the edge distance in the basic value of the concrete edge breakout | $x_1$ | - | 0.97 | |
| Exponent for the concrete strength in the basic value of the concrete edge breakout | $x_2$ | - | 0.18 | |
| Exponent for the modification factor to account for influence of member thickness on concrete edge breakout strength for anchors channels loaded in shear | $x_3$ | - | 0.25 | |
| Exponent for the modification factor for corner effects on concrete edge breakout strength for anchor channels loaded in shear | $x_4$ | - | 0.11 | |
| Modification factor for the critical anchor spacing in combination with the EDGE plate | $\alpha_{1,V}$ | - | 0.60 | |
| Coefficient for pry out strength | $k_{cp}$ | - | 2.0 | |
| Modification factor for HAC-T EDGE to control splitting | $\psi_{cp}$ | - | 1.0 | |
| Modification factor to account for influence of cracked or uncracked concrete for concrete edge breakout strength | $\psi_{c,V}$ | - | 1.0 | |
| Strength reduction factor for shear, concrete failure modes[1] | ϕ | - | 0.70 | |

1 The tabulated value of ϕ applies when both the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used and the requirements of ACI 318-14 17.3.3(c) or ACI 318-11 D.4.3(c), as applicable, for Condition B are met. Condition B applies where supplementary reinforcement is not provided.

See chapter 9 for additional design information for HAC-T S EDGE and HAC-T S EDGE C

## 2.3.25 HBC-B AND HBC-T STEEL PERFORMANCE — TENSION

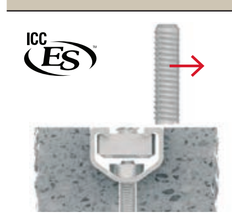
**Table 2.3.25.1 — Tension steel strengths design information for Hilti Serrated Channel Bolts (HBC-B and HBC-T).**

| Criteria | | Symbol | Bolt type | Units | Bolt type: HBC-B 4.6 | | Bolt type: HBC-T 8.8 | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | M10 | M12 | M12 | M16 | M20 |
|  | Nominal tensile strength of a channel bolt | $N_{ss}$ | HBC-T 8.8 | lb (kN) | 5,215 (23.2) | 7,575 (33.7 | 15,160 (67.4) | 28,235 (125.6) | 39,229 (174.5) |
|  | Nominal tensile strength of a channel bolt for seismic design | $N_{ss,seis}$ | HBC-T 8.8 | lb (kN) | - | 7,575 (33.7 | 15,160 (67.4) | 28,235 (125.6) | 39,229 (174.5) |
| ϕ | Strength reduction factor for tension, steel failure modes[1] | ϕ | - | - | 0.65 | | | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.

## 2.3.26 HBC-B AND HBC-T STEEL PERFORMANCE — SHEAR

**Table 2.3.26.1 — Shear steel strengths design information for Hilti Serrated Channel Bolts (HBC-B and HBC-T).**

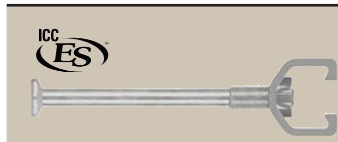
| Criteria | | Symbol | Bolt type | Units | Bolt type: HBC-B 4.6 | | Bolt type: HBC-T 8.8 | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | M10 | M12 | M12 | M16 | M20 |
|  | Nominal shear strength of a channel bolt | $V_{ss}$ | HBC-T 8.8 | lb (kN) | 3,125 (13.9) | 4,540 (20.2) | 9,095 (40.4) | 16,940 (75.3) | 27,427 (122.0) |
|  | Nominal shear strength of a channel bolt for seismic design | $V_{ss,seis}$ | HBC-T 8.8 | lb (kN) | - | 4,540 (20.2) | 9,095 (40.4) | 16,940 (75.3) | 27,427 (122.0) |
|  | Nominal shear strength of a channel bolt | $M^{o}_{ss}$ | HBC-T 8.8 | lb-in (N*m) | 265 (29.9) | 465 (52.4) | 930 (104.8) | 2,355 (266.3) | 4,768 (538.7) |
|  | Nominal shear strength of a channel bolt for seismic design | $M^{o}_{ss,seis}$ | HBC-T 8.8 | lb-in (N*m) | | 465 (52.4) | 930 (104.8) | 2,355 (266.3) | 4,768 (538.7) |
| ϕ | Strength reduction factor for shear, steel failure modes[1] | ϕ | - | - | 0.60 | | | | |

1 The tabulated value of ϕ applies when the load combinations of Section 1605.2 of the IBC, ACI 318-14 Section 5.3 or ACI 318-11 Section 9.2 are used.



# 2.4 ORDERING INFORMATION

## HAC

|  ESR-3520 | Item Number | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| HAC-40 91/150 F | 2107348 | B | 5.91 (150) | 3.7 (94.0) | 2 | 3.94 (100) | 0.79 |
| HAC-40 91/200 F | 2122491 | B | 7.87 (200) | 3.7 (94.0) | 2 | 5.91 (150) | 1.01 |
| HAC-40 91/250 F | 2122492 | A | 9.84 (250) | 3.7 (94.0) | 2 | 7.87 (200) | 1.21 |
| HAC-40 91/300 F | 2107349 | A | 11.81 (300) | 3.7 (94.0) | 2 | 9.84 (250) | 1.41 |
| HAC-40 91/350 F | 2122493 | A | 13.78 (350) | 3.7 (94.0) | 3 | 5.91 (150) | 1.72 |
| HAC-40 91/450 F | 2122494 | A | 17.72 (450) | 3.7 (94.0) | 3 | 7.87 (200) | 2.14 |
| HAC-40 91/550 F | 2122495 | B | 21.65 (550) | 3.7 (94.0) | 3 | 9.84 (250) | 2.58 |
| HAC-40 91/800 F | 2122496 | A | 31.50 (800) | 3.7 (94.0) | 4 | 9.84 (250) | 3.70 |
| HAC-40 91/5800 F | 2122536 | C | 228.35 (5800) | 3.7 (94.0) | 24 | 9.84 (250) | 26.68 |
| HAC-40 91/ "custom length" | tbd | C | other[2] | 3.7 (94.0) | | | |
| HAC-50 106/150 F | 2107510 | B | 5.91 (150) | 4.3 (109.5) | 2 | 3.94 (100) | 1.13 |
| HAC-50 106/200 F | 2122537 | B | 7.87 (200) | 4.3 (109.5) | 2 | 5.91 (150) | 1.39 |
| HAC-50 106/250 F | 2122538 | B | 9.84 (250) | 4.3 (109.5) | 2 | 7.87 (200) | 1.65 |
| HAC-50 106/300 F | 2107511 | A | 11.81 (300) | 4.3 (109.5) | 2 | 9.84 (250) | 1.92 |
| HAC-50 106/350 F | 2122539 | A | 13.78 (350) | 4.3 (109.5) | 3 | 5.91 (150) | 2.34 |
| HAC-50 106/450 F | 2122540 | A | 17.72 (450) | 4.3 (109.5) | 3 | 7.87 (200) | 2.87 |
| HAC-50 106/550 F | 2122541 | B | 21.65 (550) | 4.3 (109.5) | 3 | 9.84 (250) | 3.40 |
| HAC-50 106/800 F | 2122542 | A | 31.50 (800) | 4.3 (109.5) | 4 | 9.84 (250) | 4.87 |
| HAC-50 106/5800 F | 2122553 | C | 228.35 (5800) | 4.3 (109.5) | 24 | 9.84 (250) | 34.80 |
| HAC-50 106/ "custom length" | tbd | C | other[2] | 4.3 (109.5) | | | |
| HAC-60 148/250 F | 2075654 | B | 9.84 (250) | 6.0 (152.5) | 2 | 7.87 (200) | |
| HAC-60 148/300 F | 431850 | A | 11.81 (300) | 6.0 (152.5) | 2 | 9.84 (250) | 2.56 |
| HAC-60 148/350 F | 431851 | A | 13.78 (350) | 6.0 (152.5) | 3 | 5.91 (150) | 3.13 |
| HAC-60 148/450 F | 431852 | A | 17.72 (450) | 6.0 (152.5) | 3 | 7.87 (200) | 3.82 |
| HAC-60 148/550 F | 431853 | B | 21.65 (550) | 6.0 (152.5) | 3 | 9.84 (250) | 4.54 |
| HAC-60 148/5800 F | 431856 | C | 228.35 (5800) | 6.0 (152.5) | 24 | 9.84 (250) | 46.26 |
| HAC-60 148/ "custom length" | tbd | C | other[2] | 6.0 (152.5) | | | |
| HAC-70 175/300 F | 431860 | A | 11.81 (300) | 7.1 (180.0) | 2 | 9.84 (250) | 3.56 |
| HAC-70 175/350 F | 431861 | A | 13.78 (350) | 7.1 (180.0) | 3 | 5.91 (150) | 4.39 |
| HAC-70 175/450 F | 431862 | A | 17.72 (450) | 7.1 (180.0) | 3 | 7.87 (200) | 5.34 |
| HAC-70 175/550 F | 431863 | B | 21.65 (550) | 7.1 (180.0) | 3 | 9.84 (250) | 6.31 |
| HAC-70 175/5800 F | 431866 | C | 228.35 (5800) | 7.1 (180.0) | 24 | 9.84 (250) | 66.41 |
| HAC-70 175/ "custom length" | tbd | C | other[2] | 7.1 (180.0) | | | |

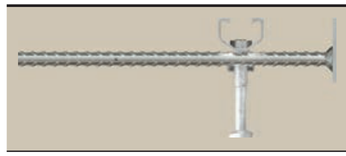
1) Lead Time Categories
A = Standard inventory item in North America, typically available from stock
B = Standard item, not stocked in North America, typical lead time 8 weeks
C = Make to order item, typical lead time 12 weeks
D = Make to order item with minimum order quantity, lead time may be longer than 12 weeks"
General note: It's recommended to always check availability with Hilti for all items

2) Custom lengths are available upon request in increments of 5 mm. Min length 150 mm, max length 5800 mm.
See section for custom made anchor channels

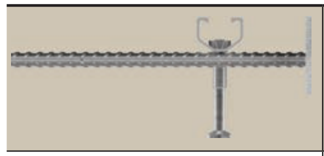
## HAC CRFoS U (Item number is for one anchor channel. A corner requires ordering a quantity of two.)

|  | Item Number | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| HAC-50 356/300 F CRFoS U | 2157397 | A | 11.81 (300) | 12.80 (325) | 2 | 9.84 (250) | 2.98 |
| HAC-50 356/350 F CRFoS U | 2157398 | A | 13.78 (350) | 12.80 (325) | 3 | 5.91 (150) | 3.92 |
| HAC-50 356/450 F CRFoS U | 2157399 | A | 17.72 (450) | 12.80 (325) | 3 | 7.87 (200) | 4.45 |
| HAC-60 396/300 F CRFoS U | 2157540 | A | 11.81 (300) | 14.17 (360) | 2 | 9.84 (250) | 4.30 |
| HAC-60 396/350 F CRFoS U | 2157541 | A | 13.78 (350) | 14.17 (360) | 3 | 5.91 (150) | 5.67 |
| HAC-60 396/450 F CRFoS U | 2157542 | A | 17.72 (450) | 14.17 (360) | 3 | 7.87 (200) | 6.39 |
| HAC-70 420/300 F CRFoS U | 2157543 | A | 11.81 (300) | 14.96 (380) | 2 | 9.84 (250) | 5.84 |
| HAC-70 420/350 F CRFoS U | 2157544 | A | 13.78 (350) | 14.96 (380) | 3 | 5.91 (150) | 7.72 |
| HAC-70 420/450 F CRFoS U | 2157545 | A | 17.72 (450) | 14.96 (380) | 3 | 7.87 (200) | 8.71 |
| HAC-70 420/350F 4R CRFoSU | 2157546 | A | 13.78 (350) | 14.96 (380) | 4 | 3.94 (100) | 9.15 |
| HAC-70 420/450F 4R CRFoSU | 2157547 | A | 17.72 (450) | 14.96 (380) | 4 | 5.25 (133) | 10.14 |
| HAC-70 420/610 F 5R CRFoS U | 2163563 | A | 24.02 (610) | 14.96 (380) | 5 | 5.51 (140) | 13.23 |

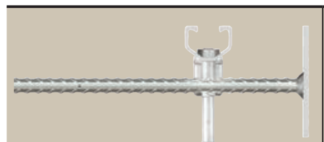
## HAC EDGE Lite

|  | Item Number[3] | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| Rebar HAC-40 91/300 F EDGE Lite | 2217526 | A | 11.81 (300) | 3.71 (94.0) | 2 | 9.84 (250) | 18.11 (460) | 4 | 3.74 (95) | 4.61 |
| Rebar HAC-50 94/300 F EDGE Lite | 2217527 | A | 11.81 (300) | 3.84 (97.5) | 2 | 9.84 (250) | 18.11 (460) | 4 | 3.74 (95) | 6.24 |
| Rebar HAC-50 106/300 F EDGE Lite | 2217528 | A | 11.81 (300) | 4.31 (109.5) | 2 | 9.84 (250) | 18.11 (460) | 4 | 3.74 (95) | 6.26 |

## HAC EDGE

|  | Item Number[3] | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| HAC-50 94/300 F EDGE | 2200864 | A | 11.81 (300) | 3.84 (97.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 8.98 |
| HAC-50 94/350 F EDGE | 2200865 | A | 13.78 (350) | 3.84 (97.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 9.70 |
| HAC-50 94/450 F EDGE | 2200866 | A | 17.72 (450) | 3.84 (97.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 10.87 |
| HAC-50 94/610 F EDGE | tbd | B | 24.00 (610) | 3.84 (97.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 15.08 |
| HAC-50 106/300 F EDGE | 2200867 | A | 11.81 (300) | 4.31 (109.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 8.68 |
| HAC-50 106/350 F EDGE | 2200868 | A | 13.78 (350) | 4.31 (109.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 9.36 |
| HAC-50 106/450 F EDGE | 2200869 | A | 17.72 (450) | 4.31 (109.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 10.42 |
| HAC-50 106/610 F EDGE | tbd | B | 24.00 (610) | 4.31 (109.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 15.10 |

## HAC EDGE C

|  | Item Number[3] | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| HAC-50 94/300 F EDGE C | 2200908 | A | 11.81 (300) | 3.84 (97.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 10.43 |
| HAC-50 94/350 F EDGE C | tbd | A | 13.78 (350) | 3.84 (97.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 11.31 |
| HAC-50 94/450 F EDGE C | 2200909 | A | 17.72 (450) | 3.84 (97.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 12.83 |
| HAC-50 94/610 F EDGE C | tbd | B | 24.00 (610) | 3.84 (97.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 17.59 |
| HAC-50 106/300 F EDGE C | 2200906 | A | 11.81 (300) | 4.31 (109.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 10.45 |
| HAC-50 106/350 F EDGE C | tbd | A | 13.78 (350) | 4.31 (109.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 11.33 |
| HAC-50 106/450 F EDGE C | 2200907 | A | 17.72 (450) | 4.31 (109.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 12.85 |
| HAC-50 106/610 F EDGE C | tbd | B | 24.00 (610) | 4.31 (109.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 17.61 |

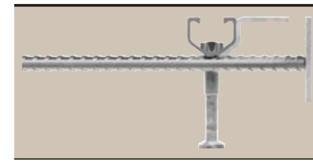
1) Lead Time Categories
A = Standard inventory item in North America, typically available from stock
B = Standard item, not stocked in North America, typical lead time 8 weeks
C = Make to order item, typical lead time 12 weeks
D = Make to order item with minimum order quantity, lead time may be longer than 12 weeks"
General note: It's recommended to always check availability with Hilti for all items

2) Custom lengths are available upon request in increments of 5 mm. Min length 150 mm, max length 5800 mm.
See section for custom made anchor channels
3) The provide Item number is for HAC EDGE products with 4.00" edge distance. If your product's edge distance differs from 4.00", Please contact Brian.Chasteen@hilti.com for the correct item number.



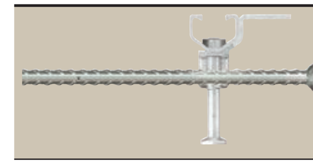
## HAC S EDGE

(for superior perpendicular shear steel performance)

|  | Item Number[3] | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| HAC-50 S 94/300 F EDGE | 2200863 | A | 11.81 (300) | 3.7 (94.0) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 10.45 |
| HAC-50 S 94/350 F EDGE | 2200873 | C | 13.78 (350) | 3.7 (94.0) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 11.44 |
| HAC-50 S 94/450 F EDGE | 2200874 | C | 17.72 (450) | 3.7 (94.0) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 13.07 |
| HAC-50 S 94/610 F EDGE | - | C | 24.00 (610) | 3.84 (97.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 18.08 |
| HAC-50 S 106/300 F EDGE | 2200875 | A | 11.81 (300) | 4.3 (109.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 10.47 |
| HAC-50 S 106/350 F EDGE | 2200876 | C | 13.78 (350) | 4.3 (109.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 11.46 |
| HAC-50 S 106/450 F EDGE | 2200877 | C | 17.72 (450) | 4.3 (109.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 13.10 |
| HAC-50 S 106/610 F EDGE | - | C | 24.00 (610) | 4.31 (109.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 18.10 |

## HAC S EDGE C

(for superior perpendicular shear steel performance)

|  | Item Number[3] | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| HAC-50 S 94/300 F EDGE C | - | A | 11.81 (300) | 3.7 (94.0) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 11.90 |
| HAC-50 S 94/350 F EDGE C | - | C | 13.78 (350) | 3.7 (94.0) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 13.05 |
| HAC-50 S 94/450 F EDGE C | - | C | 17.72 (450) | 3.7 (94.0) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 15.28 |
| HAC-50 S 94/610 F EDGE C | - | C | 24.00 (610) | 3.84 (97.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 20.59 |
| HAC-50 S 106/300 F EDGE C | 2201070 | A | 11.81 (300) | 4.3 (109.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 11.93 |
| HAC-50 S 106/350 F EDGE C | - | C | 13.78 (350) | 4.3 (109.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 13.07 |
| HAC-50 S 106/450 F EDGE C | - | C | 17.72 (450) | 4.3 (109.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 15.30 |
| HAC-50 S 106/610 F EDGE C | - | C | 24.00 (610) | 4.31 (109.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 20.61 |

## HBC-C

(t-bolt comes with nut)

| ICC ES  ESR-3520 | Item Number | Lead Time Category[1] | Material | Thread size | Channel Bolt Length in. (mm) | Pieces per sales unit | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| HBC-C M12x40 8.8F | 2095644 | B | class 8.8 steel, hot dip galvanized | M12 | 1.57 (40) | 100 | 18.17 |
| HBC-C M12x50 8.8F | 2095645 | B | | M12 | 1.97 (50) | 100 | 19.80 |
| HBC-C M12x60 8.8F | 2095646 | A | | M12 | 2.36 (60) | 100 | 21.40 |
| HBC-C M12x80 8.8F | 2095647 | A | | M12 | 3.15 (80) | 100 | 23.80 |
| HBC-C M12x100 8.8F | 2095648 | A | | M12 | 3.94 (100) | 100 | 27.10 |
| HBC-C M16x50 8.8F | 2095649 | B | | M16 | 1.97 (50) | 100 | 31.10 |
| HBC-C M16x60 8.8F | 2095650 | A | | M16 | 2.36 (60) | 100 | 34.10 |
| HBC-C M16x80 8.8F | 2095651 | A | | M16 | 3.15 (80) | 50 | 20.15 |
| HBC-C M16x100 8.8F | 2095652 | A | | M16 | 3.94 (100) | 50 | 23.05 |
| HBC-C M20x60 8.8F | 2095653 | B | | M20 | 2.36 (60) | 50 | 25.19 |
| HBC-C M20x80 8.8F | 2095654 | B | | M20 | 3.15 (80) | 50 | 29.74 |
| HBC-C M20x100 8.8F | 2095655 | B | | M20 | 3.94 (100) | 50 | 34.41 |
| HBC-C M20x125 8.8F | 2095656 | B | | M20 | 4.92 (125) | 25 | 20.24 |
| HBC-C M20x150 8.8F | 2095657 | B | | M20 | 5.91 (150) | 25 | 23.10 |

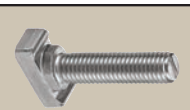
1) Lead Time Categories
A = Standard inventory item in North America, typically available from stock
B = Standard item, not stocked in North America, typical lead time 8 weeks
C = Make to order item, typical lead time 12 weeks
D = Make to order item with minimum order quantity, lead time may be longer than 12 weeks"
General note: It's recommended to always check availability with Hilti for all items
2) Custom lengths are available upon request in increments of 5 mm. Min length 150 mm, max length 5800 mm. See section for custom made anchor channels

3) HAC EDGE product line comes with the specified edge distance. Therefore, the edge distance is part of the product. The provide Item number is for HAC EDGE products with 4.00" edge distance. This item number can be used for pricing purposes. A different edge distance does not impact the price. Please contact Brian.Chasteen@hilti.com for the correct item number for a HAC EDGE product with an edge distance different to 4.00".

## HBC-C-N (t-bolt comes with nut)

|  ESR-3520 | Item Number | Lead Time Category[1] | Material | Thread size | Channel Bolt Length in. (mm) | Pieces per sales unit | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| HBC-C-N M12x40 8.8F | 2066370 | B | class 8.8 steel, hot dip galvanized | M12 | 1.57 (40) | 100 | 18.08 |
| HBC-C-N M16x40 8.8F | 2069471 | B | | M16 | 1.57 (40) | 100 | 28.62 |
| HBC-C-N M16x50 8.8F | 2019736 | A | | M16 | 1.97 (50) | 100 | 34.39 |
| HBC-C-N M16x60 8.8F | 2019736 | A | | M16 | 2.36 (60) | 100 | 34.39 |
| HBC-C-N M16x80 8.8F | 433479 | A | | M16 | 3.15 (80) | 50 | 20.16 |
| HBC-C-N M16x100 8.8F | 2019737 | B | | M16 | 3.94 (100) | 50 | 22.71 |
| HBC-C-N M16x150 8.8F | 2019738 | B | | M16 | 5.91 (150) | 50 | 30.42 |
| HBC-C-N M20x80 8.8F | 2019739 | A | | M20 | 3.15 (80) | 50 | 29.98 |
| HBC-C-N M20x150 8.8F | 2019820 | B | | M20 | 5.91 (150) | 25 | 23.13 |

## HBC-C Stainless Steel (t-bolt comes with nut)

|  ESR-3520 | Item Number | Lead Time Category[1] | Material | Thread size | Channel Bolt Length in. (mm) | Pieces per sales unit | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| HBC-C M10x40 50R | 2095682 | C | 316 stainless steel | M10 | 1.57 (40) | 50 | 7.68 |
| HBC-C M10x40 50R | 433460 | C | | M10 | 1.57 (40) | 50 | 7.68 |
| HBC-C M10x50 50R | 2095683 | C | | M10 | 1.97 (50) | 50 | 8.23 |
| HBC-C M10x50 50R | 433461 | C | | M10 | 1.97 (50) | 50 | 8.23 |
| HBC-C M12x40 50R | 2095684 | C | | M12 | 1.57 (40) | 50 | 9.36 |
| HBC-C M12x40 50R | 433463 | C | | M12 | 1.57 (40) | 50 | 9.36 |
| HBC-C M12x50 50R | 2095685 | C | | M12 | 1.97 (50) | 50 | 10.16 |
| HBC-C M12x50 50R | 433465 | C | | M12 | 1.97 (50) | 50 | 10.16 |
| HBC-C M12x80 50R | 2095686 | C | | M12 | 3.15 (80) | 50 | 12.56 |
| HBC-C M12x80 50R | 433466 | C | | M12 | 3.15 (80) | 50 | 12.56 |
| HBC-C M12x100 50R | 2095687 | C | | M12 | 3.94 (100) | 50 | 14.16 |
| HBC-C M12x100 50R | 433467 | C | | M12 | 3.94 (100) | 50 | 14.16 |
| HBC-C M16x50 50R | 2095688 | C | | M16 | 1.97 (50) | 50 | 15.58 |
| HBC-C M16x50 50R | 433471 | C | | M16 | 1.97 (50) | 50 | 15.58 |
| HBC-C M16x60 50R | 2095689 | C | | M16 | 2.36 (60) | 50 | 17.05 |
| HBC-C M16x80 50R | 2095690 | C | | M16 | 3.15 (80) | 25 | 10.11 |
| HBC-C M16x100 50R | 2095691 | C | | M16 | 3.94 (100) | 25 | 11.58 |

## Flat Washers

|  ESR-3520 | Item Number | Lead Time Category[1] | Material | Thread size | Channel Bolt Length in. (mm) | Pieces per sales unit | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| Flat washer A 13/24-F | 304771 | A | steel, hot dip galvanized | M12 | 0.95 (24) | 100 | 1.30 |
| Flat washer A 17/30-F | 304772 | A | | M16 | 1.18 (30) | 100 | 2.27 |
| Flat washer A 21/37-F | 2008399 | B | | M20 | 1.46 (37) | 200 | 6.82 |

1) Lead Time Categories
A = Standard inventory item in North America, typically available from stock
B = Standard item, not stocked in North America, typical lead time 8 weeks
C = Make to order item, typical lead time 12 weeks
D = Make to order item with minimum order quantity, lead time may be longer than 12 weeks"
General note: It's recommended to always check availability with Hilti for all items

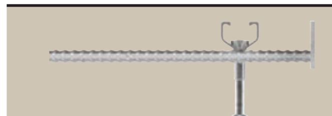
2) Custom lengths are available upon request in increments of 5 mm. Min length 150 mm, max length 5800 mm.
See section for custom made anchor channels



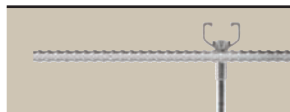
## HAC-T

|  ESR-3520 | Item Number | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| HAC-30 68/150 F | - | B | 5.91 (150) | 2.76 (70) | 2 | 3.94 (100) | 0.65 |
| HAC-30 68/200 F | 431889 | B | 7.87 (200) | 2.76 (70) | 2 | 5.91 (150) | 0.83 |
| HAC-30 68/250 F | 431890 | B | 9.84 (250) | 2.76 (70) | 2 | 7.87 (200) | 1.01 |
| HAC-30 68/300 F | 431891 | A | 11.81 (300) | 2.76 (70) | 2 | 9.84 (250) | 1.20 |
| HAC-30 68/350 F | - | B | 13.78 (350) | 2.76 (70) | 3 | 5.91 (150) | 1.39 |
| HAC-30 68/450 F | - | B | 17.72 (450) | 2.76 (70) | 3 | 7.87 (200) | 1.77 |
| HAC-30 68/550 F | 431892 | B | 21.65 (550) | 2.76 (70) | 3 | 9.84 (250) | 2.14 |
| HAC-30 68/800 F | 431893 | A | 31.50 (800) | 2.76 (70) | 4 | 9.84 (250) | 3.12 |
| HAC-30 68/5800 F | 431900 | C | 228.35 (5800) | 2.76 (70) | 24 | 9.84 (250) | 22.47 |
| HAC-30 68/"custom length" | tbd | C | other[2] | 2.76 (70) | | | |
| HAC-T50 106/150 F | 2152090 | B | 5.91 (150) | 4.3 (109.5) | 2 | 3.94 (100) | 1.13 |
| HAC-T50 106/200 F | 2152091 | B | 7.87 (200) | 4.3 (109.5) | 2 | 5.91 (150) | 1.39 |
| HAC-T50 106/250 F | 2152092 | B | 9.84 (250) | 4.3 (109.5) | 2 | 7.87 (200) | 1.65 |
| HAC-T50 106/300 F | 2152093 | A | 11.81 (300) | 4.3 (109.5) | 2 | 9.84 (250) | 1.92 |
| HAC-T50 106/350 F | 2152094 | A | 13.78 (350) | 4.3 (109.5) | 3 | 5.91 (150) | 2.34 |
| HAC-T50 106/450 F | 2152095 | A | 17.72 (450) | 4.3 (109.5) | 3 | 7.87 (200) | 2.87 |
| HAC-T50 106/550 F | 2152096 | B | 21.65 (550) | 4.3 (109.5) | 3 | 9.84 (250) | 3.40 |
| HAC-T50 106/800 F | 2152097 | A | 31.50 (800) | 4.3 (109.5) | 4 | 9.84 (250) | 4.87 |
| HAC-T50 106/5800 F | tbd | C | 228.35 (5800) | 4.3 (109.5) | 24 | 9.84 (250) | 34.80 |
| HAC-T50 106/ "custom length" | tbd | C | other[2] | 4.3 (109.5) | | | |
| HAC-T70 175/150 F | 2153637 | B | 5.91 (150) | 4.3 (109.5) | 2 | 3.94 (100) | |
| HAC-T70 175/300 F | 2152098 | A | 11.81 (300) | 7.1 (180.0) | 2 | 9.84 (250) | 3.57 |
| HAC-T70 175/350 F | 2152099 | A | 13.78 (350) | 7.1 (180.0) | 3 | 5.91 (150) | 4.39 |
| HAC-T70 175/450 F | 2152100 | A | 17.72 (450) | 7.1 (180.0) | 3 | 7.87 (200) | 5.34 |
| HAC-T70 175/550 F | 2152101 | B | 21.65 (550) | 7.1 (180.0) | 3 | 9.84 (250) | 6.31 |
| HAC-T70 175/800 F | 2152102 | A | 31.50 (800) | 7.1 (180.0) | 4 | 9.84 (250) | 9.15 |
| HAC-T70 175/5800 F | tbd | C | 228.35 (5800) | 7.1 (180.0) | 24 | 9.84 (250) | 66.41 |
| HAC-70 175/ "custom length" | tbd | C | other[2] | 7.1 (180.0) | | | |

## HAC-T EDGE Lite

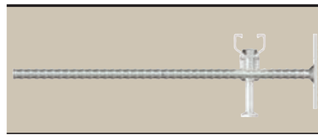
|  | Item Number[3] | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| Rebar HAC-T50 94/300 F EDGE Lite | 2217529 | A | 11.81 (300) | 3.71 (94.0) | 2 | 9.84 (250) | 19.68 (500) | 4 | 3.74 (95) | 6.24 |
| Rebar HAC-T50 106/300 F EDGE Lite | 2217930 | A | 11.81 (300) | 3.71 (94.0) | 2 | 9.84 (250) | 19.68 (500) | 4 | 3.74 (95) | 6.26 |

## HAC-T EDGE

|  | Item Number[3] | Lead Time Category[1] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| HAC-T50 94/300 F EDGE | 2200870 | A | 11.81 (300) | 3.71 (94.0) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 8.98 |
| HAC-T50 94/350 F EDGE | 2200871 | C | 13.78 (350) | 3.71 (94.0) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 9.70 |
| HAC-T50 94/450 F EDGE | 2200872 | A | 17.72 (450) | 3.71 (94.0) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 10.87 |
| HAC-T50 94/610 F EDGE | tbd | A | 24.00 (610) | 3.71 (94.0) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 15.08 |
| HAC-T50 106/300 F EDGE | 2200884 | A | 11.81 (300) | 4.31 (109.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 8.68 |
| HAC-T50 106/350 F EDGE | 2200885 | C | 13.78 (350) | 4.31 (109.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 9.36 |
| HAC-T50 106/450 F EDGE | 2200886 | A | 17.72 (450) | 4.31 (109.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 10.42 |
| HAC-T50 106/610 F EDGE | tbd | A | 24.00 (610) | 3.71 (94.0) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 15.10 |

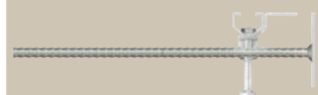
3) HAC EDGE product line comes with the specified edge distance. Therefore, the edge distance is part of the product. The provide Item number is for HAC EDGE products with 4.00" edge distance. This item number can be used for pricing purposes. A different edge distance does not impact the price. Please contact Brian.Chasteen@hilti.com for the correct item

## HAC-T EDGE C

|  | Item Number[3)] | Lead Time Category[1)] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| HAC-T50 94/300 F EDGE C | 2201073 | A | 11.81 (300) | 3.71 (94.0) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 10.43 |
| HAC-T50 94/350 F EDGE C | - | C | 13.78 (350) | 3.71 (94.0) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 11.31 |
| HAC-T50 94/450 F EDGE C | 2200904 | A | 17.72 (450) | 3.71 (94.0) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 12.83 |
| HAC-T50 94/610 F EDGE C | - | C | 24.00 (610) | 3.71 (94.0) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 17.59 |
| HAC-T50 106/300 F EDGE C | 2201071 | A | 11.81 (300) | 4.31 (109.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 10.45 |
| HAC-T50 106/350 F EDGE C | - | C | 13.78 (350) | 4.31 (109.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 11.33 |
| HAC-T50 106/450 F EDGE C | 2201072 | A | 17.72 (450) | 4.31 (109.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 12.85 |
| HAC-T50 106/610 F EDGE C | - | C | 24.00 (610) | 4.31 (109.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 17.61 |

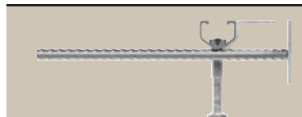
## HAC-T S EDGE

**(for superior perpendicular shear steel performance)**

|  | Item Number[3)] | Lead Time Category[1)] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| HAC-T50 S 94/300 F EDGE | 2200878 | C | 11.81 (300) | 3.71 (94.0) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 10.45 |
| HAC-T50 S 94/350 F EDGE | 2200879 | C | 13.78 (350) | 3.71 (94.0) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 11.44 |
| HAC-T50 S 94/450 F EDGE | 2200880 | C | 17.72 (450) | 3.71 (94.0) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 13.07 |
| HAC-T50 S 94/610 F EDGE | - | C | 24.00 (610) | 3.71 (94.0) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 18.08 |
| HAC-T50 S 106/300 F EDGE | 2200881 | C | 11.81 (300) | 4.31 (109.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 10.47 |
| HAC-T50 S 106/350 F EDGE | 2200882 | C | 13.78 (350) | 4.31 (109.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 11.46 |
| HAC-T50 S 106/450 F EDGE | 2200883 | C | 17.72 (450) | 4.31 (109.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 13.10 |
| HAC-T50 S106/610 F EDGE | - | C | 24.00 (610) | 4.31 (109.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 18.10 |

## HAC-T S EDGE C

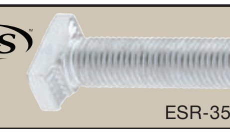
**(for superior perpendicular shear steel performance)**

|  | Item Number[3)] | Lead Time Category[1)] | Anchor Channel Length in. (mm) | Nominal Channel Depth in. (mm) | No. of Anchors | Anchor Spacing in. (mm) | Nominal Rebar Length in. (mm) | No. of Rebar-tails | Rebar Spacing in. (mm) | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|---|---|---|
| HAC-T50S 94/300 F EDGE | - | C | 11.81 (300) | 3.7 (94.0) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 11.90 |
| HAC-T50S 94/350 F EDGE | - | C | 13.78 (350) | 3.7 (94.0) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 13.05 |
| HAC-T50S 94/450 F EDGE | - | C | 17.72 (450) | 3.7 (94.0) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 15.28 |
| HAC-T50 S 94/610 F EDGE | - | C | 24.00 (610) | 3.71 (94.0) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 20.59 |
| HAC-T50S 106/300 F EDGE | 2200905 | C | 11.81 (300) | 4.3 (109.5) | 2 | 3.94 (100) | 23.6 (600) | 4 | 3.74 (95) | 11.93 |
| HAC-T50S 106/350 F EDGE | - | C | 13.78 (350) | 4.3 (109.5) | 3 | 5.91 (150) | 23.6 (600) | 4 | 4.41 (112) | 13.07 |
| HAC-T50S 106/450 F EDGE | - | C | 17.72 (450) | 4.3 (109.5) | 3 | 7.87 (200) | 23.6 (600) | 4 | 5.71 (145) | 15.08 |
| HAC-T50 S106/610 F EDGE | - | C | 24.00 (610) | 4.31 (109.5) | 4 | 7.35 (187) | 23.6 (600) | 6 | 4.68 (119) | 20.59 |

3) HAC EDGE product line comes with the specified edge distance. Therefore, the edge distance is part of the product. The provide Item number is for HAC EDGE products with 4.00" edge distance. This item number can be used for pricing purposes. A different edge distance does not impact the price. Please contact Brian.Chasteen@hilti.com for the correct item number for a HAC EDGE product with an edge distance different to 4.00".



## HBC-T

|  ESR-3520 | Item Number | Lead Time Category[1)] | Material | Thread size | Channel Bolt Length in. (mm) | Pieces per sales unit | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| HBC-T M12x40 8.8F | 2152672 | D | class 8.8 steel, hot dip galvanized | M12 | 1.57 (40) | 100 | 17.37 |
| HBC-T M12x60 8.8F | 2152673 | A | | M12 | 2.36 (60) | 100 | 20.28 |
| HBC-T M12x80 8.8F | 2152674 | A | | M12 | 3.15 (80) | 100 | 23.81 |
| HBC-T M16x60 8.8F | 2152675 | A | | M16 | 2.36 (60) | 100 | 34.13 |
| HBC-T M16x80 8.8F | 2152676 | A | | M16 | 3.15 (80) | 50 | 19.86 |
| HBC-T M16x100 8.8F | 2152677 | D | | M16 | 3.94 (100) | 50 | 22.47 |
| HBC-T M20x60 8.8F | 2152678 | D | | M20 | 2.36 (60) | 50 | 25.21 |
| HBC-T M20x80 8.8F | 2152679 | A | | M20 | 3.15 (80) | 50 | 29.76 |
| HBC-T M20x100 8.8F | 2152710 | D | | M20 | 3.94 (100) | 50 | 34.44 |

## HBC-B

|  ESR-3520 | Item Number | Lead Time Category[1)] | Material | Thread size | Channel Bolt Length in. (mm) | Pieces per sales unit | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| HBC-B M10x40 4.6G | 433527 | D | class 4.6 steel galvanized | M10 | 1.57 (40) | 100 | 16.56 |
| HBC-B M10x60 4.6G | 433528 | A | | M10 | 2.36 (60) | 100 | 15.47 |
| HBC-B M10x100 4.6G | 433529 | A | | M10 | 3.94 (100) | 100 | 19.83 |
| HBC-B M12x40 4.6F | 433534 | A | class 4.6 steel, hot dip galvanized | M12 | 1.57 (40) | 100 | 16.42 |
| HBC-B M12x60 4.6F | 433535 | A | | M12 | 2.36 (60) | 100 | 19.65 |

## Flat Washers

|  ESR-3520 | Item Number | Lead Time Category[1)] | Material | Thread size | Channel Bolt Length in. (mm) | Pieces per sales unit | Weight (lb/unit) |
|---|---|---|---|---|---|---|---|
| Flat washer A 13/24-F | 304771 | A | steel, hot dip galvanized | M12 | 0.95 (24) | 100 | 1.30 |
| Flat washer A 17/30-F | 304772 | A | | M16 | 1.18 (30) | 100 | 2.27 |
| Flat washer A 21/37-F | 2008399 | B | | M20 | 1.46 (37) | 200 | 6.82 |

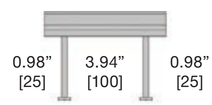
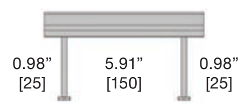
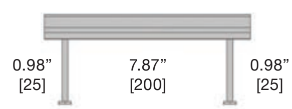
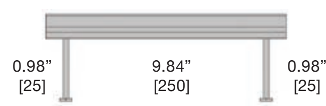
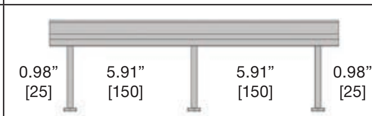
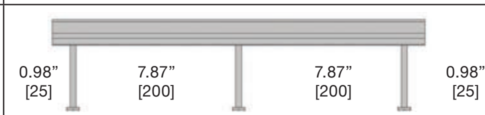
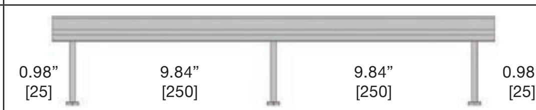
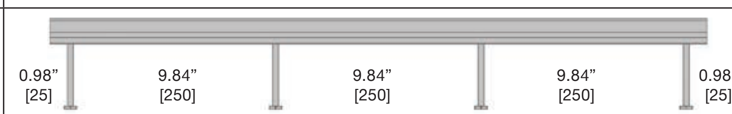
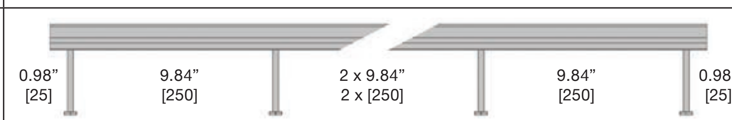
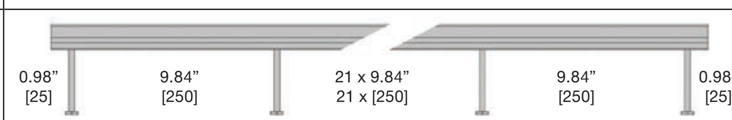
1) Lead Time Categories
A = Standard inventory item in North America, typically available from stock
B = Standard item, not stocked in North America, typical lead time 8 weeks
C = Make to order item, typical lead time 12 weeks
D = Make to order item with minimum order quantity, lead time may be longer than 12 weeks"
General note: It's recommended to always check availability with Hilti for all items

2) Custom lengths are available upon request in increments of 5 mm. Min length 150 mm, max length 5800 mm.
See section for custom made anchor channels

# 2.5 — STANDARD ANCHOR CHANNEL CONFIGURATION

## 2.5.1 HAC STANDARD ANCHOR CONFIGURATION

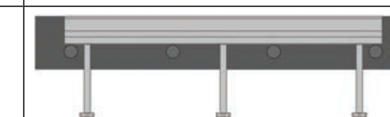
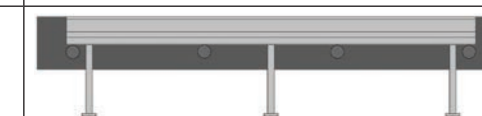
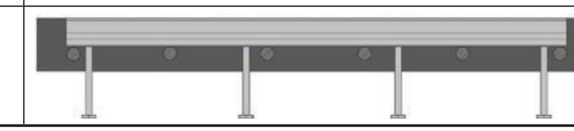
### HAC and HAC-T

| Units | Channel Length | Anchor Spacing | Number of Anchors | |
|---|---|---|---|---|
| in [mm] | 5.91 [150] | 3.94 [100] | 2 |   |
| in [mm] | 7.87 [200] | 5.91 [150] | 2 |   |
| in [mm] | 9.84 [250] | 7.87 [200] | 2 |   |
| in [mm] | 11.81 [300] | 9.84 [250] | 2 |   |
| in [mm] | 13.78 [350] | 5.91 [150] | 3 |   |
| in [mm] | 17.72 [450] | 7.87 [200] | 3 |   |
| in [mm] | 21.65 [550] | 9.84 [250] | 3 |   |
| in [mm] | 31.50 [800] | 9.84 [250] | 4 |   |
| in [mm] | 41.34 [1050] | 9.84 [250] | 5 |   |
| in [mm] | 228.35 [5800] | 9.84 [250] | 24 |   |

Custom anchor channel lengths with custom anchor configurations are available upon request.
Anchor channel figures show rounded head anchors. The configuration for HAC CRFoS U (rebar anchors) have the same anchor configuration as its matching HAC.

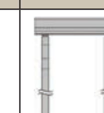
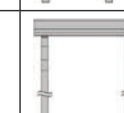
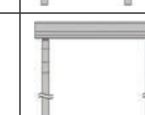
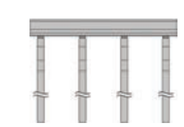
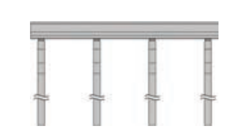
## 2.5.2 HAC EDGE LITE, HAC EDGE, AND HAC S EDGE ANCHOR AND EDGE PLATE CONFIGURATION

### HAC EDGE Lite, HAC EDGE, HAC S EDGE
### HAC-T EDGE Lite, HAC-T EDGE, HAC-T S EDGE

| Units | Channel Length | Anchor Spacing | Number of Anchors | Rebar Spacing | Number of Rebars | |
|---|---|---|---|---|---|---|
| in [mm] | 11.81 [300] | 9.84 [250] | 2 | 3.74 [95] | 4 |  |
| in [mm] | 13.78 [350] | 5.91 [150] | 3 | 4.41 [112] | 4 |  |
| in [mm] | 17.72 [450] | 7.87 [200] | 3 | 5.71 [145] | 4 |  |
| in [mm] | 24 [610] | 9.84 [250] | 3 | 4.68 [119] | 6 |  |

HAC EDGE Lite and HAC-T EDGE Lite are only available in 11.81" (300 mm) lengths.

## 2.5.3 HAC CRFOS U STANDARD ANCHOR CONFIGURATION

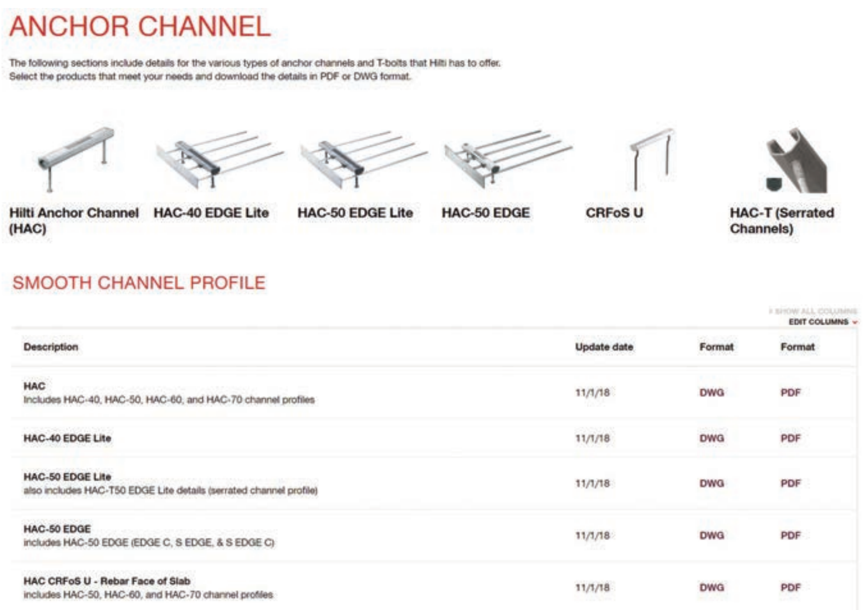
| Units | Channel Length | Anchor Spacing | Number of Anchors | |
|---|---|---|---|---|
| in [mm] | 7.87 [200] | 5.91 [150] | 2 |  |
| in [mm] | 9.84 [250] | 7.87 [200] | 2 |  |
| in [mm] | 11.81 [300] | 9.84 [250] | 2 |  |
| in [mm] | 13.78 [350] | 3 Rebars: 5.91 [150] | 3 |  |
| | | 4 Rebars: 3.94" [100] | 4 |  |
| in [mm] | 17.72 [450] | 3 Rebars: 7.87 [200] | 3 |  |
| | | 4 Rebars: 5.25 [133.33] | 4 |  |
| in [mm] | 24.00 [610] | 5.51 [140] | 5 |  |

Custom anchor channel lengths with custom anchor configurations are available upon request. The minimum anchor spacing is equal to 4.00" (102 mm).

## 2.5.3 HAC DRAWINGS AND HAC CAD DRAWINGS

DWG and pdf files for the entire HAC library can be downloaded in the following link:

https://www.hilti.com/content/hilti/W1/US/en/engineering/technical-information/specifications-and-cad-details.html#id-anchor-channel-childsection_716608241


ANCHOR CHANNEL

The following sections include details for the various types of anchor channels and T-bolts that Hilti has to offer. Select the products that meet your needs and download the details in PDF or DWG format.

Hilti Anchor Channel (HAC) | HAC-40 EDGE Lite | HAC-50 EDGE Lite | HAC-50 EDGE | CRFoS U | HAC-T (Serrated Channels)

SMOOTH CHANNEL PROFILE

| Description | Update date | Format | Format |
|---|---|---|---|
| HAC<br>Includes HAC-40, HAC-50, HAC-60, and HAC-70 channel profiles | 11/1/18 | DWG | PDF |
| HAC-40 EDGE Lite | 11/1/18 | DWG | PDF |
| HAC-50 EDGE Lite<br>also includes HAC-T50 EDGE Lite details (serrated channel profile) | 11/1/18 | DWG | PDF |
| HAC-50 EDGE<br>includes HAC-50 EDGE (EDGE C, S EDGE, & S EDGE C) | 11/1/18 | DWG | PDF |
| HAC CRFoS U - Rebar Face of Slab<br>includes HAC-50, HAC-60, and HAC-70 channel profiles | 11/1/18 | DWG | PDF |

**Figure 2.5.3.1 — HAC on-line library.**

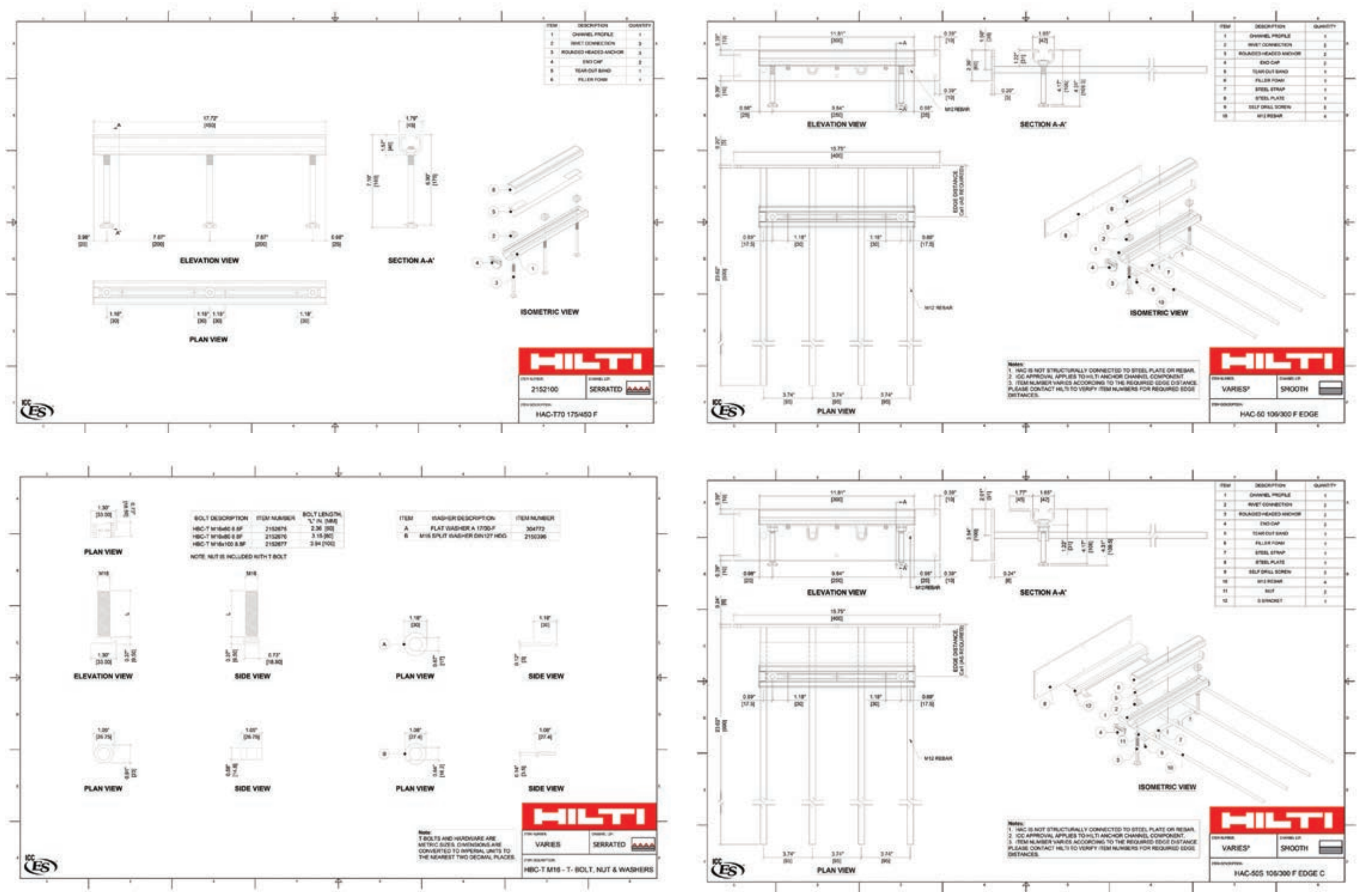


**Figure 2.5.3.2 — HAC library, "pdf" format.**

# 2.6 CUSTOM SOLUTIONS

Hilti keeps in stock anchor channel that are commonly used in North America. Non-standard and custom anchor channel can be provided upon request. A non-stock item is not necessarily a custom item. See section 2.4 for standard non-stock items. Depending on the level of customization, longer lead times and minimum order may be required.

Custom or non-stock channel may be required due to performance or geometric constraints. It is recommended to always specify products that are kept in stock in North American. However, there are cases where custom conditions cannot be avoided. The information in this section provides guidelines of the level of customization of the HAC product line. For questions, please reach out to Hilti.

Anchor channels outside the lead time category "A" provided in section 2.4 are not necessarily custom channels. What defines a custom anchor channel is whether a custom component is required. A component is referred to any member of an anchor channel (i.e. anchor, channel profile, rivet, rebar, or EDGE Plate). For instance, an anchor channel with a non-standard anchor spacing (i.e. 2 anchors at 6.75 in. O.C.) or number of anchors (i.e. 11.80 in. (300 mm) long with 3 anchors) do not require custom components. However, an anchor channel with a custom anchor length (i.e. HAC-50 with 7'' long anchors) requires the use of a new component.

The level of customization of an anchor channel may be limited by code requirements, structural performance, and design constraints.

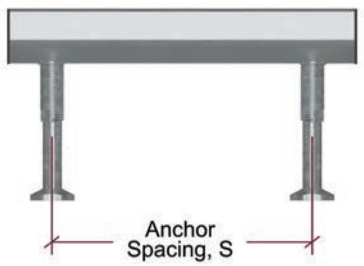
## 2.6.1 CUSTOM ANCHOR CHANNEL LENGTHS (HAC, HAC CRFOS U, HAC EDGE)

Anchor channel with custom lengths (non-standard anchor spacing) can be provided upon request. AC232 and ICC ESR-3520 have minimum spacing requirements that shall be met. The lead time for anchor channels with non-standard anchor spacing is 10-12 weeks.

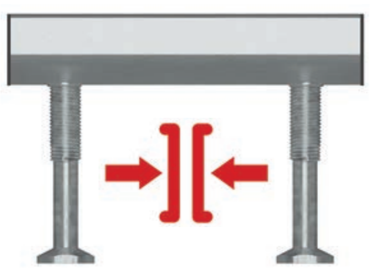
This information is applicable to HAC and HAC CRFoS U.

The minimum anchor spacing (S) for anchor channels is as follows: HAC-40, HAC-50, HAC-60, and HAC-70 is 3.94" (100 mm)

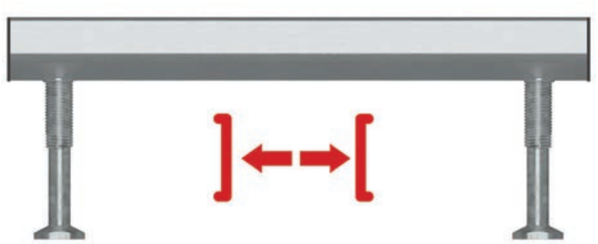
The maximum anchor spacing (S) for anchor channels is 9.84" (250 mm).




**Minimum Anchor Spacing**



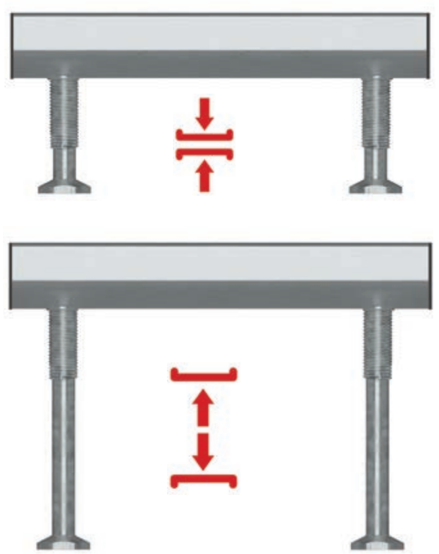
**Maximum Anchor Spacing**



## 2.6.2 CUSTOM ANCHOR LENGTH (HAC, HAC EDGE, HAC EDGE LITE)

Anchor channels with custom anchor lengths can be provided upon request. For such applications, the standard lead time (shipping via sea-freight) is 6 months. A minimum order of 4000 channels is required. The only exception is HAC-50 and HAC-60. These two channels utilize the same anchor diameter and therefore, they are interchangeable.


**Minimum Anchor Spacing**

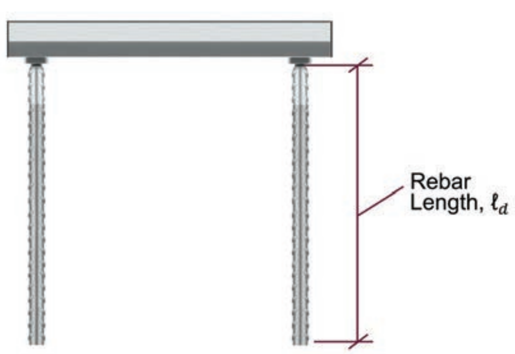


See chapter 7 for the AC232 minimum requirements and design provisions for anchor channels with reduced anchor lengths.

For rounded head anchors, the maximum anchor length is 25 in.

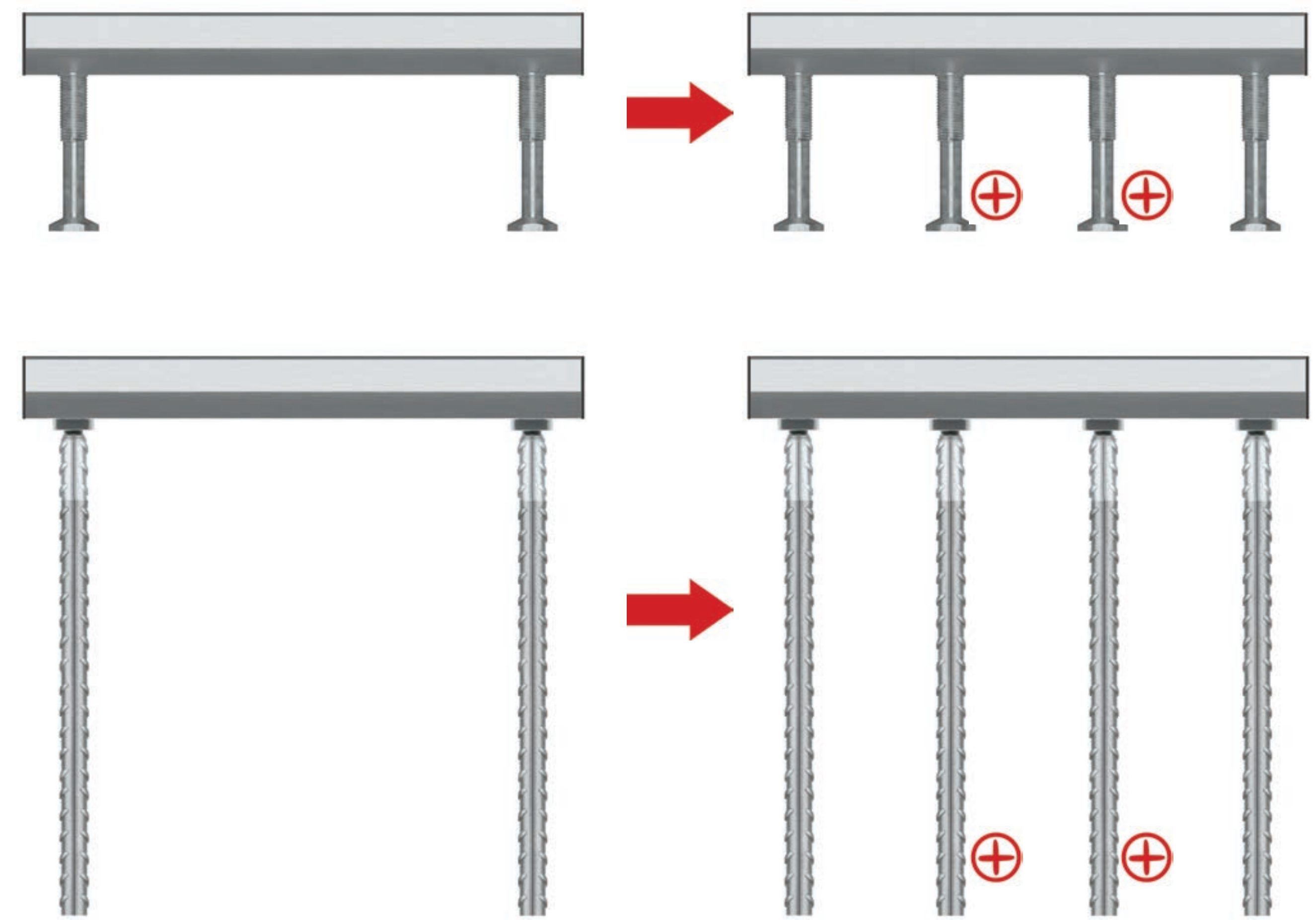
## 2.6.3 CUSTOM REBAR LENGTHS (HAC CRFOS U)

Anchor channels with custom anchor lengths can be provided upon request. For longer rebars, the lead time is 6 months and the minimum order is 1000 channels. Anchor channels with shorter rebars than the standard rebar length require two additional weeks than the standard lead time and no minimum order is required.




## 2.6.4 CUSTOM NUMBER OF ANCHORS/REBARS

The Hilti Anchor Channel portfolio comes with predetermined configurations. Some conditions may require anchor channel with different anchor configurations. The minimum anchor spacing is 3.94 in (100 mm). The maximum anchor spacing is 9.84 in (250 mm). The standard lead time (shipping via sea-freight) is 10-12 weeks.

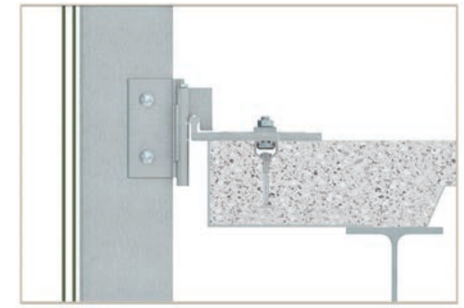


# 3. APPLICATIONS

This chapter provides a general overview of some of the most common applications. The applications of cast-in anchor channels are not limited to the ones mentioned in the chapter. Generally speaking, Hilti Anchor Channel Systems can be used in any application where a cast-in solution is needed, site tolerance is required, and/or high performing anchors are demanded based on the applied loads.

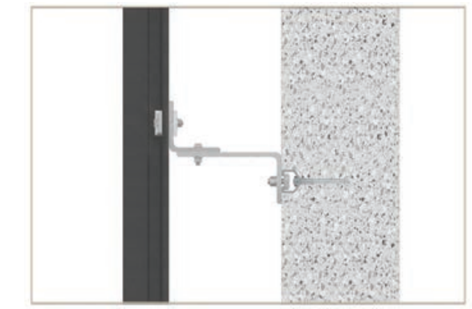


## 3.1 HILTI CAST-IN ANCHOR CHANNEL APPLICATIONS

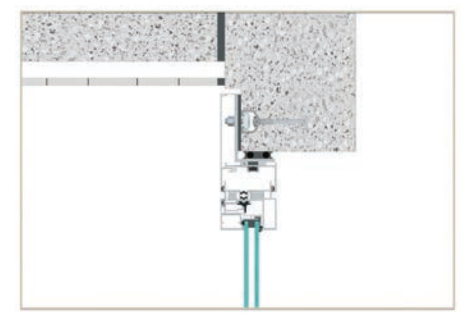


Curtain wall façade

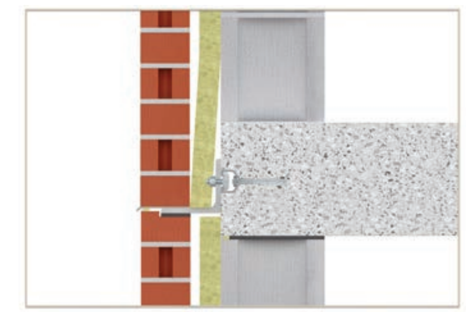
Handrail



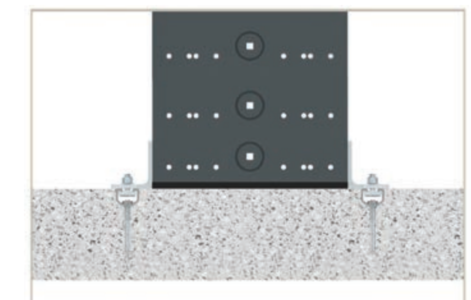
Elevator guide rail



Window wall (precast members)



Brick façade

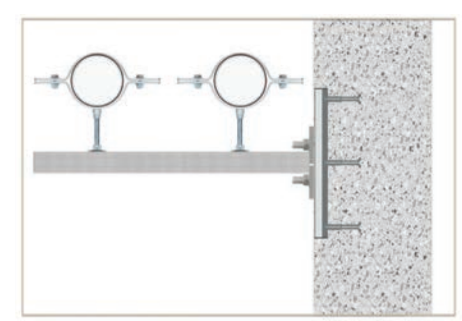


Network rack

Pipe Support

Stadium seat

Precast concrete member



Pipe support

Lateral restrain for masonry wall

Man-Lifts

# 4. DESIGN INTRODUCTION

The design of an anchor channel system depends on two different aspects; substrate type and applied loads. They are both equally important and therefore they are both essential for an accurate anchor channel analysis. The design introduction opens up the sections that cover the design of an anchor channel.

# INTRODUCTION

## 4.1 PUBLISHED LOAD VALUES

Technical data presented herein was current as of the date of publication (see back cover). Anchor channel strength (capacity) published in this technical manual are based on International Council Code Evaluation Research Report 3520 (ICC ESR-3520) when applicable. Likewise, analytical calculations are based on ICC ESR-3520 and ACI 318 when applicable.

Capacity (strength) of anchor channels outside the scope of ICC ESR-3520 are based on applicable testing protocols of Acceptance Criteria 232 (AC232). Load values obtained from testing represent the average results of multiple identical samples. Analytical calculations are based on applicable design provisions of AC232 and ACI 318.

Variations in base materials such as concrete and local site conditions require on-site testing to determine actual performance at any specific site.

The tables and diagrams in this guide are intended purely as an aid to the user and no guarantee can be given regarding their correctness or accuracy when used for design calculations for a specific application. Should you, despite the care we have taken, discover an error in the information given here, please notify us accordingly. In any event, the static system or, respectively, the specific application must always be checked for plausibility by the user.

For information regarding updates and changes, please contact Hilti, Inc. (U.S.) Technical Support at **1-877-749-6337** or Hilti (Canada) Corporation at **1-800-363-4458**.

## 4.2 UNITS

Technical data is provided in Imperial units. Metric values, when provided, use the International System of units (SI) in observance with the **Metric Conversion Act of 1975** as amended by the **Omnibus Trade and Competitiveness Act of 1988**. MI and MQ connector and base dimensions are converted from SI units, shown in parentheses, to Imperial units.

## 4.3 ANCHOR CHANNEL DESIGN

Acceptance Criteria for Anchor Channels in Concrete Elements (AC232) establishes the requirements for anchor channels in normal weight or lightweight concrete elements comply with International Building Code Evaluation Service, LLC (ICC-ES), evaluation report under the 2018, 2015, 2012, 2009, and 2006 International Building Code (IBC) and the 2018, 2015, 2012, 2009, and 2006 International Residential Code (IRC). The bases of compliance are IBC Section 104.11, and IRC Section R104.11. AC232 requires the verification of up to 20 different anchor channel failure modes, in addition to 6 additional anchor reinforcement failure modes if anchor reinforcement is used. Moreover, a total of up to 5 different interaction equations are required.

The design process of an anchor channel requires the verification of its structural adequacy to resist specific loads. Nowadays, design software such as PROFIS Anchor Channel facilitates and helps to speed up the design process. However, in order to utilize the software at its maximum potential and ensure the design is correct, a thorough understanding of several requirements is needed. For instance, PROFIS Anchor Channel does not allow the input of a cold join in the substrate element. On the other hand, even when a specific condition is fully covered by the software, one must still understand these elements for a proper design.

Such elements are as follows:
Base material (chapter 5)
Applied loads (chapter 6)
Anchor strength (chapter 2)
Anchoring to concrete theory and design guidelines (chapter 7)
Reinforcing bar theory (chapter 8)

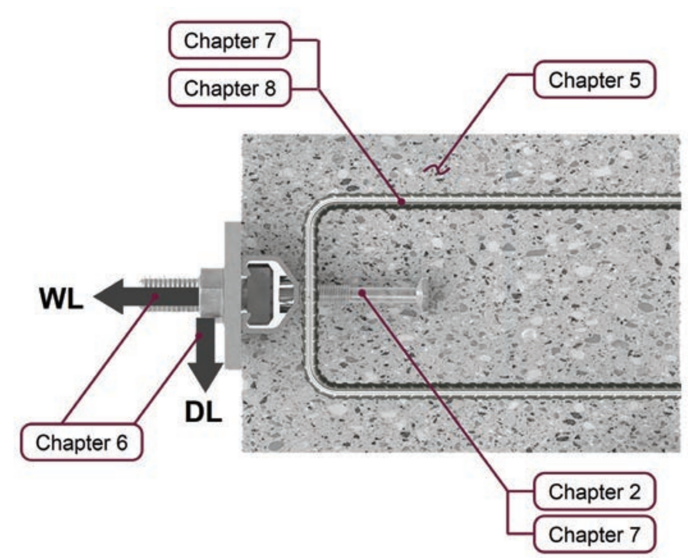
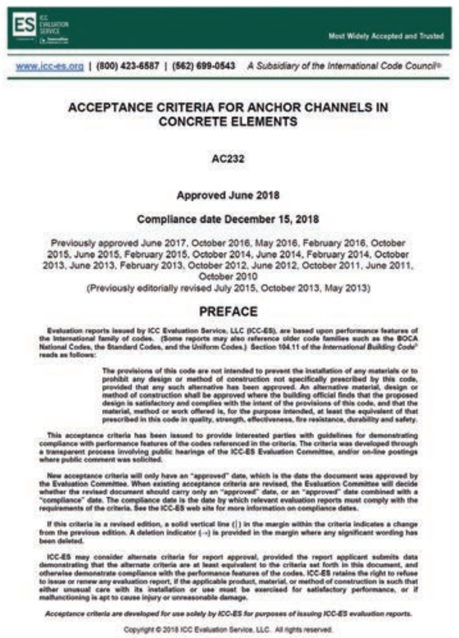



**Figure 4.3.1 — Overview of anchor channel design elements.**

The first Acceptance Criteria for Anchor Channels in Concrete Elements (AC232) was first approved by the ICC-ES Evaluation Committee in October 2010. Since then, several improvements and additions to the original AC232 provisions such as seismic provisions have been performed.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**ACCEPTANCE CRITERIA FOR ANCHOR CHANNELS IN CONCRETE ELEMENTS**

**AC232**

**Approved June 2018**

**Compliance date December 15, 2018**

Previously approved June 2017, October 2016, May 2016, February 2016, October 2015, June 2015, February 2015, October 2014, June 2014, February 2014, October 2013, June 2013, February 2013, October 2012, June 2012, October 2011, June 2011, October 2010
(Previously editorially revised July 2015, October 2013, May 2013)

**PREFACE**

Evaluation reports issued by ICC Evaluation Service, LLC (ICC-ES), are based upon performance features of the International family of codes. (Some reports may also reference older code families such as the BOCA National Codes, the Standard Codes, and the Uniform Codes.) Section 104.11 of the *International Building Code®* reads as follows:

The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

This acceptance criteria has been issued to provide interested parties with guidelines for demonstrating compliance with performance features of the codes referenced in the criteria. The criteria was developed through a transparent process involving public hearings of the ICC-ES Evaluation Committee, and/or on-line postings where public comment was solicited.

New acceptance criteria will only have an "approved" date, which is the date the document was approved by the Evaluation Committee. When existing acceptance criteria are revised, the Evaluation Committee will decide whether the revised document should carry only an "approved" date, or an "approved" date combined with a "compliance" date. The compliance date is the date by which relevant evaluation reports must comply with the requirements of the criteria. See the ICC-ES web site for more information on compliance dates.

If this criteria is a revised edition, a solid vertical line (|) in the margin within the criteria indicates a change from the previous edition. A deletion indicator (→) is provided in the margin where any significant wording has been deleted.

ICC-ES may consider alternate criteria for report approval, provided the report applicant submits data demonstrating that the alternate criteria are at least equivalent to the criteria set forth in this document, and otherwise demonstrate compliance with the performance features of the codes. ICC-ES retains the right to refuse to issue or renew any evaluation report, if the applicable product, material, or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or if malfunctioning is apt to cause injury or unreasonable damage.

***Acceptance criteria are developed for use solely by ICC-ES for purposes of issuing ICC-ES evaluation reports.***

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**Figure 4.3.2 — AC232.**

AC232 provisions are in a continuous state of development. AC232 it is still a work-in-progress document. The design provisions and testing protocols are limited to specific type of anchor channels, anchor channel configurations, base materials, and type of loads. Design information for anchor channels and configurations not implicitly covered by AC232 such as HAC EDGE and corners with pair of channels load simultaneously, are covered in **Chapter 9** of this technical manual.

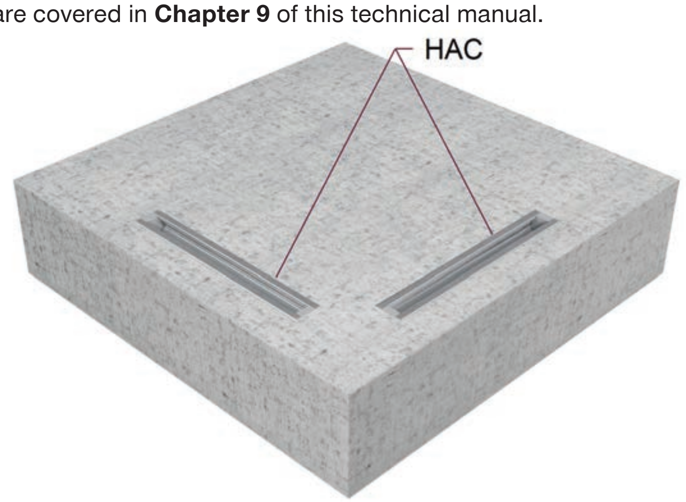



**Figure 4.3.3 — Pair of anchor channels in an outside 90, corner.**

**Chapter 10** provides a general overview of PROFIS Anchor Channel.


**Figure 4.3.4 — PROFIS Anchor Channel.**

**Chapter 11** covers a wide range of best practices for an optimal anchor channel design and ensure designers can offer value engineered anchor channel designs as well as to help contractors to minimize field fixes.

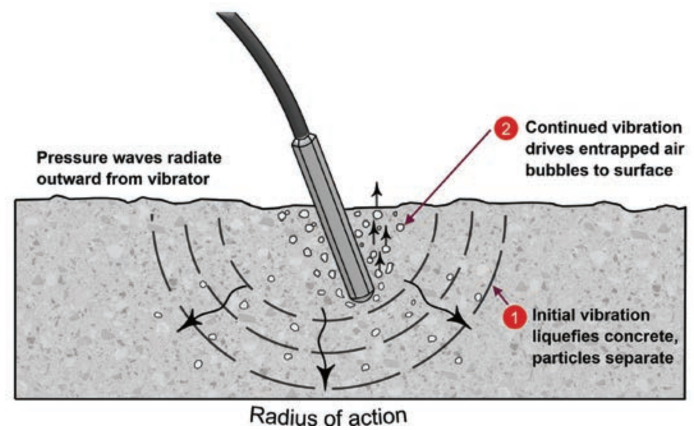



**Figure 4.3.5 — Best practices for concrete consolidaation.**

**Chapter 12** provides Instructions for use.

**Chapter 13** provides general recommendations for typical field fixes encountered in jobsites.



# 5. BASE MATERIAL

Base materials or substrate information is fundamental in determining the anchor channel strength. Oftentimes, the design of an anchor channel is limited by the substrate's strength. Therefore, the design of an anchor channel is contingent to the adequacy of the base material at the anchor zone.

Having the right substrate properties and a solid understanding of how different base materials properties impacts the design of an anchor channel design is essential. Therefore, the base material shall be carefully examined prior to the design of an anchor channel, in order to assess how the anchor channel design may be impacted.

# 5.1 BASE MATERIALS

## 5.1.1 BASE MATERIALS FOR FASTENING

The wide variety of building materials used today provides different anchoring conditions for anchors. There is hardly a base material in or to which a fastening cannot be made with a Hilti product. However, the properties of the base material play a decisive role when selecting a suitable fastener/anchor and determining the load it can hold. It is the responsibility of the designer to carefully match the type of fastener with the base material to obtain the desired results.

## 5.1.2 CONCRETE

Concrete is a synthetic stone consisting of a mixture of cement, aggregates, and water. In many cases, special additives are used to influence or change certain properties. Concrete has a relatively high compressive strength compared to its tensile strength. Thus, steel reinforcing bars are frequently cast in concrete to carry tensile forces, and this combination is referred to as reinforced concrete.

Cement is a binding agent which combines with water and aggregates and hardens through the process of hydration to form concrete. Portland cement is the most commonly used cement and is available in several different types to meet specific design requirements (ASTM C150).

The aggregates used in concrete consist of both fine aggregate (usually sand) and coarse aggregate graded by particle size. Different types of aggregates can be used to obtain concrete with specific characteristics. Normal-weight concrete is generally made from crushed stone or gravel, while lightweight concrete is obtained using expanded clay, shale, slate, or blast-furnace slag. Lightweight concrete is used when it is desirable to reduce the dead load on a structure or to achieve a superior fire rating for a floor structure. When thermal insulating properties are a prime consideration, lightweight aggregates are manufactured from perlite, vermiculite, blast-furnace slag, clay or shale. Finally, sand lightweight concrete is obtained using lightweight aggregate and natural sand. In general, all concretes with a unit weight between 85 and 115 pcf are considered to be structural lightweight concretes. The ASTM specifications related to concrete type and weight can be summarized as follows:

| ASTM concrete type | Aggregate grading specification | Concrete unit weight pcf |
|---|---|---|
| Normal-weight | Fine: ASTM C33<br>Coarse: ASTM C33 | 145-155 |
| Sand-lightweight | Fine: ASTM C33<br>Coarse: ASTM C330 | 105-115 |
| All-lightweight | Fine: ASTM C330<br>Coarse: ASTM C330 | 85-110 |

The effect of aggregate mechanical properties on anchor performance is less well understood. In general, harder/ denser aggregates (i.e. granite) tend to result in higher concrete cone breakout loads, whereas lightweight aggregates produce lower tension and shear capacities. Concrete is typically assumed to crack under normal service load conditions or, more specifically, when tensile stresses imposed by loads or restraint conditions exceed its tensile strength. Crack width and distribution are generally controlled through the use of reinforcement. With consideration for the protection of the reinforcing steel, crack widths, per ACI 318, are assumed to be less than approximately 0.012 in (0.3 mm). Under seismic loading, flexural crack widths corresponding to the onset of reinforcing yield are assumed to be approximately 1-1/2 x static crack width = 0.02” (0.5 mm). Both ACI 318 and the International Building Code conservatively assume cracked concrete as the baseline condition for the design of cast-in-place and post-installed anchors since the existence of cracks in the vicinity of the anchor can result in a reduced ultimate load capacity and increased displacement at ultimate load compared to uncracked concrete conditions. Design for uncracked concrete conditions is permitted by the model Building Codes only for cases where it can be shown that cracking of the concrete at service load levels will not occur over the anchor service life. For cases involving design for seismic actions, cast-in anchor channels must be demonstrated as being suitable for use in cracked concrete as well as for seismic loading.

Values for the ultimate strength of fasteners in concrete are traditionally given in relation to the 28-day uniaxial compressive strength of the concrete (actual, not specified). Concrete that has cured for less than 28 days is referred to as green concrete. Aggregate type, cement replacements such as fly ash, and admixtures can affect the capacity of some fasteners, and this may not be reflected in the concrete strength as measured in a standard uniaxial compression test. In general, Hilti data reflects testing with common aggregates and cement types in plain, unreinforced concrete. In questionable cases, consult with Hilti Technical Services.

In view of the significantly lower strength of green concrete (less than 28-day cure), it is recommended that cast-in anchor channels not be loaded in concretes cured for less than 7 days, unless site testing is performed to verify the fastening capacity. If an anchor is installed in green concrete, but not loaded until the concrete has achieved full cure, the capacity of the anchor can be based on the strength of the concrete at the time of loading.

## 5.1.3 PRE-TENSIONED / PRE-STRESSED CONCRETE

Pretensioned concrete refers to concrete cast around pretensioned steel tendons.

Cast-in anchor channel systems can be a solution for pretensioned concrete, as it does not require drilling into the concrete. AC232 does not provide provisions to account for the influence of pre-tensioned cables on the anchor channel concrete capacity.

Anchor channels installed near tendon(s) may induce additional stresses in the concrete. Likewise, tendon(s) near anchor channel(s) may impact the performance of the channel. Conditions where anchor channels are installed near tendon(s) shall be designed accordingly. Additional coordination with the Engineer of Records (EOR), design engineer, and/or Pre-stressed concrete engineer is required.

## 5.1.4 BONDED POST-TENSIONED CONCRETE

Post-tensioned concrete refers to a concrete member containing steel tendons that are tensioned after casting the concrete.

As with the prestressed concrete case, anchor channels close to post-tensioning strands should be designed accordingly and additional coordination with the Engineer of Records (EOR), design engineer, and/or post-tensioned concrete engineer is required. AC232 does not provide provisions to account for the influence of post-tensioned cables on the anchor channel concrete capacity.

## 5.1.5 ADMIXTURES

Chemical admixtures are ingredients added to the basic components of concrete or mortar (cement, water, and aggregates) immediately before or during mixing. Chemical admixtures are used to enhance the properties of concrete and mortar in the plastic and hardened state. These properties may be modified to increase compressive and flexural strength, decrease permeability and improve durability, inhibit corrosion, reduce shrinkage, accelerate or retard initial set, increase slump and working properties, increase cement efficiency, improve the economy of the mixture, etc.

Testing of post-installed anchors is performed in concrete without admixtures. Designers should take into consideration the effects produced by admixtures on concrete when considering the use of post-installed anchors.

# 5.2 EVALUATION OF TEST DATA

## 5.2.1 DEVELOPING FASTENER PERFORMANCE DATA

State-of-the-art anchor design uses what is known as the Strength Design Method. By using the Strength Design Method, nominal strengths are first calculated for all the possible anchor failure modes. Subsequently, strength reduction factors are applied to each nominal strength to obtain a design strength. The controlling design strength is finally compared to a factored load. The provisions of ACI 318-14 Chapter 17 are the basis used for Strength Design.

Strength Design data for Hilti anchor channels in concrete elements is derived from testing as per the provisions of ICCES AC232.

Beginning with IBC 2003, the IBC Building Codes have adopted the Strength Design Method for anchorage into concrete of both cast-in-place and post-installed anchors.

Another anchor design method known as "Allowable Stress Design" can be used as an alternative to the Strength Design provisions. Section 2.2.2 provides detailed explanations to analyze cast-in anchor channels via Allowable Stress Design. Allowable Stress Design data for Hilti cast-in anchor channels is derived from testing based on ICC-ES AC232.

Allowable loads are developed applying a statistical method to the test data which relates the allowable working load to the performance variability of the fastening.

### 5.2.2 ALLOWABLE LOADS

Historically, allowable loads for anchors have been derived by applying a global safety factor to the average ultimate value of test results as shown in Eq. (5.2.1).

$$F_{all} = \frac{\bar{F}}{v} \qquad (5.2.1)$$

Where:

$\bar{F}$ = mean ultimate value of test data (population sample)

$v$ = global safety factor

Global safety factors of 3 for cast-in anchor channels have been industry practice for nearly three decades. The global safety factor is assumed to cover expected variations in field installation conditions and in anchor performance from laboratory tests.

Note that global safety factors applied to the mean do not explicitly account for the coefficient of variation, i.e., all anchors are considered equal with respect to variability in the test data.

### 5.2.3 STATISTICAL EVALUATION OF DATA

Experience from a large number of tests on anchors has shown that ultimate loads generally approximate a normal Gaussian probability density function as shown in Fig. 5.2.1. This allows for the use of statistical evaluation techniques that relate the resistance to the system performance variability associated with a particular anchor.

The 5% fractile characteristic value has been adopted by the IBC as the basis for determining published design loads based on anchor testing results for Strength Design. There is a 90% probability that 95% of the test loads will exceed a 5% fractile value. The 5% fractile value is calculated by subtracting a certain number of standard deviations of the test results from the mean based on the number of trials. See Eq. (5.2.2) and the referenced statistical table by D. B. Owen. For a series of 5 trials, the 5% fractile value is calculated by multiplying the standard deviations by k = 3.401 and subtracting from the mean.

Owen, D.B., (1962) Handbook of Statistical Tables, Section 5.3. Reading: Addison-Wesley Publishing.

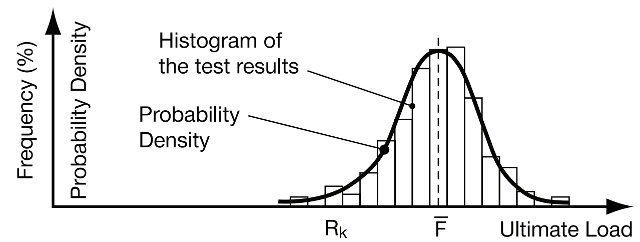



Fig. 5.2.1 Frequency distribution of anchor ultimate loads, demonstrating the significance of the 5% fractile

$$R_k = \bar{F} - k \cdot s = \bar{F}(1 - k \cdot cv) \qquad (5.2.2)$$

Where:

$R_k$ = characteristic resistance of the tested anchor system

$\bar{F}$ = mean ultimate resistance of the tested anchor system

$k$ = distribution value for test sample size n

$s$ = standard deviation of the test data

$cv$ = coefficient of variation = $\frac{s}{\bar{F}}$

Thus, test series with low standard deviations are rewarded with higher 5% fractile characteristic design values. This is typical of ductile steel failure modes.

# 5.3 CORROSION

### 5.3.1 THE CORROSION PROCESS

Corrosion is defined as the chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties (ASTM G15). The corrosion process can be very complex and have many contributing factors that lead to immediate or gradual destructive results. In anchorage and fastener design, the most common types of corrosion are direct chemical attack and electro-chemical contact.

## 5.3.2 TYPES OF CORROSION

### 5.3.2.1 DIRECT CHEMICAL ATTACK

Corrosion by direct chemical attack occurs when the base material is soluble in the corroding medium. One method of mitigating these effects is to select a fastener that is not susceptible to attack by the corroding chemical. Compatibility tables of various chemical compounds with Hilti adhesive and epoxy fastening systems are provided in this technical guide.

When selection of a base metal compatible with the corroding medium is not possible or economical, another solution is to provide a coating that is resistant to the corroding medium. This might include metallic coatings such as zinc or organic coatings such as epoxies or fluorocarbons.

### 5.3.2.2 ELECTROCHEMICAL CONTACT CORROSION

All metals have an electrical potential relative to each other and are classified accordingly in the galvanic series of metals and alloys. When metals of different potential come into contact in the presence of an electrolyte (moisture), the metal with more negative potential becomes the anode and corrodes, while the other becomes the cathode and is galvanically protected.

The severity and rate of attack are influenced by:
a. Relative position of the contacting metals in the galvanic series
b. Relative surface areas of the contacting materials
c. Conductivity of the electrolyte

The effects of electro-chemical contact corrosion may be mitigated by:
a. Using similar metals close together in the electromotive force series,
b. Separating dissimilar metals with gaskets, plastic washers or paint with low electrical conductivity. Materials typically used in these applications include:
 1. High Density Polyethylene (HDPE)
 2. Polytetrafluoroethylene (PTFE)
 3. Polycarbonates
 4. Neoprene/chloroprene
 5. Cold galvanizing compound
 6. Bituminous coatings or paint

Note: Specifiers must ensure that these materials are compatible with other anchorage components in the service environment.

c. Selecting materials so that the fastener is the cathode, the most noble or protected component
d. Providing drainage or weep holes to prevent entrapment of the electrolyte

| Galvanic Series of Metals and Alloys |
|---|
| Corroded End (anodic, or least noble) |
| Magnesium<br>Magnesium alloys<br>Zinc |
| Aluminum 1100<br>Cadmium<br>Aluminum 2024-T4<br>Steel or Iron<br>Cast Iron<br>Chromium-iron (active)<br>Ni-Resist cast iron |
| Type 304 Stainless (active)<br>Type 316 Stainless (active) |
| Lead tin solders<br>Lead<br>Tin |
| Nickel (active)<br>Inconel nickel-chromium alloy (active)<br>Hastelloy Alloy C (active) |
| Brasses<br>Copper<br>Bronzes<br>Copper-nickel alloys<br>Monel nickel-copper alloy |
| Nickel (passive)<br>Inconel nickel-chromium alloy<br>(passive) |
| Silver solder<br>Chromium-iron (passive)<br>Type 304 Stainless (passive)<br>Type 316 Stainless (passive)<br>Hastelloy Alloy C (passive) |
| Silver<br>Titanium<br>Graphite<br>Gold<br>Platinum |
| Protected End<br>(cathodic, or most noble) |

Source: IFI Fastener Standards, 6th Edition

### 5.3.2.3 HYDROGEN ASSISTED STRESS CORROSION CRACKING

Often incorrectly referred to as hydrogen embrittlement, hydrogen assisted stress corrosion cracking (HASCC) is an environmentally induced failure mechanism that is sometimes delayed and most times occurs without warning. HASCC occurs when a hardened steel fastener is stressed (loaded) in a service environment which chemically generates hydrogen (such as when zinc and iron combine in the presence of moisture). The potential for HASCC is directly related to steel hardness. The higher the fastener hardness, the greater the susceptibility to stress corrosion cracking failures. Eliminating or reducing any one of these contributing factors (high steel hardness, corrosion or stress) reduces the overall potential for this type of failure. Hydrogen embrittlement, on the other hand, refers to a potential damaging side effect of the steel fastener manufacturing process, and is unrelated to project site corrosion. Hydrogen embrittlement is neutralized by proper processing during fastener pickling, cleaning and plating operations (specifically, by "baking" the fasteners after the application of the galvanic coating).

### 5.3.3 CORROSION PROTECTION

The most common material used for corrosion protection of carbon steel fasteners is zinc. Zinc coatings can be uniformly applied by a variety of methods to achieve a wide range of coating thickness depending on the application. All things being equal, thicker coatings typically provide higher levels of protection.

An estimating table for the mean corrosion rate and service life of zinc coatings in various atmospheres is provided to the right. These values are for reference only, due to the large variances in the research findings and specific project site conditions, but they can provide the specifier with a better understanding of the expected service life of zinc coatings. In controlled environments where the relative humidity is low and no corrosive elements are present, the rate of corrosion of zinc coatings is approximately 0.15 microns per year.

Zinc coatings can be applied to anchors and fasteners by different methods. These include (in order of increasing coating thickness and corrosion protection):

a. ASTM B633 – Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel
b. ASTM B695 – Standard Specification for Coatings of Zinc Mechanically Deposited on Iron and Steel
c. ASTM A153 – Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware
d. Sherardizing Process – Proprietary Diffusion Controlled Zinc Coating Process

| Atmosphere | Mean corrosion rate |
|---|---|
| Industrial | 5.6 µm/year |
| Urban non-industrial or marine | 1.5 µm/year |
| Suburban | 1.3 µm/year |
| Rural | 0.8 µm/year |
| Indoors | Considerably less than 0.5 µm/year |

Source: ASTM B633 Appendix X1. Service life of zinc

### 5.3.3.1 SUGGESTED CORROSION RESISTANCE

Use of AISI 316 stainless steel in environments where pitting or stress corrosion is likely to occur should be avoided due to the possibility of sudden failure without visual warning. Fastenings used in these applications should be regularly inspected for serviceability conditions. See chart below for more details.

| Corrosion resistance | Typical conditions of use |
|---|---|
| Phosphate and oil coatings (Black oxide) | • Interior applications without any particular influence of moisture |
| Zinc electro-plated 5 – 10 µm (ASTM B633, SC 1, Type III) Organic coatings – KWIK Cote≥17.8 µm | • Interior applications without any particular influence of moisture<br>• If covered sufficiently by noncorrosive concrete |
| Mechanically deposited zinc coating 40 – 107 µm | • Interior applications in damp environments and near saltwater (ASTM B695) |
| Hot-dip galvanizing (HDG) >50 µm (ASTM A153) Sherardizing process > 50 µm | • Exterior applications in only slight to mild corrosive atmospheres |
| Stainless steel (AISI 303 / 304) | • Interior applications where heavy condensation is present<br>• Exterior applications in corrosive environments |
| Stainless steel (AISI 316) | • Near saltwater<br>• Exterior corrosive environments |



## 5.3.4 HILTI FASTENING SYSTEMS

### 5.3.4.1 ANCHOR CHANNELS

Most Hilti metal anchors are available in carbon steel with an electrodeposited zinc coating of at least 5 µm with chromate passivation. Chromate passivation reduces the rate of corrosion for zinc coatings, maintains color, abrasion resistance and, when damaged, exhibits a unique "self healing" property. This means that the chromium contained within the film on the anchor surface will repassivate any exposed areas and lower the corrosion rate.

## 5.3.5 APPLICATIONS

It is difficult to offer generalized solutions to corrosion problems. A general guide can be used as a starting point for fastener material selection based on the desired application.

The specifier should also consult:

a. Local and national building code requirements (e.g., IBC, UBC)
b. Standard practice manuals for specific types of construction (e.g., ACI, PCI, AISC, PCA, CRSI, AASHTO, NDS/APA)
c. Manufacturers of structural components
d. Hilti Technical Support

| Component | Carbon steel | Surface | Stainless steel |
|---|---|---|---|
| Channel Profile | Carbon steel | Hot dip galvanized (F) ≥ 55 µm[1]<br>Hot dip galvanized (F) ≥ 70 µm[2] | - |
| Rivet | | Hot dip galvanized (F) ≥ 45 µm | - |
| Anchort | | Hot dip galvanized (F) ≥ 45 µm | - |
| Rebar | BSt500 B | Hot dip galvanized (F) ≥ 45 µm | - |
| Front Plate | S235 | Hot dip galvanized (F) ≥ 45 µm | - |
| Channel bolt | Grade 4.6 and 8.8 according to DIN EN ISO 898-1:2009-8 | Hot dip galvanized (F) ≥ 45 µm, or electroplated (G) ≥ 8 µm | Grade 50 according to DIN EN ISO 3506-1:2010-4, passivation according ASTM A380 |
| Plain washer[3] ISO 7089 and ISO 7093-1 | Hardness A, 200 HV | Hot dip galvanized (F), or electroplated (G) | Hardness A, 200 HV according to ISO 3506-1 |
| Hexagonal nut ISO 4032 or DIN 934[4] | Property class 8 according to ISO 898-2, or property class 5 according to DIN 267-4 | Hot dip galvanized (F) ≥ 45 µm, or electroplated (G) ≥ 8 µm | Property class 70 according to DIN 267-11 |

### 5.3.5.1 GENERAL APPLICATION

These application charts are offered as general guidelines. Site specific conditions may influence the decision.

| Application | Conditions | Fastener recommendations |
|---|---|---|
| Structural steel components to concrete and masonry (interior connections within the building envelope not subjected to free weathering)[1,2] | Interior applications without condensation | Galvanic zinc electroplating |
| | Interior applications with occasional condensation | HDG or Sherardized |
| Structural steel components to concrete and masonry (exterior connections subjected to free weathering)[1,2] | Slightly corrosive environments | HDG or Sherardized |
| | Highly corrosive environments | Stainless steel |
| Temporary formwork, erection bracing and short-term scaffolding | Interior applications | Galvanic zinc electroplating |
| | Exterior applications | HDG or Sherardized |
| Parking garages / parking decks subject to periodic application of de-icers including chloride solutions[3] | Non-safety critical | HDG, Sherardized |
| | Safety critical | Stainless steel[1] |
| Road / bridge decks subject to periodic application of de-icers including chloride solutions | Non-safety critical | HDG or Sherardized |
| | Safety critical | Stainless steel |

1 Refer to ACI 318-14 Chapter 19 – Durability
2 Refer to ACI 530.1 Section 2.4F – Coatings for Corrosion Protection
3 Refer to PCI Parking Structures: Recommended Practice for Design and Construction – Chapters 3, 5 and Appendix
4 General guidelines address environmental corrosion (direct chemical attack). Additional considerations should be taken into account when using hardened steel fasteners susceptible to HASCC.

## 5.4 SPECIAL APPLICATIONS

This application chart offers a general guideline addressing environmental corrosion (direct chemical attack). Site specific conditions may influence the decision.

| Application | Conditions | Fastener Recommendations |
|---|---|---|
| Aluminum fastenings (flashing / roofing accessories, hand rails, grating panels, sign posts and miscellaneous fixtures) | Interior applications without condensation | Galvanic zinc plating |
| | Exterior applications with condensation | Stainless steel, X-CR |
| Water treatment | Not submerged | HDG, Sherardized or Stainless steel |
| | Submerged | Stainless steel |
| Waste water treatment | Not submerged | HDG or Stainless steel |
| | Submerged | Stainless steel |
| Marine (salt water environments, shipyards, docks, off-shore platforms) | Non-safety critical or temporary connections | HDG |
| | High humidity with the presence of chlorides — splash zone | Stainless steel[1] |
| | On the off-shore platform or rig | Stainless steel |
| Indoor swimming pools | Non-safety critical | HDG |
| | Safety critical or subjected to high concentrations of soluble chlorides | Stainless steel[1] |
| Pressure / chemically treated wood | Above grade | HDG |
| | Below grade | Stainless steel |
| Power plant stacks / chimneys | Non-safety critical | HDG or Stainless steel |
| | Safety critical or subjected to high concentration of soluble chlorides | Stainless steel |
| Tunnels (lighting fixtures, rails, guard posts) | Non-safety critical | HDG, Stainless steel |
| | Safety critical | Stainless steel[1] |

1 Steel selection depends on safety relevance

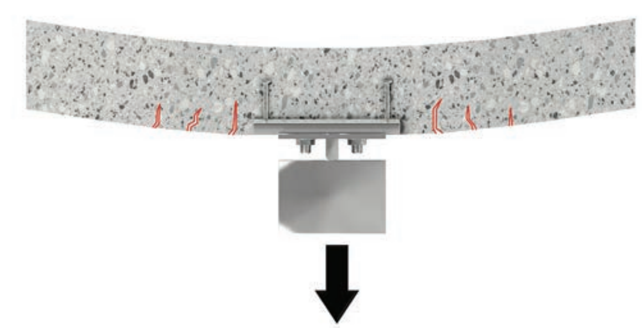


## 5.5 SEISMIC CONSIDERATIONS

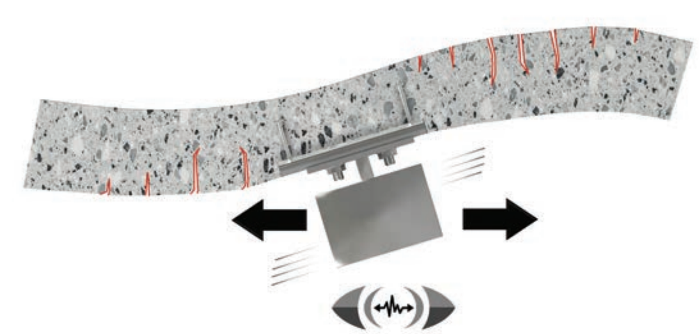
### 5.5.1 SEISMIC CONSIDERATIONS

Rapid ground movement during an earthquake leads to relative displacement of a building's foundation. Owing to the inertia of its mass, the building cannot follow this movement without experiencing deformations in the building frame. In addition, accelerations are induced in the structure. Due to the stiffness of the structure, restoring forces result and cyclic strains are induced in the structure. These strains are also experienced by anchors used for attachment of nonstructural components, such as cladding, to the structural frame. The loads acting on these anchors can be calculated directly on the basis of the dynamic characteristics of the building, local site seismicity, soil characteristics, and the dynamic characteristics of the components fastened to the building.

In general terms, the main difference between static loading and seismic loading of attachments is the multi-directional cyclic loading induced by the seismic event as shown in Figure 5.5.1.1.



No significant cyclic loading with inertia



Significant cycle loading with multi-directional inertia force

**Figure 5.5.1.1 Comparison of loading characteristics under seismic and static conditions (reinforcement not shown for clarity).**

In addition, loading frequencies during earthquakes often lead to resonance phenomena which result in greater vibration amplitudes on the upper floors than on lower floors. This may result in a need for different designs for anchor systems situated

A seismic hazard is the probability that an earthquake will occur in a given geographic area, within a given window of time, and with ground motion intensity exceeding a given threshold.

The U.S Geological Survey (USGS) has produced a one-year 2017 seismic hazard forecast for the central and eastern United States from induced and natural earthquakes that updates the 2016 one-year forecast; this map is intended to provide information to the public and to facilitate the development of induced seismicity forecasting models, methods, and data. The 2017 hazard model applies the same methodology and input logic tree as the 2016 forecast, but with an updated earthquake catalog.

In order to ensure the adequacy of the anchor to resist seismic loads, the seismic analysis needs to be performed, even when at first glance, the seismic loads seem to be significant lower than the static loads.

Figure 5.5.1.2 illustrates the different seismic design categories in different states of the United States. Although regulations in some state are more stringent than others, in order to provide IBC-compliant solutions and ensure the general welfare of citizens, seismic design verification for anchor channels is performed for anchor channels located in structures assigned to Seismic Design Categories C, D, E, or F.

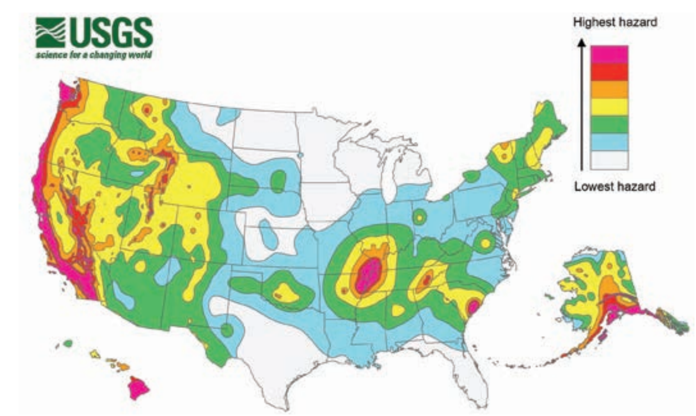


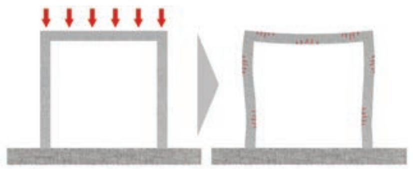

**Figure 5.5.1.2 — U.S. seismic hazard map.**

In summary:

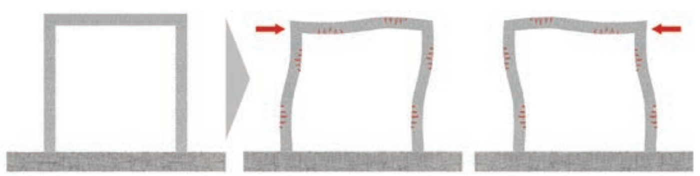
- Seismic conditions can significantly change the behavior of anchors, compared to static conditions.
- It's important to include seismic design for both structural and non-structural elements of a build, as research shows that non-structural systems suffer the largest damage in commercial buildings during an earthquake.
- Adequate seismic construction design and specification reduces the probability of a failure of the anchorage during a seismic event.
- Seismic events have a big impact on the loading and behavior of anchors in the supporting material, resulting in the possibility of some anchors being unsuitable for seismic conditions or having a lower capacity under seismic conditions than under static conditions.

## 5.5.2 BEHAVIOR OF THE MATERIALS IN WHICH ANCHORS ARE SET

Due to the multiple responses of seismic action, the assumed compression zone under static action may suddenly become the tension zone. The possibility of cracks intersecting the anchor location can therefore be assumed to be highly probable, even if the original anchoring location was assumed to be uncracked, as indicated.



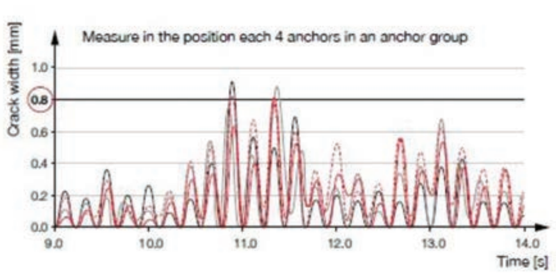
Static loading: cracks may occur in defined tension zones



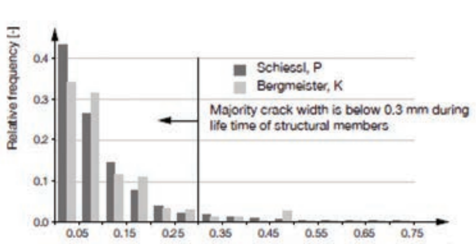
Seismic loading:cracks may occur almost everywhere in concrete members.

**Figure 5.5.2.1 — Comparison of potential crack positions under seismic and static conditions (reinforcement not shown for clarity).**

The width of cracks generated during earthquakes is, on average, significantly greater than those resulting from static loading. Under static conditions, cracks are normally restricted to a width of 0.3 mm under service load conditions, and at the load levels of designed resistance they may reach a width of up to 0.5 mm. However, during seismic events, cracks can easily reach a width of up to 0.8 mm. This has been confirmed by tests with groups of 4 anchors carried out in 2006, as shown in Figure 5.5.2.2.



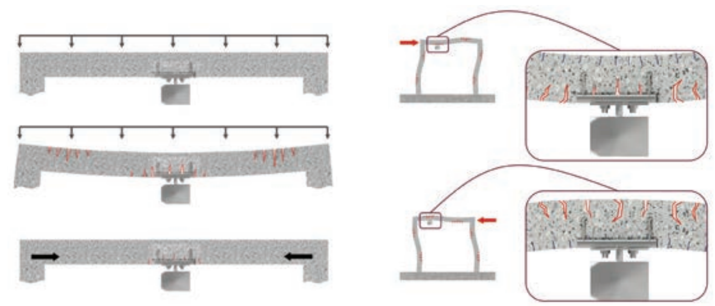

Source: Hoehler, M. S. (2006) Behavior and testing of fastenings to concrete for use in seismic applications.




Source: Eligehausen, R.; Bozenhardt, A. (1989): Crack widths as measured in actual structures and conclusions for the testing of fastening elements

**Figure 5.5.2.2 Comparison of crack width under seismic and static conditions**

The movement of concrete components under seismic actions results in opening and closing of cracks in combination with load cycling on the anchor. This crack opening and closing pattern is different to the patterns found under static conditions, as described in Figure 5.5.2.3.



The crack opens and closes with the changing of live load and rebar restrain, which is less severe compared to seismic conditions.

Concrete beside the cracks is alternately under compression and tension, resulting in the worst conditions for the anchor zone.

**Figure 5.5.2.3 — Comparison of crack width under static and seismic conditions**

The nature of seismic loads is very different than the static loads, hence there is a different testing criteria for the anchor channel used in seismic zones replicating the seismic activity and also the design methodology is more stringent.

According to ACI §318-14 17.2.3, anchors in structures assigned to Seismic Design Category (SDC) C, D, E, or F shall satisfy the additional requirements of ACI 318 § 17.3.2 through §17.2.3.7. Commentary §R17.2.3 states that these additional requirements shall be satisfied regardless of whether earthquake loads are included in the controlling load combination for the anchor design.

According to section ACI 318-14 §17.2.3.4.4, the anchor concrete design tensile strength for resisting earthquake forces shall be reduced by an additional 0.75. The reduced anchor nominal tensile strengths associated with concrete failure modes is to account for increased cracking and spalling in the concrete resulting from seismic actions.

Because seismic design generally assumes that all or portions of the structure are loaded beyond yield, it is likely that the concrete is cracked throughout for the purpose of determining the anchor strength. In locations where it can be demonstrated that the concrete does not crack, uncracked concrete may be assumed for determining the anchor strength as governed by concrete failure modes.



# 6. LOADING

Acceptance Criteria 232 (AC232) provides design guidelines for cast-in anchor channels. Anchor channels are now easier to show compliance with the International Building Code via an Evaluation Service Report. The lack of explicit provisions for anchor channels in the anchor provisions of ACI 318 are addressed by the design guidelines provided in AC232, which are written as amendments to ACI 318.

Historically, anchor channels have been designed using ASD (allowable stress design) concepts. With the introduction of AC232, the use of LRFD (strength design) for the design of anchor channels was made possible. Whereas ASD assigns global safety factors to cover all aspects of the design problem (variability, consequences of failure, etc.) strength design permits explicit consideration of the variability in resistance and loads. In many cases, strength design may result in more efficient design solutions. The ACI 318 model code has used strength design since 1971, and its use for anchorage problems is now accepted practice throughout the U.S.

# 6.1 STRENGTH DESIGN VS ALLOWABLE STRESS DESIGN

### Allowable Stress Design (ASD)

Design philosophy based on ensuring the service loads do not exceed the elastic limit. This is accomplished by ensuring that stresses remain within the limits through the use of safety factors. The safety factor accounts for all of the uncertainties in loads and strength (material).

$$\frac{R_n}{FS} \geq \sum_{i=1}^{m} L_i$$

Where:
$R_n$ = nominal or design strength (stress, moment, force, etc.) FS
FS= Safety factor 3-4 typically)
$L_i$ = nominal (or service) value for the $i^{th}$ load component out of m components

### Strength Design

Also known as Load and Resistance Factor Design (LRFD). Design philosophy considers uncertainties in material properties, construction tolerances, and loads. It incorporates state-of-the-art analysis and load and resistance factors are statistically calibrated to ensure a uniform level of safety.

$$\phi R_n \geq \sum_{i=1}^{m} \gamma_i L_{ni}$$

Where:
ø = strength reduction factor
$Y_i$ = load factor for the ith load component out of n components
$R_n$ = nominal or design strength (stress, moment, force, etc.)
$L_{n1}$ = nominal (or service) value for the ith load component out of m components

# 6.2 ANCHOR CHANNEL LOADING

## 6.2.1 ANCHOR CHANNEL LOADING

The design of anchor channels is now based on Strength Design philosophy. Applied loads shall be factored according to the applicable building code.

$$\phi R_n \geq \sum_{i=1}^{m} \gamma_i L_{ni}$$

### Terminology

**Load Factors:**

Strength Design philosophy uses load factors to amplify the magnitude of the calculated loads to account for the uncertainties involved in estimating the magnitude of different loads.

**Load Combinations:**

Different types of loads can be combined since it can be applied simultaneously, however they may not be with the same magnitudes and factors.

## 6.2.2 LOAD COMBINATIONS

Anchor channels shall be designed using the applicable load combination. When selecting the required load combination, it is important to ensure the load combinations are consistent with the International Building Code used to derive the loads. If load combinations and derive loads use different IBC versions, the anchor channel design may result in very unconservative or conservative results.

IBC refers to ASCE Standards for the determination of loads and selection of the required load combinations. Although some of the load combinations do not change in different ASCE year, ASCE 7-10 has undergone some important changes. Special attention shall be paid to the ASCE version used for the determination of forces and load combinations.

### Symbols and Notation

D = dead load
$D_i$ = weight of ice
E = earthquake load
F = load due to fluids with well-defined pressures and maximum heights
$F_a$ = Flood load
H = load due to lateral earth pressure, ground water pressure, or pressure of bulk materialsL = live load
$L_r$ = roof live load
R = rain loadS = snow load
T = self-straining forceW = wind load
Wi = wind-on-ice determined in accordance with Chapter 10.

### Load Combinations ASCE 7-05 — Strength Design

1. 1.4(D + F)
2. 1.2(D + F + T) + 1.6(L + H) + 0.5($L_r$ or S or R)
3. 1.2D + 1.6($L_r$ or S or R) + ((0.5 or 1.0)*L or 0.8W)
4. 1.2D + 1.6W + (0.5 or 1.0)*L + 0.5($L_r$ or S or R)
5. 1.2D + 1.0E + (0.5 or 1.0)*L + 0.2S
6. 0.9D + 1.6W + 1.6H
7. 0.9D + 1.0E + 1.6H

### Load Combinations ASCE 7-05 — Allowable Stress Design

1. D + F
2. D + H + F + L + T
3. D + H + F + ($L_r$ or S or R)
4. D + H + F + 0.75(L + T) + 0.75($L_r$ or S or R)
5. D + H + F + (W or 0.7E)
6. D + H + F + 0.75(W or 0.7E) + 0.75L + 0.75($L_r$ or S or R)
7. 0.6D + W + H
8. 0.6D + 0.7E + H

### Introduction

Wind design in ASCE 7-10 underwent several major changes. Wind provisions in ASCE 7-10 follow the form introduced for the seismic provisions in the 2005 edition. New wind speed maps that vary by risk category have been introduced. The wind speeds provided in such maps are applicable for determining wind pressures for strength design. Therefore, wind pressures are strength level and the wind load factor was changed to 1.0.

### Load Combinations ASCE 7-10 — Strength Design

1. 1.4D
2. 1.2D + 1.6L + 0.5($L_r$ or S or R)
3. 1.2D + 1.6($L_r$ or S or R) + (L or 0.5W)
4. 1.2D + 1.0W + L + 0.5($L_r$ or S or R)
5. 1.2D + 1.0E + L + 0.2S
6. 0.9D + 1.0W
7. 0.9D + 1.0E

### Load Combinations ASCE 7-10 — Allowable Stress Design

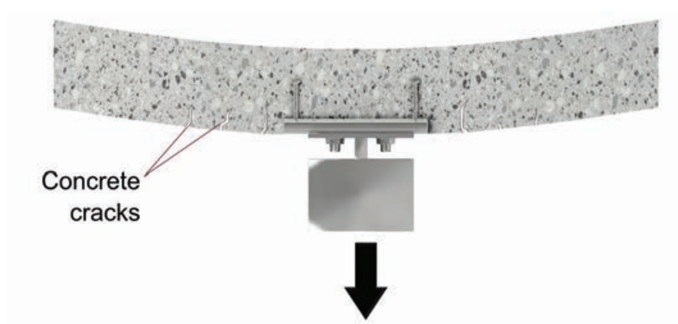
1. D
2. D + L
3. D + ($L_r$ or S or R)
4. D + 0.75L + 0.75($L_r$ or S or R)
5. D + (0.6W or 0.7E)

6a. D + 0.75L + 0.75(0.6W) + 0.75($L_r$ or S or R)
6b. D + 0.75L + 0.75(0.7E) + 0.75S
7. 0.6D + 0.6W
8. 0.6D + 0.7E

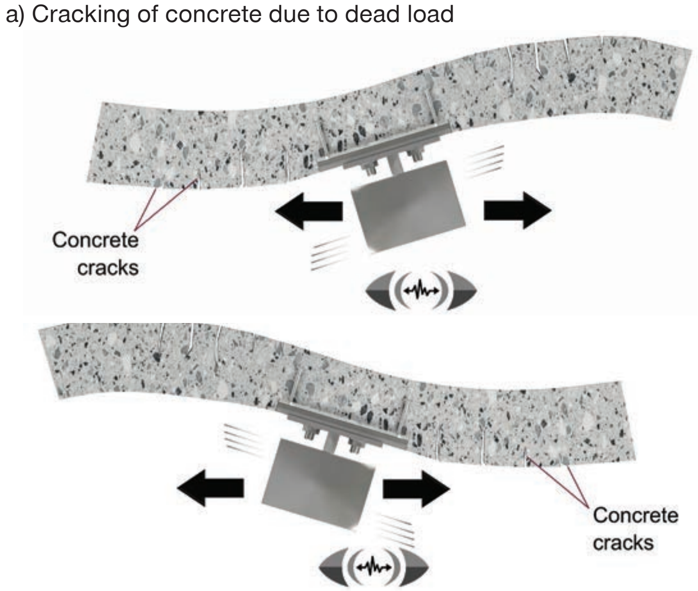
# 6.3.0 SEISMIC LOADING

## 6.3.1 SEISMIC LOAD BEHAVIOR

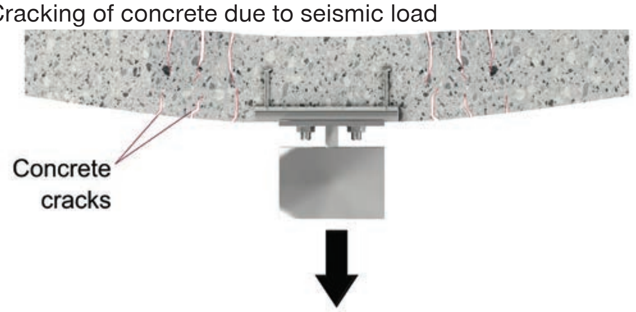
Cyclic loads are a characteristic feature of actions acting on structures and anchorages during earthquakes. During seismic events, anchors used to connect structural and non-structural elements to concrete are subjected to cyclic tension and cyclic shear loads. Cycling loads may induce additional cracking that can ultimately reduce the concrete capacity of the anchor. This effect is reflected in figure 6.3.1.Incorrectly designed or inadequately qualified anchors have caused severe damage and failure of the connection.




a) Cracking of concrete due to dead load




b) Cracking of concrete due to seismic load




c) Cracking of concrete after a seismic event

**Figure 6.3.1.1 — Cracks in a reinforced concrete member subjected to cycling loads.**

## 6.3.1 SEISMIC LOAD DERIVATION FOR NONSTRUCTURAL COMPONENTS — ASCE 7-10, CHAPTER 13

ASCE 7-10: §12.14.3.1 Seismic Load Effect The seismic load effect, E, shall be determined in accordance with the following:

1. For use in load combination 5 in ASCE 7-10 Section §2.3.2 or load combinations 5 and 6 in ASCE 7-10 Section §2.4.1, E shall be determined in accordance with ASCE 7-10 Eq. 12.14-3 as follows:

$E = E_h + E_v$ (ASCE 7-10 Eq. §12.14-3)

2. For use in load combinations 7 in ASCE 7-10 Section §2.3.2 or load combination 8 in ASCE 7-10 Section §2.4.1, E shall be determined in accordance with ASCE 7-10 Eq. §12.14-4 as follows:

$E = E_h - E_v$ (ASCE 7-10 Eq. §12.14-3)

where

E = seismic load effect
$E_h$ = effect of horizontal seismic forces as defined in ASCE 7-10 Section §12.14.3.1.1
$E_v$ = effect of vertical seismic forces as defined in ASCE 7-10 Section §12.14.3.1.2

ASCE 7-10 §12.14.3.1.1 Horizontal Seismic Load Effect

The horizontal seismic load effect, $E_h$, shall be determined in accordance with Eq. §12.14-5 as follows:

$E_h = Q_E$ (ASCE 7-10 Eq. §12.14-5)

where

$Q_E$ = effects of horizontal seismic force from V or $F_p$ as specified in ASCE 7-10 Sections §12.14.7.5, 12.14.8.1, and 13.3.1

The horizontal seismic design force ($F_p$) shall be applied at the component's center of gravity and distributed relative to the component's mass distribution and shall be determined in accordance with Eq. ASCE 7-10 Eq. §13.3-1:

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\frac{R_p}{I_p}}\left(1 + 2\frac{z}{h}\right)$$ (ASCE 7-10 Eq. §13.3-1)

$F_p$ is not required to be taken as greater than

$F_p \leq 1.6 S_{DS} \ell_p W_p$ (ASCE 7-10 Eq. §13.3-2)

and $F_p$ shall not be taken as less than

$F_p \geq 0.3 S_{DS} \ell_p W_p$ (ASCE 7-10 Eq. §13.3-3)

where
$F_p$ = seismic design force
$S_{DS}$ = spectral acceleration, short period, as determined from ASCE 7-10 Section §11.4.4
$a_p$ = component amplification factor that varies from 1.00 to 2.50 (select appropriate value from ASCE 7-10 Table § 13.5-1 or 13.6-1)
$\ell_p$ = component importance factor that varies from 1.00 to 1.50 (see ASCE 7-10 Section §13.1.3)
$W_p$ = component operating weight
$R_p$ = component response modification factor that varies from 1.00 to 12 (select appropriate value from ASCE 7-10 Table §13.5-1 or §13.6-1)
z = height in structure of point of attachment of component with respect to the base. For items at or below the base, z shall be taken as 0. The value of z/h need not exceed 1.0
h = average roof height of structure with respect to the base

The force ($F_p$) shall be applied independently in at least two orthogonal horizontal directions in combination with service loads associated with the component, as appropriate. For vertically cantilevered systems, however, the force $F_p$ shall be assumed to act in any horizontal direction. In addition, the component shall be designed for a concurrent vertical force $\pm 0.2 S_{DS} W_p$. The redundancy factor, ρ, is permitted to be taken equal to 1 and the overstrength factor, $\Omega_0$, does not apply.

ASCE 7-10 §12.14.3.1.2 Vertical Seismic Load Effect The vertical seismic load effect, Ev, shall be determined in accordance with Eq. §12.14-6 as follows:

$E_v = 0.2 S_{DS} D$ (ASCE 7-10 Eq. §12.14-6)

where

$S_{DS}$ = design spectral response acceleration parameter at short periods obtained from ASCE 7-10 §11.4.4

D = effect of dead load
EXCEPTION: The vertical seismic load effect, $E_v$, is permitted to be taken as zero for either of the following conditions:

1. In ASCE 7-10 Eqs. §12.4-3, 12.4-4, 12.4-7, and 12.14-8 where $S_{DS}$ is equal to or less than 0.125.

2. In ASCE 7-10 Eqs. §12.14-4 where determining demands on the soil-structure interface of foundations.

**ASCE 7-10 §12.14.3.1.3 Seismic Load Combinations Where the prescribed seismic load effect, E, defined in ASCE 7-10 Section §12.14.3.1 is combined with the effects of other loads as set forth in ASCE 7-10 Chapter 2, the following seismic load combinations for structures not subject to flood or atmospheric ice loads shall be used in lieu of the seismic load combinations in Sections ASCE 7-10 Sections §2.3.2 or 2.4.1:**

**Basic Combinations for Strength design (see ASCE 7-10 Sections §2.3.2 and 2.2 for notation).**

5. $(1.2 + 0.2S_{DS})D + QE + L + 0.2S$

7. $(0.9 - 0.2S_{DS})D + QE + 1.6H$

**Under seismic conditions, the direction of shear may not be predictable. The full shear force should be assumed in any direction for a safe design.**

## 6.3.2 OVERSTRENGTH FACTORS PER ASCE 7-10

Overstrength factor is used to satisfy seismic detailing requirement of ACI 318. Structures in Seismic Design Category (SDC) C, D, E or F are designed to yield which induces additional cracking in concrete. The objective of the overstrength factor is to cope with the unpredictability of the seismic forces and to avoid brittle failure (concrete failure) of the anchorage in a seismic event. This can be achieved by increasing the concrete capacity of the anchorage by increasing the seismic load by the overstrength factor.

# 6.4.0 LOADS ON HANDRAIL AND GUARDRAIL SYSTEMS — ASCE 7-10

### ASCE 7-10 §4.5.1

All handrail and guardrail systems shall be designed to resist a single concentrated load of 200 lb (0.89 kN) applied in any direction at any point on the handrail or top rail and to transfer this load through the supports to the structure to produce the maximum load effect on the element being considered.

Further, all handrail and guardrail systems shall be designed to resist a load of 50 lb/ft (pound-force per linear foot) (0.73 kN/m) applied in any direction along the handrail or top rail.

# 7. ANCHOR CHANNEL DESIGN CODE

Base material or substrate information is fundamental in determining the anchor channel strength. Although Chapter 2 provides nominal steel strengths of the anchor channel, the adequacy of an anchor in general is contingent on the adequacy of the base material.

Having the right substrate properties and a good understanding of how different base materials' properties or requirements may impact the anchor channel design. Therefore, the base material shall be carefully examined prior to the design of an anchor channel system.

This chapter contains testing, theory and design methodology of anchor channel described in AC232. The AC232 acceptance criteria describes the principles and requirements for safety, serviceability and durability of anchor channels for use in uncracked or cracked concrete.

The AC232 applies to anchor channels used to resist loads in cracked and uncracked normal weight and lightweight concrete and included assessments of strength capacity, design procedures and quality control. This chapter will cover testing procedure based on AC232 for evaluation of the steel strengths of anchor channel as well as the design methodology described in AC232 in order to evaluate the various concrete breakout failure modes for standard anchor channel with headed studs and anchor channels with deformed bars.



## 7.1 — OVERVIEW OF ANCHOR CHANNEL THEORY

Before the publication of Acceptance Criteria 232 (AC232), it was difficult to show cast-in anchor channels compliant with the International Building Code (IBC) since ACI 318 Anchoring-to-Concrete provisions exclude the design of specialty inserts. The publication of (AC232) brought significant benefits to the cast-in anchor channel industry and design community. The use of optimized anchor channel solutions and simplification of the design and approval processes for anchor channels ultimately can avoid construction shutdowns.

Cast-in anchor channels can now more easily be shown compliant with the IBC, as AC232 3.0 Design Requirements provides suggested additions to ACI 318 Anchoring-to-Concrete provisions that permit the design of anchor channel systems as if they were included in ACI 318 Anchoring-to-Concrete provisions. In addition, AC232 allows the design community to have a clear understanding of cast-in anchor channel systems.


Prior to AC232, designers had to design anchor channels via engineering judgment, which may require applying design provisions not applicable to anchor channels, research papers, and/or using manufactures' technical data. The non-model code design methodology used to approve the anchor channel design had to be backed-up by the P.E. stamp of a licensed engineer of the state of the project's location. In some extreme cases, this was not accepted by local jurisdictions and additional testing was required. Additional testing added an extra problem since testing protocol for anchor channels did not exist. Providing model code compliant designs increases the probability of acceptance by local jurisdictions and reduce the probability of additional testing.

Relying on technical data is adequate only if the tests are performed correctly. Tests results can be positively or negatively impacted if the system is not tested properly. Technical data via testing created an additional problem since prior to AC232, there were no testing protocols for cast-in anchor channel systems neither. AC232 provides testing protocols and design guidelines for anchor channels.

Since its inception, AC232 has been an ever-evolving document. In its infancy stage, AC232 did not include provisions for anchor channels systems in structures assigned to Seismic Design Category C, D, E, or F. In 2015, AC232 incorporated seismic provisions for anchor channels in Seismic Design Category C, D, E, or F. Later provisions permitting the use of anchor channels in all-lightweight concrete and sand-lightweight concrete were adopted by AC232.

Important design provisions have been added to AC232 over the last years. The ultimate goal is to have a complete framework that covers all typical and non-typical applications encountered in a building such as corners with a pair of anchor channels loaded simultaneously or parallel channels.

The scope of AC232 was limited to anchor channels with rounded head anchors or I-anchors. The latest AC232 approved in June 2018 also includes anchor channels replacing rounded head anchors with deformed reinforcing bars. AC232 also includes provisions for anchor reinforcement, where the concrete breakout in shear and/or tension can be precluded.

This chapter provides design and testing information for anchor channels covered by AC232 (HAC and HAC-T). Chapter 2 provides design steel strengths for the anchor channel system. However, additional calculations are needed to complete the steel verification of anchor channels. Moreover, this chapter provides design provisions for the verification of the concrete at the anchorage zone. Due to the number of variables that can impact the performance of the concrete, AC232 has provided additional design guidelines.

# 7.2 ANCHOR CHANNEL THEORY

## 7.2.1 ANCHOR PRINCIPLES AND DESIGN

### Definitions

**5 percent Fractile** Value corresponding to a 5 percent probability of non-exceedance

**Adhesive anchor** is a post-installed anchor that is inserted into a drilled hole in hardened concrete, masonry or stone. Loads are transferred to the base material by the bond between the anchor and the adhesive and the adhesive and the base material.

**Anchor category** is an assigned rating that corresponds to a specific strength reduction factor for concrete failure modes associated with anchors in tension. The anchor category is established based on the performance of the anchor in reliability tests.

**Anchor Channel** is steel profile with rigidly connected anchors installed prior to concrete placement.

**Anchor Channel Assemblies** anchor channel consist of a channel produced from hot rolled or cold-formed steel and at least two metal anchors on the channel web as illustrated in figure 7.2.2.1 & 7.2.2.2. The anchor channel shall be flushed with the concrete surface. A fixture shall be connected to the anchor channel by channel bolts ( hammer head or hooked channel bolts) with nut and washer in accordance with figure 7.2.2.2.

**Anchor Channel Installation** Instructions for placement of subject anchor channel.

**Anchor Channel loading: Axial Tension** is Load applied perpendicular to the surface of the base material and in direction of the anchor axis.

**Anchor Channel loading: Bending** Bending effect induced by a tension load applied in direction of the anchor axis at any location between anchors.

**Anchor Channel loading: Longitudinal shear** Loads acting parallel to the concrete surface and co-linear with the longitudinal axis of the anchor channel.

**Anchor Channel loading: Perpendicular shear** Loads acting parallel to the concrete surface and perpendicular to the longitudinal axis of the anchor channel.

**Anchor Channel System** Specific combination of anchor channel and channel bolt under consideration.

**Anchor Diameter** Nominal diameter of the anchor channel.

**Anchor group** is a group of anchors of approximately equal effective embedment and stiffness where the maximum anchor spacing is less than the critical spacing.

**Anchor reinforcement** is reinforcement used to transfer the full design load from the anchors into the structural member.

**Anchor spacing** is centerline-to-centerline distance between loaded anchors.

**Attachment** Structural assembly, external to the surface of the concrete, that transfers loads to or receives loads from the anchor channel.

**Attachment** is the structural assembly, external to the surface of the concrete, that transmits loads to or receives loads from the anchor.

**Base Material** Material, such as concrete, in which the anchor channel is installed.

**Cast-in-place anchor** is traditionally a headed bolt, headed stud or hooked bolt installed before placing concrete. Additionally, cast-in-place internally threaded inserts are a form of cast-in-place anchors.

**Channel Bolt** Threaded fastener that connects the element to be attached to the anchor channel.

**Characteristic capacity** is a statistical term indicating 90 percent confidence that there is 95 percent probability of the actual strength exceeding the nominal strength. This is also called the 5% fractile capacity.

**Characteristic spacing** Spacing for ensuring the characteristic resistance of a single anchor.

**Clamping Force** Prestressing force resulting from tightening of the channel bolt against the fixture.

**Concrete breakout** is a concrete failure mode that develops a cone or edge failure of the test member due to setting of the anchor or applied loads.

**Concrete Edge Failure** failure of an anchor channel installed at the edge of a concrete member and loaded in shear towards the edge characterized by the formation of a fracture surface originating at the channel and projecting towards the edge of the concrete member

**Concrete splitting failure** is a concrete failure mode in which the concrete fractures along a plane passing through the axis of the anchor or anchors.

**Cracked concrete** is condition of concrete in which the anchor is located. See Section 2.1.2.

**Critical edge distance** is minimum required edge distance to achieve full capacity.

**Critical spacing** is minimum required spacing between loaded anchors to achieve full capacity.

**Cure time** is the elapsed time after mixing of the adhesive material components to achieve a state of hardening of the adhesive material in the drilled hole corresponding to the design mechanical properties and resistances. After the full cure time has elapsed, loads can be applied.

**Displacement** Movement of an anchor channel, measured relative to the concrete member in which the load is transmitted. In tension tests, displacement is measured parallel to the anchor axis; in shear tests, displacement is measured perpendicular to the anchor axis.

**Displacement controlled expansion anchor** is a post-installed anchor that is set by expansion against the side of the drilled hole through movement of an internal plug in the sleeve or through movement of the sleeve over an expansion element (plug). Once set, no further expansion can occur.

**Ductile steel element** are anchors designed to be governed by ductile yielding of the steel. This is determined by performing tension testing on coupons machined from the finished anchors. The minimum requirements are 14% elongation and 30% reduction of area.

**Edge distance** is distance from centerline of anchor to the free edge of base material in which the anchor is installed.

**Effective embedment depth** is the overall depth through which the anchor transfers force to or from the surrounding concrete. The effective embedment depth will normally be the depth of the concrete failure surface in tension applications. For cast-in headed anchor bolts and headed studs, the effective embedment depth is measured from the bearing contact surface of the head. For expansion anchors, it is taken as the distance from surface of base material to tip of expansion element(s).

**Expansion anchor** is a post-installed anchor that is inserted into a drilled hole in hardened concrete or masonry. Loads are transferred to and from the base material by bearing, friction or both.

**Fastening** Assembly of fixture and anchor channel used to transmit loads to concrete.

**Fixture** Steel part attached to the anchor channel by channel bolt.

**Gel time** is the elapsed time after mixing of the adhesive material components to onset of significant chemical reaction as characterized by an increase in viscosity. After the gel time has elapsed, the anchors must not be disturbed.

**Minimum Edge Distance** Minimum distance from the concrete edge to the center of the anchor channel and the anchors fixed to the channel profile, to allow adequate placement and compaction of concrete and to avoid damage to the concrete during torqueing of the channel bolt, to be reported in the ICC-ES evaluation Service Report.

**Minimum edge distance** is the spacing from the centerline of the anchor to the edge of the base material required to minimize the likelihood of splitting of the base material during anchor installation.

**Minimum member thickness** is minimum required thickness of member where the anchor channels can be installed, to be reported in the ICC-ES Report.

**Minimum Spacing** Minimum distance between anchors of anchor channels, measured in the direction of the longitudinal channel axis to allow adequate placing and compaction of the concrete, measured centerline to centerline, to be reported in the ICC-ES Evaluation Service Report.

**Minimum spacing** is distance between the centerlines of adjacent loaded anchors to minimize the likelihood of splitting of the base material during anchor installation.

**Post-installed anchor** is an anchor installed in hardened concrete and masonry. Expansion, undercut, and adhesive anchors are examples of post-installed anchors.

**Projected area** is the area on the free surface of the concrete member that is used to represent the larger base of the assumed rectilinear failure surface.

**Pryout failure** is a failure mode where anchors having limited embedment depth and loaded in shear exhibit sufficient rotation to produce a pryout fracture whereby the primary fracture surface develops behind the point of load application. This failure mode does not depend on the presence of free edges.

**Pullout failure** is a failure mode in which the anchor pulls out of the concrete without development of the full steel or concrete capacity.

**Pull-through failure** is a failure mode in which the anchor body pulls through the expansion mechanism without development of the full steel or concrete capacity.

**Side face blowout strength** is the strength of anchors with deeper embedment but thinner side cover corresponding to concrete spalling on the side face around the embedded head while no major breakout occurs at the top concrete surface.

**Splitting Failure** A failure in which the concrete fractures along a plane passing through the axis of the tensioned anchor or anchors.

**Statistically Equivalent** Two groups of test results shall be considered as statistically equivalent if there are no significant differences between the means and between the standard deviations of the two groups. Such statistical equivalence shall be demonstrated using a one-sided Student's t-Test at a confidence level of 90 percent.

**Steel failure** is a failure mode in which the steel anchor parts fracture.

**Supplementary reinforcement** is reinforcement that acts to restrain the potential concrete breakout area but is not designed to transfer the full design load from the anchors into the structural member.

**Torque controlled expansion anchor** is a post-installed expansion anchor that is set by the expansion of one or more sleeves or other elements against the sides of the drilled hole through the application of torque, which pulls the cone(s) into the expansion sleeve(s). After setting, tensile loading can cause additional expansion (follow-up expansion).

**Undercut anchor** is a post-installed anchor that derives tensile holding strength by the mechanical interlock provided by undercutting the concrete, achieved either by a special tool or by the anchor itself during installation.

## 7.2.2 REQUIREMENTS OF ANCHOR CHANNEL WITHIN AC232.

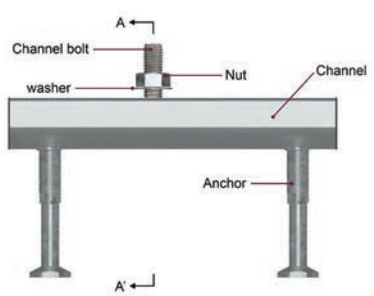
### What is an anchor channel system

Anchor channels consist of a channel produced from hot-rolled or cold-formed steel and at least two metal anchors on the channel web as illustrated in Figure 7.2.2.1.

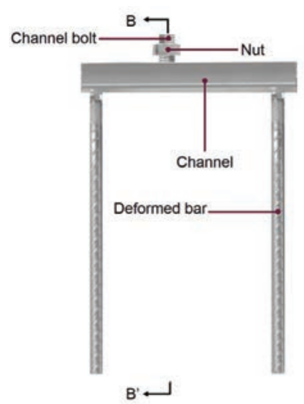
**An anchor channel system consists of**

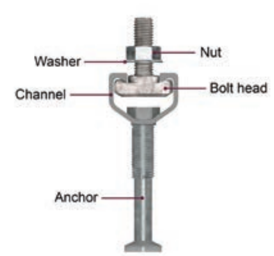
- The fixture being attached
- T-bolts attaching the fixture to the channel
- Steel channel cast into a concrete element
- Anchor elements attached to the channel and embedded into the concrete

The anchor channels shall be placed flush with the concrete surface as illustrated in Figure 7.2.2.2. A fixture shall be connected to the anchor channel by channel bolts (also known as T-bolts) with nut and washer in accordance with Figure7.2.2.1 and Figure 7.2.2.2.

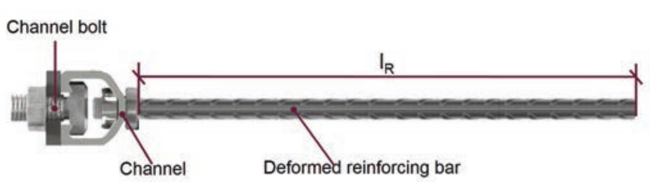



Elevation view of an anchor channel system.



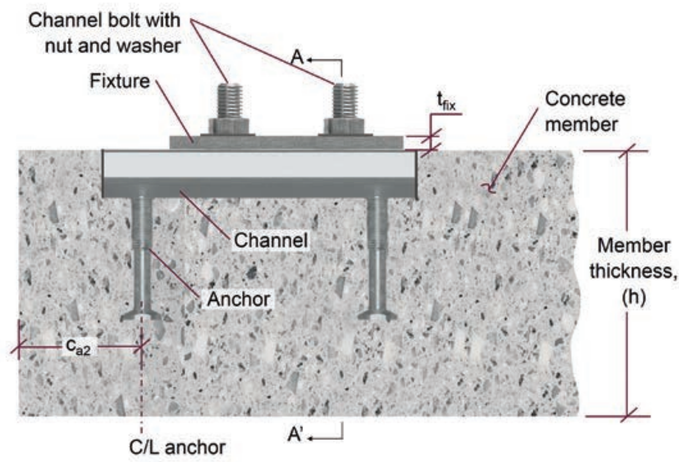




Cross-sectional view of an anchor channel system, A-A'.

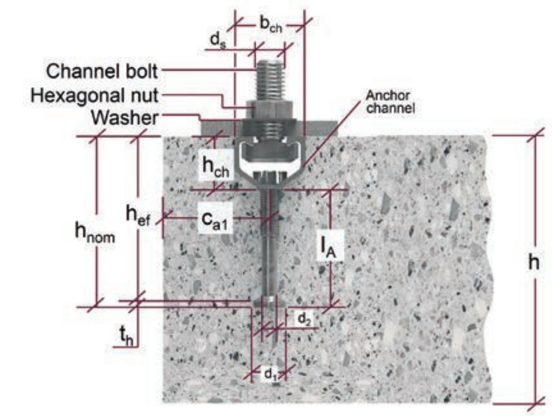



Cross-sectional view of an anchor channel system, B-B'.

**Figure 7.2.2.1 — Anchor channel with corresponding channel bolt.**




Elevation view of an anchor channel system.




Cross-sectional view of an anchor channel system, A-A'.

**Figure 7.2.2.2 — Anchor channel system in a concrete member; elevation and section view.**

### What is an anchor channel?

Steel profile with rigidly connected anchors installed prior to concrete placement. The anchors shall be produced from carbon or stainless steel. The anchors may be welded, forged or bolted to the channel. All anchors attached to the anchor channel shall be of the same type, size and embedment.


**Figure 7.2.2.3 — Anchor channel.**



### What is the minimum channel bolt (t-bolt) spacing, $S_{ch,b}$?

3 x $d_s$ Where $d_s$ is the diameter of channel bolt refer figure 7.2.2.2

### What are the anchor channel requirements according to AC232?

Channel height, $h_{ch}$: 0.60 in. (15 mm) ≤ $h_{ch}$ ≤ 2 in. (51 mm)
Channel width, $b_{ch}$: 1 in. (25.4 mm) ≤ $b_{ch}$ ≤ 3 in (76 mm).

Minimum channel length: 4 in. (102 mm).
Maximum channel length: unlimited.

The maximum effective embedment according to AC 318-14 section 17.4.2.2, $h_{ef}$ = 25 in.
Geometry requirements: $h_{ch}/h_{ef} \leq 0.5$
$b_{ch}/h_{ef} \leq 0.70$

**Figure 7.2.2.4 — Anchor channel system (HAC and HBC-C).**

Minimum number of anchors: 2
Maximum number of anchors: unlimited
Minimum round headed anchor spacing: 2.00 in. (50 mm)
Minimum deformed reinforcing bars anchor spacing: 4.00 in. (100 mm)
Maximum anchor spacing s: shall not be larger than 5 times minimum edge distance cmin and 16 in (400 mm)
Spacing between the anchors or deformed reinforcing bars should be constant.
Minimum allowable slab thickness shall be $h_{min} = h_{ef} + t_h + c_{nom}$
$t_h$ = anchor head thickness
$c_{nom}$ = required concrete cover

The anchors may be welded, forged or bolted to the channel. All anchors attached to the anchor channel shall be of the same type, size and embedment.

The axial spacing between round headed anchors, s, shall be at least 2 in. (51 mm). The axial spacing between deformed bars s, shall be at least 4 in. (100 mm).The maximum spacing, s, shall not be larger than the smaller of 5 times the minimum edge distance $c_{min}$ and 16 in. (400 mm). If more than two anchors are connected to the channel back, their spacing shall be constant.

### What are the requirements for round anchors and deforming rebars under AC232?

Round headed anchors shall comply with the following dimensions: length $l_A$ ≥ 19/16 in. (30 mm), shaft diameter $d_2$ ≥ 1/5 in. (5 mm), and head diameter $d_1$ ≥ 1/2 in. (12 mm). The head is forged to the anchor or may consist of a nut.

The anchors shall be placed into prefabricated holes in the back of the channel and connected rigidly with the channel back.

Deformed reinforcing bars as defined in section 2.3 of ACI 318-14 may be attached to the channel in lieu of anchors as described above.Deformed reinforcement is defined as that meeting the reinforcement specifications in the model Code. No other reinforcement qualifies. This definition permits accurate statement of developent lengths. Where deformed reinforcing bars are welded, they shall be of a weldable grade.

Deformed bars should conform with ACI 20.2.1.3, 20.2.1.5 or 20.2.1.7. 20.2.1.3:
Deformed bars shall conform a, b, c, d or e.
a) ASTM A615 — carbon steel
b) ASTM A706 — low-alloy steel
(c) ASTM A996 — axle steel and rail steel; bars from rail steel shall be Type R
(d) ASTM A955 — stainless steel
(e) ASTM A1035 — low-carbon chromium steel

The axial distance between the end of the channel and the nearest anchor, x, shall be ≥ 1 in. (25.4 mm).

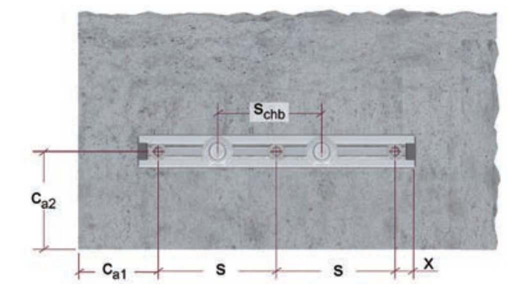



**Figure 7.2.2.5 — Plan view of an anchor channel system in a concrete member.**

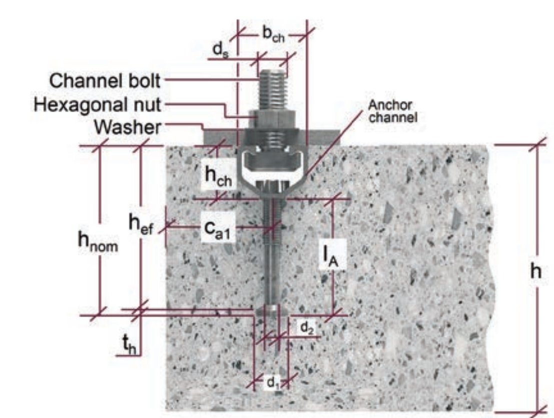



**Figure 7.2.2.6 — Section view of an anchor channel system in a concrete member.**

The elongation and reduction of area of each anchor channel component (i.e. channel profile, anchor, channel bolt) shall be determined in accordance with a recognized test standard (e.g. ASTM F606). If elongation is at least 14 percent and the reduction of area is at least 30 percent, the anchor channel component shall be considered to be a ductile steel element. If the elongation or reduction of area cannot be determined, the anchor channel shall be considered to be a brittle steel element.

## 7.2.3 ANCHOR CHANNEL WORKING PRINCIPLES

### Loading of Anchor Channels

The anchor channel may be used to transmit tensile loads, shear loads perpendicular to the longitudinal channel axis, shear loads acting in the direction of the longitudinal channel axis (optional), or any combination of these loads applied at any location between the outermost anchors of the anchor channel in accordance with Figure 7.2.3.1 as shown. Transfer of tension loads takes place via interlock between the channel bolt and the channel lips, bending of the channel, tension in the anchors, and mechanical interlock with the concrete. Shear loads perpendicular to the longitudinal channel axis are transferred by the anchors and by compression stresses between the side of the channel and the concrete. However, for reasons of simplicity, it is assumed that the shear loads are transferred by the anchors only [see D.3.1.1.3 (ACI 318-05, ACI 318-08), D.3.1.2.3 (ACI 318-11), Section 17.2.1.2.3 (ACI 318-14)]. Shear loads acting in the direction of the longitudinal channel axis are assumed to be transferred from the channel bolt via the channel and the anchors into the concrete without consideration of friction and/or adhesion [see D.3.1.1.5 (ACI 318-05, ACI 318- 08), D.3.1.2.5 (ACI 318-11), Section 17.2.1.1.5 (ACI 318-14)].

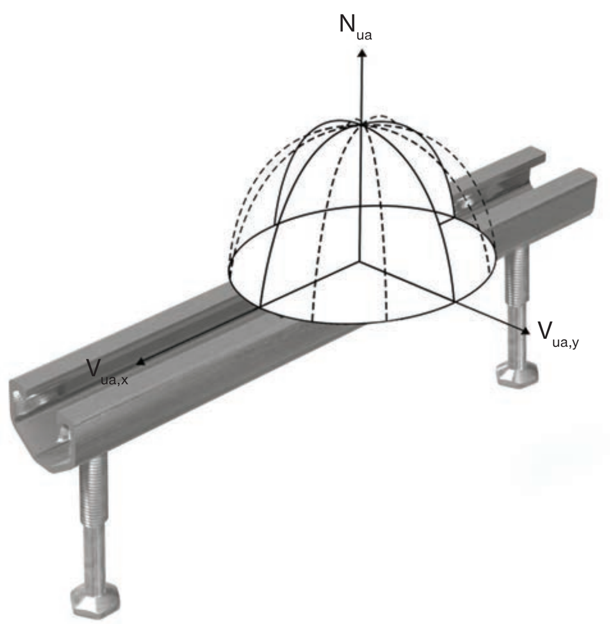



**Figure 7.2.3.1 — Anchor channel loaded in three directions.**

Where compliance is sought for static shear loading along the longitudinal axis of the anchor channel, the longitudinal loads shall be transferred by a positive load transfer mechanism [e.g. mechanical interlock between the channel bolt and the channel profile by notches in the smooth channel lips created by notching channel bolts (example see Fig. 7.2.3.2a) or by matching serrations between the channel lips and channel bolt (example see Fig. 7.2.3.2b)].

Transfer of shear load in the direction of the longitudinal channel axis from the channel bolt via channel and anchors into the concrete shall use a positive load transfer mechanism that shall be capable of ensuring safe and effective behavior under normal and adverse conditions, both during installation and in service. Factors included are installation conditions in concrete and torqueing of the channel bolt.

Where compliance is sought for seismic loading in Seismic Design Categories C, D, E and F compliance for shear loads in the direction of the longitudinal channel axis is required.


a) HAC with HBC-C


b) HAC with HBC-C-N

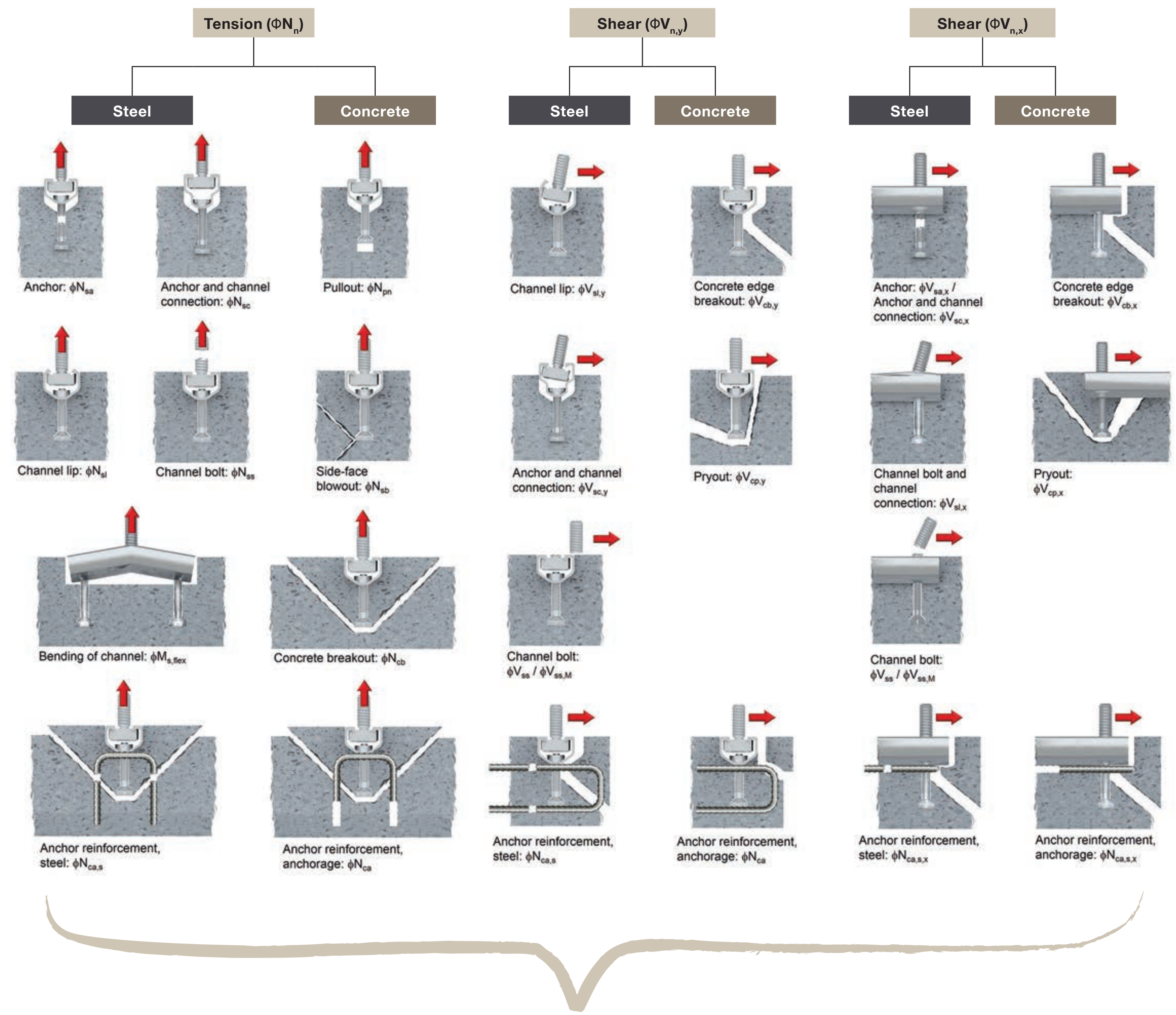

c) HAC-T with HBC-T

## 7.2.4 ANCHOR CHANNEL BEHAVIOR UNDER LOAD

When loaded to failure, anchor channels may exhibit one or more identifiable failure modes.

These include:

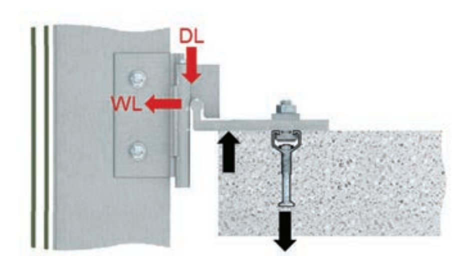
### Possible failure modes of anchor channel per AC232




Superposition of tension and shear loads
(up to 5 interaction equations)

**IMPORTANT! Failure analysis modes evaluated follow ACI 318-14, chapter 17. This DOES NOT include evaluating the base material (e.g. edge-of-slab) capacity to resist compressive forces generated by the fixture. The engineer must ALWAYS verify the base material (e.g. edge-of-slab) design is capable of resisting the applied loading.**

For additional information, please contact Hilti at US+CA.HAC@Hilti.com



## 7.2.5 ACI 318 CHAPTER 17 STRENGTH DESIGN — SD (LRFD)

The design strength of anchor channels under the 2015 IBC as well as Section R301.1.3 of the 2015 IRC must be determined in accordance with ACI 318-14 Chapter 17 and ESR-3520.

The design strength of anchor channels under the 2012 IBC as well as Section R301.1.3 of the 2012 IRC must be determined in accordance with ACI 318-11 Appendix D and ESR-3520.

The design strength of anchor channels under the 2009 IBC as well as Section R301.1.3 of the 2009 IRC must be determined in accordance with ACI 318-08 Appendix D and ESR-3520.

The design strength of anchor channels under the 2006 IBC as well as Section R301.1.3 of 2006 IRC must be determined in accordance with ACI 318-05 Appendix D and ESR-3520.

## 7.2.6 STRENGTH DESIGN TERMINOLOGY

Equations are provided in units of inches and pounds. For convenience, SI (metric) units are provided in parentheses where appropriate. Unless otherwise noted, values in SI units shall be not used in equations without conversion to units of inches and pounds.

| | |
|---|---|
| $b_{ch}$ | width of channel, as shown in Figure 7.2.2.2, inch (mm) |
| $c_a$ | edge distance of anchor channel, measured from edge of concrete member to axis of the nearest anchor, in. (mm) |
| $c_{a1}$ | edge distance of anchor channel in direction 1, in. (mm) |
| $c'_{a1}$ | net distance between edge of the concrete member and the anchor channel: $c'_{a1} = c_{a1} - b_{ch}/2$ in. (mm) |
| $c_{a1,red}$ | reduced edge distance of the anchor channel |
| $c_{a2}$ | edge distance of anchor channel in direction 2, in. (mm) |
| $c_{a,max}$ | maximum edge distance of anchor channel, in. (mm) |
| $c_{a,min}$ | minimum edge distance of anchor channel, in. (mm) |
| $c_{ac}$ | edge distance required to develop full concrete capacity in absence of reinforcement to control splitting, in. (mm) |
| $c_{cr}$ | edge distance required to develop full concrete capacity in absence of anchor reinforcement, in. (mm) |
| $c_{cr,N}$ | critical edge distance for anchor channel for tension loading for concrete breakout, in. (mm) |
| $c_{cr,Nb}$ | critical edge distance for anchor channel for tension loading, concrete blow out, in. (mm) |
| $c_{cr,V}$ | critical edge distance for anchor channel for shear loading, concrete edge breakout, in. (mm) |
| $d_1$ | width of head of I-anchors or diameter of head of round anchor, in. (mm) as shown in Figure 7.2.2.2 |
| $d_2$ | shaft diameter of round anchor, in. (mm) as shown in Figure 7.2.2.2 |
| $d_a$ | diameter of anchor reinforcement, in. (mm) as shown in Figure 7.2.2.2 |
| $d_s$ | diameter of channel bolt, in. (mm) |
| $e_1$ | distance between shear load and concrete surface, in. (mm) |
| $e_s$ | distance between the axis of the shear load and the axis of the anchor reinforcement resisting the shear load, in. (mm) |
| f | distance between anchor head and surface of the concrete, in. (mm) |
| $f'_c$ | specified concrete compressive strength, psi (MPa) |
| h | thickness of concrete member or test member, as shown in Figure 7.2.2.2, in. [mm] |
| $h_{ch}$ | height of channel, as shown in Figure 7.2.2.2, in. (mm) |
| $h_{cr,V}$ | critical member thickness, in. (mm) |
| $h_{ef}$ | effective embedment depth, as shown in Figure 7.2.2.2, in. (mm) |
| $h_{ef,red}$ | reduced effective embedment depth, in. (mm) (17.4.2.10.2c, ACI 318-14) |
| k | load distribution factor (17.2.1.2.1a, ACI 318-14) |
| $k_{cp}$ | pryout factor |
| $\ell_A$ | length of I-anchor or headed anchor, plus channel height, in. (mm) |
| $\ell$ | lever arm of the shear force acting on the channel bolt, in. (mm) |
| $\ell_{dh}$ | development length in tension of deformed bar or deformed wire with a standard hook, measured from critical section to outside end of hook, in. (mm) |
| $\ell_{in}$ | influence length of an external load Nua along an anchor channel, in. [mm] |
| s | spacing of anchors in direction of longitudinal axis of channel, in. (mm) |
| $s_{chb}$ | clear distance between channel bolts in direction of longitudinal axis of channel, in. (mm) |
| $s_{cr}$ | anchor spacing required to develop full concrete capacity in absence of anchor reinforcement, in. (mm) |
| $s_{cr,N}$ | critical anchor spacing for tension loading, concrete breakout, in. (mm) |
| $s_{max}$ | maximum spacing between anchor elements in anchor channels, in. (mm) |
| $s_{min}$ | minimum spacing between anchor elements in anchor channels, in. (mm) |
| $s_{cr,Nb}$ | critical anchor spacing for tension loading, concrete blow-out, in. (mm) |
| $s_{cr,V}$ | critical anchor spacing for shear loading, concrete edge breakout, in. (mm) |
| $t_h$ | thickness of head portion of headed anchor, in. (mm) |
| $w_A$ | width of I-shaped anchor, in. (mm) |
| x | distance between end of channel and nearest anchor, in. (mm) |
| z | internal lever arm of the concrete member, in. (mm) |
| $A_{brg}$ | bearing area of anchor head, in.² (mm²) |
| $A_i$ | ordinate at the position of the anchor I, in. (mm) |
| $A_{se,N}$ | effective cross-sectional area of anchor or channel bolt in tension, in.², (mm²) |
| $A_{se,V}$ | effective cross-sectional area of channel bolt in shear, in.², (mm²) |
| $I_y$ | moment of inertia of the channel about principal y-axis, in.⁴ (mm⁴) |
| $M_1$ | bending moment on fixture around axis in direction 1, lbf-in (Nm) |
| $M_2$ | bending moment on fixture around axis in direction 2, lbf-in (Nm) |
| $M_{s,flex}$ | nominal flexural strength of the anchor channel, lbf-in (Nm) |
| $M_{ss}$ | nominal flexural strength of the channel bolt, lbf-in (Nm) |
| $M_{u,flex}$ | bending moment on the channel due to tension loads, lbf-in (Nm) |
| $N_b$ | basic concrete breakout strength of a single anchor in tension, lbf (N) |
| $N_{ca}$ | nominal strength of anchor reinforcement to take up tension loads, lbf (N) |
| $N_{cb}$ | concrete breakout strength of a single anchor of anchor channel in tension, lbf (N) |
| $N_n$ | lowest nominal tension strength from all appropriate failure modes under tension, lbf (N) |
| $N_p$ | pullout strength of a single anchor of an anchor channel in tension, lbf (N) |
| $N_{pn}$ | nominal pullout strength of a single anchor of an anchor channel in tension, lbf (N) |
| $N_{nc}$ | nominal tension strength of one anchor from all concrete failure modes (lowest value of $N_{cb}$ (anchor channels without anchor reinforcement to take up tension loads) or $N_{ca}$ (anchor channels with anchor reinforcement to take up tension loads), $N_{pn}$, and $N_{sb}$) |
| $N_{ns}$ | nominal steel strength of anchor channel loaded in tension (lowest value of $N_{sa}$, $N_{sc}$ and $N_{sl}$), lbf (N) |
| $N_{ns,a}$ | nominal tension strength for steel failure of anchor or connection between anchor and channel (lowest value of $N_{sa}$ and $N_{sc}$) |
| $N_{sa}$ | nominal tensile steel strength of a single anchor, lbf (N) |
| $N_{sb}$ | nominal concrete side-face blowout strength, lbf (N) |
| $N^0_{sb}$ | basic nominal concrete side-face blowout strength, lbf (N) |
| $N_{sc}$ | nominal tensile steel strength of the connection channel/anchor, lbf (N) |
| $N_{sl}$ | nominal tensile steel strength of the local bending of the channel lips, lbf (N) |
| $N_{ss}$ | nominal tensile strength of a channel bolt, lbf (N) |
| $N^a_{ua}$ | factored tension load on a single anchor of the anchor channel, lbf (N) |
| $N^a_{ua,i}$ | factored tension load on anchor i of the anchor channel, lbf (N) |
| $N^s_{ua}$ | factored tension load on a channel bolt, lbf (N) |
| $N_{ua,re}$ | factored tension load acting on the anchor reinforcement, lbf (N) |
| $T_{allowable,ASD}$ | allowable tension load for use in allowable stress design environments, lb (N) |
| $T_{inst}$ | Installation torque moment given in Hilti's installation instruction, lbf-in. (N-m) |
| $V_{allowable,ASD}$ | allowable shear load for use in allowable stress design environments, lb (N) |
| $V_b$ | basic concrete breakout strength in shear of a single anchor, lbf (N) |
| $V_{ca,y}$ | nominal strength of the anchor reinforcement of one anchor to take up shear loads perpendicular to the channel axis, lbf (N) |
| $V_{ca,x}$ | nominal strength of the anchor reinforcement of one anchor to take up shear loads in longitudinal channel axis, lbf (N) |
| $V_{ca,max}$ | maximum value of $V_{ca}$ of one anchor to be used in design, lbf (N) |
| $V_{cb,y}$ | nominal concrete breakout strength in shear perpendicular to the channel axis of an anchor channel, lbf (N) |
| $V_{cb,x}$ | nominal concrete breakout strength in shear in longitudinal channel axis of an anchor channel, lbf (N) |
| $V_{cp,y}$ | nominal pry-out strength perpendicular to the channel axis of a single anchor, lbf (N) |
| $V_{cp,x}$ | nominal pry-out strength in longitudinal channel axis of a single anchor, lbf (N) |
| $V_{n,y}$ | lowest nominal steel strength from all appropriate failure modes under shear perpendicular to the channel axis, lbf (N) |
| $V_{n,x}$ | lowest nominal steel strength from all appropriate failure modes under shear loading in longitudinal channel axis, lbf (N) |
| $V_{nc}$ | nominal shear strength of one anchor from all concrete failure modes (lowest value of $V_{cb}$) anchor channels with anchor reinforcement to take up |

shear loads) or $V_{ca}$ (anchor channels with anchor reinforcement to take up shear loads) and $V_{cp}$)

$V_{ns}$ Nominal steel strength of anchor channel loaded in shear (lowest value of $V_{sa}$, $V_{sc}$, and $V_{sl}$), lbf (N)

$V_{ns,a}$ nominal shear strength for steel failure of anchor or connection between anchor and channel (lowest value of $V_{sa}$ and $V_{sc}$), lbf (N)

$V_{sa,y}$ nominal shear steel strength perpendicular to the channel axis of a single anchor, lbf (N)

$V_{sa,x}$ nominal shear steel strength in longitudinal channel axis of a single anchor, lbf (N)

$V_{sa,y,seis}$ nominal seismic shear steel strength perpendicular to the channel axis of a single anchor, lbf (N)

$V_{sa,x,seis}$ nominal seismic shear steel strength in longitudinal channel axis of a single anchor, lbf (N)

$V_{sc,y}$ nominal shear strength of connection between one anchor bolt and the anchor channel, lbf (N)

$V_{sc,x}$ nominal shear strength in longitudinal channel axis of connection between one anchor bolt and the anchor channel, lbf (N)

$V_{sc,y,seis}$ nominal seismic shear strength perpendicular to the channel axis of connection between one anchor bolt and the anchor channel, lbf (N)

$V_{sc,x,seis}$ nominal seismic shear strength in longitudinal channel axis of connection between one anchor bolt and the anchor channel, lbf (N)

$V_{sl,y}$ nominal shear steel strength perpendicular to the channel axis of the local bending of the channel lips, lbf (N)

$V_{sl,x}$ nominal shear steel strength in longitudinal channel axis of connection between channel bolt and channel lips, lbf (N)

$V_{sl,y,seis}$ nominal seismic shear steel strength perpendicular to the channel axis of the local bending of the channel lips, lbf (N)

$V_{sl,x,seis}$ nominal seismic shear steel strength in longitudinal channel axis of connection between channel bolt and channel lips, lbf (N)

$V_{ss}$ nominal strength of channel bolt in shear, lbf (N)

$V_{ua}$ factored shear load on anchor channel, lbf (N)

$V^a_{ua}$ factored shear load on a single anchor of the anchor channel, lbf (N)

$V^a_{ua,i}$ factored shear load on anchor i of the anchor channel, lbf (N)

$V^s_{ua}$ factored shear load on a channel bolt, lbf (N)

$\alpha$ exponent of interaction equation

$\alpha_{ASD}$ conversion factor for allowable stress design

$\alpha_{ch,N}$ factor to account for the influence of channel size on concrete breakout strength in tension [-]

$\alpha_M$ factor to account for the influence of restraint of fixture on the flexural strength of the channel bolt [-]

$\lambda$ Modification factor for sand-lightweight concrete in accordance with Section 8.6.1 of ACI 318-08 and 318-11 or Section 19.2.4 of ACI 318-14

$\alpha_{ch,V}$ factor to account for the influence of channel size and anchor diameter on concrete edge breakout strength in shear $(lbf^{0.5}/in)^{0.33}$ $(N^{0.5}/mm^{0.33})$

$\alpha_{v,seis,y}$ adjustment factor for seismic loading (y-direction, perpendicular to the channel axis)

$\alpha_{v,seis,x}$ adjustment factor for seismic loading (x-direction, in longitudinal channel axis)

$\psi_{c,N}$ modification factor to account for influence of cracked or uncracked concrete on concrete breakout strength [-]

$\psi_{c,Nb}$ modification factor to account for influence of cracked or uncracked concrete on concrete blowout strength [-]

$\psi_{c,V}$ modification factor to account for influence of cracked or uncracked concrete for concrete edge breakout strength [-]

$\psi_{co,N}$ modification factor for corner effects on concrete breakout strength for anchors loaded in tension [-]

$\psi_{co,Nb}$ modification factor for corner effects on concrete blowout strength for anchors loaded in tension [-]

$\psi_{co,V}$ modification factor for corner effects on concrete edge breakout strength for anchor channels loaded in shear [-]

$\psi_{cp,N}$ modification factor for anchor channels to control splitting

$\psi_{ed,N}$ modification factor for edge effect on concrete breakout strength for anchors loaded in tension [-]

$\psi_{g,Nb}$ modification factor to account for influence of bearing area of neighboring anchors on concrete blowout strength for anchors loaded in tension [-]

$\psi_{h,Nb}$ modification factor to account for influence of member thickness on concrete blowout strength for anchors loaded in tension [-]

$\psi_{h,V}$ modification factor to account for influence of member thickness on concrete edge breakout strength for anchors channels loaded in shear [-]

$\psi_{s,N}$ modification factor to account for influence of location and loading of neighboring anchors on concrete breakout strength for anchor channels loaded in tension [-]

$\psi_{s,Nb}$ modification factor to account for influence of location and loading of neighboring anchors on concrete blowout strength for anchor channels loaded in tension [-]

$\psi_{s,V}$ modification factor to account for influence of location and loading of neighboring anchors on concrete edge breakout strength for anchor channels loaded in shear [-]



## 7.2.7 LOAD DISTRIBUTION

### Determination of t-bolt forces acting on anchor channels

The forces on a t-bolt can generally be determined using general principles of structural mechanics. In doing so, the displacement of the t-bolt is usually assumed to be small (i.e negligible). The distribution of forces acting on a fixture of a t-bolt group to the individual t-bolt of the group can be calculated with elastic theory.

**Tension Loads:**

Calculation of t-bolt loads induced by tension loads and bending moments acting on the fixture per elastic theory involves the following assumptions (Fig. 7.2.7.1)

a) The fixture remains plane (flat) under the influence of internal forces. In order to warrant this supposition, the fixture must be sufficiently stiff and must be in contact with the base material. A stiff fixture may be assumed if under the design actions, the stresses in the fixture are smaller than the design resistance of the fixture material. The stiff fixture assumption corresponds to the Bernoulli hypothesis in reinforced concrete design, wherein plane cross-sections are assumed to remain plane.

b) In the part of the fixture subjected to compression, t-bolts do not act in either tension or compression.

c) The stiffness of all t-bolt in a group are identical. The t-bolt stiffness is directly proportional to the area of the stressed cross-section and the modulus of elasticity of the steel. The stiffness of the concrete is characterized by its elastic modulus and the stressed area.

Consequently, the calculation of the tension forces in the t-bolts corresponds to how one determines the tension resultant in the reinforcing bars of a reinforced concrete member. However, in contrast to strength design of reinforced concrete members, we assume here that the response of the concrete and steel elements remains linear elastic.

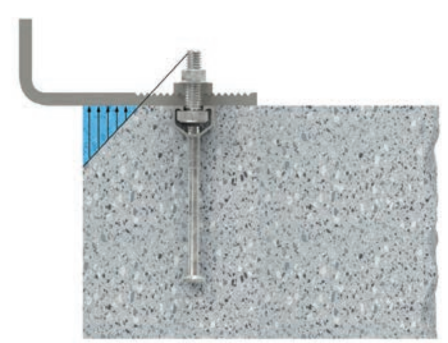


**Figure 7.2.7.1 — Distribution of forces predicted by elastic theory in an t-bolt group subjected to tension force and bending moment.**

**Shear Loads:**

In calculating the distribution of shear loads through a fixture to the t-bolts of a group positioned away from an edge, it is assumed that all t-bolts exhibit the same shear stiffness. Additionally, it is generally assumed that all t-bolts participate in accommodating the shear loads (Fig. 7.2.7.2). It is assumed that the shear load acts at the center of gravity of the group of t-bolts. When the shear load acts eccentrically, the forces in the anchors should be calculated taking into account equilibrium conditions based on steel design principles.

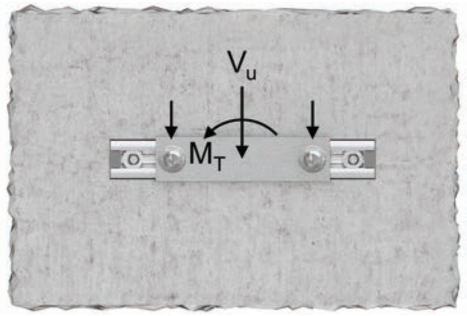



**Figure 7.2.7.2 — Distribution of shear forces in an anchor group Example of connections in which all t-bolts participate in resisting the shear load.**

In most cases, elastic analysis yields satisfactory results and is recommended. It should be noted, however, that the assumption of anchor load linearly proportional to *the magnitude of the applied load and the distance from the neutral axis of the group is valid only if the attachment (e.g. baseplate) is sufficiently stiff in comparison to the axial stiffness of the t-bolts. Note: Assuming a rigid base plate condition, Hilti's PROFIS Anchor channel analysis and design software performs a simplified finite element analysis to establish anchor load distribution on an elastic basis.

## 7.2.8 CALCULATION OF LOADS ON ANCHORS OF THE ANCHOR CHANNEL

Anchor channels is designed for critical effects of factored loads as determined by elastic analysis taking into account the elastic support by anchors and the partial restraint of the channel ends by concrete compression stresses. An alternative, the triangular load distribution method in accordance with 17.2.1.2.1 through 17.2.1.2.3 (ACI 318-14) to calculate the tension and shear loads on anchors is permitted.

**Tension Loads:**

The stiffness of an anchor channel is less than that of a stiff fixture. The distribution of tension loads acting on the channel to the anchors is calculated using a beam on elastic supports with partial restraint of the channel ends. The stiffness of the elastic supports corresponds to the displacement of the anchors which includes the displacements of the channel lips, anchors and concrete. The distribution of anchor forces can be approximated by a triangle load distribution with a peak at the applied load and an influence length $l_i$ .

The influence length depends mainly on the anchor spacing, the moment of inertia of the channel and on the head size. Further minor influencing factors are the concrete compression strength, the type of steel (galvanized or stainless steel) and the state of concrete (cracked or non-cracked). For sufficiently large head sizes (head pressure $p_u < 6.f'_c$) the influence length can be taken as:

$\ell_{in}$ = $4.93(I_y)^{0.05} \cdot \sqrt{s} \geq s$ , in

$\ell_{in}$ = $13(I_y)^{0.05} \cdot \sqrt{s} \geq s$ , mm — ESR-3520 Equation (3)

s = anchor spacing, in. (mm)

$N_{ua}$ = factored tension load on channel bolt, lb (N)

$I_y$ = the moment of inertia of the channel shall be taken from Table 2.2.1.1

For an arbitrary position of the load N the forces on the anchors can be calculated in accordance with equation:

$N_{aua,i} = k \cdot A'_i \cdot N_{ua}$ — ESR-3520 Equation (1)

where:

$A'_{iaua,i}$ = ordinate at the position of the anchor i assuming a triangle with the unit height at the position of load $N_{ua}$ and the base length $2\ell_{in}$ with $\ell_{in}$ determined in accordance with Eq. (1).

$$k = \frac{1}{\sum A'_i}$$ ESR-3520 Equation (2)

The tension loads, $N_{aua,i,}$ on an anchor due to a tension load, $N_{ua}$, acting on the channel shall be computed in accordance with Eq. (1). An example for the calculation of the tension loads acting on the anchors is given in Figure 7.2.8.1.

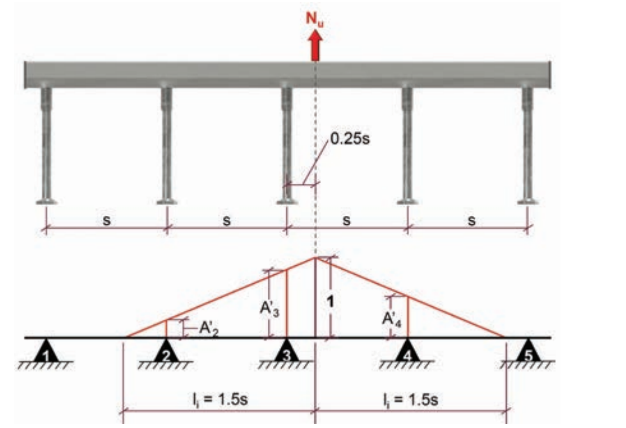



**Figure 7.2.8.1 — Example for the calculation of anchor forces in accordance with the triangular load distribution method for an anchor channel with five anchors. The influence length is assumed as $\ell_{in}$ = 1.5s.**

$$A'_2 = \left(\frac{l_{in} - s - 0.25s}{l_{in}}\right) = \left(\frac{0.25s}{l_{in}}\right) = \left(\frac{1}{6}\right)$$

$$A'_3 = \left(\frac{l_{in} - 0.25s}{l_{in}}\right) = \left(\frac{1.25s}{l_{in}}\right) = \left(\frac{5}{6}\right)$$

$$A'_4 = \left(\frac{l_{in} - s + 0.25s}{l_{in}}\right) = \left(\frac{0.75s}{l_{in}}\right) = \left(\frac{1}{2}\right)$$

$$k = \left(\frac{1}{A'_2 + A'_3 + A'_4}\right) = \left(\frac{2}{3}\right)$$

$$N^a_{ua,1} = N^a_{ua,5} = 0$$

$$N^a_{ua,2} = N_{ua} \cdot \frac{1}{6} \cdot \frac{2}{3} = \frac{1}{9} N_{ua}$$

$$N^a_{ua,3} = N_{ua} \cdot \frac{5}{6} \cdot \frac{2}{3} = \frac{5}{9} N_{ua}$$

$$N^a_{ua,4} = N_{ua} \cdot \frac{1}{2} \cdot \frac{2}{3} = \frac{1}{3} N_{ua}$$

If more than one t-bolt are transferring the tension loads on to the channel then the linear superposition of the anchor forces for all loads should be assumed as shown in the figure 7.2.8.2. If in the design the exact position of the load on the channel is unknown the most unfavorable loading position should be assumed for each failure mode (e.g. load acting over an anchor for the case of failure of an anchor by steel rupture or concrete break-out and load acting between anchor's in case of bending failure of the channel).

The bending moment, $M_{u,flex}$, on the channel due to tension loads acting on the channel shall be computed assuming a simply supported single span beam with a span length equal to the anchor spacing.

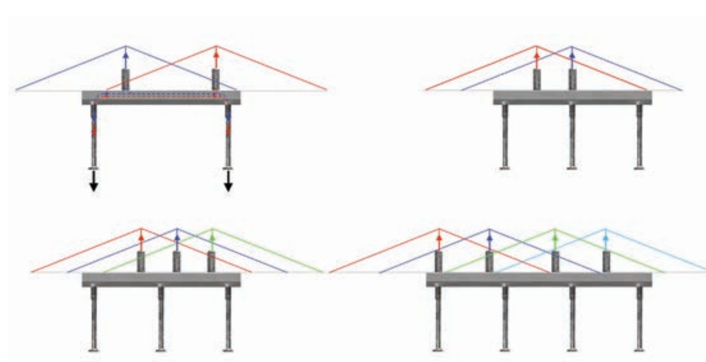


**Figure 7.2.8.2 — Triangular load distribution for different anchor channel system configurations.**

**Perpendicular Shear Loads:**

Shear loads acting on the channel are mainly transferred by compression stresses between channel profile and concrete and to a smaller extent by the anchors. However, the anchors are stressed by tension forces due to the eccentricity between the acting shear load and the resultant of the stresses in the concrete. A model to calculate the concrete edge capacity of channel anchors under shear loading towards the edge is described in section 7.4.2. It assumes that shear forces acting on the channel are transferred by bending of the channel to the anchors and by the anchors into the concrete. This approach simplifies the real behavior. It has been chosen to allow for a simple interaction between tension and shear forces acting on the channel. For reasons of simplicity it is proposed to calculate the (fictitious) shear forces on anchors using the same approach and the same influence length as for tension loads. The shear load, $V_{aua,y,i}$, on an anchor due to a shear load $V_{ua,y}$ acting on the channel perpendicular to its longitudinal axis shall be computed in accordance with the previous Section of tension replacing $N_{ua}$ in Eq. (3) by $V_{ua,y}$.

**Longitudinal Shear loads:**

- The shear loads acting in the direction of the longitudinal channel axis are transferred from the channel bolt to the channel and by the anchors into the concrete without considering friction and/or adhesion between channel and concrete.
- Longitudinal shear loads shall be transferred by a positive load transfer mechanism (e.g. mechanical interlock between the channel bolt and the channel). In the design model it is assumed that longitudinal shear loads are solely transferred by the anchors into the concrete. A positive load transfer mechanism from the channel bolt via the channel and anchors into the concrete is required.
- Load transfer in the longitudinal direction shall not rely on friction.

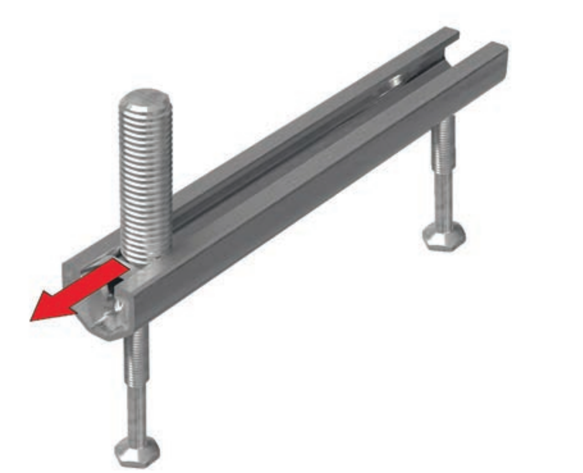
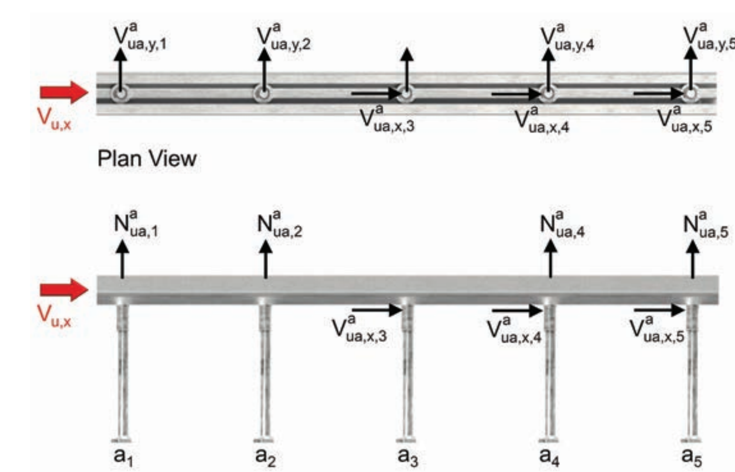


**Figure 7.2.8.3 - HAC loaded in the direction of the longitudinal channel axis.**

- The shear load, $V_{ua,x,i}$, on an anchor due to a shear load, $V_{ua,x}$, acting on the channel in direction of the longitudinal channel axis shall be computed as follows: For the verification of the strength of the anchor channel for failure of the anchor or failure of the connection between anchor and channel, pryout failure, and concrete edge failure in case of anchor channels arranged parallel to the edge without corner effects, the shear load, $V_{ua,x}$, shall be equally distributed to all anchors for anchor channels with not more than three anchors or to three anchors for anchor channels with more than three anchors (as illustrated in Figure 7.2.8.4). The shear load, $V_{ua,x}$, shall be distributed to those three anchors that result in the most unfavorable design condition [in the example given in Figure 7.2.8.4 the shear load, $V_{ua,x}$, shall be distributed to the anchors 3 to 5. For the verification of the strength of the anchor channel for concrete edge failure in case of anchor channels arranged perpendicular to the edge and in case of anchor channels arranged parallel to the edge with corner effects, the shear load, $V_{ua,x}$, shall be equally distributed to all anchors for anchor channels with not more than three anchors or to the three anchors closest to the edge or corner for anchor channels with more than three anchors (as illustrated in Figure 7.2.8.5).




$$V^a_{ua,x,3} = V^a_{ua,x,4} = V^a_{ua,x,5} = \frac{V_{u,x}}{3}$$

$$V^a_{ua,y,1} = V^a_{ua,y,2} < V^a_{ua,y,4} = V^a_{ua,y,5}$$

$$N^a_{ua,1} = N^a_{ua,2} < N^a_{ua,4} = N^a_{ua,5}$$

**Figure 7.2.8.4 — Example for the calculation of anchor forces in case of anchor channels with 5 anchors loaded in shear longitudinal to the channel axis for steel and pryout failure.**

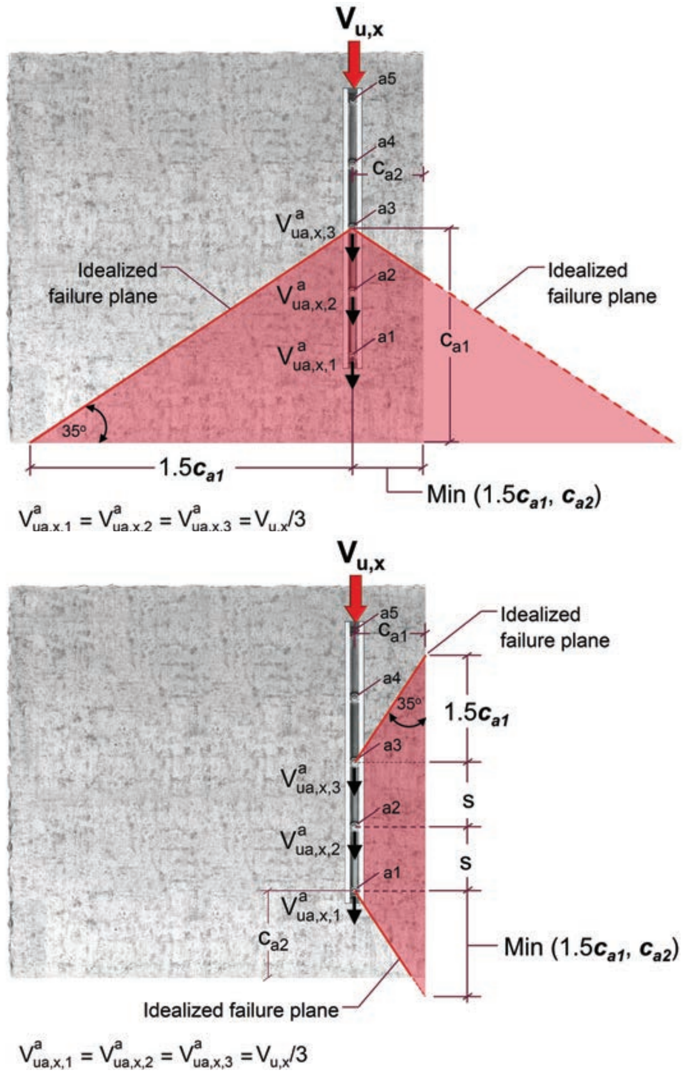



**Figure 7.2.8.5 — Example for the calculation of anchor channels with 6 anchors loaded in shear longitudinal to the channel axis for concrete edge failure.**

## 7.2.9 ANCHOR CHANNEL DESIGN

The design of anchors channel is based on an assessment of the loading conditions and anchorage capacity. Strength design (SD), limit state design (LSD), and allowable stress design (ASD) methods are currently in use in North America for the design of anchors.

**Strength Design:** The Strength Design Method for anchor design has been incorporated into several codes such as IBC and ACI 318. The method assigns specific strength reduction factors to each of several possible failure modes, provides predictions for the strength associated with each failure mode, and compares the controlling strength with factored loads. The Strength Design Method is a more accurate estimate of anchor resistance as compared to the ASD approach. The Strength Design Method, as incorporated in ACI 318-14 Chapter 17. Strength Design is state-of-the-art and Hilti recommends its use where applicable.

**Limit State Design:** The limit state design method for anchor design is described and included in the CSA A23.3 Annex D.

In principle, the method follows the strength design concept with the application of different strength reduction factors. The limit states design method generally results in a more accurate estimate of anchor resistance as compared to the ASD approach.

**Allowable loads:** Under the Allowable Stress Design Method, the allowable load, or resistance, is based on the application of a safety factor to the mean result of laboratory testing to failure, regardless of the controlling failure mode observed in the tests. The safety factor is intended to account for reasonably expected variations in loading. Adjustments for anchor spacing and edge distance are developed as individual factors based on testing of two- and four-anchor groups and single anchors near free edges. These factors are multiplied together for specific anchor layouts.

For anchors designed using load combinations in accordance with IBC Section 1605.3 (Allowable Stress Design) allowable loads shall be established using following equations.

$$T_{allowable,\,ASD} = \frac{\phi N_n}{\alpha_{ASD}}$$

$$V_{x,\,allowable,\,ASD} = \frac{\phi V_{n,\,x}}{\alpha_{ASD}}$$

$$V_{y,\,allowable,\,ASD} = \frac{\phi V_{n,\,y}}{\alpha_{ASD}}$$

$$M_{s,\,flex,\,allowable,\,ASD} = \frac{\phi M_{s,\,flex}}{\alpha_{ASD}}$$

where:

$T_{allowable,ASD}$ = Allowable tension load, lb (N)

$V_{x,allowable,ASD}$ = Allowable shear load in longitudinal channel axis, lb (N)

$V_{y,allowable,ASD}$ = Allowable shear load perpendicular to the channel axis, lb (N)

$M_{s,flex,allowable.ASD}$ = Allowable bending moment due to tension loads, lb-in (Nm)

$\phi N_n$ = Lowest design strength of an anchor, channel bolt, or anchor channel in tension for controlling failure mode, lb (N)

$\phi V_n$ = Lowest design strength of an anchor, channel bolt, or anchor channel in shear in longitudinal channel axis for controlling failure mode, lb (N).

$\phi V_{n,Y}$ = Lowest design strength of an anchor, channel bolt, or anchor channel in shear perpendicular to the channel axis for controlling failure mode lb (N).

$\alpha_{ASD}$ = Conversion factor calculated as a weighted average of the load factors for the controlling load combination. In addition, $\alpha_{ASD}$ shall include all applicable factors to account for non-ductile failure modes and required overstrength.



# 7.3 ANCHOR CHANNEL DESIGN IN TENSION

**Tension Analysis**

The ultimate load associated with tension failure of the steel bolt or anchor may be determined with equation $N^0_{u,s} = A_s.f_u$ ($f_u$=tensile steel strength, $A_s$= Tensile cross-sectional area). The failure load corresponding to rupture of the connection between the anchor and the channel web may be assessed using ordinary structural steel design principles. In contrast, the ultimate load associated with distortion of the channel flanges is quite difficult to establish without testing. The flanges are to some degree supported by the surrounding concrete and therefore exhibit a different load-bearing behavior compared to a free-standing channel. Similarly, the failure load corresponding to the separation of an anchor element that is swaged onto or pressed into the back of the channel can only be determined through testing.

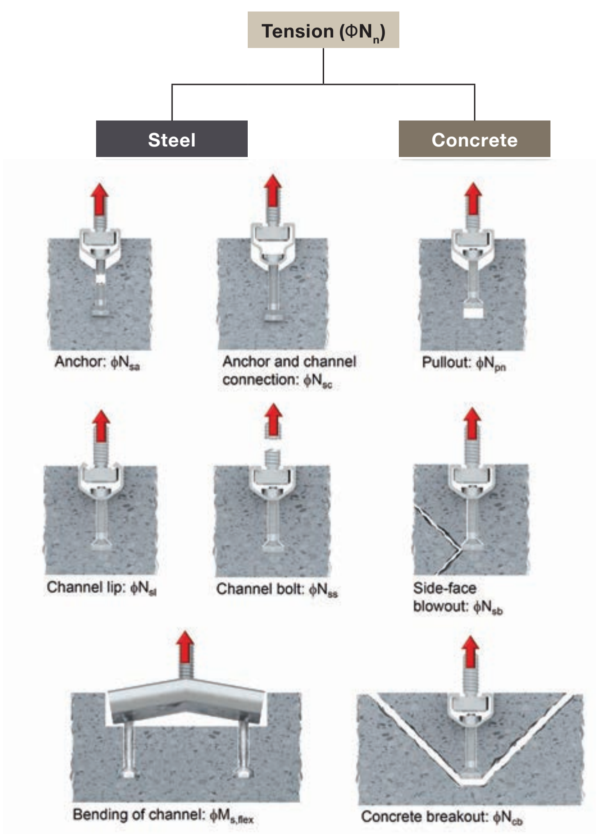



**Figure 7.3.1 — Possible tensile failure modes of an anchor channel.**

**Table 7.3.1.1 (AC232 Table 4.1) — Test program for anchor channels for use in uncracked and cracked concete**

| Test no. | Test Ref | Test description | $f_c$ | Δw | Minimum No. of tests | Channel | Anchor | Material | Channel bolt | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $d_s$ | strength |
| [-] | Secion in Annex A | [-] | psi [N/mm²] | inch (mm) | [-] | [-] | [-] | [-] | inch (mm) | [-] |
| Steel failure under tension load | | | | | | | | | | |
| 1 | 7.3 | Channel/anchor | - | - | 5[1] | See AC232 section 7.3.2 | | | | |
| 2 | 7.3 | Bending of channel lips, pull-out of channel bolt | - | - | 5[1] | | | | | |
| 3 | 7.3 | Channel bolt head | - | - | 5 | | | | | |
| 4 | 7.4 | Bending strength of the channel[2] | Low | 0 | | See AC232 section 7.4.2 | | | | |
| | | $s = s_{min}$ inch [mm] | | | 5 | | | | | |
| | | $s < s_{min}$ inch [mm] | | | 5 | | | | | |
| 5 | 7.5 | Torque tests[4] | - | - | 5 | See AC232 section 7.5.2 | | | | |
| Concrete failure under tension load | | | | | | | | | | |
| 6 | 7.6 | Splitting failure due to installation[5] $c_a = c_{a,min}$ $s < s_{min}$ $h < h_{min}$ | Low | 0 | 5 | See AC232 section 7.6.2 | | | | |
| 7 | 7.7 | Concrete breakout strength | Low | 0 | 5 | See AC232 section 7.7.2 | | | | |

1 If the coefficient of variation Vof the failure loads is V ≤ 5 percent, the number of tests can be reduced to n = 3.
2 Tests are only necessary if restraint of channels embedded in concrete shall be taken into account ($\alpha_r$> 4.0, see Section 8.8)
3 The tests shall only be performed if the conditions in Section 7.4.2.1 of this annex apply.
4 If the prestressing force is determined in accordance with Section 8.9.2 of this annex, only the smallest, medium and large channel bolts need to be tested in the corresponding medium sized channel. The most unfavorable combination of material and coating for the channel bolt and the channel shall be tested. No torque tests are required with channel bolts without lubrication or friction-reducing coatings if the prestressing force is calculated according to AC 232 Eq. (8.11) of this AC 232 annex with k = 0.15. See also Section 7.5.2.1 of AC 232 annex.
5 Only the small, medium and large channel sizes need to be tested if the conditions of Section 7.6.2.1 are fulfilled.

## 7.3.1 STEEL TENSILE STRENGTHS

### Anchor Strength, $\phi N_{sa}$

$\phi N_{sa} \geq N^a_{ua}$

Anchor strength $N_{sa}$, and $\phi$ is tabulated in Table ESR-3520 Table 8-3 for HAC and HAC-T with Hilti channel bolts (HBC-C, HBC-T and HBC-C-N).

The nominal strength $N_{sa}$, of a single shall be computed in accordance with Section 17.4.1.2 (ACI318-14) as shown below.

$N_{sa} = A_{se,N} f_{uta}$

where $A_{se,N}$ is the effective cross-sectional area of an anchor in tension, in.$^2$, and $f_{uta}$ shall not be taken greater than the smaller of $1.9f_{ya}$ and 125,000 psi.

The nominal strength of anchors in tension is best represented as a function of $f_{uta}$ rather than $f_{ya}$ because the large majority of anchor materials do not exhibit a well-defined yield point. The limitation of $1.9f_{ya}$ on $f_{uta}$ is to ensure that, under service load conditions, the anchor does not exceed $f_{ya}$. The limit on $f_{uta}$ of $1.9f_{ya}$ was determined by converting the LRFD provisions to corresponding service level conditions.

The average load factor of 1.4 (from 1.2D + 1.6L) divided by the highest $\phi$-factor (0.75 for tension) results in a limit of $f_{uta}/f_{ya}$ of 1.4/0.75 = 1.87. Although not a concern for standard structural steel anchors (maximum value of $f_{uta}/f_{ya}$ is 1.6 for ASTM A307), the limitation is applicable to some stainless steels.

### Anchor Strength of Connection Between Anchor and Channel $\phi N_{sc}$

$\phi N_{sc} \geq N_{aua}$

The connection between anchor and channel strength $N_{sc}$, and $\phi$ is tabulated in Table ESR-3520 Table 8-3 for HAC and HAC-T with Hilti Channel Bolts (HBC-C, HBC-T and HBC-C-N).

The Test No. 1 of AC232 is performed to determine the strength of the connection between anchor and channel. All anchor channel sizes with all anchor types and all materials are tested. The largest channel bolt with the maximum steel strength specified for the tested anchor channel shall be used as a component of the test specimen to avoid failure of the channel bolt. The anchors shall be tested in a tension test rig without being cast into concrete. Insert the channel bolt over one anchor and apply the load directly to channel bolt without a fixture.


**Figure 7.3.1.1 — Tension test for testing anchor channels in a universal testing machine.**



### Channel Lip Strength $\phi N_{sl}$

Channel lip strength $N_{sl}$, and $\phi$ is tabulated in Table ESR-3520 Table 8-3 for HAC and HAC-T with Hilti channel bolts (HBC-C, HBC-T and HBC-C-N).

$\phi N_{sl} \geq N_{aua}$

The Test No. 2 of AC232 is performed to determine the strength of local rupture of the channel lips. Test No. 2 the anchors shall be tested in a tension test rig without being cast into concrete (See Figure 7.3.1.2). Insert the channel bolt over one anchor and apply the load directly to channel bolt without a fixture.

Exception: In Test No. 2 (determination of the channel lip strength) tests shall be performed with anchor channels with two anchors cast into low-strength concrete with anchor spacing $s > s_{min}$ where $s_{min}$, shall be taken as the value which will be published in the ICC-ES Evaluation Service Report but shall not be taken less than 4 inches (100 mm). The distance between the end of the channel and the anchor axis shall correspond to the minimum value specified for the tested channel size. Insert the channel bolt over one anchor and apply the load directly to the channel bolt. A fixture with the following dimensions shall be used: width = $b_{ch}$ length = $3b_{ch}$, thickness = $d_f$. The fixture shall be shimmed with steel strips having a thickness = 1/8 inch (3.2 mm) located on each side of the anchor channel as shown in Figure 7.3.1.3 below. The diameter of the hole in the fixture shall be approximately 10 percent larger than the diameter of the shaft of the channel bolt. The channel bolt shall be pre-tensioned. However, the support spacing may be reduced to 1.0 $h_{ef}$ in every direction as shown in Figure 7.3.1.4. Direct contact between the test stand and the channel profile is not permitted.

The failure load, the corresponding displacement, and the failure mode shall be recorded.

Conduct of tests (locking channel bolts in combination with nonserrated channels and serrated channels in combination with matching serrated channel bolts):

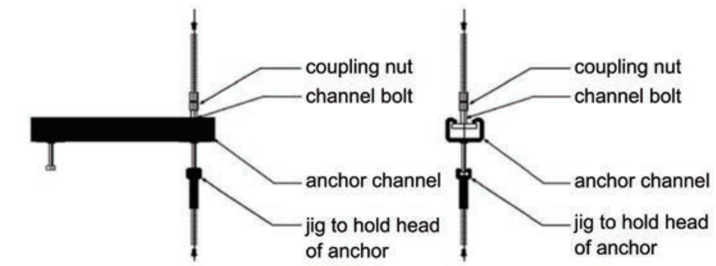



**Figure 7.3.1.2 — Tension test setup for testing anchor channels in a universal testing machine. (Figure taken from AC232, Figure 5.5).**

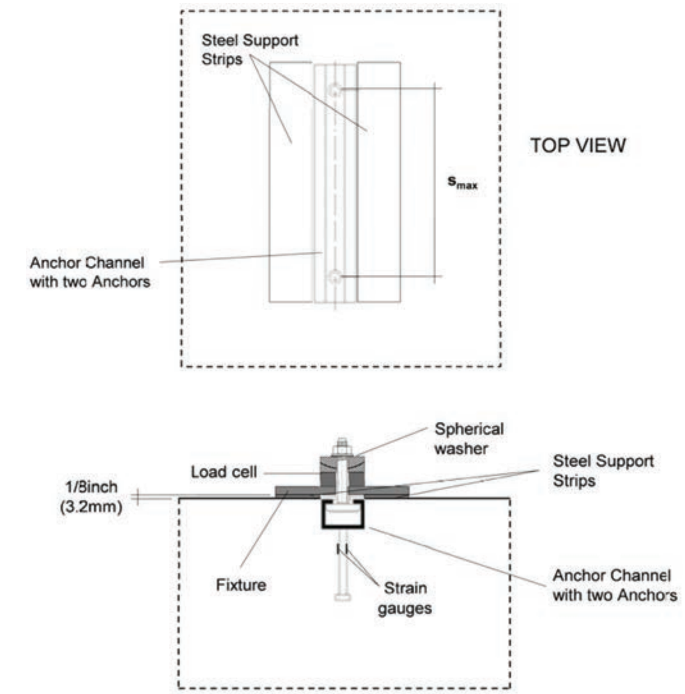



**Figure 7.3.1.3 — Test setup for tests in accordance with table 4.1 of AC232, test No. 5. (Figure taken from AC232, Figure 7.1)**

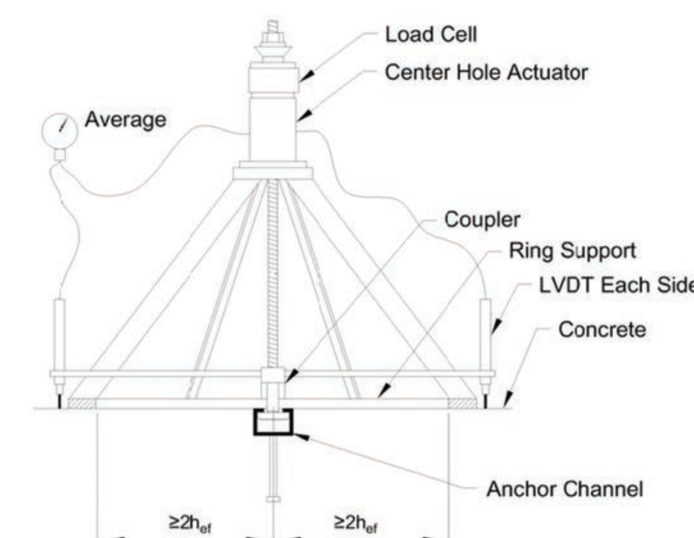



**Figure 7.3.1.4 — Example of an unconfined tension test setup for testing anchor channels (Figure taken from AC232, Figure 5.4).**

The nominal strength of the channel lips to take up tension loads transmitted by a channel bolt, $N_{sl}$, must be taken from ESR 3520 Table 8-3. This value is valid only if the center-to-center distance between the channel bolt under consideration and adjacent channel bolts, $S_{chb}$, is at least $2b_{ch}$ (see fig 7.3.1.5). If this requirement is not met then the value $N_{sl}$ given in table 8-3 must be reduced by the factor

$$\frac{1}{1+\sum_{i=2}^{n+1}\left[\left(1-\frac{s_{chb,i}}{2b_{ch}}\right)^{2}\cdot\frac{N^{b}_{ua,i}}{N^{b}_{ua,1}}\right]}$$

Where the center-to-center spacing between channel bolts shall not be less than 3-times the bolt diameter $d_s$.

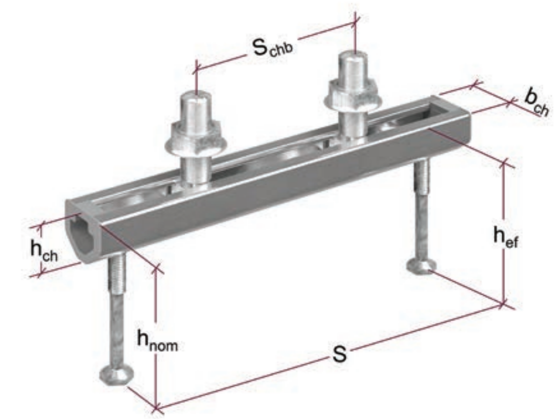
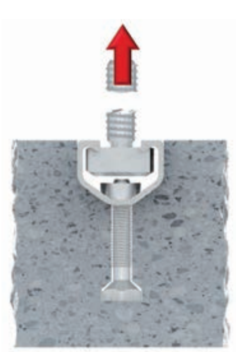



**Figure 7.3.1.5 — Anchor channel dimensions.**

## Channel Bolt Strength $\phi N_{ss}$



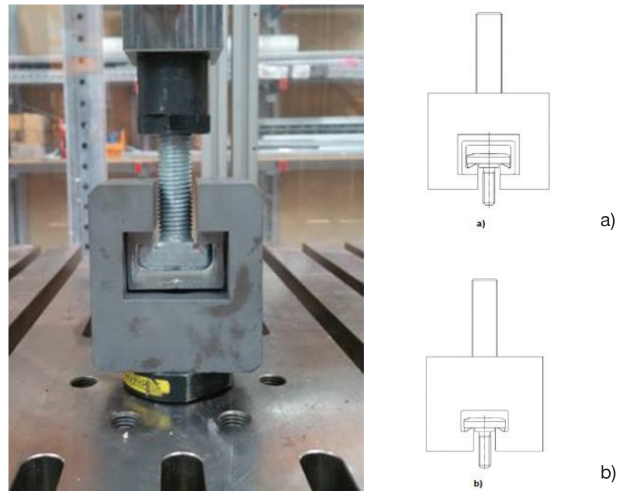
Channel bolt strength $N_{ss}$, and $\phi$ are tabulated in ESR-3520 Table 8-11 for HAC and HAC-T with Hilti channel bolts (HBC-B, HBC-C, HBC-T and HBC-C-N).

$\phi N_{ss} \geq N_{bua}$

The nominal strength of the channel bolt, $N_{ss}$, shall not exceed the value determined in accordance with the following equation:
$N_{ss} \geq A_{use,N} \cdot f_{utb}$

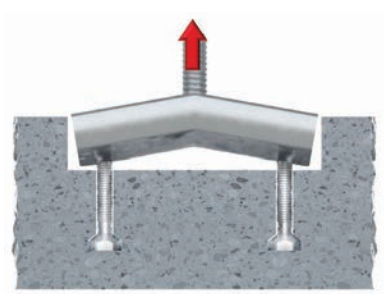
where $A_{use,N}$ is the effective cross-sectional area in tension, $in^2$ ($mm^2$); and $f_{utb}$ shall be taken as the smaller of $1.9 f_{yb}$ and 125,000 psi (860 MPa)

Test No. 3 is performed to evaluate the strength of the head of the channel bolt. All channel bolt sizes have been tested. For test No. 3, test the channel bolts in a section of channel that is sufficiently restrained to cause failure of the channel bolt (Figure 7.3.1.6 a). If the channel bolt is intended to be used for different channel sizes, conduct the tests in the channel profile with the maximum width of the slot between the channel lips. Insert the channel bolt in the channel profile and apply the load with a coupling nut to avoid thread failure. Alternatively, in case of standard channel bolts, channel bolts may be tested in a steel template (Figure 7.3.1.6 b). This template shall represent the inner profile of the channels.




(Figures a and b taken from AC232, Figure 5.8).
**Figure 7.3.1.6 — Test on channel bolts, test series No. 3.**

## Channel Flexural Strength, $\phi M_{s,flex}$



Bending strength $M_{s,flex}$, $M_{s,flex,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-3 for HAC and HAC-T with Hilti channel bolts (HBC-C, HBC-T and HBC-C-N).

$\phi M_{s,flex} \geq M_{u,flex}$

The flexural strength of an anchor channel shall be established in accordance to Test No. 4 of AC232. The purpose of this test is to measure the bending strength of the channel taking account of the restraint of the deformation of the outer ends of the channel by the concrete. The tests shall be performed with all sizes and materials of anchor channels. Anchor channels with two anchors with a maximum spacing and the minimum distance between the end of the channel and the anchor axis as specified by the manufacturer and with an anchor type that provides the lowest anchor strength shall be tested. The channel bolt with the smallest head size and maximum steel strength that, when tested, still results in steel failure of a part of the anchor channel other than the channel bolt shall be used. If the largest channel bolt size still results in bolt failure, the bolt failure load shall be taken as the load corresponding to bending failure. In case of locking channel bolts in combination with non-serrated channels, test has been performed with all channel bolt sizes.

In Test No. 4, concrete failure shall be avoided. This may be achieved by testing anchor channels with anchors that have an increased embedment depth.



In tension Test No. 4 the distance between the support reaction and any loaded anchor may be smaller than $2h_{ef}$ to avoid concrete failure.

Photo of an anchor channel after test; failure by bending of channel and distortion of anchor flanges

**Figure 7.3.1.7 — Flexural test on anchor channels.**

This behavior of anchor channel in concrete is influenced by a multitude of parameters, including the condition of the base material (cracked or uncracked), the direction of the action (tension, shear, combined tension and shear, or shear with lever arm), concrete strength, embedment depth, distance to neighboring fasteners and to edges, nature of the action (transitory, sustained, seismic or shock load) and amount and configuration of proximate reinforcement. In addition, environmental factors such as corrosion, extreme temperatures, and fire can affect anchor performance and must be properly considered in anchor channel design.

## 7.3.2 CONCRETE TENSILE STRENGTHS

### Pull Out Strength $\phi N_{pn}$

Pull-out and pull-through failure is characterized by the anchor being pulled out, whereby the concrete in the immediate vicinity of the anchor may not be damaged.

Per ESR-3520 Section 4.1.3.2.4, **nominal pullout strength ($N_{pn}$)** is calculated using ACI 318 anchoring to concrete provisions. ACI 318-11 Appendix D and ACI 318-14 Chapter 17 provisions.

$\phi N_{pn} \geq N_{aua}$
$N_{pn} = \Psi_{c,P} \cdot \lambda \cdot N_p$ reference ACI 318-14 Eq. (17.4.3.1)
$N_p = 8\, A_{brg}\, f'_c$ reference ACI 318-14 Eq. (17.4.3.4)
$f'_c$ = concrete compressive strength

**$A_{brg}$ for anchor channel is found in ESR-3520 Table 8-1**
$\lambda$ = modification factor for lightweight concrete
$\lambda$ = 1 for Normal weight concrete
$\lambda$ = 0.85 for Sand Light weight concrete
$\lambda$ = 0.75 for All Light weight concrete

The value calculated from Eq. (17.4.3.4) corresponds to the load at which crushing of the concrete occurs due to bearing of the anchor head (CEB 1997; ACI 349). It is not the load required to pull the anchor completely out of the concrete, so the equation contains no term relating to embedment depth. Local crushing of the concrete greatly reduces the stiffness of the connection, and generally will be the beginning of a pullout failure.

In lightweight concrete subjected to tensile stress, the aggregate fractures and the surface of the crack is, compared to the fracture process in concrete containing normal weight aggregate, relatively smooth. Therefore, the descending (strain softening) part of the load-deformation curve for normal weight concrete is less steep than in the case of lightweight concrete. Hence the strength is reduced using reduction factor λ.

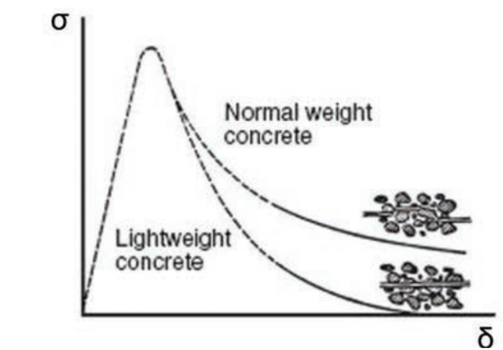



**Figure 7.3.2.1 — Influence of crack path on the stress-deformation behavior of concrete. concrete.(Picture from Anchorage in Concrete Construction, R. Eligehausen).**

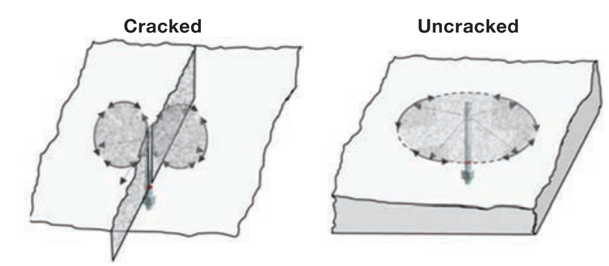



**Figure 7.3.2.2 — Concrete cone in cracked (left) and uncracked (right) concrete.**

A cracked tension zone is assumed because concrete possesses relatively low tensile strength, which may be fully or partly used by internal or restraint tensile stresses not taken into account in the design. The load-bearing behavior of an anchor can be significantly influenced by the presence of a crack passing through the anchor location. For anchor channels located in a region of a concrete member where analysis indicates no cracking at service load levels, the following modification factor shall be permitted

$\psi_{c,p} = 1.25$

Where analysis indicates cracking at service load levels $\psi_{c,p}$ shall be taken as 1.0.

| Concrete | $\psi_{c,p}$ |
|---|---|
| Cracked | 1.00 |
| Uncracked | 1.25 |

7.1 & 7.2 Introduction to Anchor Channel Design
7.3 Anchor Channel Tension Design: Steel, Concrete
7.4 Anchor Channel Shear Design (y): Steel, Concrete
7.4 Anchor Channel Shear Design (X): Steel, Concrete
7.5 Interaction Equations (Combined Loading)
7.6 Seismic Design

**φ factor:**

**Condition A (φ =0.75) is considered when**

- Supplementary reinforcement is present
- Reinforcement does not need to be explicitly designed for the anchor channel
- Arrangement should generally conform to anchor reinforcement
- Development is not required

| Condition | φ |
|---|---|
| A | 0.75 |
| B | 0.7 |

**Condition B (φ =0.70) is considered when**

- No Supplementary reinforcement is present

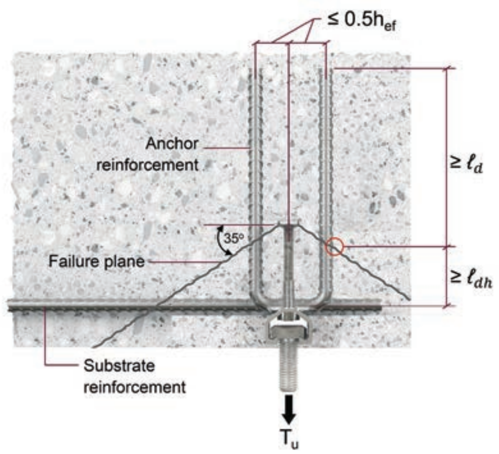



**Figure 7.3.2.3 — Arrangement of anchor reinforcement for anchor channels loaded by tension load at an edge.**

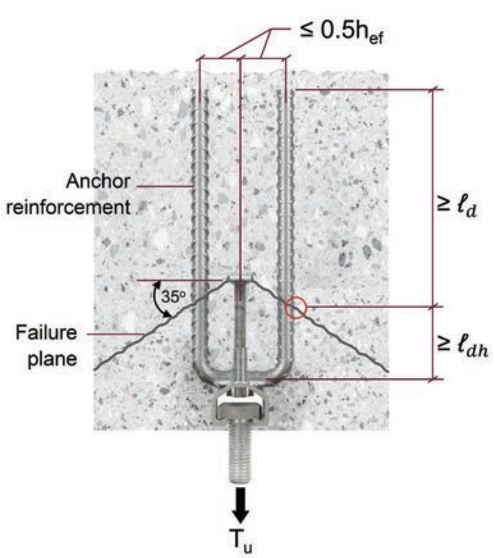
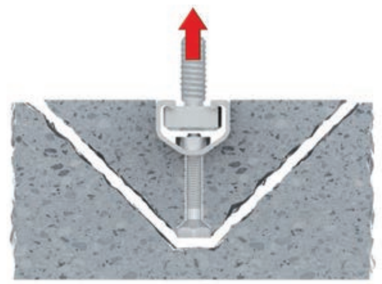



**Figure 7.3.2.4 Arrangement of anchor reinforcement for anchor channels loaded by tension load in a narrow member.**

## Concrete Breakout Strength $\phi N_{cb}$



Concrete breakout strength also known as concrete cone failure, the concrete breakout failure mode is characterized by the formation of a cone-shaped fracture surface in the concrete. The full tensile capacity of the concrete is utilized. Anchor channels with an adequately large bearing surface will generate concrete cone breakout failures if the steel capacity is not exceeded. Headed studs transfer the tensile force into the base material through bearing (mechanical interlock). Consequently, for the same load, the amount of displacement depends on the bearing contact area.

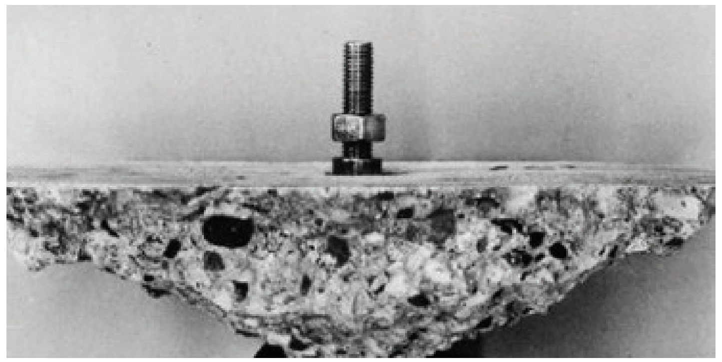


**Figure 7.3.2.5 — Concrete cone in tension. (Picture from Anchorage in Concrete Construction, R. Eligehausen).**

If the anchors are short, or if they are closely spaced or positioned near a free edge, a cone-shaped concrete breakout may limit the tension capacity of the anchor. For this type of failure the load-bearing behavior of channels with two anchors or of channels with more than two anchors and equal load on each anchor mimics that of headed studs. The presence of the channel profile in the breakout cone may influence the load-carrying capacity depending on the ratio of the height of the channel to embedment depth.

Per ESR-3520 Section 4.1.3.2.3, nominal concrete breakout strength ($N_{cb}$) is calculated using ESR 3520 Equation (6). The value calculated for concrete breakout strength in tension ($N_{cb}$) is based on the location of the anchor element being considered. The basic concrete breakout strength in tension ($N_b$)is not dependent on the anchor element being considered or the concrete geometry. Therefore, the calculated value for $N_b$ will be the same for each anchor element.

$$\phi\ N_{cb} \geq N_{ua}^{a}$$

$$N_{cb} = N_b \cdot \psi_{s,N} \cdot \psi_{ed,N} \cdot \psi_{co,N} \cdot \psi_{cp,N} \cdot \psi_{c,N}$$

ESR-3520 Equation (6)

$N_b$ = basic concrete breakout strength in tension
$\psi_{s,N}$ = modification factor for anchor spacing
$\psi_{ed,N}$ = modification factor for edge effects
$\psi_{co,N}$ = modification factor for corner effects
$\psi_{c,N}$ = modification factor cracked/uncracked concrete
$\psi_{cp,N}$ = modification factor for splitting

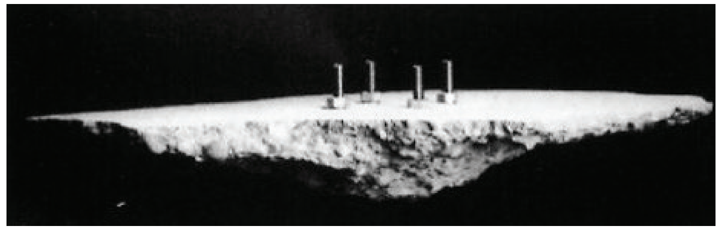


**Figure 7.3.2.6 — Concrete cone breakout of a group of anchors. (Picture from Anchorage in Concrete Construction, R. Eligehausen).**

**$N_b$ = Basic concrete breakout strength**

The basic concrete breakout strength of a single anchor in tension in cracked concrete, $N_b$, shall be determined in accordance with Eq. (7).

λ= modification factor for lightweight concrete
λ = 1 for Normal weight concrete
λ = 0.85 for Sand Light weight concrete
λ = 0.75 for All Light weight concrete
$f'_c$ = concrete compressive strength

$$N_b = 24 \cdot \lambda \cdot \alpha_{ch,N} \cdot \sqrt{f'_c} \cdot h_{ef}^{1.5}\ \text{,lb}$$

ESR-3520 Equation (7)

$$N_b = 10 \cdot \lambda \cdot \alpha_{ch,N} \cdot \sqrt{f'_c} \cdot h_{ef}^{1.5}\ \text{,N}$$

ACI 318-14: Equation17.4.2.2a

$$\alpha_{ch,N} = \left(\frac{h_{ef}}{7.1}\right)^{0.15} \leq 1.0 \quad \text{(inch-pound)}$$

ESR-3520 Equation (8)

$$\alpha_{ch,N} = \left(\frac{h_{ef}}{180}\right)^{0.15} \leq 1.0 \quad \text{(SI-units)}$$

According to ACI 318-14 of section 17.4.2.2 the basic concrete breakout strength of a single anchor in tension in cracked concrete, $N_b$, shall not exceed ESR-3520 Equation 7 or ACI 318-14: 17.4.2.2a. Alternatively in accordance to ACI 318-14, for cast-in headed studs and headed bolts with 11 in. ≤ $h_{ef}$ ≤ 25 in., $N_b$ shall not exceed ACI 17.4.2.2b. Hence in case of an anchor channel with 11 in. ≤ $h_{ef}$ ≤ 25 in., $N_b$ shall not exceed ACI 318-14 Equation 17.4.2.2b. The values of 24 in Eq. (17.4.2.2a) were determined from a large database of test results in uncracked concrete (Fuchs etal. 1995) at the 5 percent fractile. The values were adjusted to corresponding 24 value for cracked concrete (Eligehausen and Balogh 1995; Goto 1971). For anchors with a deeper embedment ($h_{ef}$ >11 in.), test evidence indicates the use of $h_{ef}^{1.5}$ can be overly conservative for some cases. An alternative expression (Eq. (17.4.2.2b)) is provided using $h_{ef}^{5/3}$ for evaluation of cast-in headed studs and headed bolts with 11 in. ≤ $h_{ef}$ < 25in.

$$N_b = 16\lambda_a \sqrt{f'_c}\, h_{ef}^{\left(\frac{5}{3}\right)}$$

ACI 318-14: Equation17.4.2.2b

A practical solution to assess the failure loads of anchors is via empirically derived equations that encompass theoretical models. This approach has led to the development of the CCD (Concrete Capacity Design) Method. Concrete cone failure loads subjected to concentric tension as a function of embedment depth.

$\alpha_{ch}$ factor to account for the influence of channel size on concrete breakout strength in tension. It decreases the concrete breakout capacity for the anchor channels with embedment depth less than 7.1".

The presence of the channel profile in the breakout cone may influence the load-carrying capacity depending on the ratio of the height of the channel to embedment depth. As shown in Fig 7.3.2.7. It has been observed in testing that having less concrete because of profile occupying the volume of concrete reduces the concrete breakout capacity in tension by the reduction factor $\alpha_{ch,N}$. Another observation that has been seen is that the anchor channels with effective embedment greater than 7.1" the reduction in this capacity is negligible. This observation has been included in the reduction ESR-3520 Equation (8).

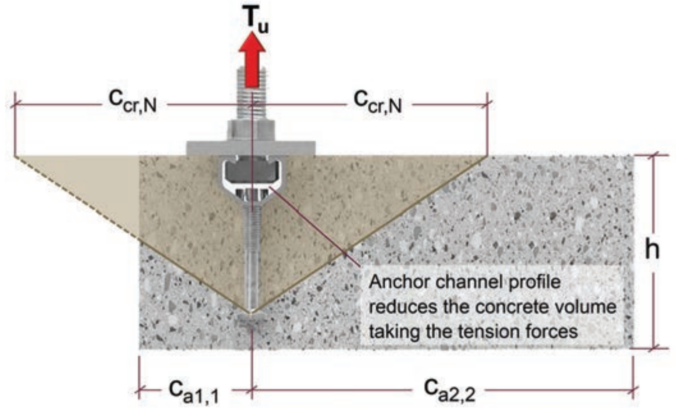



**Figure 7.3.2.7 — Concrte Breakout cone in tension**

Anchor channel $h_{ef}$ can be found in ESR-3520 Table 8-1

Where anchor channels with $h_{ef}$ > 7.1 in. (180 mm) are located in an application with three or more edges (as illustrated in Figure 7.3.2.8 & 7.3.2.9) with edge distances less than $c_{cr,N}$ ($c_{cr,N}$ in accordance with Eq. (14)) from the anchor under consideration, the values of $h_{ef}$ used in Eq. (7), (8), and (11) may be reduced to $h_{ef,red}$ in accordance with Eq. (9).

$$h_{ef,red} = \max\left(\frac{c_{a,max}}{c_{cr,N}}.h_{ef};\ \frac{s}{s_{cr,N}}.h_{ef}\right),\ in.(mm)$$

ESR-3520 Equation (9)

where:

$c_{a,max}$ = maximum value of edge or corner distance, in. (mm)
The values $c_{cr,N}$ and $s_{cr,N}$ in Eq. (9) shall be computed with $h_{ef}$.

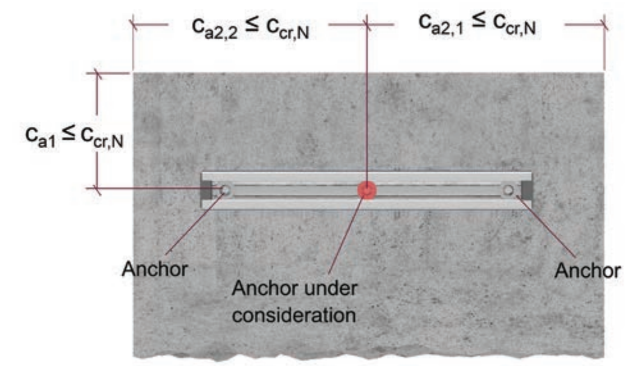



Figure 7.3.2.8 — Anchor channel with influence of one edge and two corners.

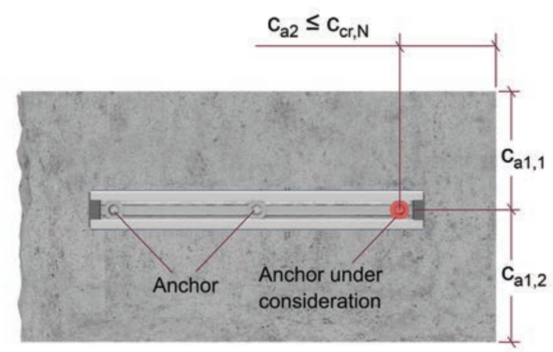



Figure 7.3.2.9 — Anchor channel with influence of two edges and one corner.

**$\psi_{s,N}$ = modification factor influencing the location of adjacent anchors**

Channels with more than two anchors and loaded in the span behave like continuous beams on springs, whereby the stiffness of the springs corresponds to the load-displacement curve of the anchor. The concrete cone capacity of the anchor in question is influenced by the distance of and the load on neighboring anchors. This is taken into account by multiplying the basic concrete cone capacity $N_b$, with the modification factor $\psi_{s,N}$. The factor $\psi_{s,N}$ replaces the ratio $A_{c,N}/A^{\circ}_{c,N}$, the factor $\psi_{ec,N}$ of ACI equation of concrete breakout of headed stud anchor. For anchor channel with two anchors the factor $\psi_{s,N}$ and the product $(A_{c,N}/A^{\circ}_{c,N})\psi_{ec,N}$ give practically the same results.

The modification factor to account for the influence of location and loading of adjacent anchors, $\psi_{s,N}$, shall be computed in accordance with Eq below.

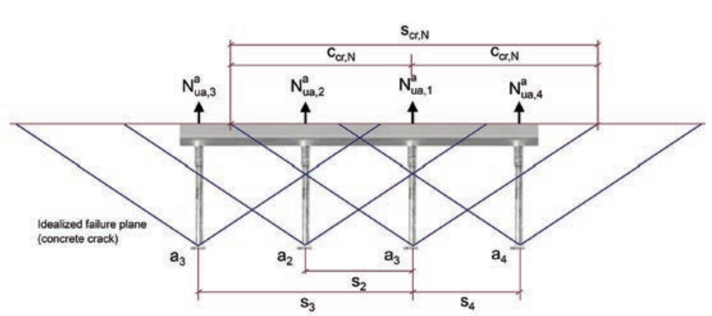



Figure 7.3.2.10— Example of anchor channel with non-uniform tension forces.

$$\psi_{s,N} = \frac{1}{1+\sum\limits_{i=2}^{i}\left[\left(1-\frac{s_i}{s_{cr,N}}\right)^{1.5}\cdot\frac{N_i}{N_1}\right]}$$ ESR-3520 Equation (10)

$$s_{cr,N} = 2\left(2.8-\frac{1.3h_{ef}}{7.1}\right)h_{ef} \geq 3h_{ef} \quad \text{in.}$$

ESR-3520 Equation (11)

$$s_{cr,N} = 2\left(2.8-\frac{1.3h_{ef}}{180}\right)h_{ef} \geq 3h_{ef} \quad \text{mm.}$$

$s_i$ = distance between the anchor under consideration and $\leq s_{cr,N}$ adjacent anchor, in. (mm)

$N_i$ = tension force of a neighboring anchor

$N_1$ = tension force of the anchor which resistance is determined

$$\psi_{s,N3} = \frac{1}{1+\sum\left[\left(1-\frac{s_2}{s_{cr,N}}\right)^{1.5}\cdot\frac{N^a_{ua,2}}{N^a_{ua,1}}\right]+\left[\left(1-\frac{s_3}{s_{cr,N}}\right)^{1.5}\cdot\frac{N^a_{ua,3}}{N^a_{ua,1}}\right]+\left[\left(1-\frac{s_4}{s_{cr,N}}\right)^{1.5}\cdot\frac{N^a_{ua,4}}{N^a_{ua,1}}\right]}$$

If an anchor channel is located with the edge $c_{a1} \geq c_{cr,N}$ in all directions the modification factors for concrete edge and corner effect is taken as 1. For applications where $c_{a1} \leq c_{cr,N}$ for example close to the edge or corner, equation should be reduced according to the modification factors given below.

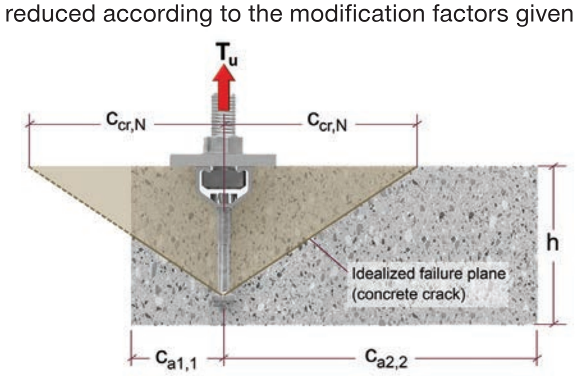



Figure 7.3.2.11 - Idealize failure plane in concrete due to tension forces.

**$\psi_{ed,N}$ = modification factor for edge effect**

The modification factor for edge effect of anchors loaded in tension, $\psi_{ed,N}$, shall be computed in accordance with Eq. (12) or (13)

If $c_{a1} \geq c_{cr,N}$

then $\psi_{ed,N} = 1.0$ ESR-3520 Equation (12)

If $c_{a1} < c_{cr,N}$ ESR-3520 Equation (13)

then $\psi_{ed,N} = \left(\frac{c_{a1}}{c_{cr,N}}\right)^{0.5} \leq 1.0$

where:

$$c_{cr,N} = 0.5s_{cr,N} \geq 1.5h_{ef}$$ ESR-3520 Equation (14)

If anchor channels are located in a narrow concrete member with multiple edge distances $c_{a1,1}$ and $c_{a1,2}$ (as shown in Figure 7.3.2.12), the minimum value of $c_{a1,1}$ and $c_{a1,2}$ shall be inserted in Eq. (13).

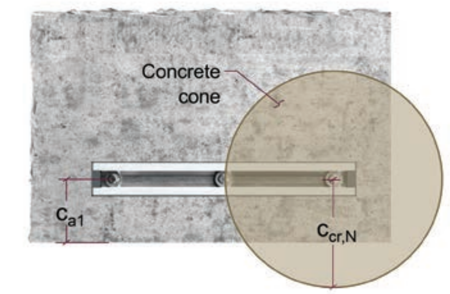



Figure 7.3.2.12 a)— at an edge

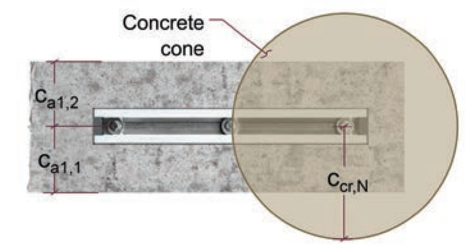



Figure 7.3.2.12 b)— in a narrow member

**Figure 7.3.2.12 — Idealized projected area of anchor of an anchor channel loaded in tension near a corner (top) near a corner and in a narrow member (bottom)**

**$\psi_{co,N}$ = modification factor for corner influence**

The modification factor for corner effect of anchors loaded in tension, $\psi_{co,N}$, shall be computed in accordance with Eq. (15) or (16)

If $c_{a2} \geq c_{cr,N}$ ESR-3520 Equation (15)

then $\psi_{co,N} = 1.0$ ESR-3520 Equation (16)

If $c_{a2} < c_{cr,N}$

then $\psi_{co,N} = \left(\frac{c_{a2}}{c_{cr,N}}\right)^{0.5} \leq 1.0$

$$c_{cr,N} = 0.5s_{cr,N} \geq 1.5h_{ef}$$ ESR-3520 Equation (14)

$c_{a2}$=distance of the anchor under consideration to the corner (see figure 7.3.2.13 a, b).

If an anchor is influenced by two corners (as illustrated in Figure 7.3.2.13 c), the factor $\psi_{co,N}$ shall be computed for each of the values $c_{a2,1}$ and $c_{a2,2}$ and the product of the factors, $\psi_{co,N}$, shall be inserted in Eq. (6).

$$\psi_{co,N,3} = \left(\frac{c_{a2.1}}{c_{cr,N}}\right)^{0.5} \leq 1.0$$

and

$$\psi_{co,N,3} = \left(\frac{c_{a2.2}}{c_{cr,N}}\right)^{0.5} \leq 1.0$$

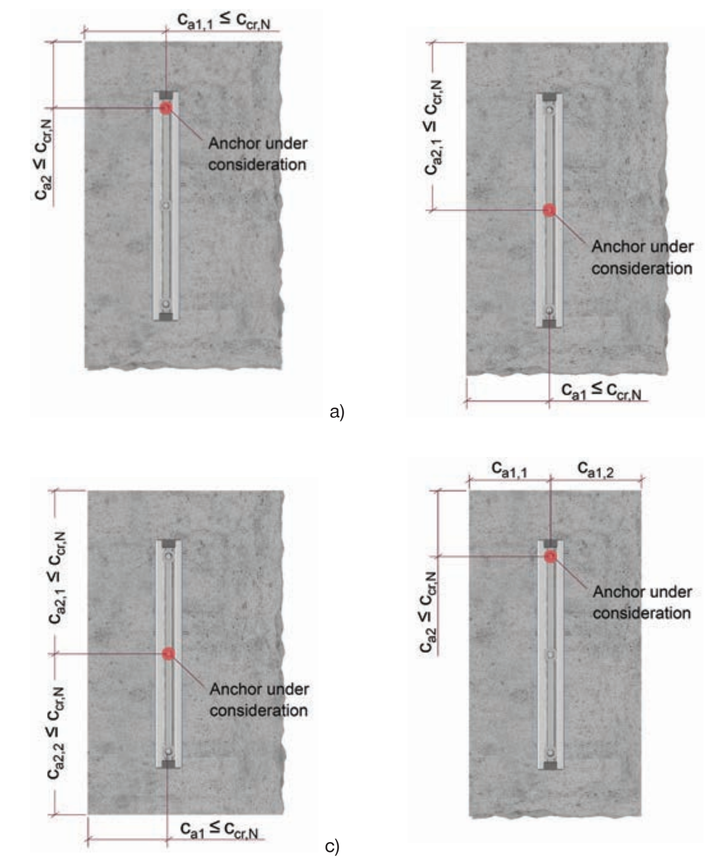



**Figure 7.3.2.13 — Anchor channel with the influence of one edge and one corner (a and b), two corners and one edge (c), and two edges and one corner (d).**

**$\psi_{c,N}$ = modification factor for cracked/uncracked concrete**

A cracked tension zone is assumed because concrete possesses relatively low tensile strength, which may be fully or partly used by internal or restraint tensile stresses not taken into account in the design. The load-bearing behavior of an anchor can be significantly influenced by the presence of a crack passing through the anchor location. For anchor channels located in a region of a concrete member where analysis indicates no cracking at service load levels, the following modification factor shall be permitted

$\psi_{c,N}$ = 1.25

Where analysis indicates cracking at service load levels $\psi_{c,N}$ shall be taken as 1.0. The cracking in the concrete shall be controlled by flexural reinforcement distributed in accordance with ACI 318-14 Section 24.3.2 and 24.3.3, or equivalent crack control shall be provided by confining reinforcement.

| Concrete | $\psi_{c,N}$ |
|---|---|
| Cracked | 1 |
| Uncracked | 1.25 |

The anchor qualification tests of ACI 355.2 or ACI 355.4 require that anchors in cracked concrete zones perform well in a crack that is 0.012 in. wide. If wider cracks are expected, confining reinforcement to control the crack width to approximately 0.012 in. should be provided.

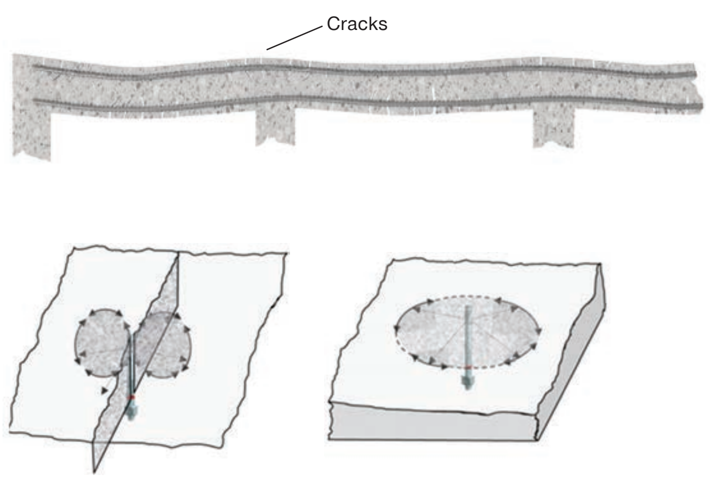



**Figure 7.3.2.14 — Cracked and uncracked concrete.**

**$\psi_{cp,N}$ = modification factor for splitting**

The modification factor for anchor channels designed for uncracked concrete without supplementary reinforcement to control splitting, $\psi_{cp,N}$, shall be computed in accordance with Eq. (17) or (18). The critical edge distance, $c_{ac}$, shall be taken from Table 8-4 of ESR-3520.

$c_{ac}$ = critical edge distance for splitting
$c_{cr,N}$ = critical anchor edge distance
$c_{s,min}$ = minimum edge distance

| | $\psi_{cp,N}$ |
|---|---|
| Uncracked concrete with no supplementary reinforcement | |
| If $c_{a,min} \geq c_{ac}$ ESR 3520 eq (17) | 1 |
| If $c_{a,min} < c_{ac}$ ESR 3520 eq (18) | $\psi_{cp,N} = MAX\left\{\left(\frac{c_{a,min}}{c_{ac}}\right);\left(\frac{c_{cr,N}}{c_{ac}}\right)\right\}$ |
| Uncracked concrete with supplementary reinforcement | 1 |
| Cracked concrete | 1 |

The basic concrete breakout strength can be achieved if the minimum edge distance ca,min equals $c_{cr,n}$. Test results, however, indicate that it require minimum edge distances exceeding $c_{cr,n}$ to achieve the basic concrete breakout strength when tested in uncracked concrete without supplementary reinforcement to control splitting. When a tension load is applied, the resulting tensile stresses at the embedded end of the anchor are added to the tensile stresses induced due to anchor installation, and splitting failure may occur before reaching the concrete breakout strength. To account for this potential splitting mode of failure, the basic concrete breakout strength is reduced by a factor $\psi_{cp,N}$ if $c_{a,min}$ is less than the critical edge distance $c_{ac}$. If supplementary reinforcement to control splitting is present or if the anchors are located in a region where analysis indicates cracking of the concrete at service loads, then the reduction factor $\psi_{cp,N}$ is taken as 1.0. The presence of supplementary reinforcement to control splitting does not affect the selection of Condition A or B.

**ϕ factor for concrete breakout strength in tension**

Condition A (ϕ=0.75) is considered when

- Supplementary reinforcement is present
- Reinforcement does not need to be explicitly designed for the anchor channel
- Arrangement should generally conform to anchor reinforcement
- Development is not required

Condition B (ϕ =0.70) is considered when

- No Supplementary reinforcement is present

| Condition | ϕ |
|---|---|
| A | 0.75 |
| B | 0.70 |

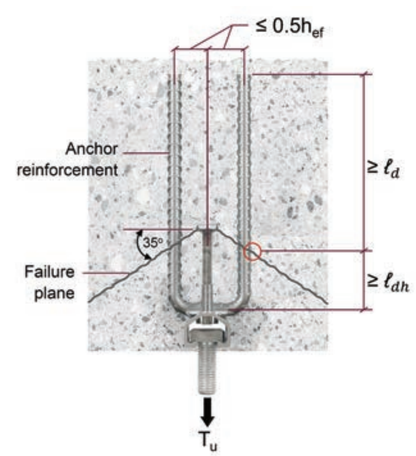



**Figure 7.3.2.15 — Arrangement of anchor reinforcement for anchor channels loaded by tension load in a narrow member.**

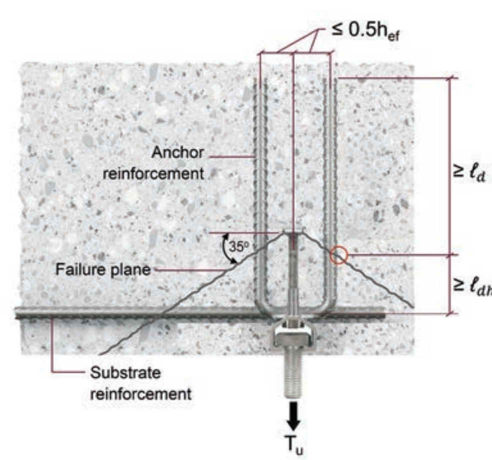



**Figure 7.3.2.16 — Arrangement of anchor reinforcement for anchor channels loaded by tension load at an edge.**



**Anchor reinforcement in tension**

As opposed to supplementary reinforcement, anchor reinforcement acts to transfer the full design load from the anchors into the reinforcement. Hence, concrete breakout is precluded. Where anchor reinforcement is developed in accordance with ACI 318 on both sides of the breakout surface for an anchor of an anchor channel, the design strength of the anchor reinforcement shall be permitted to be used instead of the concrete breakout strength in determining ΦNn or ΦVn, dependent upon the if the load is tension or shear. A strength reduction factor of 0.75 shall be used in the design of the anchor reinforcement. Anchor reinforcement can be utilized in tension, longitudinal shear, and perpendicular shear. An explicit design and full development are required for anchor reinforcement.

**Tension* (AC232 D5.2.10.9)**

In accordance with the provisions of AC232 D5.2.10.9, the tension anchor reinforcement shall consist of stirrups made from deformed reinforcing bars with a maximum diameter of 5/8 in (No. 5 bar)

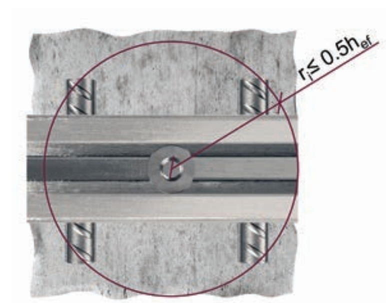
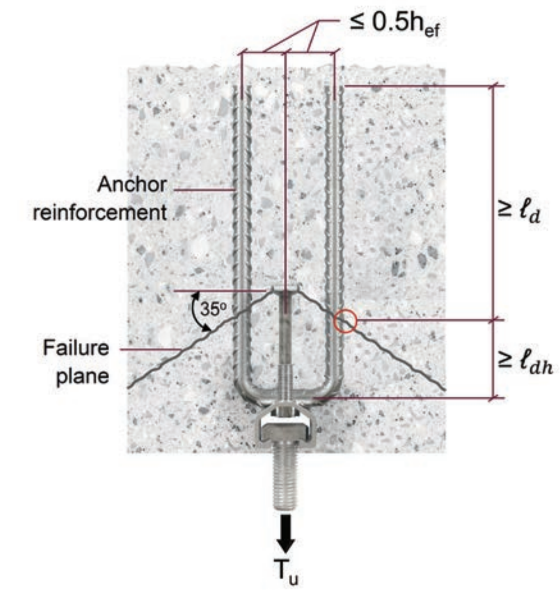



**Figure 7.3.2.17 — Arrangement of anchor reinforcement for anchor channels loaded in tension, plan view.**

$h_{ef}$ = effective embedment depth
$N_{ua}$ = factored tension load
$\ell_d$ = development length
$\ell_{dh}$ = development length in tension of a deformed bar or deformed wire with a standard hook, measured from critical section to outside end of hook

Where anchor reinforcement is developed in accordance with ACI 318-11 Chapter 12 or ACI 318-14 Chapter 25 on both sides of the breakout surface for an anchor of an anchor channel, the design strength of the anchor reinforcement, $\phi N_{ca}$, shall be permitted to be used instead of the concrete breakout strength, $\phi N_{cb}$, in determining $\phi N_n$. The anchor reinforcement for one anchor shall be designed for the tension force, $N^a_{ua}$, on this anchor using a strut-and-tie model. The provisions in Figure - 7.3.2.17 shall be taken into account when sizing and detailing the anchor reinforcement. Anchor reinforcement shall consist of stirrups made from deformed reinforcing bars with a maximum diameter of 5/8 in. (No. 5 bar) (16 mm). A strength reduction factor, ϕ, of 0.75 shall be used in the design of the anchor reinforcement.



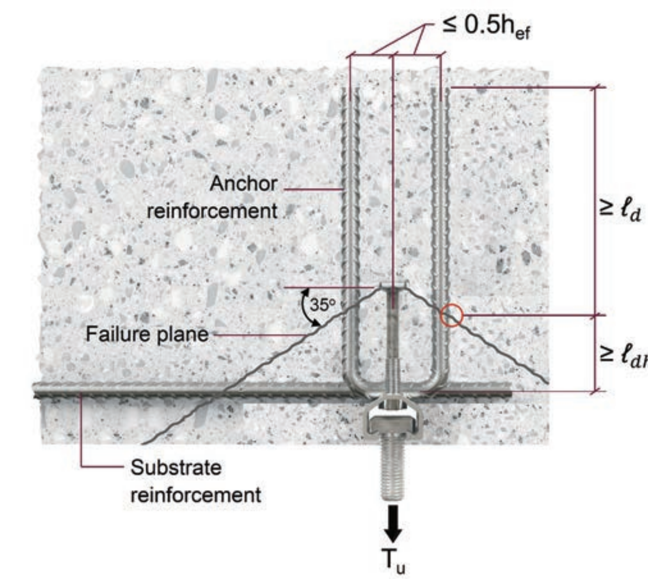
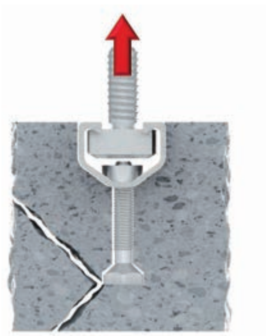




**Figure 7.3.2.17 — Arrangement of anchor reinforcement for anchor channels loaded in tension, section view.**

## Concrete side-face blowout strength $\phi N_{sb}$



Tension-loaded headed studs provided with small edge distances can generate local blowout failures in the vicinity of the head. Side blow-out failure will govern the concrete capacity of studs having small edge distance (concrete cover) in combination with large embedment depth. Local concrete side blow-out failure is caused by the quasi-hydrostatic pressure in the region of the head of the stud which gives rise to a lateral bursting force. The failure load will increase in proportion to the edge distance $c_{a1}$. For anchor channels located perpendicular to the edge and loaded uniformly, verification is only required for the anchor closest to the edge.

For anchor channels with deep embedment close to an edge ($h_{ef} > 2c_{a1}$) the nominal side-face blowout strength, $N_{sb}$, of a single anchor shall be computed in accordance with Eq. (19).

$$\phi N_{sb} \ge N^a_{ua}$$

$$N_{sb} = N^0_{sb} \cdot \psi_{s,Nb} \cdot \psi_{g,Nb} \cdot \psi_{co,Nb} \cdot \psi_{h,Nb} \cdot \psi_{c,Nb},\ lb(N)$$

ESR-3520 Equation (19)

| | | |
|---|---|---|
| $N_b$ | = | basic concrete side-face blowout strength in tension |
| $\psi_{s,Nb}$ | = | modification factor for effect of distance to neighboring anchors |
| $\psi_{a,Nb}$ | = | modification factor for effect of influence of the bearing area of neighboring anchors |
| $\psi_{co,Nb}$ | = | modification factor to account for influence of corner effects |
| $\psi_{h,Nb}$ | = | modification factor to account for influence of the member thickness |
| $\psi_{c,Nb}$ | = | modification factor to account for influence of uncracked concrete |
| $N_{sb}$ | = | Basic concrete side-face blowout strength |

**$N_{sb}$ = Basic concrete side-face blowout strength**

The basic nominal strength of a single anchor without influence of neighboring anchors, corner or member thickness effects in cracked concrete, $N^0_{sb}$, shall be computed in accordance with Eq. (20).

$$N^0_{sb} = 128 \cdot \lambda \cdot c_{a1} \cdot \sqrt{A_{brg}} \cdot \sqrt{f'_c},\ lb$$
$$N^0_{sb} = 10.5 \cdot \lambda \cdot c_{a1} \cdot \sqrt{A_{brg}} \cdot \sqrt{f'_c},\ N$$

ESR-3520 Equation (20)

**$\psi_{s,Nb}$ = modification factor for effect of distance to neighboring anchors**

The modification factor accounting for the distance to and loading of neighboring anchors, $\psi_{s,Nb}$, shall be computed in accordance with Eq. (10), however $s_{cr,N}$ shall be replaced by $s_{cr,Nb}$, which shall be computed in accordance with Eq. (21).

$$s_{cr,Nb} = 4c_{a1},\ in.(mm)$$

ESR-3520 Equation (21)

**$\psi_{s,Nb}$ = modification factor to account for influence of uncracked concrete**

The following modification factor to account for influence of uncracked concrete, $\psi_{c,Nb}$, shall be permitted:

$\psi_{c,Nb}$ = 1.25

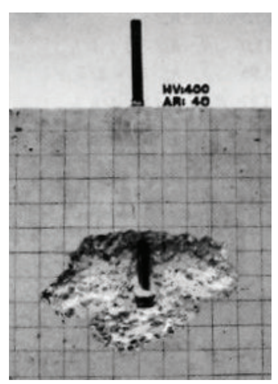


Figure 7.3.2.18 — Blowout failure of a deep anchor near an edge. (Picture from Anchorage in Concrete Construction, R. Eligehausen).

**$\psi_{g,Nb}$ = modification factor for effect of influence of the bearing area of neighboring anchors**

The modification factor to account for influence of the bearing area of neighboring anchors, $\Psi_{g,Nb}$, shall be computed in accordance with Eq. (22) or Eq. (23).

$$If\ s \ge 4c_{a1},\ then\ \Psi_{g,Nb} = 1.0$$
$$If\ s < 4c_{a1},\ then\ \Psi_{g,Nb} = \sqrt{n} + (1-\sqrt{n}).\frac{s}{4c_{a1}} \ge 1.0$$

ESR-3520 Equation (22)
ESR-3520 Equation (23)

where:
n = number of tensioned anchors in a row parallel to the edge

**$\psi_{co,Nb}$ = modification factor to account for influence of corner effects**

The modification factor to account for influence of corner effects, $\psi_{co,Nb}$, shall be computed in accordance with Eq. (24).

$$\psi_{co,Nb} = \left(\frac{c_{a2}}{c_{cr,Nb}}\right)^{0.5} \le 1.0$$

ESR-3520 Equation (24)

$c_{a2}$ = corner distance of the anchor for which the resistance is computed, in. (mm)

$$c_{cr,Nb} = 2c_{a1},\ in.\ (mm)$$

ESR-3520 Equation (25)

If an anchor is influenced by two corners ($c_{a2} < 2c_{a1}$), then the factor, $\psi_{co,Nb}$, shall be computed for $c_{a2,1}$ and $c_{a2,2}$ and the product of the factors shall be inserted in Eq. (19).

**$\psi_{h,Nb}$ = modification factor to account for influence of the member thickness**

The modification factor to account for influence of the member thickness, $\psi_{h,Nb}$ shall be computed in accordance with Eq. (26) or Eq. (27).

$$\text{If } f \ge 2c_{a1}\ then\ \psi_{h,Nb} = 1.0$$
$$\text{If } f \ge 2c_{a1}\ then\ \psi_{h,Nb} = \left(\frac{h_{ef}+f}{4c_{a1}}\right) \le \left(\frac{2c_{a1}+f}{4c_{a1}}\right)$$

ESR-3520 Equation (26)
ESR-3520 Equation (27)

where:
f = distance between the anchor head and the surface of the concrete member opposite to the anchor channel (as illustrated in Figure 7.3.2.19), in. (mm)

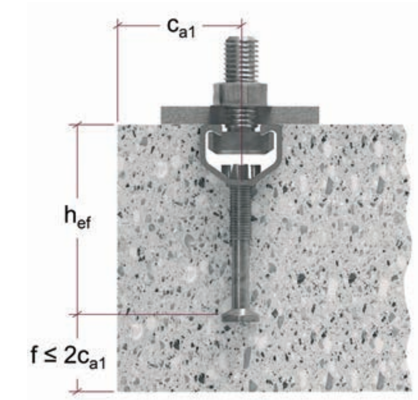



Figure 7.3.2.19 — Anchor channel at the edge of thin concrete member

**ϕ factor for concrete side-face blowout strength**

Condition A (ϕ=0.75) is considered when

- Supplementary reinforcement is present
- Reinforcement does not need to be explicitly designed for the anchor channel
- Arrangement should generally conform to anchor reinforcement
- Development is not required

Condition B (ϕ =0.70) is considered when

- No Supplementary reinforcement is present

| Condition | ϕ |
|---|---|
| A | 0.75 |
| B | 0.70 |

## Anchor cahnnel with deformed rebar anchors

Where anchors consist of deformed reinforcing bars, verification for concrete breakout is not required provided that the deformed reinforcing bars are lap spliced with reinforcing bars in the member according to the requirements of ACI 318-14 Section 25.5. Refer Section 8.6 of Chapter 8 regarding splice length.

# 7.4 ANCHOR CHANNEL DESIGN IN SHEAR

## Shear Load Acting Perpendicular to Channel

### 7.4.1 STEEL STRENGTHS IN PERPENDICULAR SHEAR

Steel failure Anchors loaded in shear exhibit steel failure when the edge distance and the embedment depth are sufficiently large, whereby conical spalling of the surface concrete precedes steel failure Figure 7.4.1.1. For a given anchor, steel failure represents a limit on the maximum shear capacity. Anchors made of ductile steels can develop relatively large displacements at failure.


**Figure 7.4.1.1 — Steel failure in shear of anchor channel lip.**

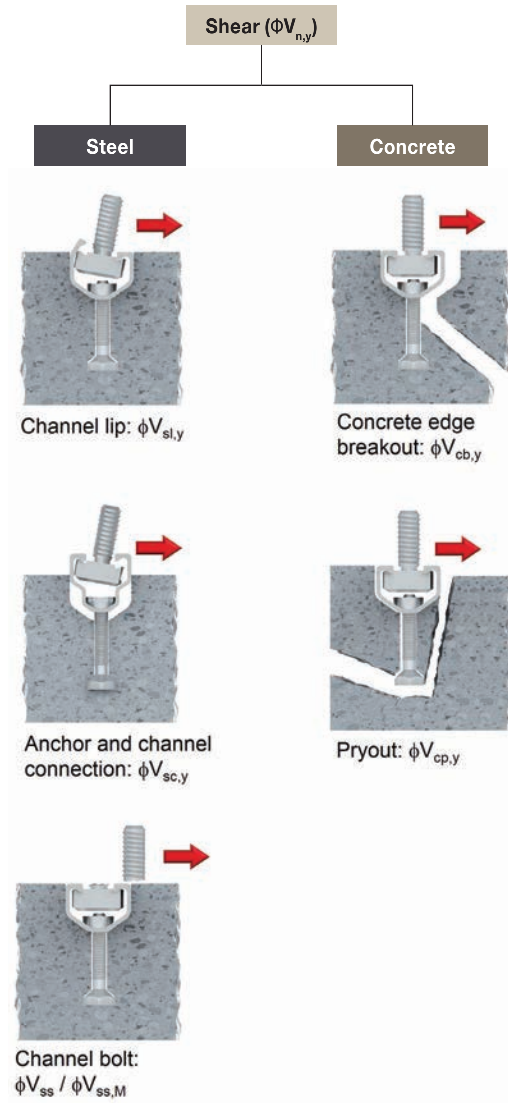



**Figure 7.3.1.1— Possible tensile failure modes of an anchor channel.**

**Table 7.4.1.1 — Test program for anchor channels for use in uncracked and cracked concrete (Table 4.1 of AC232).**

| Test no. | Test Ref | Test description | $f_c$ | Δw | Minimum No. of tests | Channel | Anchor | Material | Channel bolt $d_s$ | Channel bolt strength |
|---|---|---|---|---|---|---|---|---|---|---|
| [-] | Secion in Annex A | [-] | psi [N/mm²] | inch (mm) | [-] | [-] | [-] | [-] | inch (mm) | [-] |
| Steel failure under Shear load | | | | | | | | | | |
| 8 | 7.8 | Failure of anchor, failure of connection between anchor and channel, local rupture of channel lips[6] | Low | 0 | 5[1,8] | See AC 232 section 7.8.2 | | | | |
| 9 | | intentionally left blank | | | | | | | | |
| Concrete failure under shear load | | | | | | | | | | |
| 10 | 7.10 | Concrete edge failure[7] factor $\alpha_{ch,V}$ $c_a = c_{a,min}$, $s = s_{max}$, and $h > h_{cr,V}$ | Low | 0 | 5 | See AC 232 section 7.10.2 | | | | |
| 11 | | intentionally left blank | | | | | | | | |

1 If the coefficient of variation Vof the failure loads is V ≤ 5 percent, the number of tests can be reduced to n = 3.
6 Tests may be omitted if the nominal shear strength of the channel, $V_{nsy}$, is taken as < $N_{ns}$.
7 Tests may be omitted if the nominal strength, $V_{ns,y}$, is computed in accordance with Eq. (D-24a, ACI 318-05,-08), (D-33a, ACI 318-11), (17.5.2.10.2, ACI 318-14) with $\alpha_{ch,v}$= 5.6 $lbf^{1/2}/in^{1/3}$ ($\alpha_{ch,v}$= 4.0 $N^{1/2}/mm^{1/3}$ for SI) (Normal weight concrete)
8 Five tests need to be conducted with the channel bolt positioned over the anchor and an additional five tests with the channel bolt positioned midway between the two anchors, unless footnote 1 applies.



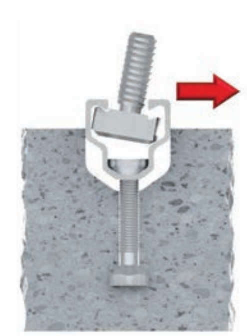
### Channel Lip Strength $\phi V_{sl,y}$

The nominal strength of the channel lips to take up shear loads perpendicular to the channel transmitted by a channel bolt, $V_{sl,y}$, must be taken from Table 8-5 for HAC and HAC-T with Hilti channel bolts (HBC-B, HBC-C, HBC-T and HBC-C-N).

Local rupture of channel lips is determined from Test 8. The test is performed on anchor channels cast into concrete.

$\phi V_{sl,y} \geq V^a_{uay}$

### Anchor Strength $\phi V_{sa,y}$ and Anchor and Channel Connection Strength $\phi V_{sc,y}$



The nominal strength of one anchor, $V_{sa,y}$, and anchor and channel connection $V_{sc,y}$ to take up shear loads perpendicular to the channel must be taken from Table 8-5 for HAC and HAC-T with Hilti channel bolts (HBC-B, HBC-C, HBC-T and HBC-C-N).

Anchor strength is determined from Test 8. The test is performed on anchor channels cast into concrete.

$\phi V_{sa,y} \geq V^a_{uay}$ $\phi V_{sc,y} \geq V^a_{uay}$

Tests 8 can be omitted if the nominal shear strength of the channel, $V_{ns,y}$, is taken as ≤ $N_{ns}$. $V_{ns}$ is the nominal steel strength of anchor channel loaded in shear (lowest value of $V_{sa}$, $V_{sc}$, and $V_{sl}$. $N_{ns}$ is the nominal steel strength of the anchor channel loaded in tension (lowest value of $N_{sa}$, $N_{sc}$ and $N_{sl}$).

$V_{ns}$: Nominal steel strength of anchor channel loaded in shear (lowest value of $V_{sa}$, $V_{sc}$, and $V_{sl}$)

### Bolt Strength $\phi V_{ss}$, $\phi V_{ss,M}$

$\phi V_{ss} \geq V^b_{ua}$ $\phi V_{ss,M} \geq V^b_{ua}$

The nominal strength of a channel bolt in shear, $V_{ss}$, must be taken from Table 8-12. The maximum value shall be computed in accordance with Eq. 17.5.1.4.1a, ACI 318-14).

$V_{ss} = 0.6.A_{se,V}.f_{utb}$ , lbf (N)

where

$f_{utb}$ shall be taken as the smaller of 1.9 $f_{yb}$ and 125,000 psi (860 MPa)

If the fixture is not clamped against the concrete but secured to the channel bolt at a distance from the concrete surface (e.g. by double nuts), the nominal strength of a channel bolt in shear, $V_{ss,M}$, shall be computed in accordance with Eq. (28).

$$V_{ss,M} = \frac{\alpha_M . M_{ss}}{l}, \ \text{lb(N)}$$ ESR-3520 Equation (28)

$\alpha_M$ = factor to take into account the restraint condition of the fixture
= 1.0 if the fixture can rotate freely (no restraint)
= 2.0 if the fixture cannot rotate (full restraint)

$$M_{ss} = M^0_{ss}\left(1 - \frac{N_{ua}}{\phi N_{ss}}\right), \ \text{lb-in (N-mm)}$$ ESR-3520 Equation (29)

$f_{utb}$ =minimum [(1.9 fyb and 125,000 psi (860 MPa)], psi (MPa)).
$M^0_{ss}$= nominal flexural strength of channel bolt according to Table 8-12.
= 1.2($S_{chb}$)$f_{utb}$, lbf-in (N-mm)
≤ 0.5$N_{sl.}$a
≤ 0.5$N_{ss.}$a
ℓ = lever arm, in. (mm)
a = internal lever arm, in. (mm) as illustrated in Figure 7.4.1.2
$T_s$ = tension force acting on channel lips
$C_s$ = compression force acting on channel lips

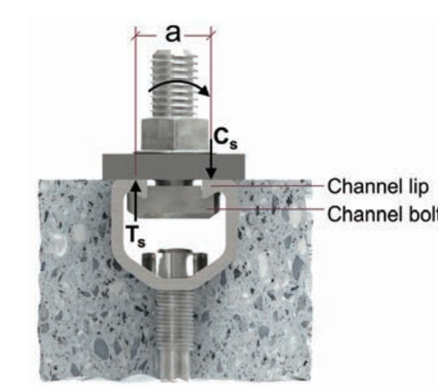
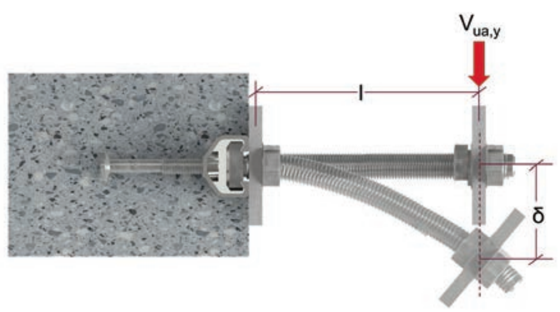
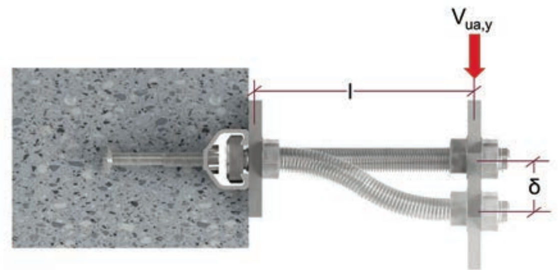



**Figure 7.4.1.2 - Definition of internal lever arm.**




a) α = 1; fixture can rotate

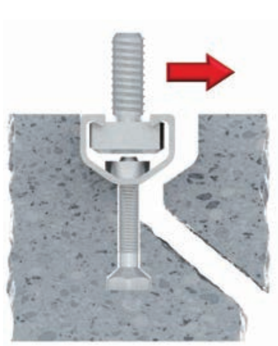



b) α = 2; fixture cannot rotate

**Figure 7.4.1.4 — Channel bolt resisting shear forces with stand off.**

## 7.4.2 CONCRETE STRENGTHS IN PERPENDICULAR SHEAR

### Concrete Edge Breakout Shear Strength ϕ $V_{cb,y}$



Concrete edge breakout failure: Failure of an anchor channel installed at the edge of a concrete member and loaded in shear towards the edge characterized by the formation of a fracture surface originating at the channel and projecting towards the edge of the concrete member as shown in the figure 7.4.2.1.

Anchors loaded in shear toward a proximate free edge may fail by development of a semi-conical fracture surface in the concrete originating at the point of bearing and radiating to the free surface Fig. 7.4.2.2 b1. A group of anchors loaded in shear and proximate to an edge may develop a common conical fracture surface (Anchors loaded in shear toward a proximate free edge may fail by development of a semi-conical fracture surface in the concrete originating at the point of bearing and radiating to the free surface Fig. b1. A group of anchors loaded in shear and proximate to an edge may develop a common conical fracture surface Fig. b2, and the development of the fracture surface is interrupted by the presence of a corner Fig. b3 by the limited depth of the member (Fig. b4) or by proximate edges parallel with the load direction (Fig. b5). In these cases the failure load associated with the anchor or one anchor of the group is reduced compared to the application shown in Fig. b1. Fig. b2) and the development of the fracture surface may be interrupted by the presence of a corner (Fig. b3) by the limited depth of the member Fig. b4 ) or by proximate edges parallel with the load direction (Fig. b5). In these cases the failure load associated with the anchor or one anchor of the group is reduced compared to the application shown in Fig. b1

The behavior of anchor channels loaded towards the free edge is based on numerical and experimental investigations. The shear load is initially transferred into the concrete via the channel and the anchors. Owing to the edge distance from the front face of the channel closer to the edge, which is smaller than the edge distance of the anchor, a local concrete failure starting at the front edge of the channel frequently occurs before the ultimate load is reached. Thereafter, the entire load is transferred to the concrete via the anchors.

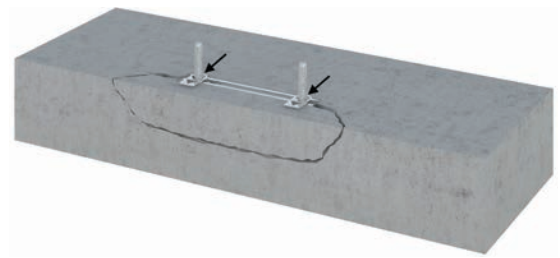


**Figure 7.4.2.1 — Concrete edge failure due to an anchor channel loaded in shear. Spacing of anchors equal to 5 times the edge distance**

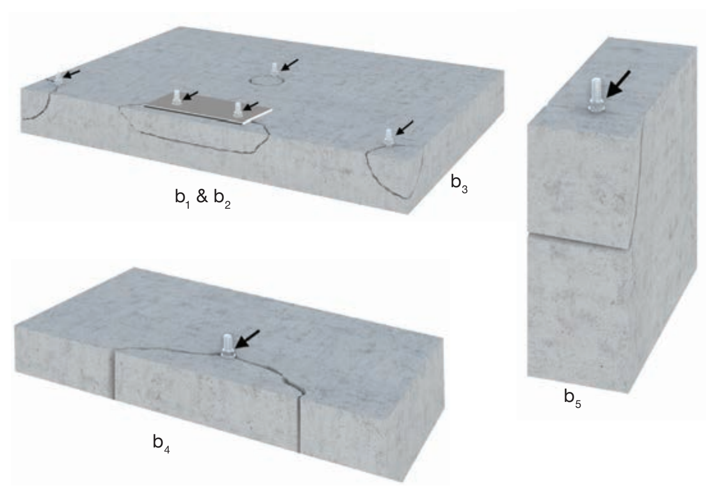



**Figure 7.4.2.2 — Failure of concrete breakout in shear $b_1$, $b_2$ and $b_3$) close to an edge, close to an edge and corner, away from the edge $b_4$ close to an edge, $b_5$ close to an edge and two corners in a deep member.**



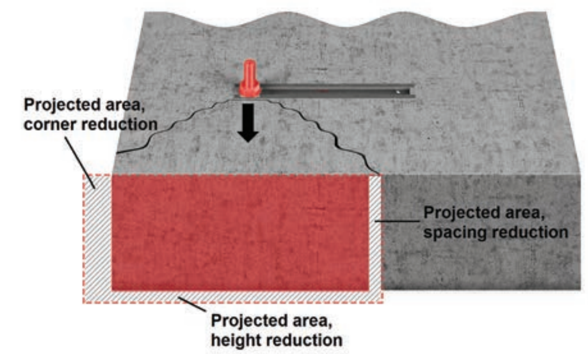



**Figure 7.4.2.3 — Projected area of an anchor channel loaded in shear.**

The ultimate load of a channel segment with one anchor depends on the size of the channel and anchor and is given by :
$V_b$ = Basic concrete breakout strength in shear

$$V_b = \lambda \cdot \alpha_{ch,V} \cdot \sqrt{f'_c} \cdot (c_{a1})^{4/3} \qquad \text{ESR-3520 Equation (31)}$$

$f'_c$ = the lesser of the specified concrete compressive strength and 8,500 psi (59 MPa)

λ... Modification for lightweight concrete
Lightweight concrete = 0.75
Sand-Lightweight concrete = 0.85

$\alpha_{ch,V}$ ... Influence factor for channel size (channel factor depending on dimensions of profile and anchor) (10.50, max) AC232 test 10 has been used to determine $\alpha_{ch,V}$ for various anchor channel. Tests may be omitted if the nominal strength, $V_b$, is computed in accordance with (17.5.2.10.2, ACI 318-14) with $\alpha_{ch,V}$ = 5.6 lbf$^{1/2}$/in$^{1/3}$ ($\alpha_{ch,V}$ = 4.0 N$^{1/2}$/mm$^{1/3}$ for SI) (Normal weight concrete)

The model described for the calculation of the concrete edge capacity of anchor channels under shear loading towards the edge assumes that shear forces are transferred by bending of the channel to the anchors and from the anchors into the concrete. This approach simplifies the real behavior. It has been chosen to allow for a simple interaction between tension and shear forces acting on the channel. Equation 31 gives the failure load of one anchor of an anchor channel. The influence of the geometric parameters edge distance, anchor spacing and component thickness is taken into account with sufficient accuracy. The nominal concrete breakout strength, $V_{cb,y}$, in shear perpendicular to the channel of a single anchor of an anchor channel in cracked concrete shall be computed as follows:

a) For a shear force perpendicular to the edge by Eq. (30)

$$\phi V_{cb} \ge V^a_{ua}$$

$$V_{cb} = V_b \cdot \psi_{s,V} \cdot \psi_{co1,V} \cdot \psi_{co2,V} \cdot \psi_{h,V} \cdot \psi_{c,V} \qquad \text{ESR-3520 Equation (30)}$$

$V_b$ = Basic concrete breakout strength in shear
$\psi_{s,V}$ = Modification factor for anchor spacing
$\psi_{co,V}$ = Modification factor for corner effects
$\psi_{c,V}$ = Modification factor cracked/uncracked concrete
$\psi_{h,V}$ = Modification factor for concrete thickness

b) For a shear force parallel to an edge (as shown in Figure 7.4.2.4), $V_{cb,y}$ shall be permitted to be 2.5 times the value of the shear force determined from Eq. (30) with the shear force assumed to act perpendicular to the edge.

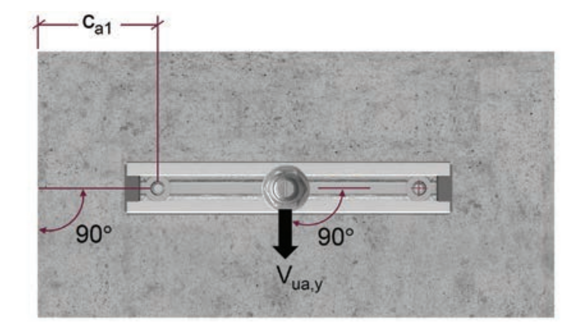



**Figure 7.4.2.4— Anchor channel arranged perpendicular to the edge and loaded parallel to the edge.**

**$\psi_{s,V}$ : The modification factor to account for the influence of location and loading of adjacent anchors shall be computed in accordance with Eq. (32).**

$s_i$ = distance between the anchor under consideration and the adjacent anchors ≤ $s_{cr,V}$
$s_{cr,V}$ = $4c_{a1} + 2b_{ch}$
$V_{aua,i}$ = factored shear load of an influencing anchor, lb (N)
$V_{aua,1}$ = factored shear load of the anchor under consideration, lb (N)
n = number of anchors within a distance $s_{cr,V}$ to both sides of the anchor under consideration

$$\psi_{s,V} = \frac{1}{1+\sum_{i=2}^{n+1}\left[\left(1-\frac{s_i}{s_{cr,V}}\right)^{1.5} \cdot \frac{V^a_{ua,i}}{V^a_{ua,1}}\right]} \qquad \text{ESR-3520 Equation (32)}$$

The value calculated for concrete breakout strength in shear ($V_{cb}$) is based on the location of the anchor element being considered. The basic concrete breakout strength in shear ($V_b$) is not dependent on the anchor element being considered, but it is dependent on the concrete geometry via the parameter $c_{a1}$. However, the calculated value for $V_b$ will be the same for each anchor element if the $c_{a1}$ value is the same for each element. The parameter $\psi_{s,V}$ will be dependent on the anchor element being considered and the concrete geometry. Reference ESR-3520 Equation (32) for more information on how to calculate $\psi_{s,V}$.

The parameter $s_{cr,V}$ corresponds to the maximum distance that is assumed with respect to the influence of an anchor element on the anchor element being considered. Any anchor elements that are within $s_{cr,V}$ from the anchor element being considered are assumed to have an influence on that anchor element. The calculated value for $s_{cr,V}$ will be the same for each anchor element if the $c_{a1}$ value is the same for each element; however, the number of anchor elements within the distance $s_{cr,V}$ from the anchor element being considered may not always be the same. Reference ESR-3520 Equation (33) for more information on how to calculate $s_{cr,V}$. Example for finding $s_{cr,v}$ is demonstrated below.

$$\psi_{s,V,1} = \frac{1}{1+\left[\left(1-\frac{s_2}{s_{cr,V}}\right)^{1.5}\cdot\frac{V_2}{V_1}\right]+\left[\left(1-\frac{s_3}{s_{cr,V}}\right)^{1.5}\cdot\frac{V_2}{V_1}\right]+\left[\left(1-\frac{s_4}{s_{cr,V}}\right)^{1.5}\cdot\frac{V_2}{V_1}\right]}$$

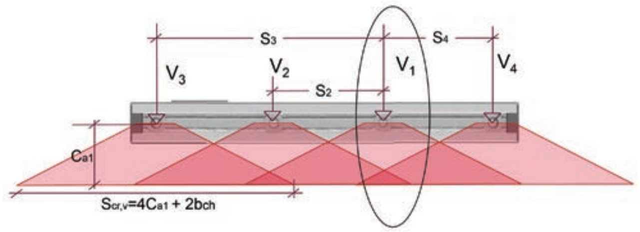



Figure 7.4.2.5 — Example of an anchor channel with different anchor shear forces.

**$\psi_{co,V}$: The modification factor for corner effect for an anchor loaded in shear perpendicular to the channel, shall be computed in accordance with Eq. (34) or (35).**

If $c_{a2} \geq c_{cr,V}$ then $\psi_{co,V} = 1.0$ — ESR-3520 Equation (34)

If $c_{a2} < c_{cr,V}$ then $\psi_{co,V} = (c_{a2}/c_{cr,V})^{0.5}$ — ESR-3520 Equation (35)

where:
$c_{cr,V} = 0.5 \cdot s_{cr,V} = 2c_{al} + b_{ch}$ in. (mm) — ESR-3520 Equation (36)

If an anchor is influenced by two corners (as shown in Figure e), then the factor $\psi_{co,V}$ shall be computed for each corner in accordance with Eq. (34) or (35) and the product of the values of $\psi_{co,V}$ shall be inserted in Eq. (30).

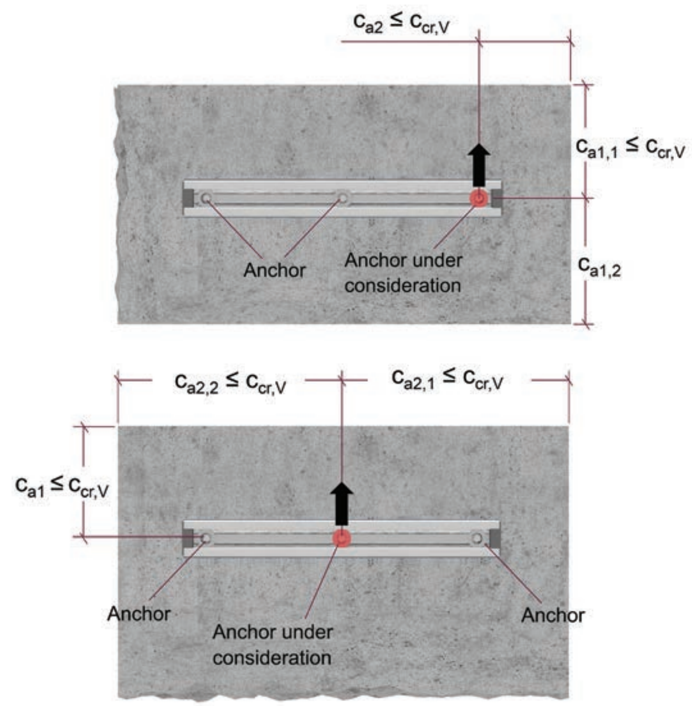



Figure 7.4.2.6 — Example of an anchor channel loaded in shear with anchors a) influenced by one corner and b) influenced by two corners.

**$\psi_{c,V}$ : The modification factor for cracked/uncracked concrete.**

Cracked concrete conditions with no supplementary reinforcement → $\psi_{c,V} = 1.0$

Note: if cracked concrete conditions are assumed, and supplementary edge reinforcement as defined in ESR-3520 Section 4.1.3.3.3 is used, $\psi_{c,V}$ can be increased to either $\psi_{c,V} = 1.2$ or $\psi_{c,V} = 1.4$.

**Cracked concrete $\psi_{c,V} = 1.0$**

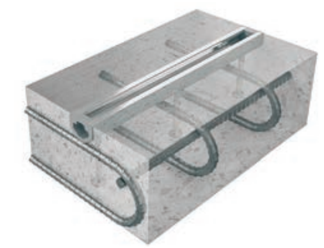
No supplementary reinforcement

With supplementary reinforcement

- Cracked concrete with edge reinforcement (#4 min.)

$\psi_{c,V} = 1.2$

- Cracked concrete with edge reinforcement (#4 min.) and stirrups (#4 min.) spaced at 4" O.C.



$\psi_{c,N} = 1.4$

**Uncracked Concrete $\psi_{c,V} = 1.4$**

Anchor channels located in a region of a concrete member where analysis indicates no cracking at service load levels.

Note: in order to activate the reinforcement, concrete has to crack. Therefore, if uncracked concrete is assumed, supplementary reinforcement does not impact this factor.

Concrete is typically assumed to be cracked under normal service load conditions. If cracked concrete conditions are assumed, an increase in $V_{cb,y}$ is permitted via the modification factor $\psi_{c,V}$ if supplementary edge reinforcement is used. If uncracked concrete conditions are assumed, an increase in $V_{cb,y}$ is likewise permitted via the modification factor $\psi_{c,V}$. Reference ESR-3520 Section 4.1.3.3.3 for more information.

**$\psi_{h,V}$ : The modification factor for member thickness.**

The modification factor for anchor channels located in a concrete member with $h < h_{cr,V}$, $\psi_{cr,V}$ (an example is given in Figure 7.4.2.7), shall be computed in accordance with Eq. (37).

$c_{a1}$ is measured perpendicular to the anchor channel longitudinal axis, and is considered when calculating the basic concrete breakout strength in shear ($V_b$) and the modification factor for member thickness ($\psi_{h,V}$).

$h_{ch}$ ... height of anchor channel
$\beta_1$... Given in ICC-ESR alternatively a default value of 0.50 shall be used
$h_{cr,V}$ ... critical member thickness

$h_{cr,V} = 2c_{a1} + 2h_{ch}$ — ESR-3520 Equation (38)

$$\psi_{h,V} = \left(\frac{h}{h_{cr,V}}\right)^{\beta_1} \leq 1.0$$ — ESR-3520 Equation (37)

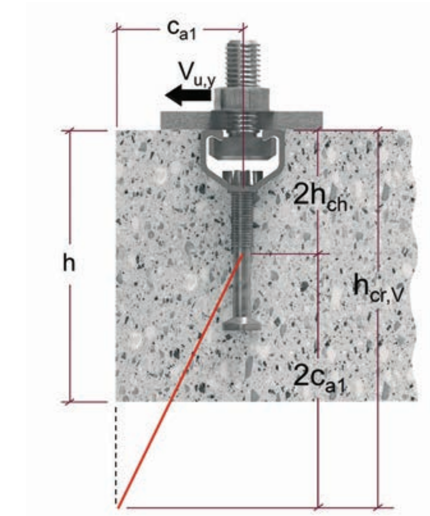



Figure 7.4.2.7 — Example of an anchor channel in a member with a thickness $h < h_{cr,V}$

**Anchor channel influenced by two corners and member thickness ($c_{a1,red}$)**

Where an anchor channel is located in a narrow member ($c_{a2,max} < c_{cr,V}$) with a thickness $h < h_{cr,V}$ (see Figure 7.4.2.8), the edge distance $c_{a1}$ in Eq. (31), (33), (36) and (38) shall not exceed the value $c_{a1,red}$ determined in accordance with Eq. (39).

$$c_{a1,red} = \max\left(\frac{c_{a2,max} - b_{ch}}{2}, \frac{h - 2h_{ch}}{2}\right), \quad in.\ (mm)$$

ESR-3520 Equation (39)

where $c_{a2,max}$ is the largest of the edge distances perpendicular to the longitudinal axis of the channel. For this example, the value of $c_{a1,red}$ is obtained by moving the failure surface forward until it intersects the corner as shown.

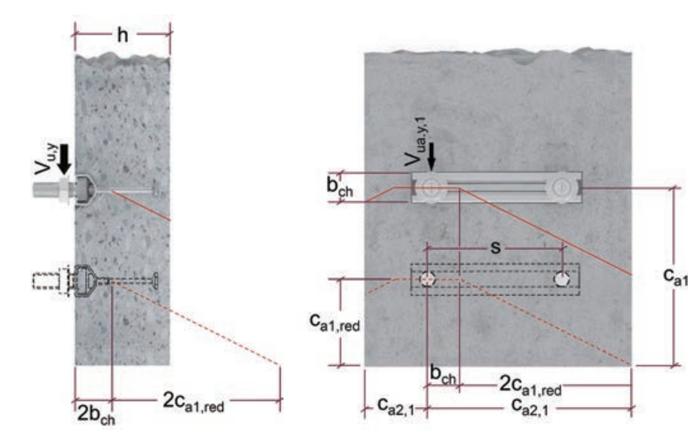



Figure 7.4.2.8 — Example of an anchor channel influenced by two corners and member thickness (in this example $c_{a2,2}$ is decisive for the determination of $c_{a1,red}$)

## Anchor reinforcement in perpendicular shear, ACI 318-14 17.5.2.10.1

For condition where reinforcement is anchored as illustrated in figure 7.4.2.9, the concrete breakout strength in perpendicular shear can be that of the reinforcement strength.

The anchor reinforcement of an anchor channel shall be designed for the maximum perpendicular shear load acting at the anchor channel anchors and channel bolts. Such anchor reinforcement shall be arranged at all anchors of an anchor channel. The maximum strength of the anchor reinforcement ($V_{ca,y,max}$) of a single anchor of an anchor channel shall be computed in accordance with ACI 318-14,

$$V_{ca,y,\max} = \left(\frac{2.85}{(c_{a1})^{0.12}}\right)(V_{cb,y}) \;,\; lbf$$

$c_{a1}$ = edge distance (in)
$V_{cb,y}$ = nominal concrete breakout strength in shear perpendicular to the channel axis of an anchor channel

In accordance with the provisions of ACI 318-14, 17.5.2.10.8.2, perpendicular shear anchor reinforcement shall consist of stirrups made from deformed reinforcing bars with a maximum diameter of 5/8 in (No. 5 bar) and straight edge reinforcement with a diameter not smaller than the diameter of the stirrups. Only one bar at both sides of each anchor shall be assumed as effective. The distance of this bar from the anchor shall not exceed 0.5ca1 and the anchorage length in the breakout body shall not be less than 4 times the bar diameter. The distance between stirrups shall not exceed the smaller of anchor spacing or 6 inches.

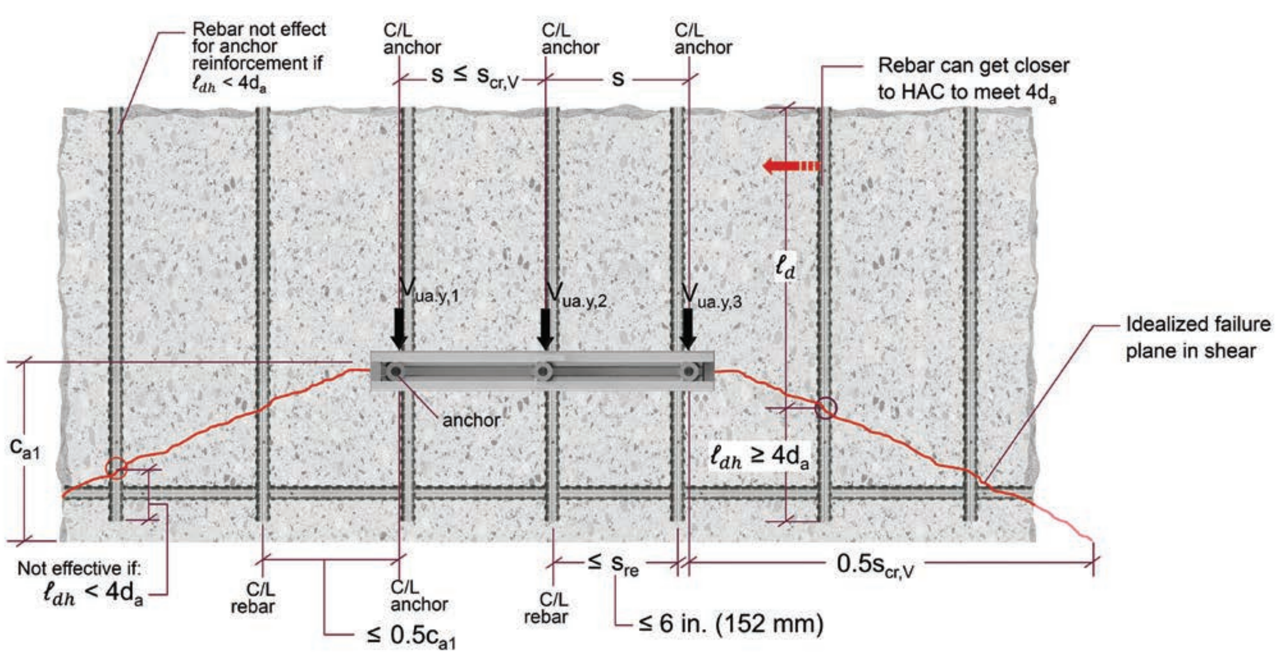
Because the anchor reinforcement is placed below where the shear is applied, the force in the anchor reinforcement will be larger than the shear force acting on the anchor channel bolts. If a shear load ($V_{ua,y}$) is acting on the anchor channel, the resultant factored tension force of the anchor reinforcement $N_{ua,re}$, shall be computed by the following equation

$$N_{ua,re} = V_{ua,y}\left(\frac{e_s}{z}+1\right)\; lbf\,(N)$$

$e_s$ = distance between reinforcement and shear force acting on the anchor channel (in)
z = internal lever arm of the concrete member, (in)
= 0.85 (h – $h_{ch}$ – 0.5$d_a$)
≤ (2$h_{ef}$, 2$c_{a1}$)

$c_{a1}$ = edge distance of anchor channel in direction 1
s = spacing on anchors in direction of longitudinal axis of channel
$s_{cr,v}$ = critical anchor spacing for shear loading, concrete edge breakout
$d_a$ = diameter of anchor reinforcement
$\ell_d$ = development length
$\ell_{dh}$ = development length in tension of a deformed bar or deformed wire with a standard hook, measured from critical section to outside end of hook

The anchor reinforcement of an anchor channel shall be designed for the highest anchor load, $V_{aua,y}$, of all anchors but at least for the highest individual shear load, $V_{bua,y}$, acting on the channel. This anchor reinforcement shall be arranged at all anchors of an anchor channel.




- Anchor reinforcement is effective if rebar is embedded a minimum of 4da (da = rebar diameter) after idealized failure plane in shear meets the rebar.
- Reinforcing outside the anchor channel is effective if it is located within 0.5Ca1 from the center of the outer anchor.

**Figure 7.4.2.9a — Detailing requirements for anchor reinforcement to resist shear loads; plan view.**

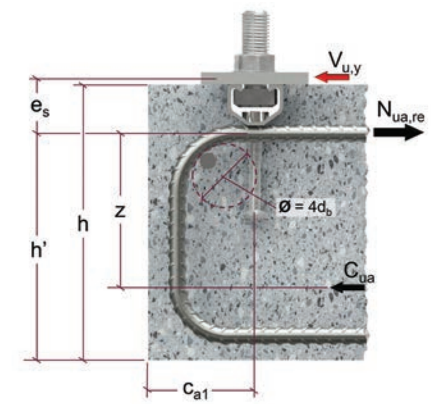
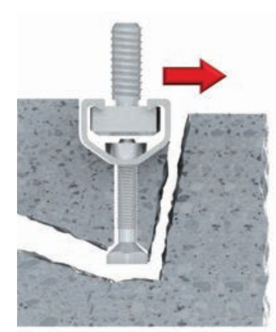



**Figure 7.4.2.9b — Internal forces and detailing requirements for anchor reinforcement to resist shear loads; section view.**

### Concrete Pryout Strength of Anchor Channels in Shear Perpendicular to the Longitudinal Channel Axis $\phi V_{cp,y}$



Failure load associated with pry-out; The load-bearing mechanism of a single headed stud anchorage subjected to a shear load is illustrated schematically in Fig 7.4.2.10. The applied shear load gives rise to bearing stresses in the concrete. With increasing load the surface concrete is crushed or spalled, shifting the centroid of resistance $V_b$ to a location deeper in the concrete.

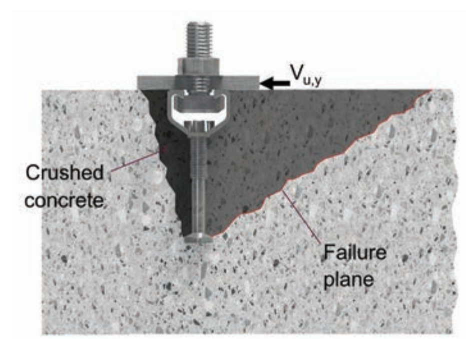



**Figure 7.4.2.10 — Load-bearing mechanism of headed stud anchorage subjected to shear loading (schematic).**

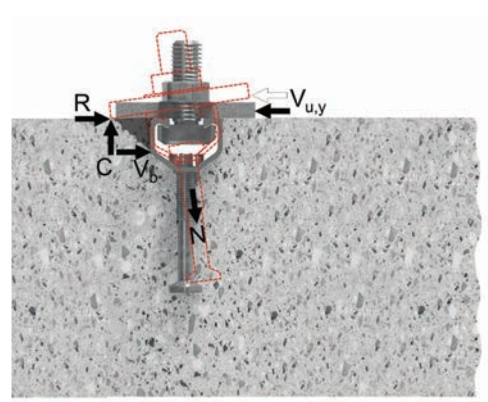



**Figure 7.4.2.11 — Typical failure body of a stud anchorage far from an edge loaded in shear : Cross-section of failure body (schematic).**

Also with increasing load and stud elongation, the baseplate rotates and loses contact with the concrete on the loaded side. These two mechanisms act to further increase the eccentricity between the applied shear load V and the stress resultant $V_b$ in the concrete. The moment resulting from this eccentricity generates a compressive force C between baseplate and concrete and a tensile force N in the stud. If the tensile force in the stud exceeds the tensile capacity associated with the maximum fracture surface that can be activated by the stud, a fracture surface originating at the head of the stud and projecting in conical fashion behind the stud forms Figure 7.4.2.11. This is defined as a pry-out failure.

$$V_{cp} = V_{cp,y} = k_{cp} N_{cb},\; lb(N)$$
$$k_{cp} = 2.0$$

ESR-3520 Equation (41)

The nominal pryout strength, $V_{cp,y}$, in shear of a single anchor of an anchor channel without anchor reinforcement shall be computed in accordance with Eq. (41).

where:
$k_{cp}$ = shall be taken from ESR-3520 Table 8-10
$N_{cb}$ = nominal concrete breakout strength of the anchor under consideration, lb (N), determined in accordance with breakout in tension; however in the determination of the modification factor $\psi_{s,N}$, the values $N^a_{ua,1}$ and $N^a_{ua,i}$ in Eq. (10) shall be replaced by $V^a_{ua,1}$ and $V^a_{ua,i}$, respectively.

Tests indicates that the pryout shear resistance can be approximated as one to two times the anchor tensile resistance with the lower value appropriate for hef less than 2.5 in.

$k_{cp}$ = 1.0 for $h_{ef}$ < 2.5 in.; and $k_{cp}$ = 2.0 for $h_{ef}$ ≥ 2.5 in.

The nominal pryout strength, $V_{cp,y}$, in shear of a single anchor of an anchor channel with anchor reinforcement shall not exceed:

$$V_{cp} = V_{cp,y} = 0.75 \cdot k_{cp} N_{cb},\; lb(N)$$

ESR-3520 Equation (42)

The ICC-ES Acceptance Criteria AC232 includes amendments to the ACI 318 anchoring to concrete provisions. These amendments are given in Section 3.1 Strength Design — Amendments to ACI 318. Part D.6.3.2 (ACI 318-11) and Section 17.5.3.2 (ACI 318-14) of these amendments require the factor $\psi_{s,N}$ to be modified when calculating concrete pryout strength in shear. All of the parameters used to calculate $\psi_{s,N}$ in tension are used except the parameter ($N^a_{ua,i}$/ $N^a_{ua,1}$). The shear loads acting on the anchor elements are substituted for the tension loads such that ($V^a_{ua,i}$ / $V^a_{ua,1}$) is used instead of ($N^a_{ua,i}$ / $N^a_{ua,1}$).

## 7.4.3 STEEL STRENGTHS IN LONGITUDINAL SHEAR

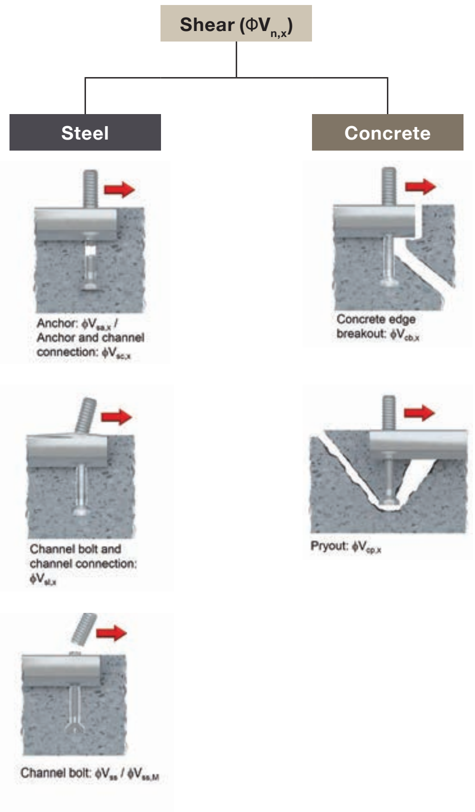



Figure 7.4.3.1 — Possible tensile failure modes of an anchor channel.

### Anchor Strength $\phi V_{sa,x}$ and Anchor and Channel Connection Strength $\phi V_{sc,x}$

$\phi V_{sa,x} \geq V^a_{uax}$ $\phi V_{sc,x} \geq V^a_{uax}$

The nominal strength of one anchor, $V_{sa,x}$, and anchor and channel connection $V_{sc,x}$ to take up shear loads acting in longitudinal channel axis must be taken from Table 8-5 for HAC and HAC-T with Hilti channel bolts (HBC-C, HBC-T and HBC-C-N).

**Table 7.4.3.1 — Test program for anchor channels for use in uncracked and cracked concete (Table 4.2 of AC232)**

| Test no. | Test Ref | Test description | $f_c$ | Δw | Minimum No. of tests | Channel | Anchor | Material | Channel bolt $d_s$ | Channel bolt strength |
|---|---|---|---|---|---|---|---|---|---|---|
| [-] | Secion in Annex A | [-] | psi [N/mm²] | | [-] | [-] | [-] | [-] | inch (mm) | [-] |
| Steel failure under shear load acting in longitudinal chaennel axis | | | | | | | | | | |
| 15 | 7.14 | Failure of connection between channel lips and channel bolt | Low | 0 | 5 | see AC232 Section 7.14.2 | | | | 1 |
| 16 | 7.16 | Failure of connection between channel lips and channel bolt — influence of level of prestressing force | Low | 0 | 5 | see AC232 Section 7.16.2 | | | | 1 |
| 17 | 1.17 | Failure of connection between channel lips and channel bolt — influence of channel below concrete surface | Low | 0 | 5 | see AC232 Section 7.17.2 | | | | 1 |

### Channel Lip Strength $\phi V_{sl,x}$

$\phi V_{sl,x} \geq V^b_{uax}$

The nominal strength of the connection between channel lips and channel bolt to take up shear loads acting in longitudinal channel axis, $V_{sl,x}$, must be taken from ESR-3520 Table 8-7 , 8-8 or 8-9, as applicable. Table 8-9 gives steel strength information for shear acting in longitudinal direction of the channel axis for anchor channel HAC-T and channel bolts HBC-T. Please note the following:

The ϕ value is 0.65 for in which periodical inspection is provided for M12 to M20 t-bolts.

The ϕ value is 0.75 for in which continuous inspection is provided for M12 to M20 t-bolts.

Table 8-8 gives steel strength information for shear acting in longitudinal direction of the channel axis for anchor channel HAC and channel bolts HBC-C-N. Please note the following:
The ϕ value is 0.55 for which periodical inspection is provided for all t-bolts.

The ϕ value is 0.65 for which continuous inspection is provided for M16 and M20 t-bolts. The steel strength for M12 t-bolts used with continuous inspection an increased value of 2,021lbs should be used with ϕ value of 0.55. Test No 15, 16 and 17 of AC-232 table 4.2, is performed.

Table 8-7 gives steel strength information for shear acting in longitudinal direction of the channel axis for anchor channel HAC and channel bolts HBC-B.

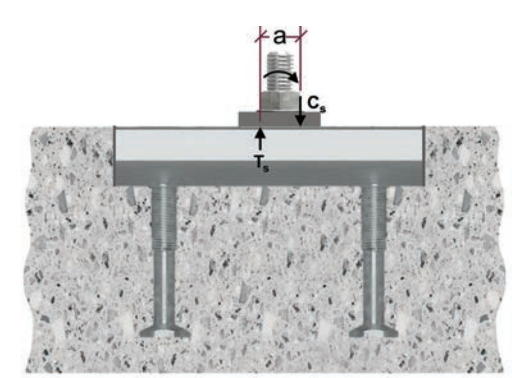



Figure 7.4.3.1 — Definition of lever arm.

### Channel Bolt in Shear, $\phi V_{ss}$, $\phi V_{ss,M}$

$\phi V_{ss,x} \geq V^b_{uax}$ $\phi V_{ss,M,x} \geq V^b_{uax}$

The nominal strength of a channel bolt in shear, $V_{ss}$, must be taken from ESR-3520 Table 8-6 of this report.

Shear load with lever arm In stand-off installations, t-bolt are clearly subjected to cantilever bending. Flexural failure of the steel rod generally defines the capacity.

If the fixture is not clamped against the concrete but secured to the channel bolt at a distance from the concrete surface (e.g. by double nuts), the nominal strength of a channel bolt in shear, $V_{ss,M}$, shall be computed in accordance with Eq. (28).

The coefficient αM depends on the degree of rotational fixity of the anchor where it joins the baseplate.

$$V_{ss,M} = \frac{\alpha_M . M_{ss}}{l}, \ \text{lb(N)}$$ ESR-3520 Equation (28)

$\alpha_M$ = factor to take into account the restraint condition of the fixture
= 1.0 if the fixture can rotate freely (no restraint)
= 2.0 if the fixture cannot rotate (full restraint)

$$M_{ss} = M^0{}_{ss}\left(1 - \frac{N_{ua}}{\phi N_{ss}}\right), \ \text{lb-in (N-mm)}$$ ESR-3520 Equation (29)

$M^0_{ss}$ = nominal flexural strength of channel bolt according to Table 8-12.
≤ $0.5N_{sl.}a$
≤ $0.5N_{ss.}a$
ℓ = lever arm, in. (mm)
α = internal lever arm, in. (mm) as illustrated in Figure 7.4.3.1

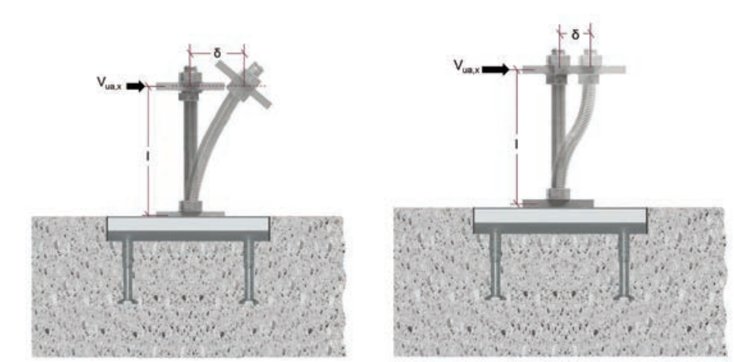
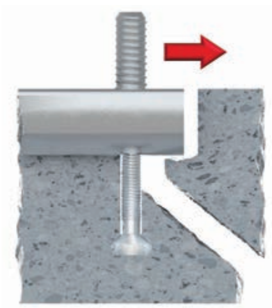



Figure 7.4.3.2— Channel bolt resisting shear forces with stand off.

## 7.4.4 CONCRETE STRENGTHS IN LONGITUDINAL SHEAR

### Longitudinal Concrete Edge Breakout Strength, $\phi V_{cb,x}$



The nominal concrete breakout strength, $V_{cb,x}$, in shear acting in the longitudinal direction of an anchor channel in cracked concrete shall be computed as follows:

a) For a shear force perpendicular to the edge, by Eq. (17.5.2.1a), Section 17.5.2.1 (ACI 318-14). The basic concrete breakout strength in shear in longitudinal channel axis of a single round anchor in an anchor channel in cracked concrete, $V_b$, shall be computed in 17.5.2.2 (ACI 318-14).

b) For a shear force parallel to an edge, $V_{cb,x}$ shall be permitted to be twice the value of the shear force determined from Eq. (17.5.2.1a), Section 17.5.2.1 (ACI 318-14) with the shear force assumed to act perpendicular to the edge.

The shear strength equations were developed from the CCD method. They assume a breakout cone angle of approximately 35 degrees (refer to Fig. 7.4.4.1) and consider fracture mechanics theory. The effects of multiple anchors, spacing of anchors, edge distance, and thickness of the concrete member on nominal concrete breakout strength in shear are included by applying the reduction factor of $A_{Vc}/A_{Vco}$ in Equation (43) .

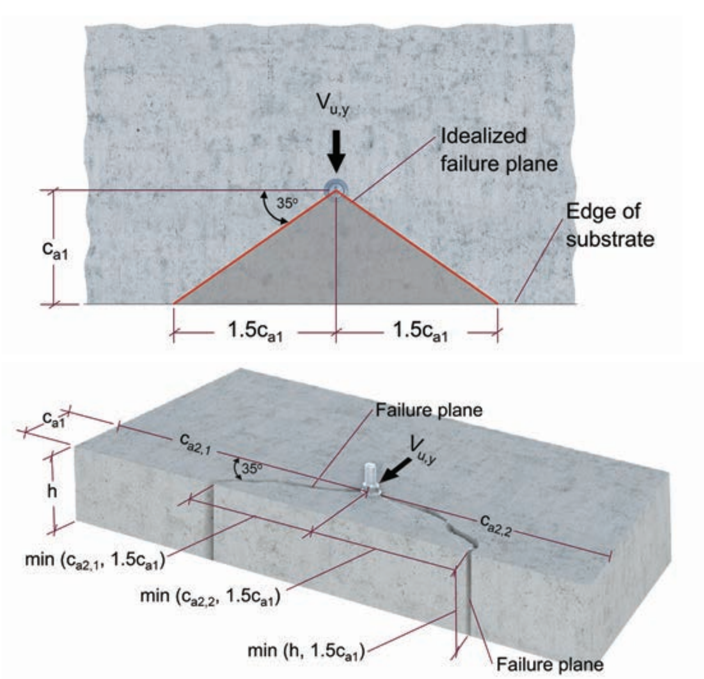



**Figure 7.4.4.1 — Idealized failure planes and projected area of a cast-in anchor in accordance with ACI 318-14.**

$V_b$: Basic concrete breakout strength in shear of a single anchor in cracked concrete, Vb, shall be the smaller of (a) and (b):

$$V_b = 7.(l_e/d_a)^{0.2}.\sqrt{d_a}.\lambda\cdot\sqrt{f'_c}\cdot(c_{a1})^{1.5} \quad \text{Equation (43-a)}$$

$$V_b = 9\lambda\sqrt{f'_c}\,c_{a1}^{(1.5)} \quad \text{Equation (43-b)}$$

$$V_{cb,x} = (A_{vc}/A_{vco})\cdot\psi_{ed,V}\cdot\psi_{c,V}\cdot\psi_{h,V}\cdot\psi_{parallel,V}\cdot V_b$$

Equation (44)

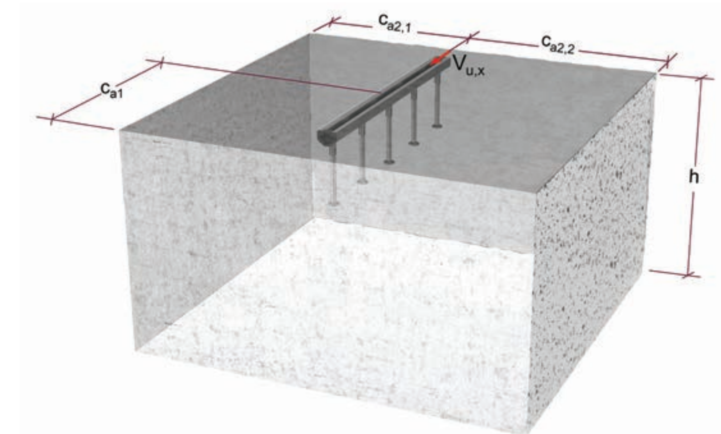
$V_b$ = Basic concrete breakout strength in shear
$A_{vc}$ = Projected area of the failure surface
$A_{vco}$ = Projected area for a single anchor in a deep member
$\psi_{ed,V}$ = Modification factor for edge effect
$\psi_{c,V}$ = Modification factor cracked/uncracked concrete
$\psi_{h,V}$ = Modification factor for concrete thickness
$\psi_{parallel,V}$ = Modification factor for shear force $V_{II}$ parallel to the edge
λ ……Modification for lightweight concrete
Lightweight concrete = 0.75
Sand-Lightweight concrete = 0.85
$\ell_e$. …..Minimum ($h_{eff,}$ $8d_a$) according to section 17.5.2.2a of ACI 318-14. $\ell_e$ is the load-bearing length of the anchor for shear:
$\ell_e = h_{ef}$ for anchors with a constant stiffness over the full length of embedded section, such as headed studs. $\ell_e \le 8d_a$
$d_a$ ….Anchor shaft diameter ( value can be taken from Table 8-1 ESR 3520)
$f'_c$ …..Concrete compressive strength (psi) (8,500 psi, max)
$c_{a1}$ ….Distance from the edge to axis (in.) (edge to center line of channel)

- According to AC232 the shear load $V_{ua,x}$ shall be equally distributed to not more than three anchors
- $c_{a1}$ is based on distance from edge to farthest anchor and all of the shear is assumed to be carried by that anchor.
- Like the concrete breakout tensile strength, the concrete breakout shear strength does not increase with the failure surface, which is proportional to $(c_a1)^2$. Instead, the strength increases proportionally to $(c_{a1})^{1.5}$ due to size effect.
- The strength is also influenced by the anchor stiffness and the anchor diameter (Fuchs et al. 1995; Eligehausen and Balogh 1995; Eligehausen et al. 1987/1988, 2006b).
- The influence of anchor stiffness and diameter is not apparent in large-diameter anchors (Lee et al. 2010), resulting in a limitation on the shear breakout strength provided by Eq.(43).
- The constant, 7, in the shear strength equation was etermined from test data reported in Fuchs et al. (1995) at the 5 percent fractile adjusted for cracking.
- For shear force perpendicular to an edge
  $\psi_{parallel,V} = 1.0$
- For shear force parallel to an edge
  $\psi_{parallel,V} = 2.0$
- Minimum value of $V_{cb}$ is considered of the two cases for corner anchors

- ACI 318-14 (eqn 17.5.2.1c)

$$A_{Vco} = 4.5.(c_{a1})^2 \quad \text{Equation (45)}$$

**$A_{vco}$: Projected area for a single anchor in a deep member**




**Case I: Concrete edge failure governs, Ψparallel=1.0**

**Case I-a:**

Full shear forces acting on the 3rd anchor away from the edge. The anchor close to the edge is anchor 1.

- AC232 limits the number of anchors to effectively resist longitudinal forces to three, if more than three anchors are present.
- Having the full shear load at the 3rd anchor verifies the adequacy of the concrete as a system (group of anchors).
- $C_{a1}$ is measured from the edge to the center of the third anchor.
- Projected areas are in accordance with ACI 318-14.

Calculation of projected area for a single anchor in a deep member,
$A_{vco}$:
$A_{vco} = (1.5c_{a1})(2)(1.5c_{a1})$
$A_{vco} = (4.5)(c_{a1})^2$

Calculation of projected area of the failure surface, $A_{vc}$:
$A_{vc}$ = {min (h, 1.5 $c_{a1}$)[min ($c_{a2,1}$, $1.5c_{a1}$) + ($c_{a2,2}$, $1.5c_{a1}$)]}

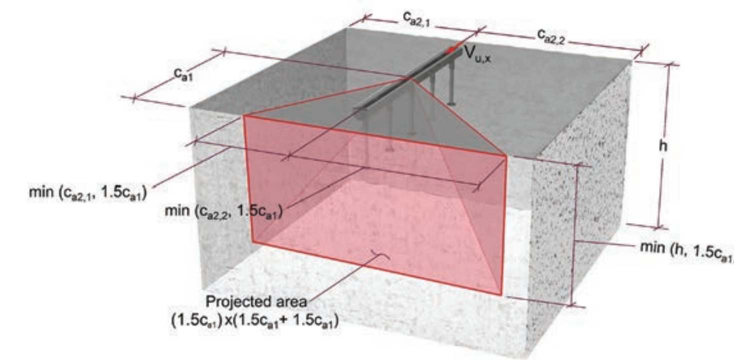



**Figure 7.4.4.2 — Projected area due to an anchor channel loaded in shear acting parallel to the long channel axis. Full shear loading acting on the 3rd anchor away from the edge.**

**Case I-b:**

Shear forces are distributed amongst the three anchors closer to the edge. The leading/front anchor is the controlling one.

- $V_{ux}/3$ is applied to the front anchor.
- Projected area is based on the edge distance of the first anchor.
- $C_{a1}$ is measured from the edge of the slab to the center of the first anchor.
- Projected areas are in accordance with ACI 318-14.

Calculation of projected area for a single anchor in a deep member,
$A_{vco}$:
$A_{vco} = (1.5c_{a1})(2)(1.5c_{a1})$
$A_{vco} = (4.5)(c_{a1})^2$

Calculation of projected area of the failure surface, $A_{vc}$:
$A_{vc}$ = {min (h, 1.5 $c_{a1}$) [min ($c_{a2,1}$, $1.5c_{a1}$) + ($c_{a2,2}$, $1.5c_{a1}$)]}

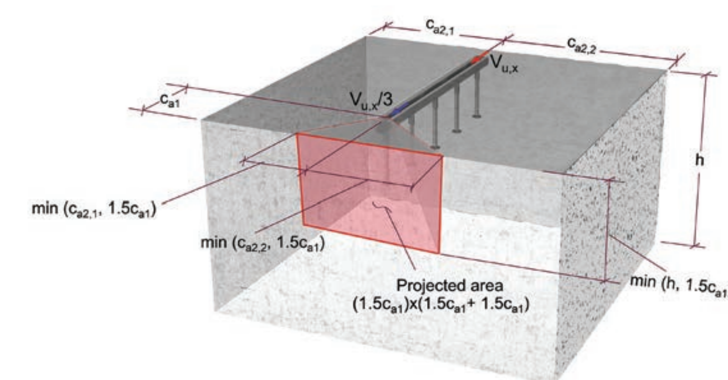



**Figure 7.4.4.3 — Projected area due to an anchor channel loaded in shear acting parallel to the long channel axis. Shear forces acting on the leading anchor.**

**Case II: Shear force parallel, Ψparallel=2.0**

Concrete edge breakout may be limited by the side concrete edge breakout, even if the load acts in a different direction. The side concrete edge breakout is equal to twice the perpendicular concrete edge breakout strength.

- $C_{a1}$ is measured from the corner to the center of the anchor channel.
- The analysis shall consider a maximum of three anchors.
- Projected areas are in accordance with ACI 318-14.

Calculation of projected area for a single anchor in a deep member, $A_{vco}$ :

$A_{vco} = (1.5c_{a1}) \times \{[2(1.5c_{a1}) \times [(1.5c_{a1}) + [(N_a - 1) \times s)] + (1.5c_{a2})\}$

Calculation of projected area of the failure surface, Avc:

$A_{vc} = \{\min (h, 1.5\ c_{a1}) \times [\min (c_{a2,1}, 1.5c_{a1}) + (N_a - 1) + (c_{a2,2}, 1.5c_{a1})]\}$

where

$N_a$ = number of anchors

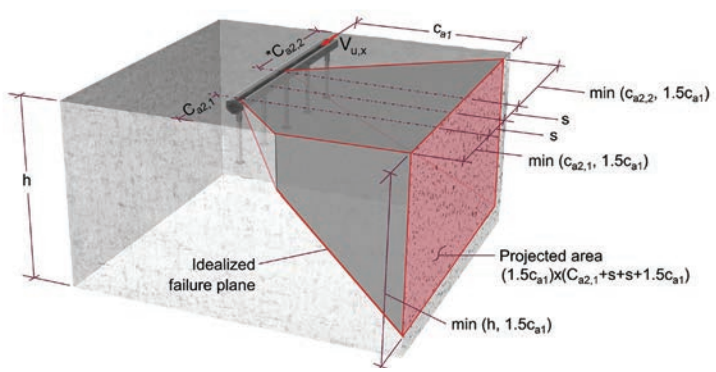



**Figure 7.4.4.4 — Projected area due to an anchor channel loaded in shear acting parallel to the long channel axis. Verification of side concrete edge breakout.**

**$\Psi_{ed,v}$ : Modification factor for edge effect in Shear**

The modification factor for edge effect for a single anchor or group of anchors loaded in shear, $\psi_{ed,V}$, shall be calculated as follows using the smaller value of $c_{a2}$.

If $c_{a2} \geq 1.5c_{a1}$, then $\psi_{ed,V} = 1.0$
If $c_{a2} < 1.5c_{a1}$, then

$$\Psi_{ed,V} = 0.7 + 0.3(\frac{Ca2}{1.5Ca1}) \leq 1.0$$

$c_{a1}$ : Distance from the edge to axis (in.) (edge to center line of channel)
$c_{a2}$ : Edge distance (in) of anchor channel in direction 2

If anchors are located close to an edge so that there is not enough space for a complete breakout prism to develop, the strength of the anchor is further reduced beyond that reflected in $A_{Vc}/A_{Vco}$. If the smallest side cover distance is greater than or equal to 1.5hef, a complete prism can form and there is no reduction ($\psi_{ed,V}$ = 1). If the side cover is less than $1.5h_{ef}$, the factor $\psi_{ed,N}$ is required to adjust for the edge effect

**$\Psi_{c,v}$: Modification factor for cracked/uncracked concrete**

For anchors located in a region of a concrete member where analysis indicates no cracking at service loads, the following modification factor shall be permitted $\psi_{c,V}$ = 1.4

$\psi_{c,V}$ = 1.4 For anchors located in a region of a concrete member

where analysis indicates cracking at service load levels, the following modification factors shall be permitted:

$\psi_{c,V}$ = 1.0 For anchors in cracked concrete without supplementary reinforcement or with edge reinforcement smaller than a No. 4 bar

$\psi_{c,V}$ = 1.2 For anchors in cracked concrete with straight reinforcement of a No. 4 bar or greater between the anchor and the edge

$\psi_{c,V}$ = 1.4 For anchors in cracked concrete with reinforcement of a No. 4 bar or greater between the anchor and the edge, and with the reinforcement enclosed within stirrups spaced at not more than 4 in.

**$\Psi_{h,v}$ : Modification factor for concrete thickness**

The modification factor for anchors located in a

concrete member where ha < $1.5c_{a1}$, $\psi_{h,V}$ shall be calculated as

$$\Psi_{h,V} = \frac{\sqrt{1.5 c_{a1}}}{\sqrt{h_a}} \geq 1.0$$

$c_{a1}$ ...Distance from the edge to axis (in.)
$h_a$ ....Height of the concrete member (in)

$\psi_{h,V}$ shall not be taken less than 1.0.
For anchors located in a concrete member where $h_a < 1.5c_{a1}$, tests have shown that the concrete breakout strength in shear is not directly proportional to the member thickness $h_a$. The factor $\psi_{h,V}$ accounts for this effect.

For anchors located in a concrete member where $h_a < 1.5c_{a1}$, tests (CEB 1997; Eligehausen et al. 2006b) have shown that the concrete breakout strength in shear is not directly proportional to the member thickness $h_a$. The factor $\psi_{h,V}$ accounts for this effect

## Anchor reinforcement in longitudinal shear(ACI 318-11 D6.2.9)

For conditions where anchor reinforcement is provided as illustrated in figure 7.4.4.5, the concrete breakout strength in longitudinal shear can be that of the reinforcement strength.

The anchor reinforcement of an anchor channel shall be designed for the total longitudinal shear load acting at the anchor channel anchors and channel bolts. Such anchor reinforcement shall be arranged at all anchors of an anchor channel.

Anchor reinforcement shall consist of stirrups made from deformed reinforcing bars with a maximum diameter of 5/8 in (No. 5 bar). The enclosing anchor reinforcement should be in contact with the anchor and as close to the concrete surface as possible, while still observing minimum cover requirements.

To ensure yielding of the anchor reinforcement, the enclosing anchor reinforcement in Fig. R17.5.2.9a should be in contact with the anchor and placed as close as practicable to the concrete surface

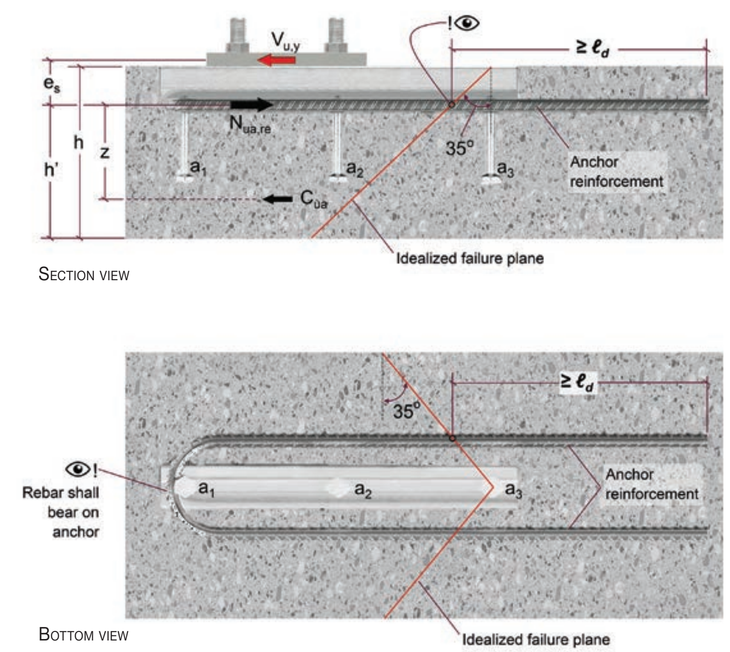



**Figure 7.4.4.5 — Anchor reinforcement to preclude concrete breakout in shear acting along the longitudinal axis of the anchor channel**

In accordance with the provisions of ACI 318-14, 17.5.2.10.8.2, longitudinal shear anchor reinforcement shall consist of stirrups made from deformed reinforcing bars with a maximum diameter of 5/8 in (No. 5 bar) and straight edge reinforcement with a diameter not smaller than the diameter of the stirrups. Only one bar at both sides of each anchor shall be assumed as effective. The distance of this bar from the anchor shall not exceed $0.5c_{a1}$ and the anchorage length in the breakout body shall not be less than 4 times the bar diameter. The distance between stirrups shall not exceed the smaller of anchor spacing or 6 inches.

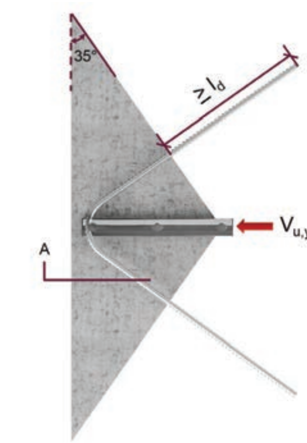


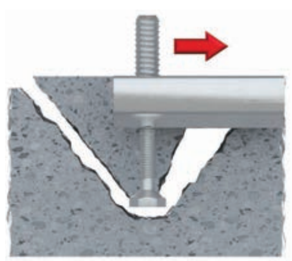

**Figure 7.4.4.6 — Anchor reinforcement to resist shear loads acting along the longitudinal axis of the anchor channel.**

Because the anchor reinforcement is placed below where the shear is applied, the force in the anchor reinforcement will be larger than the shear force acting on the anchor channel bolts. If a shear load ($V_{ua,y}$) is acting on the anchor channel, the resultant factored tension force of the anchor reinforcement, $N_{ua,re}$, shall be computed by the following equation:

$$N_{ua,re} = V_{ua,y}\left(\frac{e_s}{z} + 1\right)\ lbf\,(N)$$

$e_s$ = distance between reinforcement and shear force acting on the anchor channel (in)
z = internal lever arm of the concrete member, (in)
= 0.85 (h – $h_{ch}$ – $0.5d_a$)
< ($2h_{ef}$, $2c_{a1}$)

## Concrete Pryout Strength of Anchor Channels in Shear Longitudinal to the Channel Axis $\phi V_{cp,x}$



Failure load associated with pry-out; The load-bearing mechanism of a single headed stud anchorage subjected to a shear load is illustrated schematically in Figure 7.4.47. The applied shear load gives rise to bearing stresses in the concrete. With increasing load, the surface concrete is crushed or spalled, shifting the centroid of resistance $V_b$ to a location deeper in the concrete.

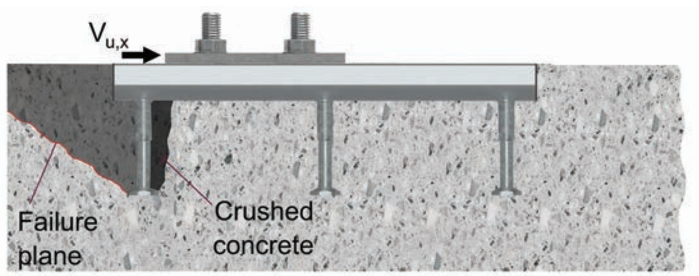



**Figure 7.4.4.7 — Load-bearing mechanism of headed stud anchorage subjected to shear loading (schematic).**

Also with increasing load and stud elongation, the baseplate rotates and loses contact with the concrete on the loaded side. These two mechanisms act to further increase the eccentricity between the applied shear load V and the stress resultant Vb in the concrete. The moment resulting from this eccentricity generates a compressive force C between baseplate and concrete and a tensile force N in the stud. If the tensile force in the stud exceeds the tensile capacity associated with the maximum fracture surface that can be activated by the stud, a fracture surface originating at the head of the stud and projecting in conical fashion behind the stud forms. This is defined as a pry-out failure.

$$V_{cp,x} = k_{cp} N_{cb}, \; lb(N)$$
$$k_{cp} = 2.0$$

ESR-3520 Equation (41)

The nominal pryout strength, $V_{cp,x}$, in shear of a single anchor of an anchor channel without anchor reinforcement shall be computed in accordance with ESR 3520 Eq. (41).

$$N_{cb} = N_b \cdot \psi_{s,N} \cdot \psi_{ed,N} \cdot \psi_{co,N} \cdot \psi_{c,N} \cdot \psi_{cp,N}$$

where:

$k_{cp}$ = shall be taken from Table 8-10

$N_{cb}$ = nominal concrete breakout strength of the anchor under consideration, lb (N), determined in accordance with breakout in tension; however in the determination of the modification factor $\psi_{s,N}$, the values $N^a_{ua,1}$ and $N^a_{ua,i}$ in Eq. (10) shall be replaced by $V^a_{ua,1}$ and $V^a_{ua,i}$, respectively.

The nominal pryout strength, $V_{cp,y}$, in shear of a single anchor of an anchor channel with anchor reinforcement shall not exceed:

$$V_{cp} = V_{cp,x} = 0.75 k_{cp} N_{cb}, \; lb(N)$$

ESR-3520 Equation (42)

The ICC-ES Acceptance Criteria AC232 includes amendments to the ACI 318 anchoring to concrete provisions. These amendments are given in Section 3.1 Strength Design — Amendments to ACI 318. Part D.6.3.2 (ACI 318-11) and Section 17.5.3.2 (ACI 318-14) of these amendments requires the factor $\psi_{s,N}$ to be modified when calculating concrete pryout strength in shear. All of the parameters used to calculate $\psi_{s,N}$ in tension are used except the parameter ($N^a_{ua,i}$ / $N^a_{ua,1}$). The shear loads acting on the anchor elements are substituted for the tension loads such that ($V^a_{ua,i}$ / $V^a_{ua,1}$) is used instead of ($N^a_{ua,i}$ / $N^a_{ua,1}$).

**Minimum Member Thickness, Anchor Spacing, and Edge Distance:**

Anchor channels shall satisfy the requirements for edge distance, spacing, and member thickness.

The minimum edge distance, minimum and maximum anchor spacing and minimum member thickness shall be taken from Table 8-1 ESR-3520. The critical edge distance, $c_{ac}$, shall be taken from Table 8-4 ESR-3520.

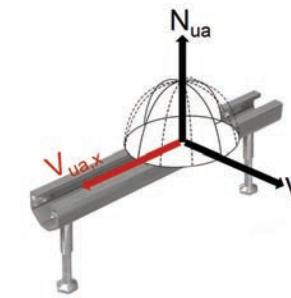
$c_{ac}$ : Edge distance required to develop full concrete capacity in absence of anchor reinforcement.

**Requirements for lightweight concrete:**

For the use of anchor channels in lightweight concrete, the modification factor λ shall be taken as 0.75 for all-lightweight concrete and 0.85 for sand-lightweight concrete. Linear interpolation shall be permitted if partial sand replacement is used.



# 7.5 INTERACTION EQUATIONS:




If forces act in more than one direction, the combination of loads has to be verified. Anchor channels subjected to combined tension and shear loads shall be designed to satisfy the following requirements by distinguishing between steel failure of the channel bolt, steel failure modes of the channel and concrete failure modes. Interaction equations for each anchor channel element are required. Moreover, concrete and steel utilizations need not to be combined. The verification of up to 5 interaction equations are required.

## Steel Failure of Channel Bolts Under Combined Loads

$$\left(\frac{N^b_{ua}}{\phi N_{ss}}\right)^2 + \left(\frac{V^b_{ua}}{\phi V_{ss}}\right)^2 \le 1.0$$

ESR-3520 Equation (43)

$$V^b_{ua} = \left[\left(V^b_{ua,y}\right)^2 + \left(V^b_{ua,x}\right)^2\right]^{0.5}$$

This verification is not required in case of shear load with lever arm as Eq. (28) accounts for the interaction.

## Steel Failure Modes of Anchor Channels Under Combined Loads:

Interaction equations based on Acceptance Criteria 232, February 2019. ICC ESR-3520 to be updated.

**a) Anchor and connection between anchor and channel:**

$$\max\left(\frac{N^a_{ua}}{\phi N_{sa}}, \frac{N^a_{ua}}{\phi N_{sc}}\right)^{\alpha} + \max\left(\frac{V^a_{ua,y}}{\phi V_{sa,y}}, \frac{V^a_{ua,y}}{\phi V_{sc,y}}\right)^{\alpha} + \max\left(\frac{V^a_{ua,x}}{\phi V_{sa,x}}, \frac{V^a_{ua,x}}{\phi V_{sc,x}}\right)^{2} \le 1.0$$

ESR-3520 Equation (44)

where:

α = 2 for anchor channels with max ($V_{sa,y}$; $V_{sc,y}$) ≤ min ($N_{sa}$; $N_{sc}$)

In all other cases:

α = 1 for anchor channels with max ($V_{sa,y}$; $V_{sc,y}$) > min ($N_{sa}$; $N_{sc}$)

It shall be permitted to assume reduced values for $V_{sa,y}$ and $V_{sc,y}$ corresponding to the use of an exponent α = 2. In this case the reduced values for $V_{sa,y}$ and $V_{sc,y}$ shall also be used.

**b) At the point of load application:**

$$\left(\frac{N^b_{ua}}{\phi N_{sl}}\right)^{\alpha} + \left(\frac{V^b_{ua,y}}{\phi V_{sl,y}}\right)^{\alpha} + \left(\frac{V^b_{ua,x}}{\phi V_{sl,x}}\right)^{2} \le 1.0$$

ESR-3520 Equation (45)

$$\left(\frac{M_{u,flex}}{\phi M_{s,flex}}\right)^{\alpha} + \left(\frac{V^b_{ua,y}}{\phi V_{sl,y}}\right)^{\alpha} + \left(\frac{V^b_{ua,x}}{\phi V_{sl,x}}\right)^{2} \le 1.0$$

ESR-3520 Equation (46)

where:

α = 2 for anchor channels with $V_{sl,y}$ ≤ $N_{s,l}$

α = 1 for anchor channels with $V_{sl,y}$ > $N_{s,l}$

It shall be permitted to assume reduced values for $V_{sl,y}$ corresponding to the use of an exponent α = 2. In this case the reduced value for $V_{sl,y}$ shall also be used.

Concrete failure modes of anchor channels under combined loads:

## Concrete Failure Modes of Anchor Channels Under Combined Loads:

For concrete failure modes, anchor channels shall be designed to satisfy the requirements given in a) through d). D.7.4.3, Section D.7.4.3 (ACI 318-14) :

Section D.7.4.3.1, Section 17.6.4.3.1 (ACI 318-14) through D.7.4.3.3, Section 17.6.4.3.3 (ACI 318-14).

a) D.7.4.3.1, Section 17.6.4.3.1 (ACI 318−14) − If

$$\left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right) + \left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right) \le 0.2$$

then the full strength in tension shall be permitted:

$$\left(\frac{N^a_{ua,y}}{\phi N_{nc}}\right) \le 1.0$$

b) D.7.4.3.2, Section 17.6.4.3.2 (ACI 318−14) − If

$$\left(\frac{N^a_{ua,y}}{\phi N_{nc}}\right) \le 0.2$$

then the full strength in shear shall be permitted:

$$\left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right) + \left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right) \le 1.0$$

c) D.7.4.3.3, Section 17.6.4.3.3 (ACI 318−14)− If

$$\left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right) + \left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right) > 0.2 \quad and \quad \left(\frac{N^a_{ua,y}}{\phi N_{nc}}\right) > 0.2$$

then Eq. (D−32e), Eq. ( 17.6.4.3.a ACI318−14) applies:

$$\left(\frac{N^a_{ua}}{\phi N_{nc}}\right) + \left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right) + \left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right) \le 1.2$$

d) D.7.4.3.4, Section 17.6.4.3.4 (ACI 318−14) − Alternatively, instead of satisfying “a” through “c” , the interaction equation may be satisfied:

$$\left(\frac{N^a_{ua}}{\phi N_{nc}}\right)^{\frac{5}{3}} + \left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right)^{\frac{5}{3}} + \left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right)^{\frac{5}{3}} \le 1.0$$

# 7.6 SEISMIC DESIGN

## 7.6.1 SEISMIC CONSIDERATIONS

The anchors in structures assigned to Seismic Design Category (SDC) C, D, E, or F shall satisfy the additional requirements of 17.2.3.2 through 17.2.3.7 of ACI 318-14.Unless 17.2.3.4.1 or 17.2.3.5.1 apply, all anchors in structures assigned to Seismic Design Categories (SDC) C, D, E, or F are required to satisfy the additional requirements of 17.2.3.1 through 17.2.3.7, regardless of whether earthquake loads are included in the controlling load combination for the anchor design.

- The most recent development of structural classification has been the establishment of seismic design categories to determine seismic detailing requirements. Recognizing that building performance during a seismic event depends not only on the severity of subsurface rock motion, but also on the type of soil upon which a structure is founded, the Seismic Design Category (SDC) is a function of location, building occupancy, and soil type.
- Seismic provisions are applicable for all the load combinations if the condition is in a project located in SDC C, D, E or F.
- The behavior of concrete under static and seismic loading is
- different. Concrete member statically loaded have defined tensile and compression zones. Cracking of the concrete due to static loads is predictable, well understood, and the crack width is limited to 0.3 mm.
- Concrete members that undergo seismic loads deal with more unpredictable loads. Additional safety factors are built-in the seismic design to deal with such variances. Due to the cycling nature of seismic loads, tension and compression zones can be inverted and cracking of the concrete can occur through the structure. Moreover, according to extensive research results, the crack width can be up to 0.5mm during seismic events. Crack open and closes dramatically, concrete tends to pushing anchor out during crack closing. Where as crack open and close with changing of live load, crack close naturally.
- The wind analysis should also have the seismic design provision of reduced tensile strengths associated with concrete failure modes. This is applicable to account for increased cracking and spalling in the concrete resulting from seismic actions.
- Non-structural systems (suspended ceilings, conduit attachments, mechanical, plumbing, electrical and communications equipment, doors, windows, wood sill plates, cold-formed steel track attachments, and architectural components) suffer the largest damage in commercial buildings during an earthquake. Since nonstructural elements of a building are not a part of the main load resisting system, they are often neglected from the structural design point of view. It's important to include seismic design for both structural and non-structural elements as Seismic conditions significantly change the behavior of anchors, compared to static conditions. Research is compelling! The percentage of damage caused by non-structural elements is significantly higher than structural elements.

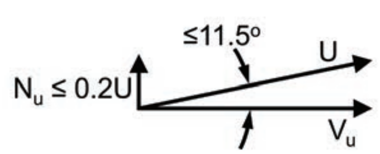
According to ACI 318-14 Section 17.2.3.2: The provisions of the chapter 17 do not apply to the design of anchors in plastic hinge zones of concrete structures under earthquake forces.

- The possible higher levels of cracking and spalling in plastic hinge zones are beyond the conditions for which the nominal concrete governed strength values are applicable.
- Plastic hinge zones are considered to extend a distance equal to twice the member depth from any column or beam face, and also include any other sections in walls, frames, and slabs where yielding of reinforcement is likely to occur as a result of lateral displacements.
- Where anchors must be located in plastic hinge regions, they should be detailed so that the anchor forces are transferred directly to anchor reinforcement that is designed to carry the anchor forces into the body of the member beyond the anchorage region. Configurations that rely on concrete tensile strength should not be used.

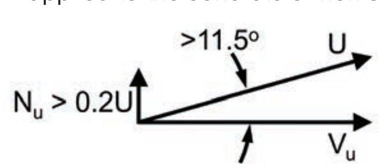
## 7.6.2 SEISMIC CONSIDERATIONS TENSION

**The Requirements for tensile loading is stated in section 17.2.3.4 of ACI 318-14**

- 17.2.3.4.1 Where the tensile component of the strength level earthquake force applied to a single anchor or group of anchors is equal to or less than 20 percent of the total factored anchor tensile force associated with the same load combination, it shall be permitted to design a single
- anchor or group of anchors.

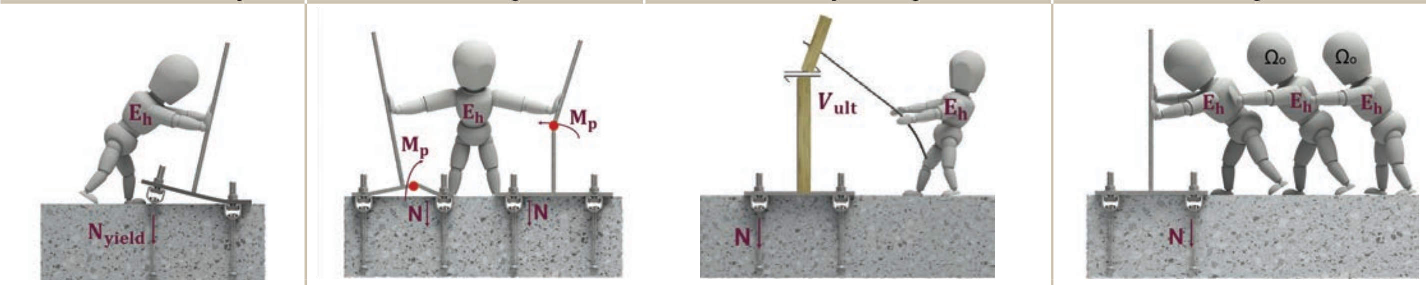



- 17.2.3.4.2 Where the tensile component of the strength level earthquake force applied to anchors exceeds 20 percent of the total factored anchor tensile force associated with the same load combination, anchors and their attachments shall be designed in accordance with 17.2.3.4.3 as described in Figure 7.6.2.1 and 7.6.2.2 . The anchor design tensile strength shall be determined in accordance with 17.2.3.4.4, which states that an additional seismic reduction factor of 0.75 is applied to the concrete or non steel tensile design strengths.




- The requirements of 17.2.3.4.3 need not apply where the applied earthquake tensile force is a small fraction of the total factored tension force.

| Anchor | Design of Attachment | | Seismic Load |
|---|---|---|---|
| Option a) Anchor Ductility | Option b) Yielding | Option c) Non-yielding | Option d) Overstrength Factor |




a) Anchor resistance governed by ductile anchor yield 17.2.3.4.3(a) | b) Anchorage designed for a plastic hinge 17.2.3.4.3(b) | c) Anchorage designed for capacity of structural system 17.2.3.4.3(c) | d) Anchorage designed for a multiple of the calculated seismic force 17.2.3.4.3(d)

**Figure 7.6.2.1— Seismic provisions for tension; ACI 318-14 Section 17.2.3.4.3.**

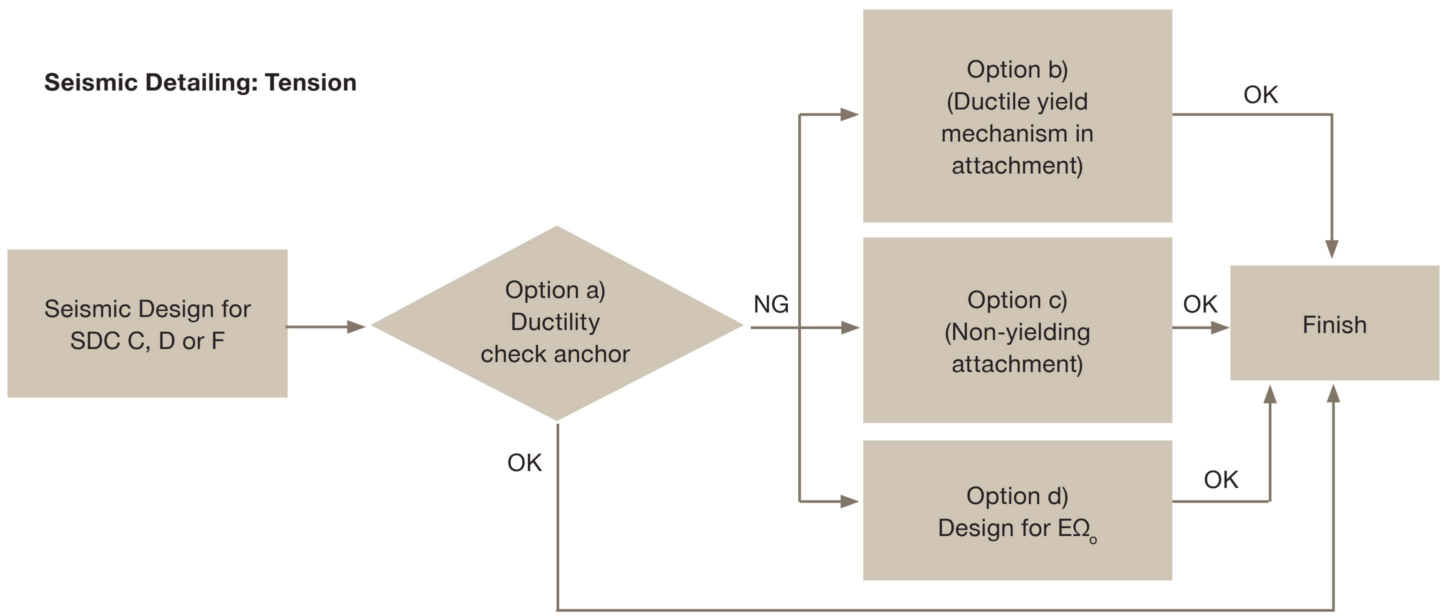



**Figure 7.6.2.2 — Flow chart — Seismic provisions for tension; ACI 318-14 Section 17.2.3.4.3**

**Refer to Figure 7.6.2.1 and 7.6.2.2 explaining the requirements in ACI 318-14 Section 17.2.3.4.3 in figure and in a flow chart.**

- **Option a):** For tension loadings, anchor strength should be governed by yielding of the ductile steel element of the anchor. For single anchors, the concrete-governed strength shall be greater than the steel strength of the anchor. For anchor groups, the ratio of the tensile load on the most highly stressed anchor to the steel strength of that anchor shall be equal to or greater than the ratio of the tensile load on tension loaded anchors to the concrete-governed strength of those anchors. In each case:
  (i) The steel strength shall be taken as 1.2 times the nominal steel strength of the anchor.
  (ii) The concrete-governed strength shall be taken as the nominal strength considering pullout, side-face blowout, concrete breakout, and bond strength as applicable. For consideration of pullout in groups, the ratio shall be calculated for the most highly stressed anchor. In addition, the following shall be satisfied:
  (iii) Anchors shall transmit tensile loads via a ductile steel element with a stretch length of at least eight anchor diameters unless otherwise determined by analysis.
  (iv) Where anchors are subject to load reversals, the anchor shall be protected against buckling.
  (v) Where connections are threaded and the ductile steel elements are not threaded over their entire length, the ratio of $f_{uta}/f_{ya}$ shall not be less than 1.3 unless the threaded portions are upset. The upset portions shall not be included in the stretch length.
  (vi) Deformed reinforcing bars used as ductile steel elements to resist earthquake effects shall be limited to ASTM A615 Grades 40 and 60 satisfying the requirements of ACI 318-14 20.2.2.5(b) or ASTM A706 Grade 60.

The design of anchors in accordance with option (a) should be used only where the anchor yield behavior is well defined and where the interaction of the yielding anchor with other elements in the load path has been adequately addressed

Please note that when it comes to anchor channel none of the manufacturers satisfy ductility requirements. We are now left with satisfying one of the other three seismic requirement options.

**Option b)** The anchor or group of anchors shall be designed for the maximum tension that can be transmitted to the anchor or group of anchors based on the development of a ductile yield mechanism in the attachment in tension, flexure, shear, or bearing, or a combination of those conditions, and considering both material overstrength and strain hardening effects for the attachment. The anchor design tensile strength shall be calculated from 17.2.3.4.4, which states that an additional seismic reduction factor of 0.75 is applied to the concrete or non steel tensile design strengths. For the design of anchors, the force associated with yield of a steel attachment, such as an angle, baseplate, or web tab, should be the expected strength, rather than the specified yield strength of the steel.

**Option (c)** The anchor or group of anchors shall be designed for the maximum tension that can be transmitted to the anchors by a non-yielding attachment. The anchor design tensile strength shall be calculated from 17.2.3.4.4, which states that an additional seismic reduction factor of 0.75 is applied to the concrete or non steel tensile design strengths. This option may apply to a variety of special cases, such as the design of sill bolts where the crushing of the wood limits the force that can be transferred to the bolt, or where the provisions of the American National Standards Institute/American Institute of Steel Construction (AISC) Code Seismic Provisions for Structural Steel Buildings (AISC 341) specify loads based on member strengths.

**Option d)** The anchor or group of anchors shall be designed for the maximum tension obtained from design load combinations that include E, with E increased by $\Omega_o$. The anchor design tensile strength shall satisfy the tensile strength requirements of 17.2.3.4.4, which states that an additional seismic reduction factor of 0.75 is applied to the concrete or non steel tensile design strengths. This seismic provisions intend to ensure anchors resisting significant seismic forces do not undergo sudden brittle failure. One way to achieve this is to add sufficient extra strength to the anchor by design, so that the failure must occur elsewhere in the system. Increasing the earthquake inertial load with an overstrength factor Ωo has been included in the ACI 318-14 standard as one of four possible options for preventing premature anchor failure. Here ACI refers us back to ASCE 7-10 load combination 5 and 7 of chapter 12.

5. (1.2+ 0.2SDS) D+ $\Omega_o Q_E$+ L + 0.2S

6. (0.9- 0.2SDS) D + $\Omega_o Q_E$ + 1.6H

$\Omega_o$ overstrength factor for architectural component can be obtained from Table 13.5.1 of ASCE 7-10 and for structural components from Table 12.2.1.

| $\Omega_o$ Structural component | ASCE 7-10 chapter 12 Table 12.2.1 |
|---|---|
| $\Omega_o$ Non structural component | ASCE 7-10 chapter 13 Table 13.5.1 |

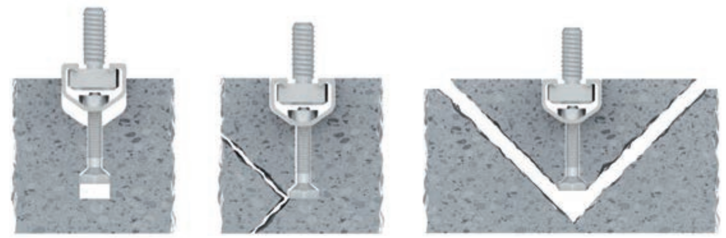


**Figure 7.6.2.3 — Tensile anchor channel failure modes with an additional 0.75 reduction strength when resisting earthquake forces**

According to ACI 318-14 section 17.2.3.4.4 The anchor design tensile strength for resisting earthquake forces shall be determined from consideration of (a) through (e) for the non steel tensile failure modes assuming the concrete is cracked unless it can be demonstrated that the concrete remains uncracked:

(a) $\phi N_{sa}$ for a single anchor, or for the most highly stressed individual anchor in a group of anchors
(b) $0.75\phi N_{cb}$ or $0.75\phi N_{cbg}$, except that $N_{cb}$ or $N_{cbg}$ need not be calculated where anchor reinforcement is provided
(c) $0.75\phi N_{pn}$ for a single anchor, or for the most highly stressed individual anchor in a group of anchors
(d) $0.75\phi N_s$b or $0.75\phi N_{sbg}$
(e) $0.75\phi N_a$ or $0.75\phi N_{ag}$

where ϕ is in accordance with ACI 318-14 section 17.3.3.

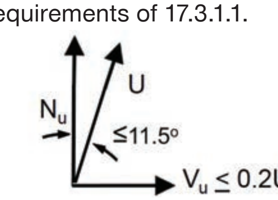
Where anchor reinforcement is provided in accordance with 17.4.2.9, no reduction in design tensile strength beyond that specified in 17.4.2.9 shall be required. The reduced anchor nominal tensile strengths associated with concrete failure modes is to account for increased cracking and spalling in the concrete resulting from seismic actions. Because seismic design generally assumes that all or portions of the structure are loaded beyond yield, it is likely that the concrete is cracked throughout for the purpose of determining the anchor strength. In locations where it can be demonstrated that the concrete does not crack, uncracked concrete may be assumed for determining the anchor strength as governed by concrete failure modes.



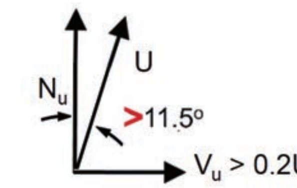
## 7.6.3 SEISMIC CONSIDERATIONS SHEAR

**Requirements for shear loading is stated in ACI 318-14 Section 17.2.3.5**

- According to ACI-318-14 section 17.2.3.5.1. Where the shear component of the strength level earthquake force applied to the anchor or group of anchors is equal to or less than 20 percent of the total factored anchor shear force associated with the same load combination, it shall be permitted to design the anchor or group of anchors to satisfy 17.5 and the shear strength requirements of 17.3.1.1.




- 17.2.3.5.2 Where the shear component of the strength level earthquake force applied to anchors exceeds 20 percent of the total factored anchor shear force associated with the same load combination, anchors and their attachments shall be designed in accordance with 17.2.3.5.3 as described in Figure 7.6.3.1 and 7.6.3.2 .



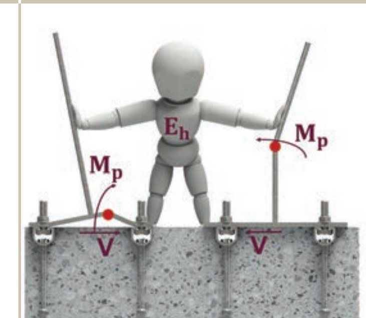
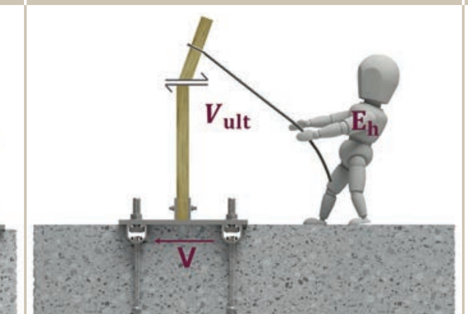
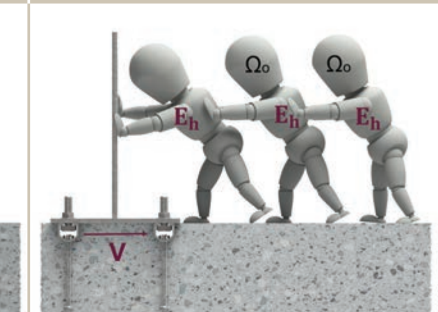

| Anchor | Design of Attachment | | Seismic Load |
|---|---|---|---|
| Anchor Ductility | Option a) Yielding | Option b) Non-yielding | Option c) Overstrength Factor |
|  |   a) Anchorage designed for a plastic hinge 17.2.3.5.3(a) |   (b) Anchorage designed for capacity of structural system 17.2.3.5.3(b) |   c) Anchorage designed for a multiple of the calculated seismic force 17.2.3.5.3(c) |

**Figure 7.6.3.1 — Seismic provisions for tension; ACI 318-14 Section 17.2.3.5.3.**

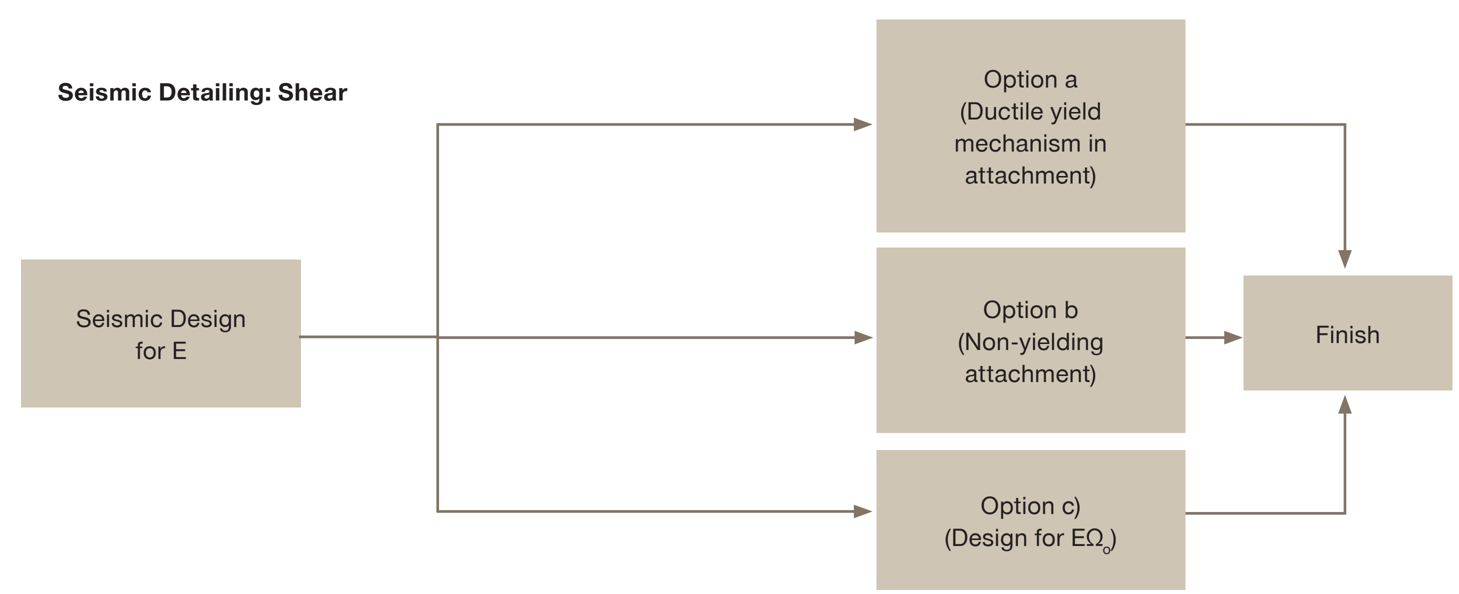



**Figure 7.6.3.2 — Flow chart - Seismic provisions for tension; ACI 318-14 Section 17.2.3.5.3**

- Refer to Figure 7.6.3.1 and 7.6.3.2 explaining the requirements in ACI 318-14 Section 17.2.3.5.3 in figure and in a flow chart.

  **Option (a)** of 17.2.3.4.3 Ductility requirement of tension is not available for shear because the cross section of the steel element of the anchor cannot be configured so that steel failure in shear provides any meaningful degree of ductility.

  17.2.3.5.3 Anchors and their attachments shall be designed using one of options (a) through (c):

- **Option a)** The anchor or group of anchors shall be designed for the maximum shear that can be transmitted to the anchor or group of anchors based on the development of a ductile yield mechanism in the attachment in flexure, shear, or bearing, or a combination of those conditions, and considering both material overstrength and strain hardening effects in the attachment.

- **Option b)** The anchor or group of anchors shall be designed for the maximum shear that can be transmitted to the anchors by a nonyielding attachment.

- **Option c)** The anchor or group of anchors shall be designed forthe maximum shear obtained from design load combinations that include E, with E increased by $\Omega_o$. This seismic provisions intend to ensure anchors resisting significant seismic forces do not undergo sudden brittle failure. One way to achieve this is to add sufficient extra strength to the anchor by design, so that the failure must occur elsewhere in the system. Increasing the earthquake inertial load with an overstrength factor Ωo has been included in the ACI 318-14 standard as one of four possible options for preventing premature anchor failure. Here ACI refers us back to ASCE 7-10 load combination 5 and 7 of chapter 12.

5. (1.2+ 0.2SDS) D+ ΩoQE+ L + 0.2S

6. (0.9- 0.2SDS) D + ΩoQE + 1.6H

$\Omega_o$ overstrength factor for architectural component can be obtained from Table 13.5.1 of ASCE 7-10 and for structural components from Table 12.2.1.

| $\Omega_o$ Structural component | ASCE 7-10 chapter 12 Table 12.2.1 |
|---|---|
| $\Omega_o$ Non structural component | ASCE 7-10 chapter 13 Table 13.5.1 |

## 7.6.4 TRANSFER OF LONGITUDINAL FORCES

- Historically, longitudinal loads in anchor channels have been transferred by means of friction. AC232 requires a positive connection for transferring of the forces.
- Traditionally the longitudinal loads are transferred by means of friction
- The loads are assumed to be transferred is larger than the frictional resistance caused by tightening the bolts
- The bolts are fully pretensioned to cause a clamping force between the connected components, which allows frictional resistance to develop between them
- The frictional resistance prevents the connected components from slipping into bearing against the body of the bolt
- To ensure successful performance, the faying surfaces require special preparation
- The longitudinal load transfer depended on installation and special inspection on site
- There were no measures that would include into the design for reduction of capacity

In order to validate the global level of safety or conservatism for a product application, AC232 section 1.3.2 states that the load transfer in the longitudinal direction shall not rely on friction.

Where compliance is sought for seismic loading or for static shear loading along the longitudinal axis of the anchor channel, the longitudinal loads shall be transferred by a positive load transfer mechanism.

The anchor channel must be flush with the substrate surface and installed with specified installation torque to ensure proper interlock between channel lip and t-bolt.

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Transfer of shear load in the direction of the longitudinal channel axis from the channel bolt via channel and anchors into the concrete shall use a positive load transfer mechanism that shall be capable to ensure safe and effective behavior under normal and adverse conditions., both during installation and in service. Factors included are installation conditions in concrete and torqueing of the channel bolts.

The transferring of longitudinal forces shall not rely on friction. The cycling nature of seismic loading combined with the long-term relaxation of the nut and the high sensitivity to installation error are some of the major reasons why a positive load transfer mechanism (a connection that does not rely on friction) is required.

Anchor channels provide two options to positively transfer longitudinal forces; using locking channel bolts with smooth channel profiles or serrated channels with serrated bolts. AC232 covers both systems. The load transfer mechanism is mechanical interlock.

**Locking t-bolt HBC-N with HAC plain profile**

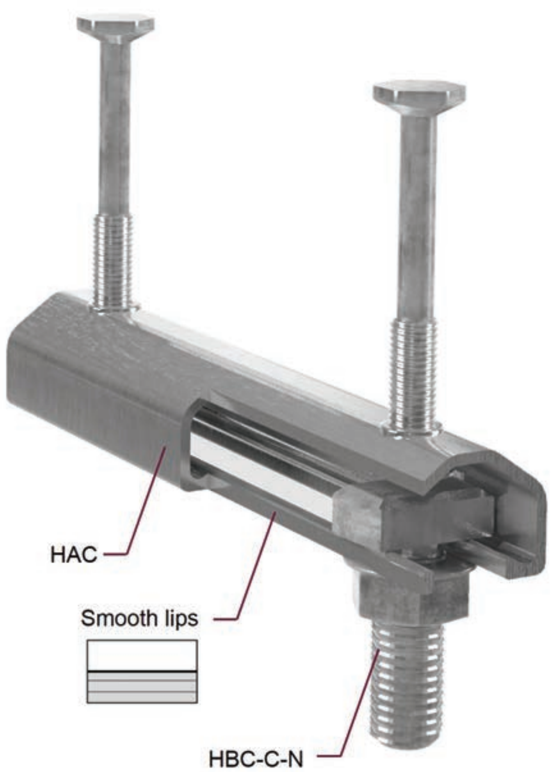



**Figure 7.6.4.1: Standard HAC channel with locking t-bolt HBC-C-N.**

- Positive connection via mechanical interlock between channel lips and t-bolt head
- (4) Notches in channel lip are created by HBC-C-N after installation torque is applied.
- The ϕ value is 0.55 for in which periodical inspection is provided for all t-bolts.
- The ϕ value is 0.65 for in which continuous inspection is provided for M16 and M20 t-bolts.
- The steel strength for M12 t-bolts used with continuous inspection an increased value of 2,021lbs should be used with ϕ value of 0.55.

**Serrated t-bolt HBC-T with HAC-T serrated profile**

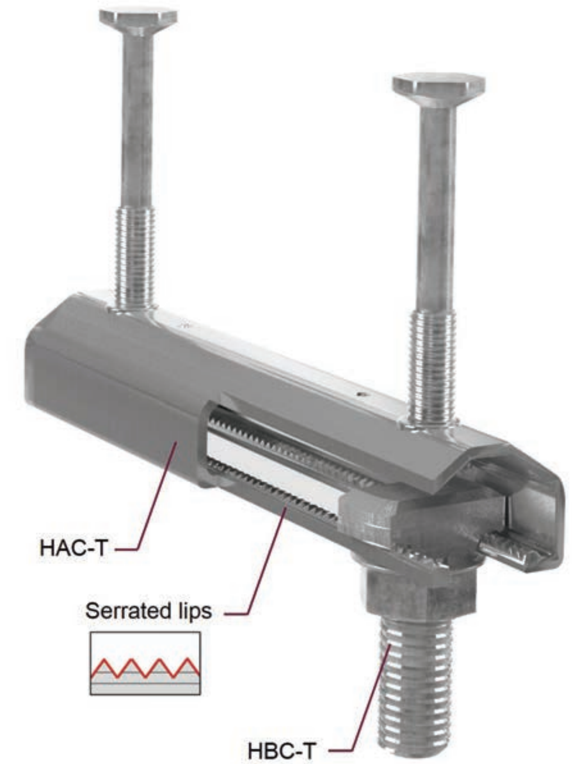



**Figure 7.6.4.2 Serrated channel-HAC-T with HBC-T bolts.**

- Positive connection via mechanical interlock between channel lips and t-bolt head.
- Channel comes with pre-made serrations. Installation torque is lower than the one required for the notched t-bolt.
- The ϕ value is 0.65 for in which periodical inspection is
- provided for M12 to M20 t-bolts.
- The ϕ value is 0.75 for in which continuous inspection is
- provided for M12 to M20 t-bolts.

Note:
HAC-30 comes with serrated channel lips. HAC-30 matching serrated t-bolts are HBC-B.

## 7.6.5 ANALYSIS IN SCD A OR AND SDC C, D, E OR F

**Seismic tension Seismic Loading (SDC C, D, E and F)**

All anchor channels systems in a test series shall complete the simulated seismic-tension load history. Subject the anchor channel to the sinusoidal tension loads with a cycling frequency between 0.1 and 2 Hz. All anchor channels systems in a test series shall complete the simulated seismic-tension load history specified. Failure of an anchor channel system to develop the required tension resistance in any cycle before completing the loading history shall be recorded as a failure of an anchor channel system to develop the required tension resistance in any cycle before completing the loading history. Test No. 12 is performed to extract seismic strength values for various failure listed above.

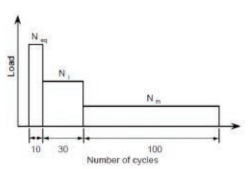



Figure 7.6.4.1 — Required load history for simulated seismic tension test

**Table 7.1-a — Required load history for simulated seismic tension test**

| Load level | $N_{eq}$ | $N_i$ | $N_m$ |
|---|---|---|---|
| Number of cycles | 10 | 30 | 100 |

Nominal bending strength of the anchor channel for seismic design HBC-C-N and HBC-T

$\phi M_{s,flex,seis} \geq M_{u,flex}$

$M_{s,flex,seis}$ and $\phi$ are tabulated in Table ESR-3520 Table 8-3

Nominal tensile strength of a channel bolt for seismic design

$\phi N_{ss,seis} \geq N^{b}_{ua}$

$N_{ss,seis}$ and $\phi$ are tabulated in Table ESR-3520 Table 8-10

Nominal tensile steel strength for local failure of channel lips for seismic design

$\phi N_{sl,seis} \geq N^{b}_{ua}$

$N_{sl,seis}$ and $\phi$ are tabulated in Table ESR-3520 Table 8-3

Nominal tensile steel strength of a single anchor for seismic design

$\phi N_{sa,seis} \geq N_{aua}$

$N_{sa,seis}$, and $\phi$ are tabulated in Table ESR-3520 Table 8-3

Nominal tensile steel strength of connection between anchor and channel for seismic design

$\phi N_{sc,seis} \geq N_{aua}$

$N_{sc,seis}$ and $\phi$ are tabulated in Table ESR-3520 Table 8-3

Anchors in structures assigned to Seismic Design Category (SDC) C, D, E, or F shall satisfy the additional requirements

According to section ACI 318-14 section17.2.3.4.4 $0.75\phi N_{pn}$ for a single anchor, or for the most highly stressed individual anchor in a group of anchors. $\phi_{seis}$ is 0.75.

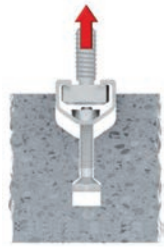
**AC232 Table 4.2 — Optional test program for anchor channels for use in uncracked and cracked concete for shear loading in longitudinal channel axis and for siesmic loading (SDS C, D, E and F)**

| Test no. | Test Ref | Test description | $f_c$ | Δw | Minimum No. of tests | Channel | Anchor | Material | Channel bolt $d_s$ | Channel bolt strength |
|---|---|---|---|---|---|---|---|---|---|---|
| [-] | Secion in Annex A | [-] | psi [N/mm²] | inch (mm) | [-] | [-] | [-] | [-] | inch (mm) | [-] |
| Seismic Tests | | | | | | | | | | |
| 12 | 7.12 | Seismic tension | Low | 0.020 (0.5) | 5 | see Section 7.12.2 | | | | 1 |
| 13 | 7.13 | Seismic shear perpendicular to the channel profile | Low | 0 | 5 | see Section 7.13.2 | | | | 1 |
| 14 | 7.14 | Seismic shear in longtitudinal channel axis | Low | 0.020 (0.5) | 5 | see Section 7.15.2 | | | | 1 |



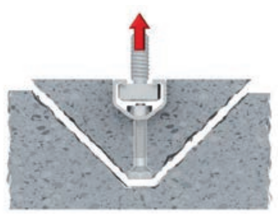
Apply a seismic reduction factor ($\phi_{seismic}$) of 0.75 to non-steel tension design strengths per ACI 318-14 Section 17.2.3.4.4.

The reduced anchor nominal tensile strengths associated with concrete failure modes is to account for increased cracking and spalling in the concrete resulting from seismic actions. Because seismic design generally assumes that all or portions of the structure are loaded beyond yield, it is likely that the concrete is cracked throughout for the purpose of determining the anchor strength. In locations where it can be demonstrated that the concrete does not crack, uncracked concrete may be assumed for determining the anchor strength as governed by concrete failure modes.



$\phi \cdot \phi_{seismic} N_{pn} \geq N^{a}_{ua}$

$\phi \cdot \phi_{seismic} N_{sb} \geq N^{a}_{ua}$



$\phi \cdot \phi_{seismic} N_{cb} \geq N^{a}_{ua}$

**Seismic shear perpendicular to the channel profile Seismic Loading (SDC C, D, E and F)**

All anchor channels systems in a test series shall complete the simulated seismic-shear loads. Test No. 13 is performed to extract seismic strength values for the various failures listed below.

Perform the tests on anchor channels with two anchors embedded in concrete. The frequency of loading shall be between 0.1 and 2 Hz. To reduce the potential for uncontrolled slip during reversal, the alternating shear loading shall be permitted to be approximated by the application of two half-sinusoidal load cycles at the desired frequency connected by a reduced-speed, ramped load as shown in figure 7.8. The edge distance shall be large enough to avoid an edge influenced failure.

**Table 7.1-b — Required load history for simulated seismic shear test**

| Load level | $\mp V_{eq}$ | $\mp V_i$ | $\mp V_m$ |
|---|---|---|---|
| Number of cycles | 10 | 30 | 100 |

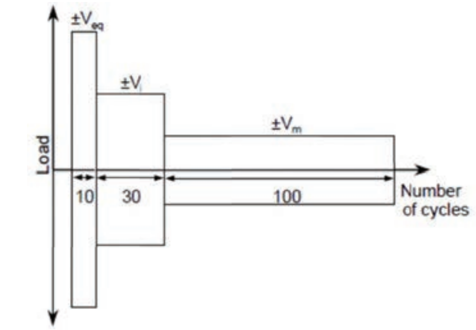



Figure 7.5.4.2 — Required load history for simulated seismic shear test (Figure taken from AC232, Figure 7.7).

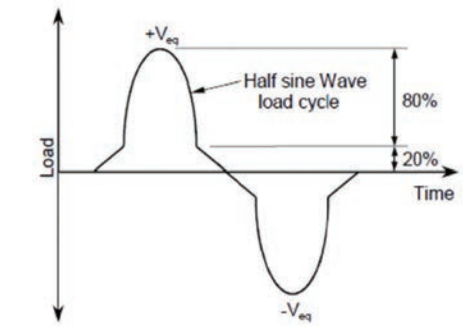



Figure 7.5.4.3— Permitted approximation of seismic shear cycle (Figure taken from AC232, Figure 7.8).

Nominal shear steel strength for local failure of the channel lips for seismic design

$\phi V_{sl,y,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-5
$\phi V_{sl,y,seis} \geq V^{b}_{ua}$

Nominal shear steel strength of a single anchor for seismic design

$V_{sa,y,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-5
$\phi V_{sa,y,seis} \geq V^{a}_{ua}$

Nominal shear steel strength of connection between anchor and channel for seismic design

$V_{sc,y,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-5
$\phi V_{sc,y,seis} \geq V^{a}_{ua}$

Nominal shear steel strength of a single anchor for seismic design

$V_{sa,y,seis}$, and $\phi$ are tabulated in ESR-3520 Table 8-5
$\phi V_{sa,y,seis} \geq N^{a}_{ua}$

Nominal shear strength of a channel bolt for seismic design and Nominal flexural strength of the channel bolt for seismic design

$V_{ss,seis}$ , $M_{ss,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-11
$\phi V_{ss,y,seis} \geq V^{b}_{ua}$

**Seismic shear longitudinal to the channel profile**
**Seismic Loading (SDC C, D, E and F)**

All anchor channels systems in a test series shall complete the simulated seismic-shear loads. Test No. 14 is performed to extract seismic strength values for the various failures listed below.

Perform the tests on anchor channels to evaluate the nominal shear strength of the connection between the channel lips and channel bolt for shear acting in longitudinal axis without influence of concrete edges. Test No. 14 shall be permitted to be performed with anchor channels with two anchors outside of the concrete with the maximum anchor spacing and the minimum distance between the end of the channel and the anchor axis. The frequency of loading shall be between 0.1 and 2 Hz. To reduce the potential for uncontrolled slip during load reversal, the alternating shear loading shall be permitted to be approximated by the application of two half-sinusoidal load cycles at the desired frequency connected by a reduced-speed, ramped load as shown in Figure 7.8 of this annex.

Nominal shear steel strength in the longitudinal direction for local failure of the channel lips for seismic design anchor channel HAC-T with t-bolt HBC-T

$\phi\, V_{sl,x,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-6
$\phi\, V_{sl,x,seis} \geq V^{b}_{ua}$

Please note the following:

- The $\phi$ value is 0.65 for which periodical inspection is provided for M12 to M20 t-bolts
- The $\phi$ value is 0.75 for which continuous inspection is provided for M12 to M20 t-bolts

Nominal shear steel strength in longitudinal direction for local failure of the channel lips for seismic design anchor channel HAC with t-bolt HBC-C-N

$\phi\, V_{sl,x,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-7
$\phi\, V_{sl,x,seis} \geq V^{b}_{ua}$

Please note the following:

- The $\phi$ value is 0.55 for which periodical inspection is provided for all t-bolts
- The $\phi$ value is 0.65 for which continuous inspection is provided for M16 and M20 t-bolts
- The steel strength for M12 t-bolts used with continuous inspection gives an increased value of 2,021lbs which should be used with $\phi$ value of 0.55

Nominal longitudinal shear steel strength of a single anchor for seismic design

$V_{sa,x,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-5
$\phi\, V_{sa,x,seis} \geq V^{a}_{ua}$

Nominal longitudinal shear steel strength of connection between anchor and channel for seismic design

$V_{sc,x,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-5
$\phi\, V_{sc,y,seis} \geq V^{a}_{ua}$

Nominal longitudinal shear steel strength of a single anchor for seismic design

$V_{sa,x,seis}$, and $\phi$ are tabulated in ESR-3520 Table 8-5
$\phi\, V_{sa,x,seis} \geq N^{a}_{ua}$

Nominal shear strength of a channel bolt for seismic design and Nominal flexural strength of the channel bolt for seismic design

$V_{ss,seis}$, $M_{oss,seis}$ and $\phi$ are tabulated in ESR-3520 Table 8-11
$\phi\, V_{ss,y,seis} \geq V^{b}_{ua}$

## Interaction equation seismic loading (SDC C, D, E and F) :

According to AC 232 June 2018 there is no distinction made in interaction equation, if project is in SDC A or B versus project located in SDC C, D E or F. Please refer to section 7.4.5.

| | SDC A or B | SDC C, D, E or F |
|---|---|---|
| Testing | The anchor channel is subjected to tests to determine the performance of anchor channel under service conditions in accordance with AC232 | Simulated seismic tests are performed where an anchor channel is subjected to the sinusoidal loads. (refer to AC232 section 7.12 to 7.13) |
| Concrete breakout in tension | The reduction factor of 0.75 is not required. | Apply a seismic reduction factor of 0.75 to non-steel tension design strengths per ACI 318-14 Section 17.2.3.4.4. |
| Concrete breakout in shear | An overstrength factor ($\Omega_0$) must not be applied. | Load combination is based on ASCE 7-10 chapter 12 and ACI 318-14. When the anchorage design is controlled by a brittle anchor failure mode, an over strength factor ($\Omega_0$) must be applied to the earthquake component (E) of the factored load. |



# 8. REINFORCING BAR ANCHORAGE

Anchor channels equipped with headed and T-shaped anchors are generally adequate for applications with thick concrete members, large edge and corner distances, normal weight concrete, high concrete compressive strengths, and medium load range, etc. However, the need for anchor channel solutions suitable for more stringent applications such as thin concrete members, lightweight concrete, high loads, corners, amongst others, led manufacturers, designers, and contractors to look beyond typical anchor channel geometries. For example concrete edge breakout typically governs the design of anchor channels used for near-edge applications such as curtain wall anchorage.

Anchor channels equipped with reinforcing bars that can engage the reinforcing in the slab directly are one way to extend anchor channel application range and efficiency. The use of anchor reinforcement and anchor channels with reinforcing bars requires a thorough understanding of development length theory as expressed in the ACI 318 model code. This chapter provides background on reinforcing bar development as it relates to the specific problem of anchor channel anchorage (see HAC CRFoS U and HAC EDGE).

**Rebar theory presented in this chapter is based on ACI 318-14 and Reinforced Concrete Mechanics & Design, by James K. Wight and James G. MacGregor.**

# 8.1 REINFORCING BAR THEORY

**The information presented in this chapter is mainly based on Reinforced Concrete Mechanics & Design, by Jams K. Wight and James G. MacGregor, chapter 8 and ACI 318-14.**

## Introduction

In reinforced concrete structures, concrete resists flexural compressive forces, while the reinforcement resists the flexural tensile forces. Therefore, the bond between the two materials is necessary to ensure the transfer of forces. If no bond stresses are present, the bar will pull out of the concrete causing the reinforced concrete structure to fail.

Bond refers to the interaction between reinforcing steel and the surrounding concrete which allows for transferring of tensile stress from the steel into the concrete.

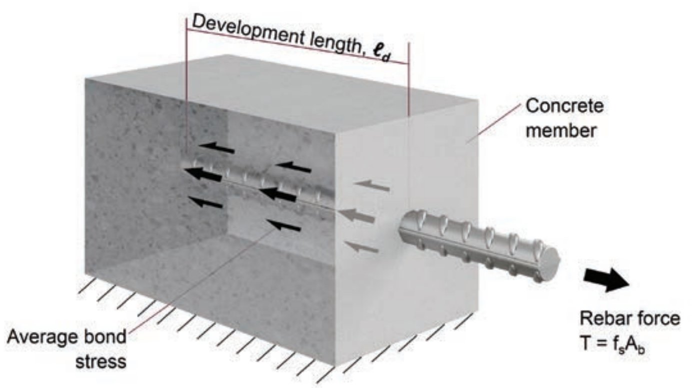



**Figure 8.1.1.1 — Bond stresses on a reinforcing bar.**

The bond-transfer mechanism via mechanical interlock between reinforcing bar (transverse ribs on reinforcing bar) and concrete is shown in Figure 8.1.1.1. The reinforcing bar acts to transfer the forces into the concrete via bearing on the deformations of the reinforcing bar. While adhesion and friction are present initially, they are quickly lost as the rebar is loaded in tension. Figure 8.1.1.2 a, b, c, and d illustrate the equal and opposite bearing stresses that act on the concrete. The forces on the concrete have a longitudinal and a radial component. The component force causes circumferential tensile stresses in the concrete around the reinforcing bar as illustrated on Figure 8.1.1.2 f and g.

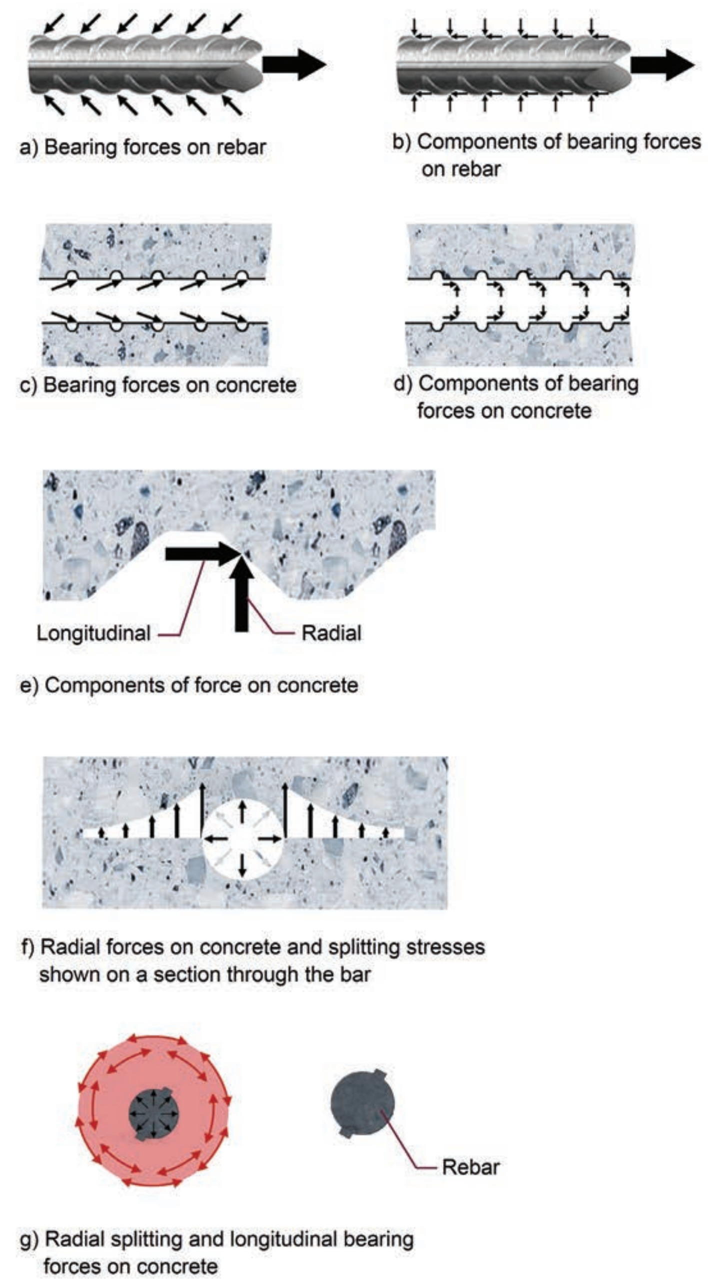



**Figure 8.1.1.2 — Stresses and forces on a reinforcing bar and concrete. Source: Wight, James & MacGregor, James. Reinforced Concrete Mechanics & Design, 2012.**

When reinforcing bars are loaded beyond the bond strength, the concrete will split parallel to the bar. The resulting crack will follow the path of least resistance, propagating out to the surface of the substrate. The splitting cracks follow the reinforcing bars along the bottom, top, and side surfaces. Splitting cracks along the reinforcing bar will generally occur in vertical and horizontal planes. The splitting crack may also occur between two rebars if the spacing is less than the distance between the reinforcing bar and an edge. Figure 8.1.1.3 illustrates different potential splitting cracks patterns.

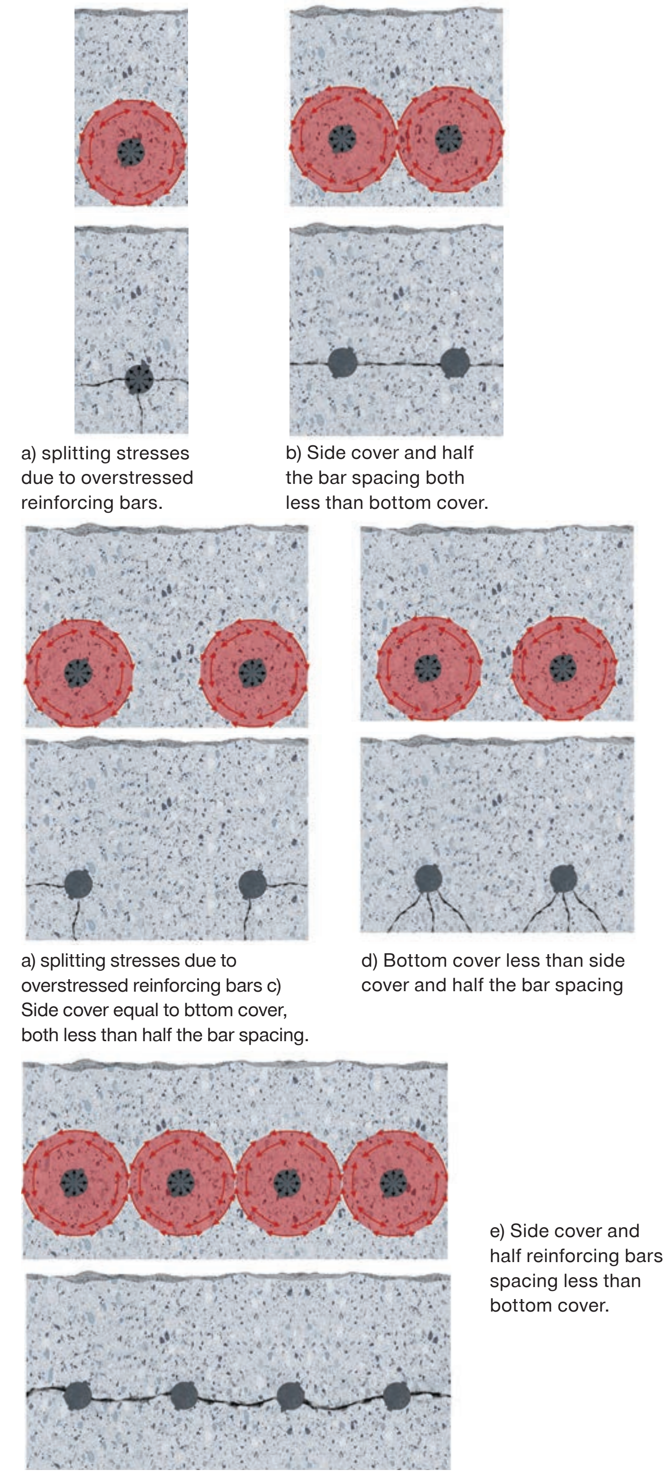



**Figure 8.1.1.3 — Radial splitting stresses and splitting crack patterns. Source: Wight, James & MacGregor, James. Reinforced Concrete Mechanics & Design, 2012.**

Splitting cracks occur mainly due to the wedging action of the reinforcing bar bearing against the concrete. Horizontal splitting cracks generally begin diagonally. The dowel action increases the tendency toward splitting.

After development of the cracks occurs, the bond transfer drops rapidly unless reinforcement is provided to restrain the opening of the splitting crack.

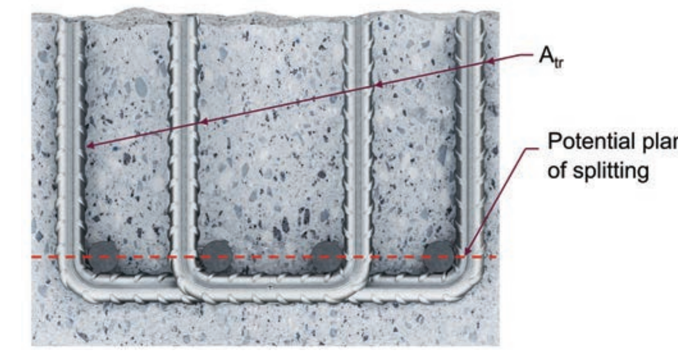



**Figure 8.1.1.4 — Potential plane of splitting due to closely spaced reinforcing bars.**

The load at which splitting failure develops is a function of

1. The minimum distance from the reinforcing bar to the surface of the concrete or to the next reinforcing bars — the smaller this distance, the smaller is the splitting load.
2. The tensile strength of the concrete.
3. The average bond stress—as this increases, the wedging forces increase, leading to a splitting failure.

If the cover and reinforcing bar spacing are large compared to the bar diameter, a pull-out failure can occur, where the bar and the annulus of concrete between successive deformations pull out along a cylindrical failure surface joining the tips of the deformations.

# 8.2 DEVELOPMENT LENGTH

## Establishing the required reinforcing bar length

Although bond stress varies along the length of a bar anchored in a tension zone, ACI uses the concept of development length rather than bond stress. The development length concept is based on the attainable average bond stress over the length of embedment of the reinforcement.

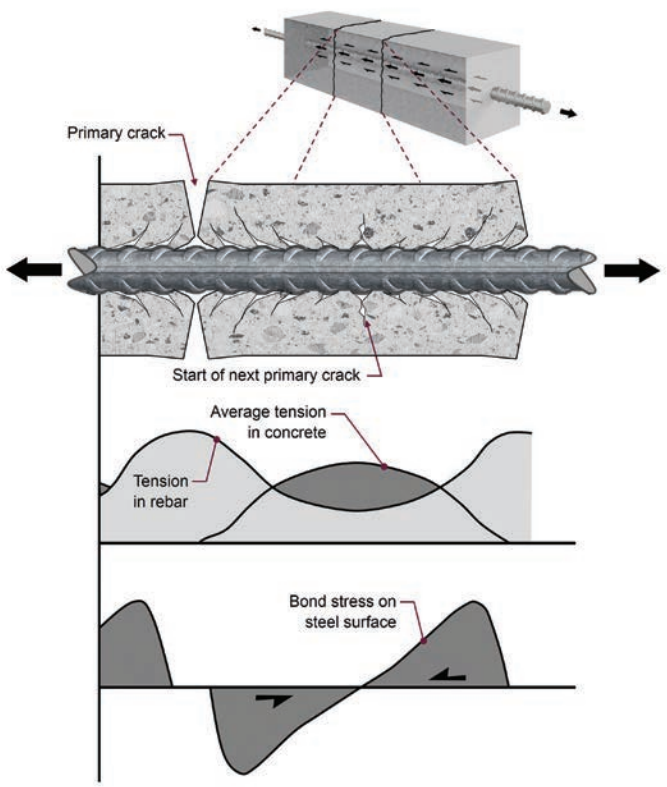



**Figure 8.2.1.1 — Stresses in concrete and rebar.**

## Development length

As stated before, the ACI concept of development length is based on the attainable average bond stress over the length of embedment of the reinforcement. Development length ($\ell_d$) can be defined as the shortest length in which the bar stress increases from zero to the nominal yield strength ($f_y$). Providing the minimum development length of a bar ensures adequate load transfer from the reinforcing bar to the concrete.

Development lengths are required to avoid splitting of the substrate (especially thin substrates) when rebars are highly stressed. The development length concept requires minimum lengths beyond all points of peak stress in the reinforcement. In other words, the reinforcement needs to be anchored properly beyond the point of peak stress. Figure 8.2.1.2 illustrates rebars developed beyond all points of peak stress.

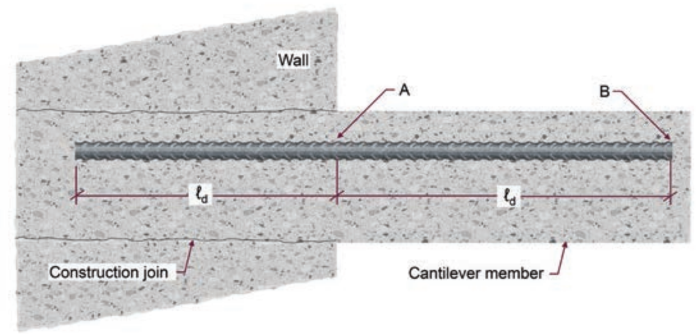



**Figure 8.2.1.2 — Development length of a reinforcing bar in a cantilever member. Source: Wight, James & MacGregor, James. Reinforced Concrete Mechanics & Design, 2012.**

The development length concept incorporates two very important concepts — reinforcing bar stress and nominal yield strength. Bar stress is the force per unit area of the bar cross-section. The nominal yield strength is the minimum bar stress at which permanent (inelastic) deformation occurs.

Structural reinforced concrete design is based on the assumption that the reinforcing bar will develop its yield strength before premature failure occurs due to inadequate bond. Development length is intended to ensure that the nominal yield strength of the bar can be developed under structure loading.

Orangun, et al. [13] proposed an expression for determining the development length $\ell_d$ of deformed reinforcing bars in tension. The ACI bond committee simplified the design expression

## Development length in accordance with the provisions of ACI 318-14

ACI 318-14 Chapter 25 contains provisions for reinforcing bar development lengths. Development lengths are assumed to preclude concrete splitting and reinforcing bar pullout failure prior to "development" (attainment) of bar yield stress.

In all cases, the development length of a reinforcing bar in tension should not be less than 12 in. Moreover, the values of $\sqrt{f'_c}$ used to calculate development length shall not exceed 100 psi

## Development length for straight deformed bars in tension given in §25.4.2.3 of ACI 318-14 as follows:

Deformed bars or deformed wires, development length ($\ell_d$) shall be calculated as follows:

$$\ell_d = \left( \frac{3}{40} \frac{f_y}{\lambda \sqrt{f'_c}} \frac{\psi_t \psi_e \psi_s}{\left( \frac{c_b + k_{tr}}{d_b} \right)} \right) d_b$$

where:

$\ell_d$ = development length, in.
$\ell_d \geq 12$ in.

$f_y$ = yield strength of bar

**$\psi_t$ = bar-location factor**
Horizontal reinforcement so placed that more than 12 in. of fresh concrete is cast in the member below the development length or splice ........ 1.3
Other reinforcement ........ 1.0

**$\psi_e$ = epoxy-coating factor**
Epoxy-coated bars or wires with cover less than 3db or clear spacing less than $6d_b$........ 1.5
All other epoxy-coated bars or wires........ 1.2
Uncoated and galvanized reinforcement ........ 1.0

The product $\psi_t \psi_e$ need not exceed 1.7

**$\psi_s$ = bar-size factor**
No. 6 and smaller bars and deformed wires ........ 0.8
No. 7 and larger bars ........ 1.0

**λ = modification factor for lightweight concrete**
When any lightweight-aggregate concrete is used ........0.75
When the splitting tensile strength $f_{c,t}$ is specified, shall be permitted to be taken as $f_{c,t}/6.7\sqrt{f'_c}$ but not more then ........ 1.0
When normal-weight concrete is used ........ 1.0

**ACI 318-14, §R25.4.2.4** The lightweight factor λ for calculating development length of deformed bars and deformed wire in tension is the same for all types of lightweight aggregate concrete. Research does not support the variations of this factor in Codes prior to 1989 for all-lightweight and sand-lightweight concrete. Section 25.4.2.4 allows a higher factor to be used when the splitting tensile strength of the lightweight concrete is specified. Refer to 19.2.4.

**$f'_c$ = concrete compressive strength**
$f'_c \leq 10{,}000$ psi

**$c_b$ = reinforcing bar cover factor**

Reinforcing bar cover factor is:
a) the least of the side cover
b) the concrete cover to the bar or wire
c) One-half the center-to-center spacing of the bars.

In all cases, $c_b$ is measured from the center of the bar.

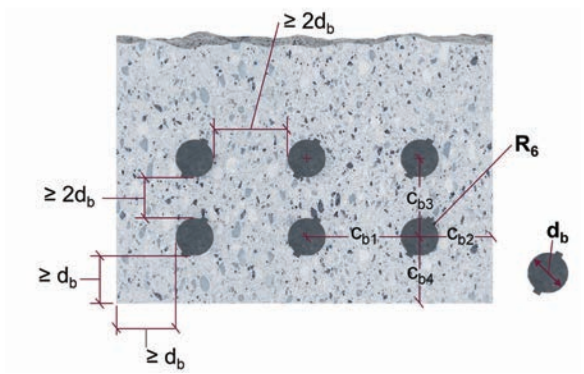



**Figure 8.2.1.3 — Minimum reinforcing bar cover. Source:Wight, James & MacGregor, James. Reinforced Concrete Mechanics & Design, 2012.**

**$d_b$ = nominal diameter of the reinforcing bar**

**$k_{tr}$ is a confining reinforcement across potential splitting planes factor**

$$= \frac{40 A_{tr}}{s \cdot n}$$

where

$A_{tr}$ = total cross-sectional area of all transverse reinforcement within the spacing s, which crosses the potential plane of splitting along the reinforcement being developed within the development length, (illustrated in Fig. 8-11)

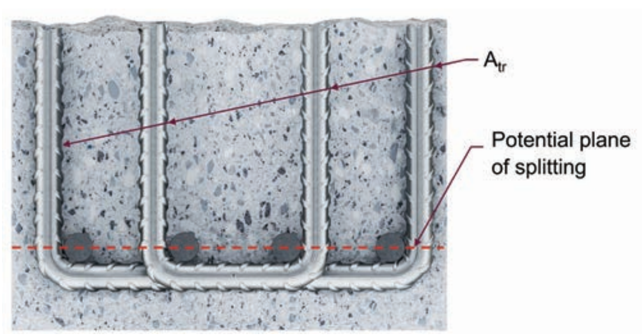



**Figure 8.2.1.4 — Transverse reinforcement ($A_{tr}$).**

s = maximum center-to-center spacing of transverse reinforcement within $\ell_d$, in

n = number of bars or wires being developed or spliced along the plane of splitting.

For simplicity, $K_{tr}$ can be taken equal to zero, even if there is transverse reinforcement. This assumption results in conservative development lengths.

A limit of 2.5 is placed on the term $(c_b + K_{tr})/d_b$. When $(c_b + K_{tr})/d_b$ is less than 2.5, splitting failures are likely to occur. For values above 2.5, a pullout failure is expected, and an increase in cover or transverse reinforcement is unlikely to increase the anchorage capacity.

## Reduction of development length for excess reinforcement

A reduction in development length is permitted in limited circumstances. If the flexural reinforcement provided exceeds the amount required to resist the factored moment required by analysis, reduction of development length is allowed. In such a case, ACI 318-14, §25.4.10 allows to be multiplied by ($A_{s,required}$/ $A_{s,provided}$).

A reduction of development length in accordance with 25.4.10.1 is not permitted for (a) through (e): (a) At non-continuous supports
(b) At locations where anchorage or development for $f_y$ is required
(c) Where bars are required to be continuous
(d) For headed and mechanically anchored deformed reinforcement
(e) In seismic-force-resisting systems in structures assigned to Seismic Design Categories D, E, or F

$\ell_d$ shall not be taken less than 12 in.

## Additional requirements

ACI 318-14, §18.8.5.3 For bar sizes No. 3 through No. 11, $\ell_d$, the development length in tension for a straight bar, shall be at least the greater of (a) and (b):

(a) 2.5 times the length in accordance with 18.8.5.1 if the depth of the concrete cast in one lift beneath the bar does not exceed 12 in.
(b) 3.25 times the length in accordance with 18.8.5.1 if the depth of the concrete cast in one lift beneath the bar exceeds 12 in.

ACI 318-14, §18.8.5.4 Straight bars terminated at a joint shall pass through the confined core of a column or a boundary element. Any portion of $\ell_d$ not within the confined core shall be increased by a factor of 1.6.

# 8.3 PULLOUT STRENGTH OF STRAIGHT REINFORCING BARS

## Pullout strength of reinforcing bar per ACI 318-14, §25.4.2.3

The ACI concept of development length is based on the attainable average bond stress over the length of embedment of the reinforcement.

If a reinforcing bar provides the required development length, the reinforcing bar will yield before it is pulled-out of the concrete. In situations where the force at the reinforcing bar is less than its yield strength, ACI 318 allows reducing the excess reinforcement.

The simplified development length equation for a reinforcing bar in tension is as follows:

ACI 318-11 Equation (25.4.2.3a) for deformed bars in tension can be recast in terms of an equivalent bond stress equation as follows:

$A_{sfy} = \tau_{bond} \pi d_b \ell_d$

where

$\tau_{bond}$ is the equivalent bond stress

Substituting $A_s = \pi d_b{}^2/4$, the following expression for bond can be derived from the development length equation given in Section 12 2 3:

$$(f_y =)\sigma_d = \ell_{d,prov}\left(\frac{3}{40}\right)\lambda\sqrt{f_c'}\left(\frac{c_b + k_{tr}}{d_b}\right)\left(\frac{1}{\psi_t\psi_e\psi_s}\right)\left(\frac{1}{d_b}\right)$$

$$N_{p,R} = \frac{\pi d_{s,R}^2}{4}$$

$$N_{p,R} = \ell_{d,prov}\pi d_b\left(\frac{10}{3}\right)\lambda\sqrt{f_c'}\left[\min\left(\frac{c_b + k_{tr}}{d_b}, 2.5\right)\right]\left(\frac{1}{\psi_t\psi_e\psi_s}\right)$$

## Pullout strength reduction ∅-factor

ACI 318-14 development length equation does no require a ∅ factor to be applied to the development length equation. An allowance for strength reduction is already included in the expression for determining development length. R25.4.1.3

When calculating the pull-out strength of the reinforcing reinforcing bar, per ACI 318-14, §17.4.2.9 a reduction factor, ∅ of 0.75 shall be applied to the nominal pull-out rebar strength.



## Pullout strength of reinforcing bar per ACI 318-14 with $(c_b + K_{tr})/d_b < 2.5$

R25.4.2.2 This provision recognizes that many current practical construction cases use spacing and cover values along with confining reinforcement, such as stirrups or ties, that result in a value of $(c_b + K_{tr})/d_b$ of at least 1.5. Examples include a minimum clear cover of $d_b$ along with either minimum clear spacing of $2d_b$, or a combination of minimum clear spacing of $d_b$ and minimum ties or stirrups. For these frequently occurring cases, the development length for larger bars can be taken as $\ell_d = [f_y \psi_t \psi_e/(20\lambda\sqrt{f'_c})]d_b$. In the formulation of the provisions in ACI 318-95, a comparison with past provisions and a check of a database of experimental results maintained by ACI 408.1R indicated that for No. 6 deformed bars and smaller, as well as for deformed wire, the development lengths could be reduced 20 percent using $\psi_s = 0.8$. This is the basis for the No. 6 and smaller bars and deformed wires column of Table § 25.4.2.2.

With less cover and in the absence of minimum ties or stirrups, the minimum clear spacing limits of 25.2.1 and the minimum concrete cover requirements of 20.6.1.3 result in minimum values of $c_b$ equal to $d_b$. Thus, for "other cases," the values are based on using $(c_b + K_{tr})/d_b = 1.0$ in Eq. (25.4.2.3a).

As long as minimum cover of $d_b$ is provided along with a minimum clear spacing of $2d_b$, or a minimum clear cover of db and a minimum clear spacing of $d_b$ are provided along with minimum ties or stirrups, then $\ell_d = 47d_b$. The penalty for spacing bars closer or providing less cover is the requirement that $\ell_d = 71d_b$.

§ 25.4.2.2 For deformed bars or deformed wires, $\ell_d$ shall be calculated in accordance with Table 25.4.2.2.

**Table 8.3.1.1 (ACI 318-14 Table 25.4.2.2) —Development length for deformed bars and deformed wires in tension**

| Spacing and cover No. 6 and smaller bars and deformed wires No. 7 and larger bars | Spacing and cover No. 6 and smaller bars and deformed wires No. 7 and larger bars | Spacing and cover No. 6 and smaller bars and deformed wires No. 7 and larger bars |
|---|---|---|
| Clear spacing of bars or wires being developed or lap spliced not less than db, clear cover at least $d_b$, and stirrups or ties throughout $\ell_d$ not less than the Code minimum<br><br>or<br><br>Clear spacing of bars or wires being developed or lap spliced at least $2_{db}$ and clear cover at least $d_b$ | $\left(\frac{f_y\psi_t\psi_e}{25\lambda\sqrt{f_c'}}\right)d_b$ | $\left(\frac{f_y\psi_t\psi_e}{20\lambda\sqrt{f_c'}}\right)d_b$ |
| Other cases | $\left(\frac{3f_y\psi_t\psi_e}{50\lambda\sqrt{f_c'}}\right)d_b$ | $\left(\frac{3f_y\psi_t\psi_e}{40\lambda\sqrt{f_c'}}\right)d_b$ |

# 8.4 PULLOUT STRENGTH OF HEADED BARS IN TENSION

## Headed anchored bars in tension

When adequate space is not provided to reach full development length of a straight reinforcing bar, ACI 318 allows the use of headed reinforcing bars to reduce the development length. The development length for a headed reinforcing bar generally will be shorter than that for a straight or hooked rebar. Headed reinforcing bars are ideal for applications where there is limited space available to develop bars in tension.

The transfer of force from the bar to the concrete is assumed to be achieved by a combination of bond-transfer mechanism along the straight portion of the bar and bearing forces at the head.

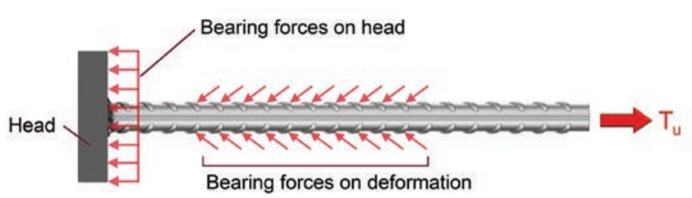



Figure 8.4.1.1 — Stresses on headed anchored reinforcing bars.

## Headed anchored bars in tension, $\ell_{dt}$ per ACI 318-14, 25.4.4

The provision for headed deformed bars were formulated with due consideration of the provisions for anchorage in ACI 318-14 Chapter 17 and the bearing strength provisions of ACI 318-14 Chapter 22.

The use of heads to develop deformed bars in tension shall be permitted if conditions (a) through (g) are satisfied:

(a) Bar shall conform to 20.2.1.3

(b) Bar $f_y$ shall not exceed 60,000 psi

(c) Bar size shall not exceed No. 11

(d) Net bearing area of head Abrg shall be at least $4A_b$

(e) Concrete shall be normal weight

(f) Clear cover for bar shall be at least $2d_b$

(g) Clear spacing between bars shall be at least $4d_b$

The provisions for developing headed deformed bars give the length of bar, $\ell_{dt}$, measured from the critical section to the bearing face of the head, as shown in Fig.###

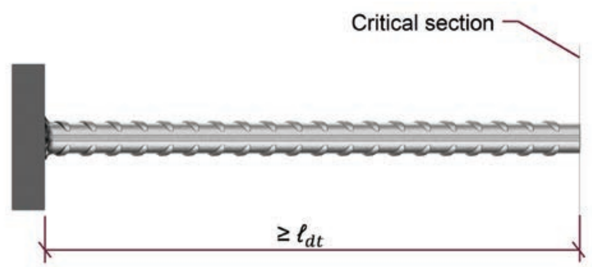



Figure 8.4.1.2 — Development length of headed anchored reinforcing bar.

The head is considered to be part of the bar for the purposes of satisfying the specified cover requirements in 20.6.1.3, and aggregate size requirements of 26.4.2.1(a)(4).

25.4.4.2 Development length $\ell_{dt}$ for headed deformed bars in tension shall be the greatest of (a) through (c):

$(a)\quad \ell_d = \left(\frac{0.016 f_y \psi_e}{\lambda \sqrt{f'_c}}\right) d_b,$ With $\psi_e$ given in ACI 318-14 25.4.4.3 and value of $f'_c$ shall not exceed 6,000 psi

$(b)\quad 8d_b$

$(c)\quad 6\ in.$

**$\ell_{dt}$ = development length of headed anchored rebar, in.**

**$f_y$ = yield strength of bar**

**$\psi_e$ = epoxy-coating factor**

All other epoxy-coated bars or wires........................................1.2

Uncoated and galvanized reinforcement..................................1.0

**$f'_c$ = concrete compressive strength**

$f'_c \leq 10{,}000$ psi

**$d_b$ = nominal diameter of the reinforcing bar**

Transverse reinforcement, however, helps limit splitting cracks in the vicinity of the head and for that reason is recommended.

# 8.5 PULLOUT STRENGTH OF STANDARD HOOKS

## Behavior of hooked rebar

When adequate space is not provided to reach full development length of a straight reinforcing bar, the reinforcing bar can be hooked or bent. The behavior of the hooked reinforcing bar changes as a result of the bend in the reinforcing bar. Hooked reinforcing bar resists bond failure by bond strength along the straight portion, anchorage provided by the hook, and by the bearing on the concrete inside the hook.

The forces that develop in a 90° hook are shown in Figure 8.5.1.1. The developed stresses cause the bar to move inwards, leaving a gap of concrete on the outside of the hook. The bar tends to straighten out due to the formation of the gap and directional change in force along the bend, causing compressive stresses on the outside of the tail. Because the compressive force inside the bend is not collinear with the applied tensile force, the bar tends to straighten out, producing compressive stresses on the outside of the tail. Therefore, the failure of the hook can most often be attributed to the crushing of concrete inside the hook. If the hook is close to a side face, the crushing may extend to the surface of the concrete, removing the side cover. If cracking in the outside of the tail occurs, the tail may straighten.

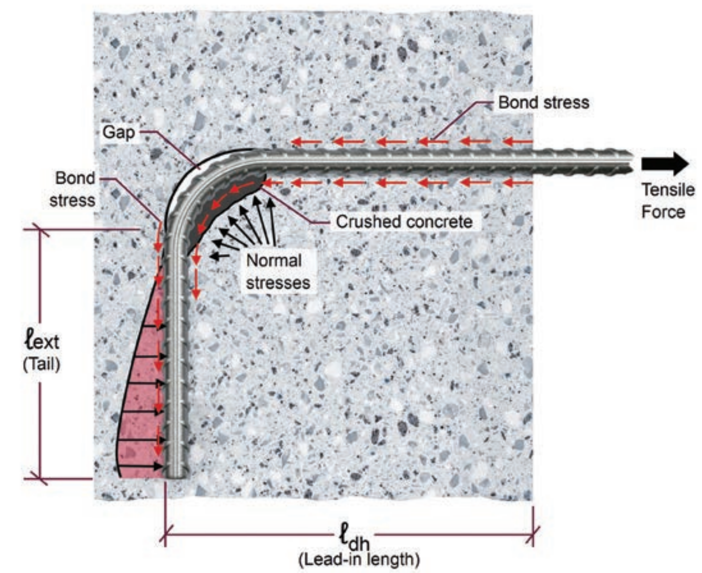



Figure 8.5.1.1 — Stresses in standard 90 degree hook. Source: Wight, James & MacGregor, James. Reinforced Concrete Mechanics & Design, 2012.

The stresses and slip of the reinforcing bar are also dependent upon the degree of bend of the reinforcing bar, as shown in Figure 8.5.1.2. The slip of the rebar at point A is nearly twice as large in the 180-degree hook as compared to the 90-degree hook.

The main cause of failure of hooked bars is splitting failure of the concrete cover in the plane of the hook. Splitting failure depends on hook cover and anchorage strength can be improved through confinement provided by stirrups.

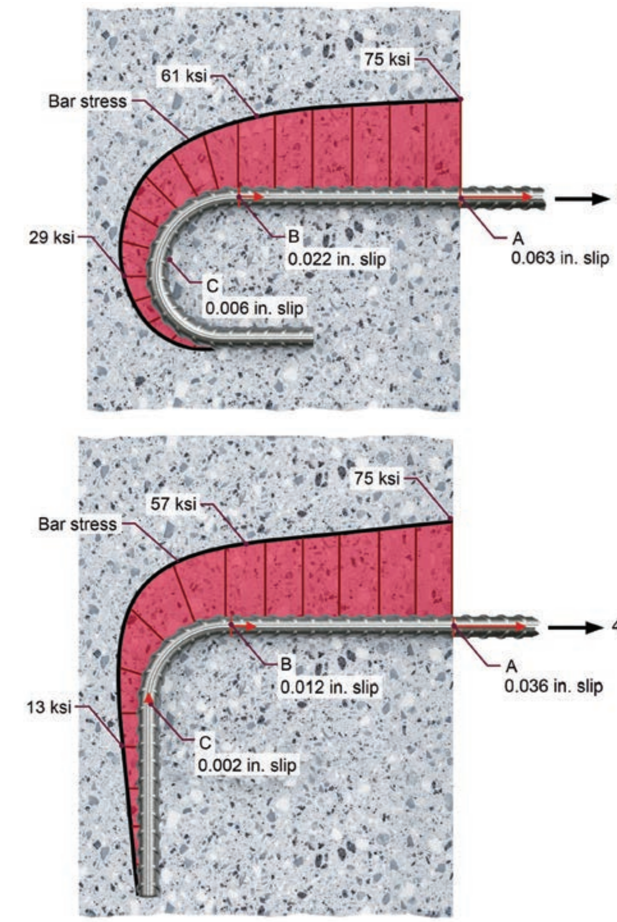



Figure 8.5.1.2 — Stresses in 90 and 180 degree hooks. Source: Wight, James & MacGregor, James. Reinforced Concrete Mechanics & Design, 2012.

## Tension development length of hooked reinforcing bar: ACI 318-14, §25.4.3.1

A minimum value of hook development length ($\ell_{dh}$) is specified to prevent failure by direct pullout in cases where a hook may be located very near the critical section. The development length for deformed bars in tension terminating in a standard hook (90°and 180° or between top and bottom bar hooks) shall be the greater of (a) through (c):

$(a)\quad \ell_{dh} = \left(\frac{f_y \psi_e \psi_c \psi_r}{50\lambda \sqrt{f'_c}}\right) d_b,$

$(b)\quad 8d_b$

$(c)\quad 6\ in.$

The modification factors applicable to hooked reinforcing bar development length are as follows:

**$\ell_{dh}$ = development length of a standard hook, in.** measured from the critical section to the outside end (or edge of the hook)

**$f_y$ = yield strength of bar**

**$\psi_e$ = epoxy-coating factor**

All other epoxy-coated bars or wires.......................................1.2

Uncoated and galvanized reinforcement ................................1.0

**$\psi_c$ = bar-cover factor**
No. 11 bar and smaller hooks with side cover (normal to plane of hook) ≥ 2-1/2 in and for 90-degree hook with cover on bar extension beyond hook ≥ 2 in ................................................ 0.7
Other ...................................................................................... 1.0

**$\psi_r$ = confining reinforcement factor**
For 90-degree hooks of No. 11 and smaller bars
(1) enclosed along $\ell_{dh}$ within ties or stirrups perpendicular to $\ell_{dh}$ at s ≤ $3d_b$, or
(2) enclosed along the bar extension beyond hook including the bend within ties or stirrups perpendicular to $\ell_{ext}$ at s ≤ $3d_b$ .................................................................... 0.80

For 180-degree hooks of No. 11 and smaller bars enclosed along $\ell_{dh}$ within ties or stirrups perpendicular to $\ell_{dh}$ at s ≤ $3d_b$ ........................................................................ 0.80
Other ..................................................................................... 1.00

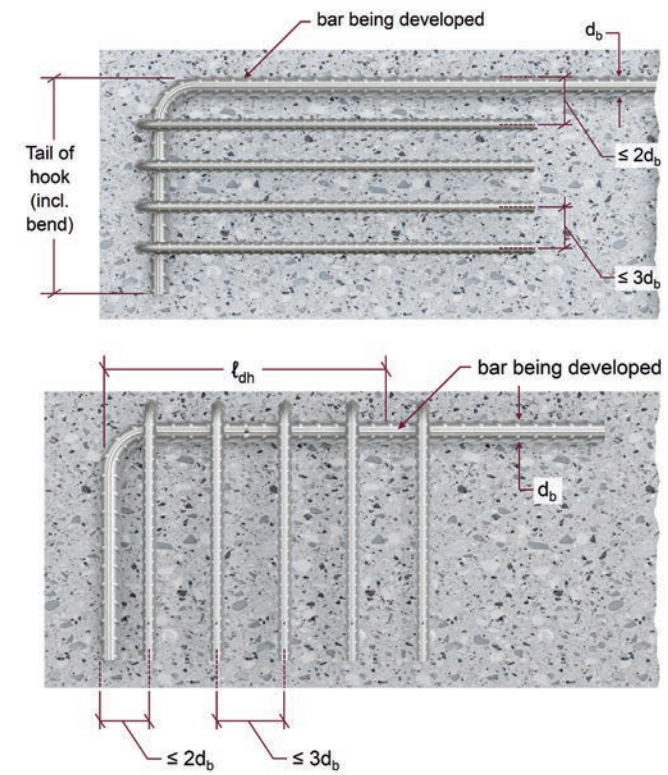



**Figure 8.5.1.3 — Confinement of hooks by stirrups and ties. Source: Wight, James & MacGregor, James. Reinforced Concrete Mechanics & Design, 2012.**

**λ = modification factor for lightweight concrete**
When any lightweight-aggregate concrete is used ...............0.75
When the splitting tensile strength $f_{c,s}$ is specified, shall be permitted to be taken as $f_{c,t}/6.7\sqrt{f'_c}$ but not more then ........... 1.0
When normal-weight concrete is used ................................... 1.0

**ACI 318-14, §R25.4.2.4** The lightweight factor λ for calculating development length of deformed bars and deformed wires in tension is the same for all types of lightweight aggregate concrete. Research does not support the variations of this factor in Codes prior to 1989 for all-lightweight and sand-lightweight concrete. Section 25.4.2.4 allows a higher factor to be used when the splitting tensile strength of the lightweight concrete is specified. Refer to 19.2.4.

**$f'_c$ = concrete compressive strength**
$f'_c$ ≤ 10,000 psi

**$d_b$ = nominal diameter of the reinforcing bar**

Bar hooks are especially susceptible to a concrete splitting failure if both side cover (perpendicular to plane of hook) and top or bottom cover (in plane of hook) are small. For bars being developed by a standard hook at discontinuous ends of members with both side covers and top (or bottom) cover to hook less than 2-1/2 in., (a) through (c) shall be satisfied:
(a) The hook shall be enclosed along $\ell_{dh}$ within ties or stirrups perpendicular to $\ell_{dh}$ at s ≤ $3d_b$
(b) The first tie or stirrup shall enclose the bent portion of the hook within $2d_b$ of the outside of the bend
(c) $\psi_r$ shall be taken as 1.0 in calculating $\ell_{dh}$ in accordance with 25.4.3.1(a)

## Reduction of development length for excess reinforcement

A reduction in development length is permitted in limited circumstances. If the flexural reinforcement provided exceeds the amount required to resist the factored moment, the bar stress that must be developed is less than In such a case, ACI 318-14, §25.4.10 allows to be multiplied by ($A_{s,required}/A_{s,provided}$).

A reduction of development length in accordance with 25.4.10.1 is not permitted for (a) through (e):

(a) At non-continuous supports
(b) At locations where anchorage or development for $f_y$ is required
(c) Where bars are required to be continuous
(d) For headed and mechanically anchored deformed reinforcement
(e) In seismic-force-resisting systems in structures assigned to Seismic Design Categories D, E, or F

## Minimum bending requirements: ACI 318-14, §25.4.3.1.

Standard hooks need to follow some specific geometrical requirements. Standard hooks should meet the minimum lengths and bending requirements provided in ACI 318-14. The primary factors affecting the minimum bend diameter are feasibility of bending without breakage and avoidance of crushing the concrete inside the bend.

The minimum inside bend diameter and extension length for a hooked reinforcing bar is as follows in the table:

[1]The first tie or stirrup shall enclose the bent portion of the hook within 2db of the outside of the bend.



## Pull-out strength reduction factor, ∅

ACI 318-14 development length equation does not require a ∅ factor to be applied to the development length equation. An allowance for strength reduction is already included in the expression for determining development length. R25.4.1.3

When calculating the pull-out strength of the reinforcing bar, per ACI 318-14, §17.4.2.9 a reduction factor, ∅ of 0.75 shall be applied to the nominal pull-out reinforcing bar strength.

## Pull-out strength of L-bolts

If standard hook requirements of ACI are not met, the reinforcing bar may behave similar to the one of an L-bolt

The pullout strength in tension of a single hooked bolt ($N_p$) per ACI 318-14, §17.4.3.5 shall not exceed

$$N_p = 0.9 f'_c e_c d_a$$

where: $3d_a \le e_h \le 4.5d_a$

**R17.4.3.5** Equation (17.4.3.5) for hooked bolts was developed by Lutz based on the results of Kuhn and Shaikh (1996). Reliance is placed on the bearing component only, neglecting any frictional component because crushing inside the hook will greatly reduce the stiffness of the connection and generally will be the beginning of pullout failure. The limits on $e_h$ are based on the range of variables used in the three tests programs reported in Kuhn and Shaikh (1996).

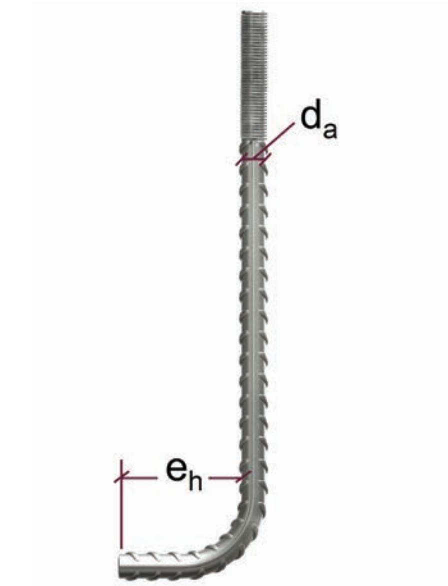
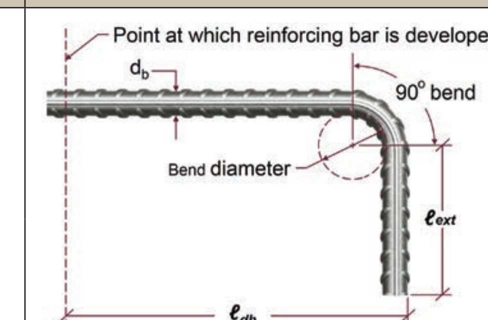
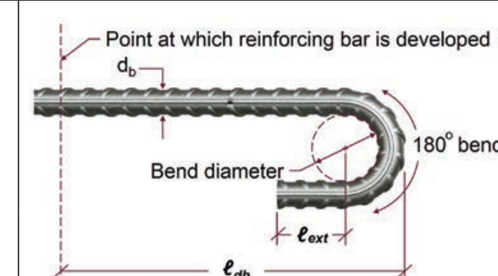



**Figure 8.5.1.4 — L-reinforcing bar**

**Table 8.5.1.1 (ACI 318-14 Table 25.3.1) — Bending Requirements for Development of Standard Hook**

| Type of standard hook | Bar size | Minimum inside bend diameter(in) | Straight extension lext, (in) | Type of standard hook |
|---|---|---|---|---|
| 90-degree hook | No. 3 through No. 8 | $6d_b$ | $12d_b$ |   |
| | No. 9 through No. 11 | $8d_b$ | | |
| | No. 14 through No. 18 | $10d_b$ | | |
| 180-degree hook | No. 3 through No. 8 | $6d_b$ | Greater of: $4d_b$ 2.5 in |   |
| | No. 9 through No. 11 | $8d_b$ | | |
| | No. 14 through No. 18 | $10d_b$ | | |

# 8.6 REINFORCING BAR LAP SPLICES

## Behavior of lap splices

Opposed to development length where the length of the reinforcing bar needed to transfer the stresses to the concrete is calculated, lap splice calculates the lap length of the reinforcing bar needed to transfer the stresses to another bar.

The mechanism of force-transfer in lap splicing is the force in one reinforcing bar is transferred into the concrete, which then is transferred to the adjacent reinforcing bar, or spliced reinforcing bar. This behavior is shown in Figure 8.6.1.1 and 8.6.1.2. Although the term "lap splice" implies direct transfer of stress from bar to bar, forces between bars are transferred via struts and hoop stresses in the concrete.

The transfer of forces out of the reinforcing bar into the concrete causes radially outward pressures on the concrete, as shown in figure 8.6.1.3. This force transfer may create pressures that result in splitting cracks on concrete between and along the two reinforcing bar. When such cracks occur, the splice fails. Therefore, transverse reinforcement can be supplemented to delay the openings of the splitting cracks and improve the splice capacity.

**Figure 8.6.1.1 — Forces on bars at splice**

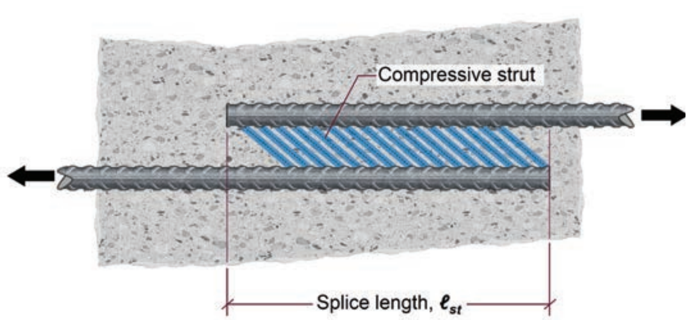



**Figure 8.6.1.2 — Compressive struts at splice.**

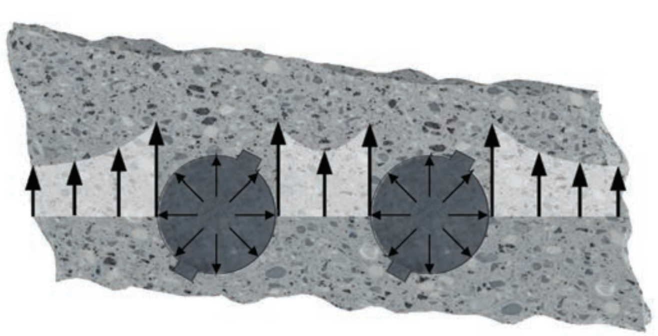


**Figure 8.6.1.3 - Radial forces on concrete and splitting stresses shown on section through the splice.**

## Tension lap splices per ACI 318-14 25.5.2.1

Lap splices in tension in accordance to ACI 318-14 are classified as a Class A or Class B splice. The lap splice length ($\ell_{st}$). is a multiple of the tensile development length ($\ell_d$).

A class B splice taken as the greater of $1.3\ell_d$ and 12 in. is required in all cases unless 1) the area of reinforcement is at least twice that determined by analysis over the entire length of the splice and 2) one-half or less of the total reinforcement is spliced within the lap length. Where 1) and 2) are satisfied, a Class A splice taken as the greater of $1.0\ell_d$ and 12 in. may be used.

The transverse center-to-center spacing of spliced bars shall not exceed the lesser of one-fifth the required splice length and 6 in. If individual bars are too widely spaced, an unreinforced section is created causing potential cracks.

**Table 8.6.1.1 (ACI 318-14 Table 25.5.2.1) — Lap splice lengths of deformed bars and deformed wires in tension**

| As,provided/ As,required[1] over length of splice | Maximum percent of As spliced within required lap Length | Splice type | $\ell_{st}$ | |
|---|---|---|---|---|
| ≥ 2.0 | 50 | Class A | Greater of: | $1.0\ell_d$ and 12 in. |
| | 100 | Class B | Greater of: | $1.3\ell_d$ and 12 in. |
| < 2.0 | All cases | Class B | | |

**§ 25.5.1.2** For contact lap splices, minimum clear spacing between the contact lap splice and adjacent splices or bars shall be in accordance with the requirements for individual bars in 25.2.1.

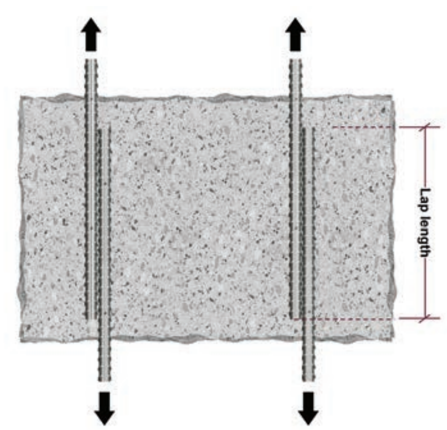



**Figure 8.6.1.4 — Contact lap splice.**

**§ 25.5.1.3** For non-contact splices in flexural members, the transverse center-to-center spacing of spliced bars shall not exceed the lesser of one-fifth the required lap splice length and 6 in.

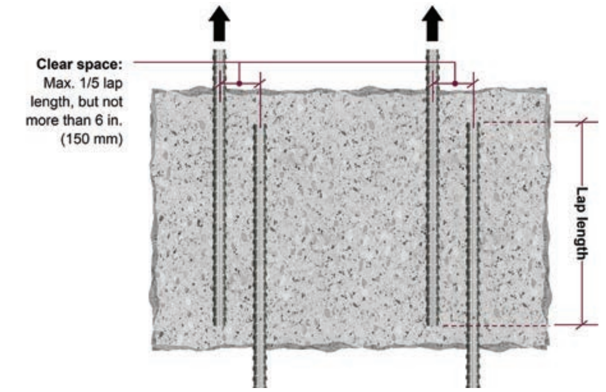



**Figure 8.6.1.5 — Non-contact lap splice.**

If individual bars in noncontact lap splices are too widely spaced, an unreinforced section is created. Forcing a potential crack to follow a zigzag line (5-to-1 slope) is considered a minimum precaution. The 6 in. maximum spacing is added because most research available on the lap splicing of deformed bars was conducted with reinforcement within this spacing.

There is no difference in the performance of contact and noncontact lap splices. Forces are transferred from one bar to another via the concrete.

**§ 25.5.1.4** Reduction of development length in accordance with § 25.4.10.1 is not permitted in calculating lap splice lengths. Because the splice classifications already reflect excess reinforcement, the development length, $\ell_d$, used to determine the lap length should not include reduction factors for excess reinforcement.

**§ 25.5.2.2** If bars of different size are lap spliced in tension, $\ell_{st}$ shall be the greater of $\ell_d$ of the larger bar and $\ell_{st}$ of the smaller bar.

## 8.7 CONCRETE COVER

### Minimum cover requirements: ACI 318-14 20.6.1.3

The specified concrete cover is measured as the distance between the outermost surface of embedded reinforcement and the closest outer surface of the concrete. The concrete cover can also be measured as the spacing from rebar to rebar. The tables below further explain the specified concrete cover requirements.

**Table 8.7.1.1 (ACI 318-14 Table 20.6.1.3.1) — Specified concrete cover for cast-in-place nonprestressed concrete members**

| Concrete exposure | Member | Reinforcement | Specified cover, in. |
|---|---|---|---|
| Cast against and permanently in contact with ground | All | All | 3 |
| Exposed to weather or in contact with ground | All | No. 6 through No. 18 bars | 2 |
| | | No. 5 bar, W31 or D31 wire, and smaller | 1-1/2 |
| Not exposed to weather or in contact with ground | Slabs, joists, and walls | No. 14 and No. 18 bars | 1-1/2 |
| | | No. 11 bar and smaller | 3/4 |
| | Beams, columns, pedestals, and tension ties | Primary reinforcement, stirrups, ties, spirals, and hoops | 1-1/2 |

**Table 8.7.1.2 (ACI 318-14 Table 20.6.1.3.2) — Specified concrete cover for cast-in-place prestressed concrete members**

| Concrete exposure | Member | Reinforcement | Specified cover, in. |
|---|---|---|---|
| Cast against and permanently in contact with ground | All | All | 3 |
| Exposed to weather or in contact with ground | Slabs, joists, and walls | All | 1 |
| | All other | All | 1-1/2 |
| Not exposed to weather or in contact with ground | Slabs, joists, and walls | All | 3/4 |
| | Beams, columns, and tension ties | Primary reinforcement, stirrups, ties, spirals, and hoops | 1-1/2 |
| | | Stirrups, ties, spirals, and hoops | 1 |

For corrosive environments, the concrete cover shall be increased as deemed necessary and specified by the licensed design professional per the exposure categories and classed in ACI 318-14 Section 19.3. The recommended cover for corrosive environments is not less than 2 in for walls and slabs and not less than 2-1/2 in. for other members.

For fire protection requirements, the general building code may require greater concrete cover than the required cover specified in ACI 318-11 7.7.1 through 7.7.7.



# 9. SPECIAL ANCHOR CHANNEL DESIGN

Chapter 7 (Anchor Channel Design Code) and chapter 8 (Reinforcing Bar Theory) provide the required information to have a deep understanding of the behavior of an anchor channel with rounded headed anchors and rebars.  This chapter combines the information presented in chapter 7 and 8 and covers the design models for HAC, HAC CRFoS U, and HAC EDGE. The special conditions like anchor channels installed in metal deck, two anchor channels installed parallel to each other at an edge, anchor channels installed top and bottom of slab at the same elevation are the few examples. This chapter also introduces and explains the design methodology of the anchor channels used for high wind loads.

Design methods provided in chapter 9 are allowed for applications with known boundary conditions. The provisions described in this section are only valid for Hilti Anchor Channels. The design models presented in this chapter have not been evaluated with any other anchor channel type or anchoring technology. For applications that deviate from the design boundary conditions presented in this chapter, reach out to Hilti.

# 9.1 — OVERVIEW OF HILTI ANCHOR CHANNEL SYSTEMS DESIGN

## Introduction

Prior to the publication of the Acceptance Criteria 232 (AC232), cast-in anchor channels could not receive recognition under the International Building Code (IBC) as ACI 318 Anchor-to-Concrete provisions exclude specialty inserts. The publication of (AC232) brought major benefits to the cast-in anchor channel industry and design community. The use of optimized anchor channel solutions and simplification of the design and approval processes for anchor channels ultimately can avoid construction shutdowns.

Cast-in anchor channels can now receive recognition under the IBC, as AC232 3.0 Design Requirements provides amendments to ACI 318 Anchoring-to-Concrete provisions that permit the design of anchor channel systems as if they were included in ACI 318 Anchoring-to-Concrete provisions. In addition, AC232 allows the design community to have a clear understanding of the behavior of cast-in anchor channel systems.


**Figure 9.1.1 — Anchor Channel Code Landscape**

Prior to AC232, designers had to design via engineering judgment, applying provisions not fully applicable to anchor channels, research papers, and/or using manufactures' technical data. The design methodology used to approve the anchor channel design would have to be backed-up by the P.E. stamp of a licensed engineer of the state of the project's location and still might have to go to local jurisdiction for final approval. In some extreme cases, this was not accepted by local jurisdictions and additional testing was required. This added an extra problem since testing protocol for anchor channels did not exist neither.

Relying on technical data is adequate only if the tests are performed correctly. Tests results can be positively or negatively altered if they are not tested properly. Technical data via testing was a problem since prior to AC232, there were no testing protocols for cast-in anchor channel systems. As mentioned in chapter 7, AC232 provides testing protocols and design guidelines for anchor channels.

Since its inception, AC232 has been an ever-evolving document. In its infancy stage, it did not include provisions for the qualification and design of anchor channels systems in structures assigned to Seismic Design Category C, D, E, or F.

In 2015, AC232 incorporated the so needed seismic provisions for anchor channels in Seismic Design Category C, D, E, or F. Later that year, provisions permitting the use of anchor channels in all-lightweight concrete and sand-lightweight concrete were adopted by AC232.

Important design provisions have been added to AC232 over the last years. The ultimate goal is to have a complete framework that covers all common applications encountered in a building such as corners with a pair of anchor channels loaded simultaneously, parallel channels, and wind corner zones with practical design requirements (i.e typical edge distance). For these conditions, it is typically concrete that is limiting factor and having "fixed" design parameter such as member thickness, concrete type, concrete compressive strength, etc., brings the need of the so call anchor channels with rebars.

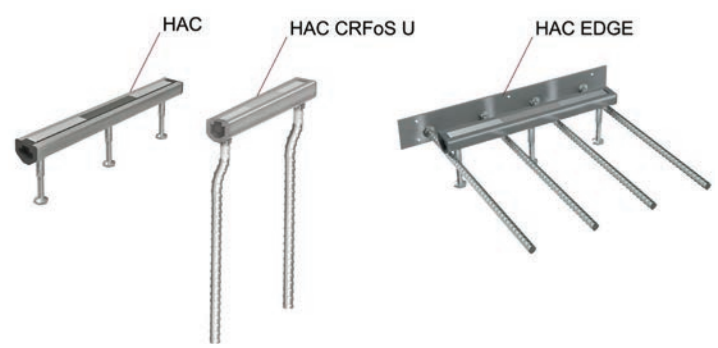



**Figure 9.1.2 — HAC Channel Protfolio**

The scope of AC232 is limited to anchor channels with rounded headed anchors or I-anchors and anchor channels with rebars replacing headed anchors or I-anchors. AC232 includes provisions for anchor reinforcement, where the concrete breakout in shear and/or tension can be precluded, but specifying additional reinforcement implies additional burdens and is typically an unpractical solution. The use of a complete anchor channel systems that allow the introduction of higher loads into the structure without specifying anchor reinforcement is the preferred solution.

All Hilti anchor channels covered by AC232 (HAC and HAC-T) are designed in accordance to ESR-3520. Hilti's mission is to create a better future. That is why these so needed anchor channels with rebars are tested in accordance with AC232 and the design models are using AC232 principles and applicable provisions of AC232 and ACI 318. Table 9.1.1 provides a summary of the design method of the Hilti anchor channel systems. Our ultimate goal is to offer designers and contractors anchor channel system solutions that are 100 percent IBC compliant.

**Table 9.1.1 — Overview of Hilti anchor channel systems design method**

| Tension design model | | | | |
|---|---|---|---|---|
| **Failure mode** | **Symbol** | **HAC HAC-T** | **HAC CRFoS U HAC-T CRFoS U** | **HAC EDGE HAC-T EDGE** |
| Anchor | $\Phi N_{sa}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Anchor and channel connection | $\Phi N_{sc}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Channel lip | $\Phi N_{sl}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Bending of channel | $\Phi M_{s,flex}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt | $\Phi N_{ss}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Pullout | $\Phi N_{pn}$ | ESR-3520 | ACI 318[2] | ESR-3520 |
| Side-face blowout | $\Phi N_{sb}$ | ESR-3520 | N/A | ESR-3520 |
| Concrete breakout | $\Phi N_{cb}$ | ESR-3520 | N/A | ESR-3520 |

| Perpendicular shear design model | | | | |
|---|---|---|---|---|
| **Failure mode** | **Symbol** | **HAC HAC-T** | **HAC CRFoS U HAC-T CRFoS U** | **HAC EDGE HAC-T EDGE** |
| Channel lip | $\Phi V_{sl,y}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Anchor | $\Phi V_{sa,y}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Anchor and channel connection | $\Phi V_{sc,y}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Channel bolt | $\Phi V_{ss}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt with bending | $\Phi V_{ss,M}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Concrete edge breakout | $\Phi V_{cb,y}$ | ESR-3520 | ESR-3520 | Hilti Method[3] |
| Pryout | $\Phi V_{cp,y}$ | ESR-3520 | N/A | ESR-3520 |

| Longitudinal shear design model | | | | |
|---|---|---|---|---|
| **Failure mode** | **Symbol** | **HAC HAC-T** | **HAC CRFoS U HAC-T CRFoS U** | **HAC EDGE HAC-T EDGE** |
| Anchor | $\Phi V_{sa,x}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Anchor and channel connection | $\Phi V_{sc,x}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Channel bolt and channel connection | $\Phi V_{sl,x}$ | ESR-3520 | AC232 based[1] | ESR-3520 |
| Channel bolt | $\Phi V_{ss}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt with bending | $\Phi V_{ss,M}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Concrete edge breakout | $\Phi V_{cb,x}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Pryout | $\Phi V_{cp,x}$ | ESR-3520 | N/A | ESR-3520 |

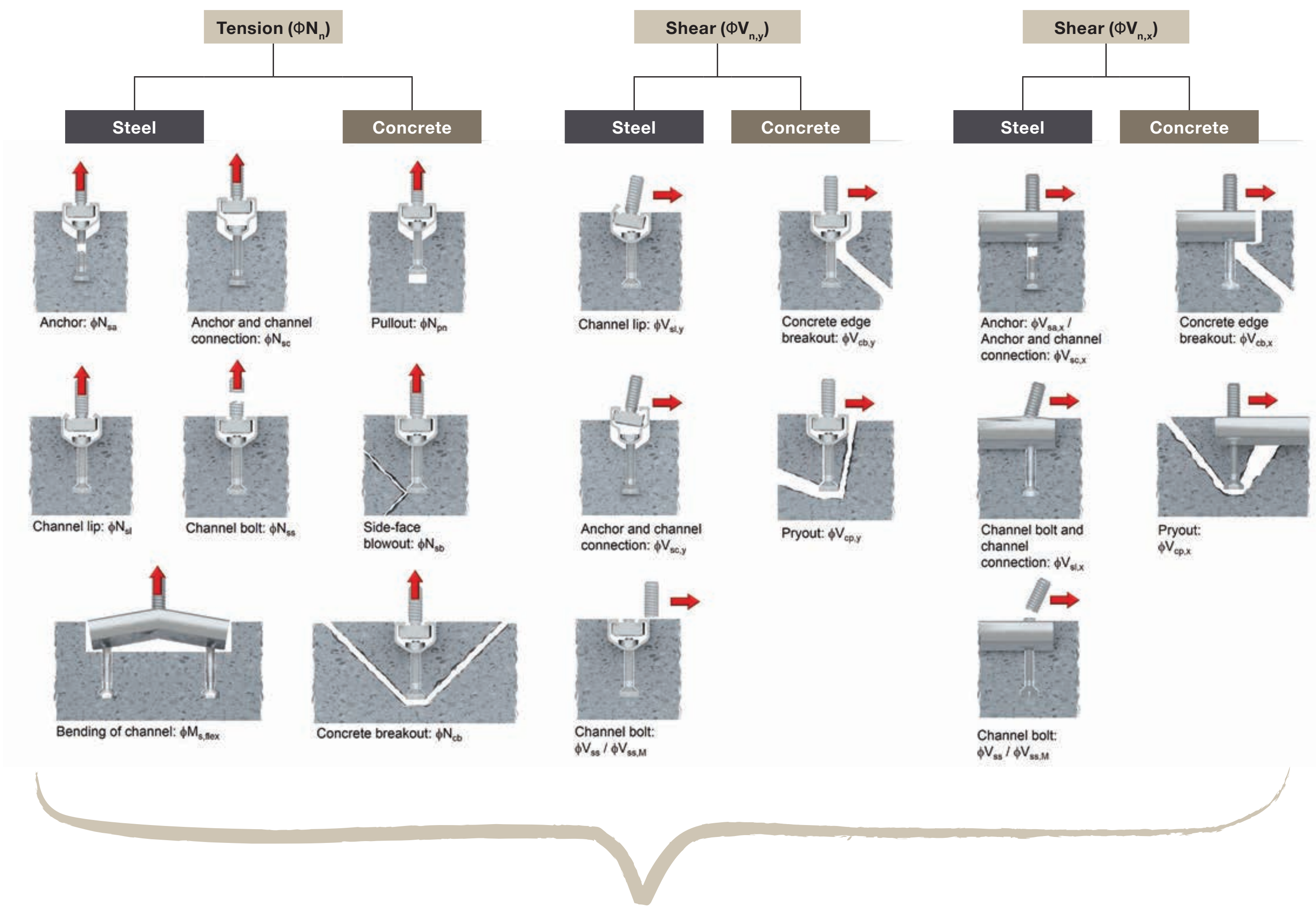
1 AC232 based indicates product has been tested in accordance to AC232 testing protocols for that specific failure mode and the design is based on applicable provisions and/or fundamentals of AC232 and/or ACI 318.
2 ACI 318 indicates the analysis of that specific failure modes is in accordance to the applicable ACI 318 provision.
3 Hilti method is derived based on testing according to AC232 testing protocols for that specific failure mode. However, the design is adjusted accordingly to account for the additional contribution of the added rebars.

# 9.2 — HAC AND HAC-T DESIGN

The general design of HAC and HAC-T is based on ICC ESR-3520. The design theory of rounded headed anchors is presented in chapter 7. This section provides additional design information for applications outside the scope of AC232 and therefore ESR-3520 such as corners and parallel channels.

The anchor channel design encompasses the verification of the steel and concrete at the anchorage zone. For conditions outside the scope of AC232, it is only the concrete failure mode that are excluded. The steel strengths of the anchor channel do not depend on the concrete and therefore, the steel strengths of HAC and HAC-T are based on ESR-3520.

This section provides guidelines to determine the concrete strengths of anchor channels for applications outside the scope of AC232. The design methodology of such applications is based on applicable provisions and principles of AC232. Table 9.2.1 summarizes the design methodology for each potential failure mode of HAC and HAC-T for intermediate, corners, and parallel anchor channels applications.




Superposition of tension and shear loads
(up to 5 interaction equations)

**IMPORTANT! Failure analysis modes evaluated follow ACI 318-14, chapter 17. This DOES NOT include evaluating the base material (e.g. edge-of-slab) capacity to resist compressive forces generated by the fixture. The engineer must ALWAYS verify the base material (e.g. edge-of-slab) design is capable of resisting the applied loading.**

For additional information, please contact Hilti at US+CA.HAC@Hilti.com

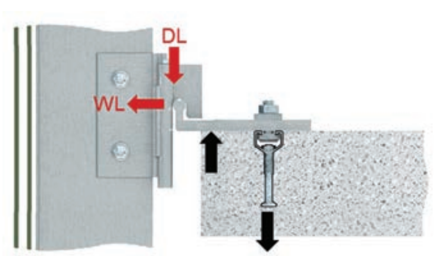





**Table 9.2.1 — Design methodology for all potential failure modes of HAC and HAC-T for common applications**

| Tension design model | | | | |
|---|---|---|---|---|
| Failure mode | Symbol | HAC & HAC-T | | |
| | | Intermediate | Corners | Parallel channels |
| Anchor | $\Phi N_{sa}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Anchor and channel connection | $\Phi N_{sc}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel lip | $\Phi N_{sl}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Bending of channel | $\Phi M_{s,flex}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt | $\Phi N_{ss}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Pullout | $\Phi N_{pn}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Side-face blowout | $\Phi N_{sb}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Concrete breakout | $\Phi N_{cb}$ | ESR-3520 | AC232 principles | AC232 principles |

| Tension design model | | | | |
|---|---|---|---|---|
| Failure mode | Symbol | HAC & HAC-T | | |
| | | Intermediate | Corners | Parallel channels |
| Channel lip | $\Phi V_{sl,y}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Anchor | $\Phi V_{sa,y}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Anchor and channel connection | $\Phi V_{sc,y}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt | $\Phi V_{ss}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt | $\Phi V_{ss,M}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Concrete edge breakout | $\Phi V_{cb,y}$ | ESR-3520 | AC232 principles | AC232 and ACI 318 principles |
| Pryout | $\Phi V_{cp,y}$ | ESR-3520 | AC232 principles | AC232 principles |

| Tension design model | | | | |
|---|---|---|---|---|
| Failure mode | Symbol | HAC & HAC-T | | |
| | | Intermediate | Corners | Parallel channels |
| Anchor | $\Phi V_{sa,x}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Anchor and channel connection | $\Phi V_{sc,x}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt and channel connection | $\Phi V_{sl,x}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt | $\Phi V_{ss}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Channel bolt | $\Phi V_{ss,M}$ | ESR-3520 | ESR-3520 | ESR-3520 |
| Concrete edge breakout | $\Phi V_{cb,x}$ | ESR-3520 | AC232 principles | AC232 and ACI principles |
| Pryout | $\Phi V_{cp,x}$ | ESR-3520 | AC232 principles | AC232 principles |

1 1AC232 based indicates product has been tested in accordance to AC232 testing protocols for that specific failure mode and the design is based on applicable provisions and/or fundamentals of AC232 and/or ACI 318.
2 AC232 and ACI 318 based indicates the analysis of that specific failure modes is in accordance to the applicable ACI 318 provision.

# 9.2.1 — HAC AND HAC-T DESIGN: INTERMEDIATE APPLICATIONS

HAC and HAC-T at intermediate applications are designed in accordance with ESR-3520. Design methodology is fully in accordance with the anchor channel Design Code presented in chapter 7.

Figure 9.2.1.1: FOS

Figure 9.2.1.2:TOS

# 9.2.2 — HAC AND HAC-T DESIGN: FACE OF SLAB OUTSIDE CORNER WITH A SINGLE ANCHOR CHANNEL

## 90° corners

Outside corners where only one anchor channel is present are fully covered by ESR-3520. The design methodology is fully in accordance with the anchor channel Design Code presented in Chapter 7.

AC232 includes design provisions to account for the influence of a corner. The concrete strengths in tension and shear of the anchor channel may be reduced (depending on how far the anchor channel is away from the corner) since the concrete cones may not be fully developed. See chapter 7 for design provisions for corners.

In PROFIS Anchor Channel, these conditions can be simply modeled by reducing the corner distance.

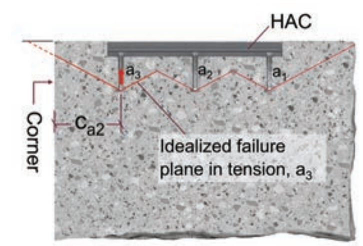



Figure 9.2.2.1: 90° Corner with single channel.

## Acute and obtuse corners

Although AC232 does not specifically address acute and obtuse corners, Hilti's general recommendation is to not follow the idealized failure planes but the path of least resistance to assess the concrete volume available for the anchor channel. Upon determination of the corner distance, AC232 provisions can be used to analyze this type of corners.

In order to avoid calculating unconservative concrete strength, the path of least resistance for the crack should be always considered.

**OPTION I.** This condition should be modeled in PROFIS anchor channel software with a corner ($C_{a2}$) distance of the closest anchor and the corner. Therefore, the concrete represented by the darker shade of gray shall be ignored.

**OPTION II:** This is an optimized condition where the analysis of the $a_1$ anchor is performed using new $h'_{eff}$ as the new embedment depth with side edge distance of $C'_{a2}$ and ignoring the concrete represented by the darker shade of gray. The $h_{eff}$ for rest of the other anchors will not change. This can be solved using hand calculations only. Please contact Hilti for support if any obtuse angle conditions need an optimized solution.

## Obtuse corners: Tension analysis

Corner distance shall be considered assuming an imaginary edge at the joint of the corner. The following two options that has been illustrated and used for the analysis

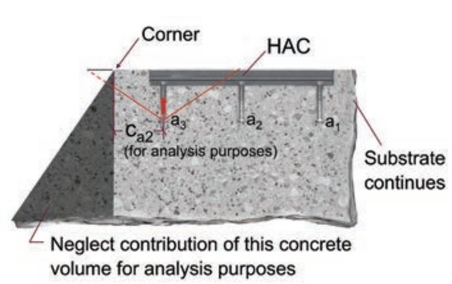



Figure 9.2.2.2 — Obtuse — Tension-Option I.

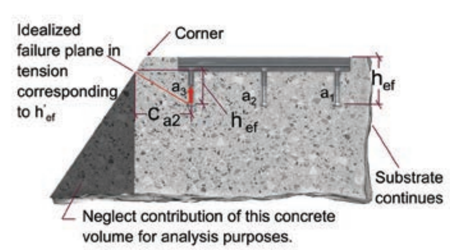



Figure 9.2.2.3 — Obtuse -Tension-Option II.

## Obtuse corners: Perpendicular shear analysis

Conservatively the side edge distance of $C_{a2}$ should be assumed as seen in figure: 9.2.2.4 and figure: 9.2.2.5 because of the discontinuity in the propagation of breakout failure plane in perpendicular shear. This will reduce the perpendicular shear capacity by introducing the reduction factor for corner effect.

$$c_{cr,V} = 0.5 \cdot s_{cr,V} = 2c_{a1} + b_{ch}$$ ESR-3520 Equation (36)

$$\psi_{co,V} = \left(\frac{c_{a2}}{c_{cr,V}}\right)^{0.5} \le 1.0$$ ESR-3520 Equation (35)

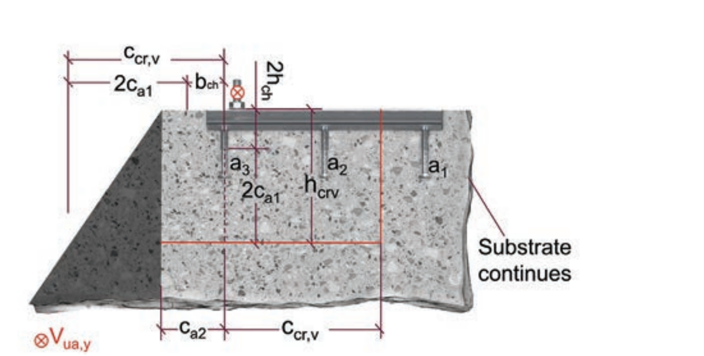



Figure 9.2.2.4 — Obtuse corner — perpendicular shear —Section view.

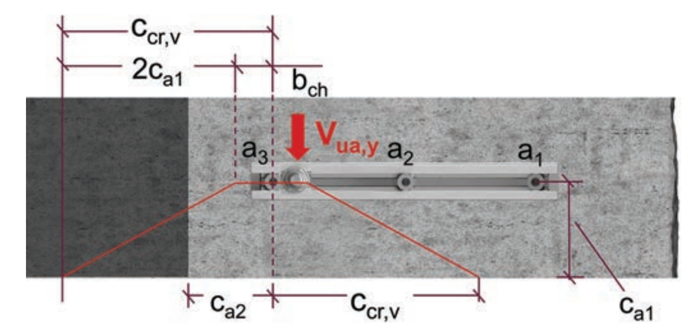



Figure 9.2.2.5 — Obtuse corner — perpendicular shear —Plan view.

## Obtuse corners: Longitudinal shear analysis

Conservatively the side edge distance of $C'_{a1}$ should be assumed as seen in figure: 9.2.2.6 and figure: 9.2.2.7 because of the discontinuity in the propagation of breakout failure plane in longitudinal shear. Having a $C'_{a1}$ will reduce the $A_{vc}$ and also reduces $V_b$ , ($V_b$ basic longitudinal shear capacity depends on the longitudinal distance) which in turn reduces the Longitudinal shear capacity as seen in fig 9.2.2.6.

$$V_{cb,x} = (A_{vc}/A_{vco}) \cdot \psi_{ed,V} \cdot \psi_{c,V} \cdot \psi_{h,V} \cdot \psi_{parallel,V} \cdot V_b$$

ESR-3520 Equation (44)

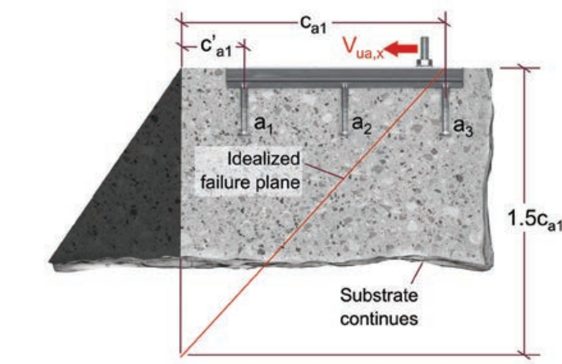



Figure 9.2.2.6 — Obtuse corner — Longitudinal shear —Section view.

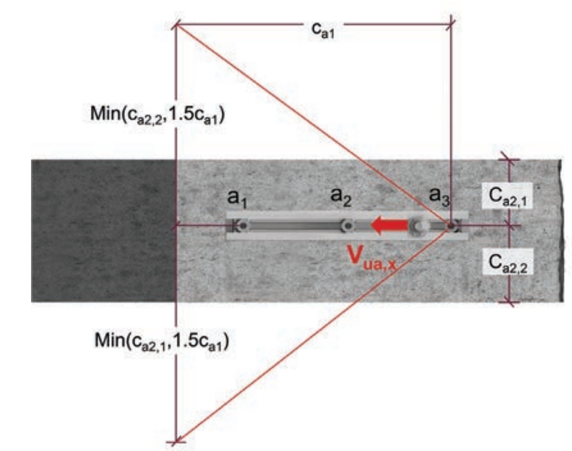



Figure 9.2.2.7 — Obtuse corner — Longitudinal shear —Plan view.

### Acute corners: Tension analysis

Corner distance shall be considered as the shortest distance between the anchor and the edge. The straight line is drawn from the end of the headed stud of anchor channel. The line is extended until it intersects the edge of the acute angle corner. The point of intersection is extended back to the face of slab edge as shown in the Figure 9.2.2.8. The side edge distance $C_{a2}$ is used for analyzing the tension breakout capacity of anchor channel which reduces the tension concrete breakout capacity by introducing the corner factor as seen in the equation below.

$$c_{cr,N} = b_{ch} + 2c_{a1} \geq 1.5h_{ef}$$ ESR-3520 Equation (14)

If $c_{a2} < c_{cr,N}$

$$then\ \psi_{co,N} = \left(\frac{c_{a2}}{c_{cr,N}}\right)^{0.5} \leq 1.0$$ ESR-3520 Equation (16)

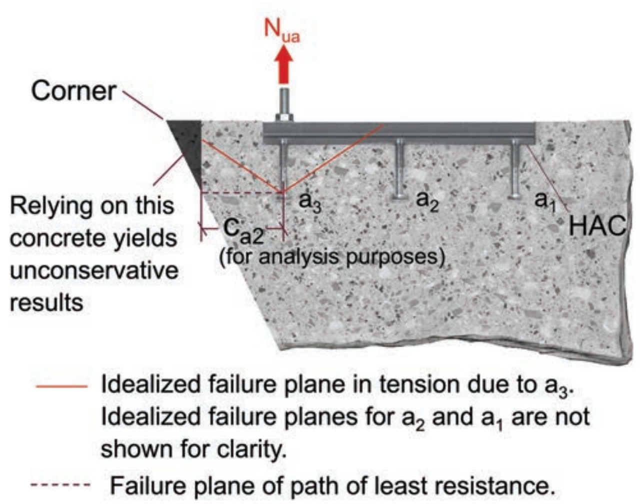



Figure 9.2.2.8 — Acute corner — Tension.

### Acute corners: Perpendicular Shear analysis

A path of least resistance line is drawn emitting from the headed stud $a_3$ as shown in Figure 9.2.2.9, intersecting thee edge 2 at 90°. A straight line is drawn limiting the height of the substrate going through the intersection of path of least resistance and edge 2. This straight line that limits the height of the substrate is drawn parallel to edge 1 as shown in Figure 9.2.2.9. The distance of path of least resistance is measured and modelled as $c_{a2}$ in profis anchor channel software. By limiting the side edge distance to $c_{a2}$ , we will reduce the perpendicular shear capacity. This is done by introducing stringent corner factor reflecting an acute angle corner effect. The substrate height is also measured and modelled in Profis anchor channel software. By limiting the height of the substrate we will introduce the height reduction factor, hence further reducing the overall capacity of perpendicular shear. Please refer to Figure 9.2.2.9 and Figure 9.2.2.10.

$$h_{cr,V} = 2c_{a1} + 2h_{ch}$$ ESR-3520 Equation (38)

$$\psi_{h,V} = \left(\frac{h}{h_{cr,V}}\right)^{\beta_1} \leq 1.0$$ ESR-3520 Equation (37)

$$c_{cr,V} = 0.5 \cdot s_{cr,V} = 2c_{a1} + b_{ch}\ in.(mm)$$ ESR-3520 Equation (36)

$$\psi_{co,V} = \left(\frac{c_{a2}}{c_{cr,V}}\right)^{0.5} \leq 1.0$$ ESR-3520 Equation (35)

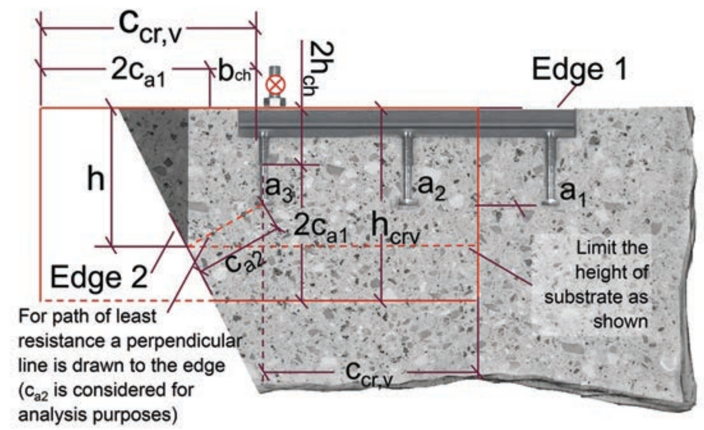



Figure 9.2.2.9 —Acute corner— Perpendicular shear — Section view.

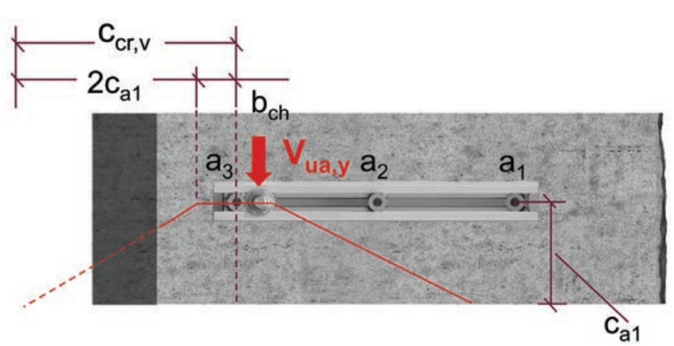



Figure 9.2.2.10 — Acute corner — Perpendicular shear — Plan view.

### Acute corners: Longitudinal Shear analysis

The straight line is drawn limiting the height of the substrate. The line is extended until it intersects the edge of the acute angle corner. The point of intersection is extended back to the face of slab edge as shown in the Figure 9.2.2.11 and Figure 9.2.2.12. By limiting the height of the substrate we will reduce the $A_{cv}$ in a basic longitudinal shear capacity which in turns reduces the longitudinal capacity.

$$V_{cb,x} = (A_{vc} / A_{vco}) \cdot \psi_{ed,V} \cdot \psi_{c,V} \cdot \psi_{h,V} \cdot \psi_{parallel,V} \cdot V_b$$

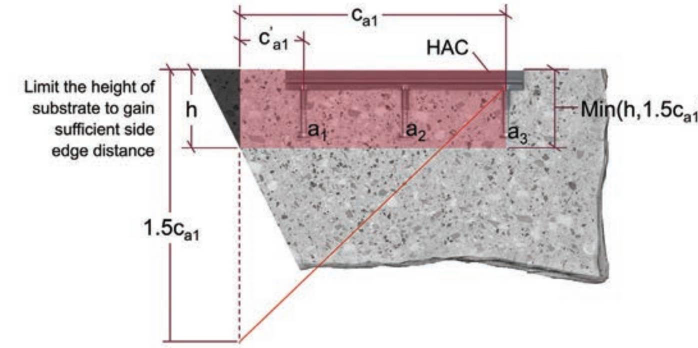



Figure 9.2.2.11 — Acute corner — Longitudinal shear — Section view.

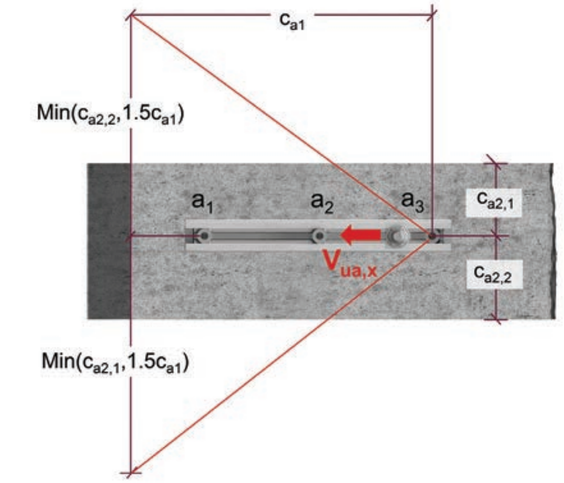



Figure 9.2.2.12 — Acute corner — Longitudinal shear — Plan view.

## 9.2.3 — HAC AND HAC-T DESIGN: FACE OF SLAB OUTSIDE CORNER WITH PAIR OF ANCHOR CHANNEL LOADED SIMULTANEOUSLY

### 90° corners

Outside corners where two anchor channels are present and are loaded simultaneously are outside the scope of AC232. Most of the AC232 provisions can be applied to this type of application. However, the influence of the adjacent anchor channel shall be considered, as the concrete strength may be negatively impacted.

The concrete at the corner is shared by the two anchor channels and therefore, using the AC232 provisions with the actual corner distance for analysis purposes can yield very unconservative concrete strengths. The crack will propagate along the path of least resistance at the corner instead of following idealized failure plane. Figure 9.2.3.1 shows an example of a FOS corner, where anchor channels are installed at the distance away from the corner that the failure planes do not intersect, hence there will not be any reduction in concrete breakout capacity in tension. A side edge distance of $h_{eff}$ + $C_{cr,N}$ at the corner should be provided to make sure that the planes do not intersect.

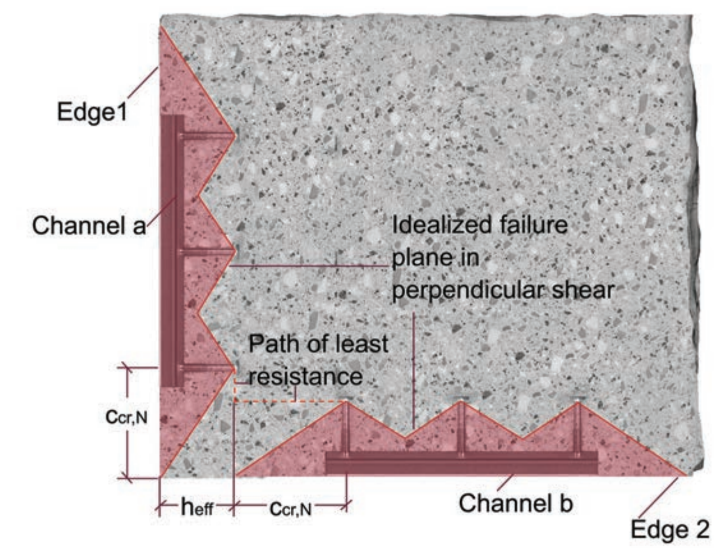



Figure 9.2.3.1 — 90° corner with anchor channels on both sides — Failure planes does not intersect.

### Tension

For the concrete failure modes in tension, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner change the concrete behavior. The concrete crack instead of following the idealized failure plane ($C_{cr,N}$), it takes the path of least resistance at the corner. This concept is illustrated in figure 9.2.3.2.

Hilti uses applicable provisions of AC232 to analyze this type of anchor application. To account for the influence of the adjacent corner anchor channel, the corner distance is reduced by assuming the concrete crack follows the path of least resistance and considering the corner distance where the "crack" of each anchor channel overlaps. The shaded area for 90° angle outside corner with anchor channel with studs, the true side edge can be used once in an analysis of one of the two channel as shown in Figure 9.2.3.3. Concrete breakout in tension check for Channel a, the side edge is $C_{a2,a}$ is used in the analysis. Concrete breakout tension check for Channel b, the true side edge is $C_{a2,b}$ is used in the analysis. This has been illustrated in Figure 9.2.3.3. The total distance of (a+b) can be divided between the two channels, while analyzing the individual channels. For example if channel a is loaded more than channel b than side edge distance of 3/4(a+b) can be assumed for channel a and side edge distance 1/4(a+b) can be assumed for channel b.

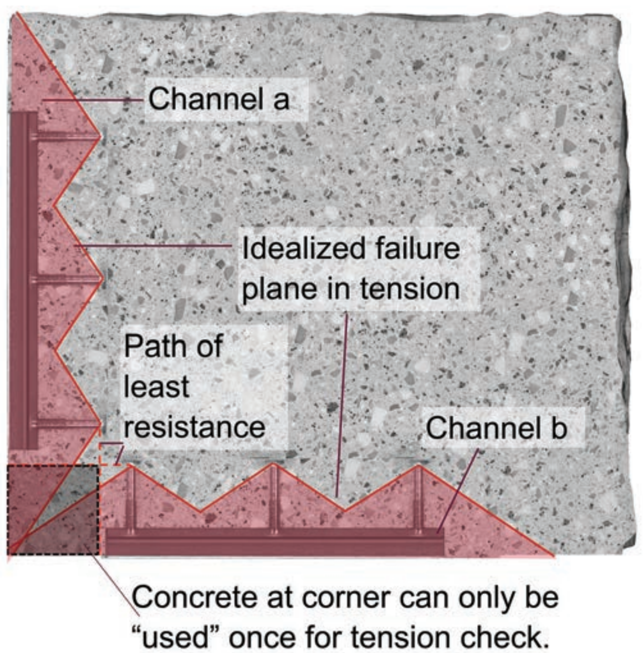



**Figure 9.2.3.2 — 90° corner with anchor channels on both sides — overlapping of tension failure planes.**

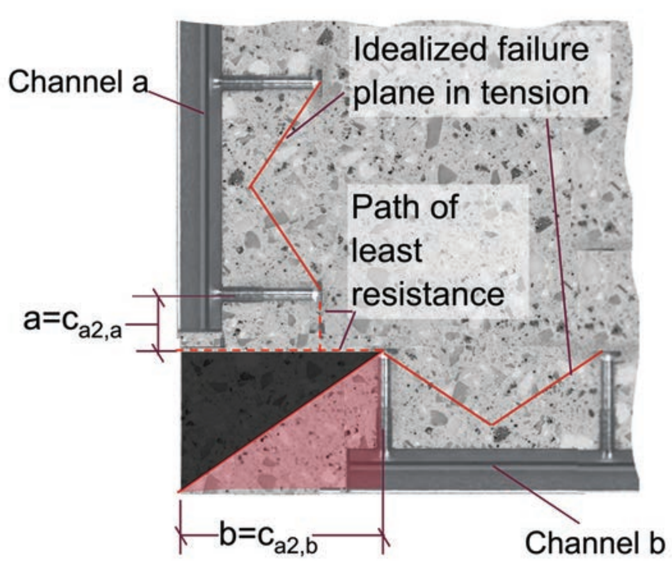



**Figure 9.2.3.3 — 90° corner with anchor channels on both sides — Detail showing the edge distance that needed be used in analysis.**

## Perpendicular shear analysis

In simplified analysis concrete breakout perpendicular shear check at outside corner for Channel a or b, the side edge distance of true edge is considered for analysis with multiplying corner reduction factor of 0.8 to the perpendicular shear capacity. True side edge distance is the distance from the anchor to the edge at the corner.

On other hand detailed analysis can be performed which takes into account the effect of adjacent anchor channel with headed studs. This is incorporated in modification spacing factor $\psi_{s,v}$ as described below. The diagonal distance from the second channel is taken into consideration along with the ratio of the shear load that each of the anchor has over anchor in consideration. Side edge used in the analysis will remain the true side edge distance. Determination of the critical spacing $s_{cr,V}$:

$$b = max\left(\frac{(4c_{a1} + 2b_{ch})}{2}; 2c_{a1} + 2h_{ch}\right)$$

Considering the linear distance between the anchors as $s_i$ =

$$s_i = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

is equivalent to use a circular idealized

breakout body. Condition to ensure the same area as for the

rectangles: $: s_{cr,V} = 2 * \frac{2}{\sqrt{\pi}} b = 2 * 1.13b$

$$V_{cb} = V_b \cdot \psi_{s,V} \cdot \psi_{ed,V} \cdot \psi_{co,V} \cdot \psi_{c,V}$$

$$\psi_{s,V} = \frac{1}{1 + \sum_{i=2}^{n_1+n_2+1}\left[\left(1 - \frac{s_i}{s_{cr,V}}\right)^{1.5} \cdot \frac{V^a_{ua,j}}{V^a_{ua,1}}\right]}$$

$n_1$= number of anchors of channel 1
$n_2$= number of anchors of channel 2

$$s_i = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

$\psi_{s,V}$ modification factor for spacing influence for 90° angle corner: Example of spacing factor $\psi_{s,V}$ calculation for $a_1$. Please refer to Figure 9.2.3.7 for understanding the distance of anchor $a_1$ from anchor $b_1$, $b_2$ and $b_3$ as well as anchor $a_2$ and $a_3$ . The shear force experienced by theses anchors.

$$b = \max(c_{crv};\ h_{crv})$$

$$s_{cr,V} = 2 * \frac{2}{\sqrt{\pi}} b = 2 * 1.13b$$

$$\psi_{s,v,a1} = \frac{1}{1 + \left[\left(1 - \frac{s_{b,1,1}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b1}}{V^a_{ua,a1}}\right] + \left[\left(1 - \frac{s_{b,1,2}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b2}}{V^a_{ua,a1}}\right] + \left[\left(1 - \frac{s_{b,1,3}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b3}}{V^a_{ua,a1}}\right] + \left[\left(1 - \frac{s_{a,1,2}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,a2}}{V^a_{ua,a1}}\right] + \left[\left(1 - \frac{s_{a,1,3}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,a3}}{V^a_{ua,a1}}\right]}$$

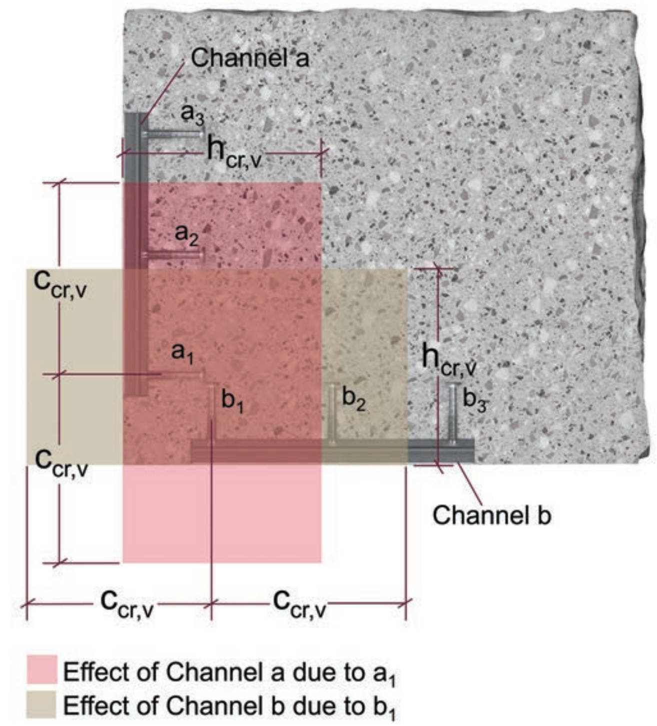



**Figure 9.2.3.4 — 90° FoS corner with anchor channels on both sides — Determination of b.**

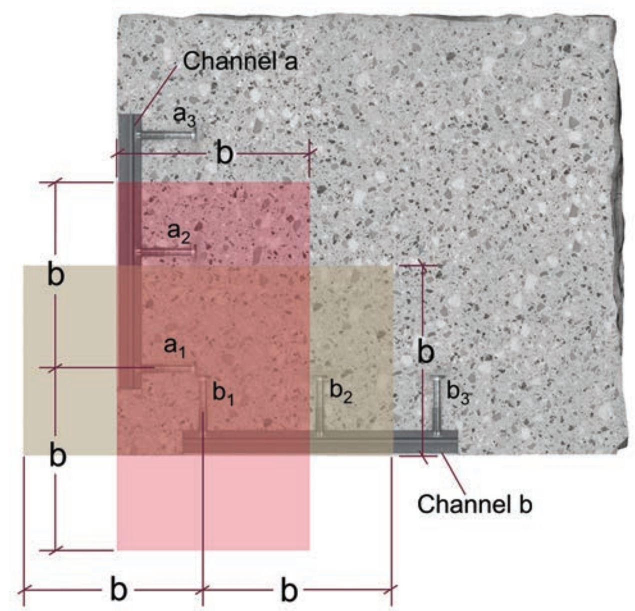



**Figure 9.2.3.5 — 90° FoS corner with anchor channels on both sides — Effect of anchors closest to the edges.**

$\psi_{co,V}$ modification factor for corner influence for 90° angle corner: The true edge distance is taken into consideration for determination of reduction factor for corner distance $C_{a2,a}$ or $C_{a2,b}$ is taken as distance in case of a 90° angle corner for corner anchors $a_1$ or $b_1$ respectively.

$C_{a2}$=($C_{a2,a}$ ) distance of the anchor $a_1$ under consideration to the corner (see Figure 9.2.3.7).

$$If\ \ C_{a2} \geq C_{cr,v}\ than\ \psi_{co,V} = 1.0$$

$$If\ \ C_{a2} < C_{cr,v}\ than\ \psi_{co,V} = \left(\frac{C_{a2,a}}{C_{cr,V}}\right)^{0.5} \leq 1.0$$

$$S_{cr,v} = 2b_{ch} + 4C_{a1}$$
$$C_{cr,v} = 0.5S_{cr,v} = b_{ch} + 2C_{a1}$$

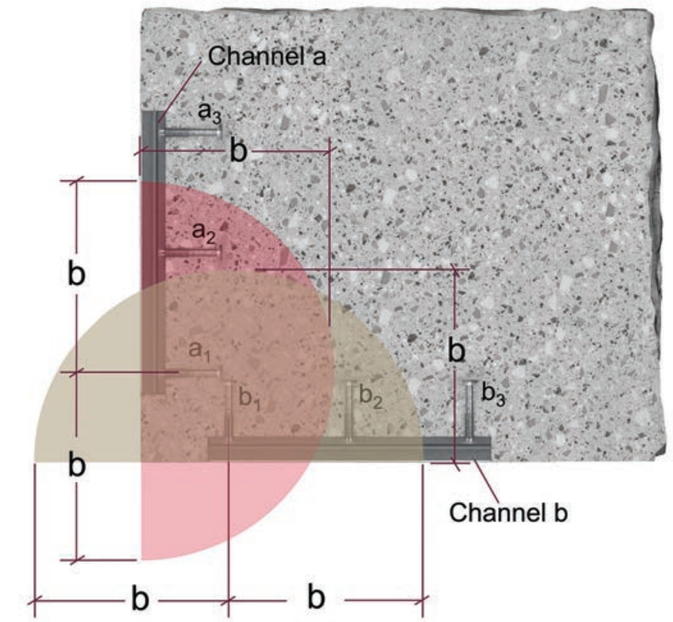



**Figure 9.2.3.6 — 90° FoS corner with anchor channels on both sides — $S_{cr,v}$.**

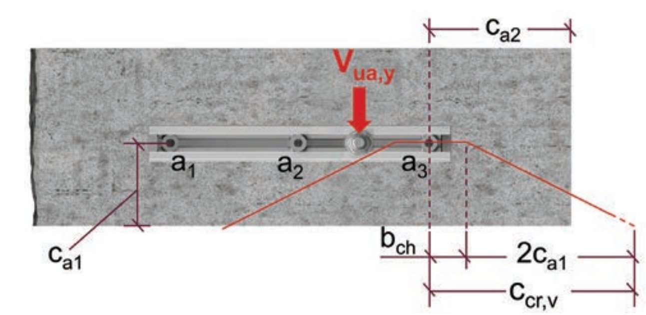



**Figure 9.2.3.7.a — 90° FoS corner with anchor channels on both sides — Plan view.**

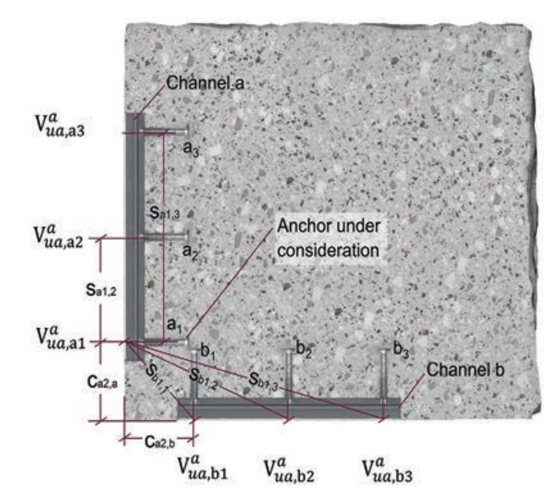



**Figure 9.2.3.7.b — 90° FoS corner with anchor channels on both sides — Example of determination of $\psi_{s,v,a1}$ — Section view.**

## Longitudinal shear analysis

When Longitudinal shear is applied on both sides of the anchor channel towards the corner edge. The longitudinal shear capacity is determined with the edge distance of $c_{a1}$ or with $c'_{a1}$ which ever controls. Please refer Figure 9.2.3.8 and Figure 9.2.3.9.

## Interaction Equation

Interacting the concrete utilization in tension, perpendicular shear and longitudinal shear of both channels which will include the effect of all of these breakout cones as described below. 3D Load Interaction for Front of Slab solutions (verification for every anchor):

$$\beta_{N+V,c} = (\beta_N + max(\beta_{Vx})_{chj,Edi})^{\alpha} + (\beta_{Vy})^{\alpha} + (\beta_{Vx\,chi})^{\alpha}$$

$$\beta_{N+V,c} = \left(\left(\frac{N^a_{ua}}{\phi \cdot N_{nc}}\right) + \max\left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)_{ch"b"Edb}\right)^{\alpha} + \left(\frac{V^a_{ua,y}}{\phi \cdot V_{nc,y}}\right)^{\alpha} + \left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)^{\alpha} \leq 1.0$$

with α=1.67

$\frac{N^a_{ua}}{\phi \cdot N_{nc}}$ : Tension of anchor channel in consideration ( channel a - anchor $a_1$)

- Concrete breakout in tension utilization (anchor, including influence of the other channels)
- Pull Out Strength Utilization

$\max\left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)_{ch"b"Edb}$ : Longitudinal shear of anchor channel on perpendicular edge (channel b)

- Longitudinal concrete edge failure Utilization
- Anchor reinforcement for concrete edge failure Utilization

$\frac{V^a_{ua,y}}{\phi \cdot V_{nc,y}}$ : Perpendicular shear of anchor channel in consideration ( channel a - anchor $a_1$)

- Maximum Concrete edge breakout utilization for Perpendicular shear

$\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}$ : Longitudinal shear of anchor channel in consideration ( channel a - anchor $a_1$)

- Concrete edge (anchor)
- Anchor reinforcement for concrete edge failure

Please note that using this interaction equation is a conservative method to incorporate longitudinal force utilization in the analysis. In order to optimize the design contact Hilti. We will optimize the design using the method that takes into consideration the longitudinal utilization of both the anchor channels.

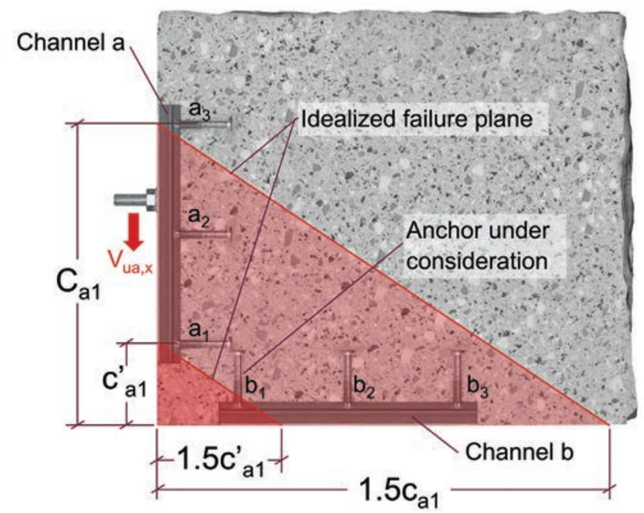



**Figure 9.2.3.8 — 90° FoS corner with anchor channels on both sides — Effect of longitudinal, perpendicular shear and tension.**

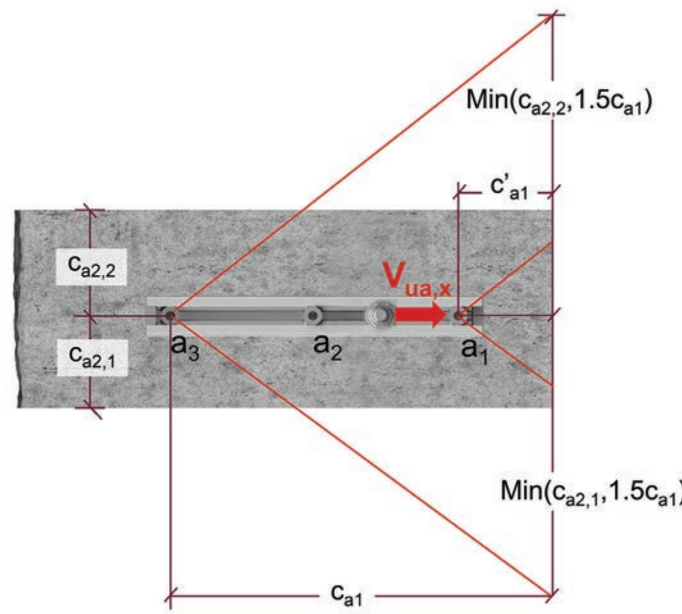



**Figure 9.2.3.9 — 90° FoS corner with anchor channels on both sides —Effect of longitudinal, perpendicular shear and tension—section view**

## Acute and obtuse corners

**Acute Corner:**

Acute angle corners with HAC (rounded headed anchors) loaded simultaneously in tension, perpendicular shear and longitudinal shear

**Tension analysis:** .

The crack will propagate along the path of least resistance at the corner instead of following idealized failure plane. The side edge distance used in the analysis should be as shown in the Figure 9.2.3.10. This approach is followed in order to avoid utilizing the same concrete twice in the analysis, hence generating the results replicating the real condition. The shaded region of concrete shown in the figure is not utilized. Please refer Figure 9.2.3.10. The total distance of (a+b) can be divided between the two channels, while analysing the individual channels. For example if channel a is loaded more than channel b than side edge distance of 3/4(a+b) can be assumed for channel a and side edge distance 1/4(a+b) can be assumed for channel b.

**Perpendicular shear analysis:**

The reduced side edge distance needed to be considered as shown in Figure 9.2.3.12. The ideal failure plane for perpendicular shear breakout is drawn propagating into the slab. The line is drawn parallel to edge 1 at a distance $h_{cr,v}$ $(2(h_{ch}+c_{a1}))$. The intersection point of this line with edge 2 is projected back to edge 1 in order to determine side edge distance $c'_{a2}$ for the analyses of channel b. Similar line can be drawn parallel to edge 2 at a distance $h_{cr,v}$ $(2(h_{ch}+c_{a1}))$ to determine the side edge distance of channel a. This side edge is measured from that point to the anchor and is modelled in profis for analysis for analyses of individual channels. This will reduce the perpendicular shear capacity by taking into consideration the small edge introducing the more stringent corner modification factor. Please refer Figure 9.2.3.11 and Figure 9.2.3.12.

Moreover, the $\psi_{s,v}$ is calculated taking into consideration the respective distances of neighboring anchors with respect to the anchor that is in consideration. Refer to 90° corner section describing the method in detail. Please refer Figure 9.2.3.14

Example of spacing factor $\psi_{s,v}$ calculation for $a_1$ with respect to $a_1$.

$\psi_{s,V}$ modification factor for spacing influence for acute angle corner: Example of spacing factor $\psi_{s,v}$ calculation for $b_1$ of anchor channel "b" taking into consideration the presence of anchor channel a.

$$b = max(c_{crv};\ h_{crv})$$

$$s_{cr,V} = 2 * \frac{2}{\sqrt{\pi}} b = 2 * 1.13b$$

$$\psi_{s,v,a1} = \frac{1}{1+\left[\left(1-\frac{s_{b,1,1}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b1}}{V^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{b,1,2}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b2}}{V^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{b,1,3}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b3}}{V^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a,1,2}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,a2}}{V^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a,1,3}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,a3}}{V^a_{ua,a1}}\right]}$$

$\psi_{co,V}$ modification factor for corner influence for acute angle corner: A reduced edge distance is taken into consideration for determination of reduction factor for corner distance $C'_{a2}$ is taken as distance in case of a acute angle corner for corner anchor $b_1$. Refer Figure 9.2.3.12

$C_{a2}$=($C'_{a2}$ ) distance of the anchor a1 under consideration to the corner (see Figure 9.2.3.12).

$$If\ C'_{a2} \geq C_{cr,v}\ than\ \psi_{co,V} = 1.0$$

$$If\ C'_{a2} < C_{cr,v}\ than\ \psi_{co,V} = \left(\frac{C'_{a2}}{C_{cr,V}}\right)^{0.5} \leq 1.0$$

$$S_{cr,v} = 2b_{ch} + 4C_{a1}$$
$$C_{cr,v} = 0.5S_{cr,v} = b_{ch} + 2C_{a1}$$

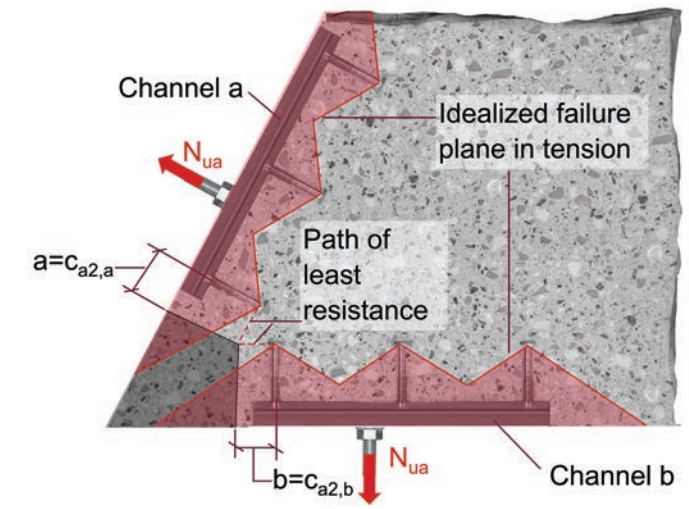



**Figure 9.2.3.10 — Acute angle FoS corner with anchor channels on both sides — Tension analysis.**

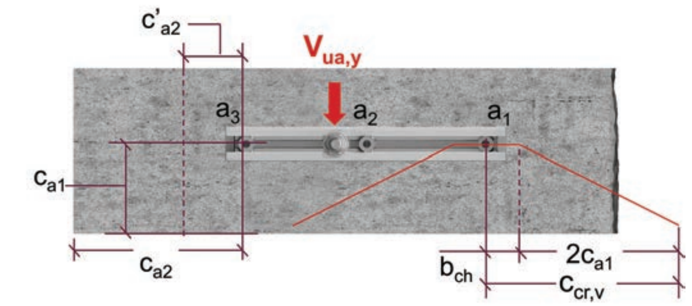



**Figure 9.2.3.11 — Acute angle FoS corner with anchor channels on both sides — Perpendicular shear analysis — Plan view.**

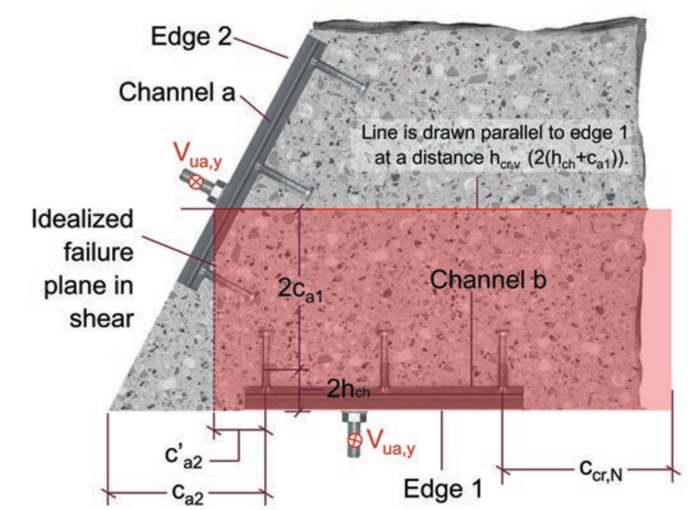



**Figure 9.2.3.12 — Acute angle FoS corner with anchor channels on both sides — Perpendicular shear analysis- Section view.**

## Longitudinal shear analysis:

The reduced side edge distance needed to be conservatively considered as shown in Figure 9.2.3.14 as done for perpendicular shear for determining the longitudinal shear capacity.

## Interaction Equation:

Interacting the concrete utilization in tension, perpendicular shear and longitudinal shear of both channel will include the effect of all of these breakout cones as described below. Refer section for 90° corner describing the longitudinal shear check.

3D Load Interaction for Front of Slab solutions (verification for every anchor):

$$\beta_{N+V,c} = \left(\left(\frac{N^a_{ua}}{\phi \cdot N_{nc}}\right) + \max\left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)_{ch"a"Eda}\right)^{\alpha} + \left(\frac{V^a_{ua,y}}{\phi \cdot V_{nc,y}}\right)^{\alpha} + \left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)^{\alpha} \leq 1.0$$

with $\alpha$=1.67

$\frac{N^a_{ua}}{\phi \cdot N_{nc}}$: Tension of anchor channel in consideration (channel b)

- Concrete breakout in tension utilization (anchor, including influence of the other channels)
- Pull Out Strength Utilization

$\max\left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)_{ch"a"Eda}$ : Longitudinal shear of anchor channel on acute edge (channel a)

- Longitudinal concrete edge failure utilization
- Anchor reinforcement for concrete edge failure

$\frac{V^a_{ua,y}}{\phi \cdot V_{nc,y}}$ : Perpendicular shear of anchor channel in consideration (channel b)

- Maximum Concrete edge breakout utilization for Perpendicular shear

$\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}$ : Longitudinal shear of anchor channel in consideration (channel a)

- Concrete edge (anchor)
- Anchor reinforcement for concrete edge failure

Please note that using this interaction equation is a conservative method to incorporate longitudinal force utilization in the analysis. In order to optimize the design contact Hilti. We will optimize the design using the method that takes into consideration the longitudinal utilization of both the anchor channels.

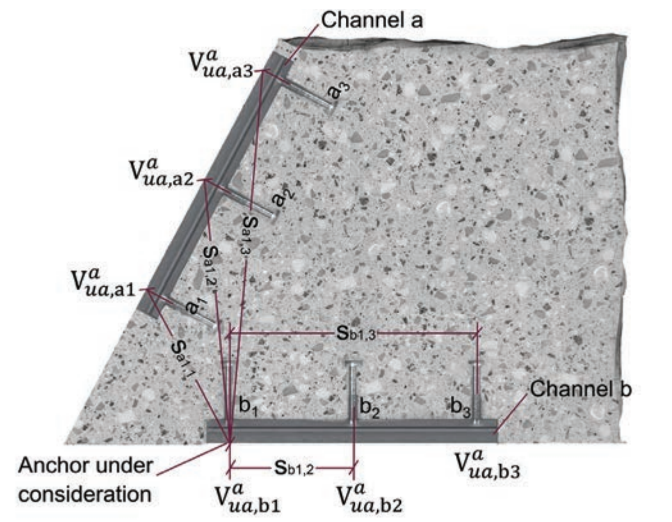



**Figure 9.2.3.13 — Acute FoS corner with anchor channels on both sides — Example of determination of $\psi_{s,v,a1}$.**

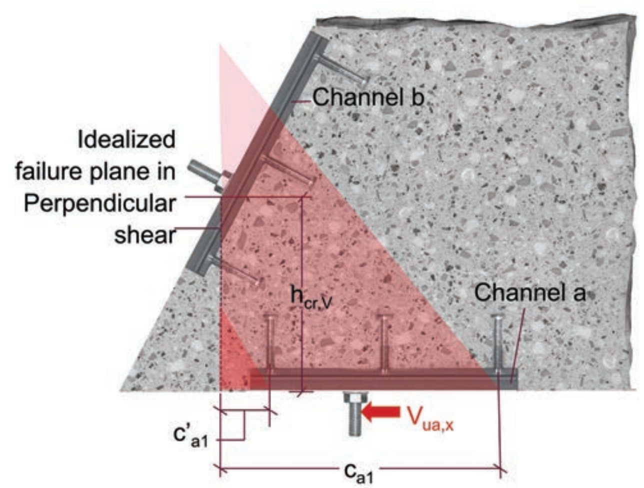



**Figure 9.2.3.14— Acute FoS corner with anchor channels on both sides — Effect of longitudinal, perpendicular shear and tension.**



## Obtuse Corner

**Tension:**

Obtuse angle corners with headed studs HAC channel loaded only in **tension**: The crack will propagate along the path of least resistance at the corner instead of following idealized failure plane. The side edge distance used in the analysis should be as shown in Figure 9.2.3.15. This approach is followed in order to avoid utilizing the same concrete twice in the analysis, hence generating the results replicating the real condition. The shaded region of concrete shown in Figure 9.2.3.15 is not utilized.

The shaded area for obtuse angle corner with headed studs anchor channel the true side edge can be used once in an analysis as shown in Figure 9.2.3.16. Assigning true edge to one channel and assigning reduced edge to another channel. Concrete breakout in tension check for Channel a, the reduced side edge is $C_{a2,a}$ can be used in the analysis. Concrete breakout tension check for Channel b, the true side edge is $C_{a2,b}$ can be used in the analysis. The total distance of (a+b) can be divided between the two channels, while analyzing the individual channels. For example if channel a is loaded more than channel b than side edge distance of 3/4(a +b) can be assumed for channel a and side edge distance 1/4(a+b) can be assumed for channel b.

**Perpendicular shear:**

Concrete breakout perpendicular shear check at outside corner for Channel a or b, the side edge distance of true edge is considered for analysis in determining the perpendicular shear capacity. True side edge distance is the distance from the anchor to the corner edge at the corner. Moreover, the $\psi_{s,v}$ is calculated taking into consideration the respective distances of neighboring anchors with respect to the anchor that is in consideration. Refer to 90° corner section describing the method in detail. Please refer to the Figure 9.2.3.17.

$\psi_{s,V}$ modification factor for spacing influence for acute angle corner:

Example of spacing factor $\psi_{s,v}$ calculation for $a_1$ of channel a with respect to $a_1$ channel b on the other side of obtuse angle corner. Please refer to the Figure 9.2.3.17.

$$b = max(c_{crv};\ h_{crv})$$

$$s_{cr,V} = 2 * \frac{2}{\sqrt{\pi}} b = 2 * 1.13b$$

$$\psi_{s,v,a1} = \frac{1}{1+\left[\left(1-\frac{s_{b,1,1}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b1}}{V^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{b,1,2}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b2}}{V^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{b,1,3}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,b3}}{V^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a,1,2}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,a2}}{V^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a,1,3}}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,a3}}{V^a_{ua,a1}}\right]}$$

$\psi_{co,V}$ modification factor for corner influence for an obtuse angle corner: A true side edge distance is taken into consideration for determination of reduction factor for corner distance $C_{a2,a}$ or $C_{a2,b}$ is taken as distance in case of a obtuse angle corner for corner anchor $a_1$ and $b_1$ respectively.

$$If\ C_{a2,a} \geq C_{cr,v}\ than\ \psi_{co,V} = 1.0$$

$$If\ C_{a2,a} < C_{cr,v}\ than\ \psi_{co,V} = \left(\frac{C_{a2,a}}{C_{cr,V}}\right)^{0.5} \leq 1.0$$

$$S_{cr,v} = 2b_{ch} + 4C_{a1}$$
$$C_{cr,v} = 0.5S_{cr,v} = b_{ch} + 2C_{a1}$$

$C_{a2}$=($C_{a2,a}$ ) distance of the anchor $a_1$ under consideration to the corner (see Figure 9.2.3.17).

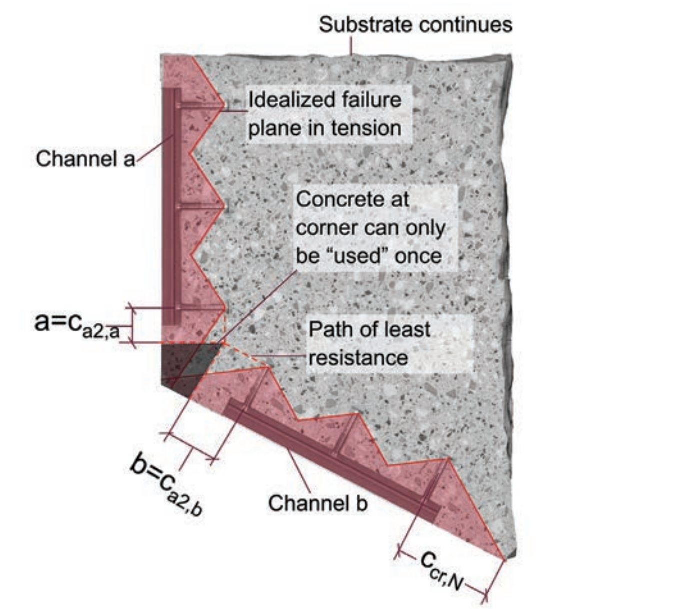



**Figure 9.2.3.15 — Obtuse angle FoS corner with anchor channels on both sides — Tension analysis.**

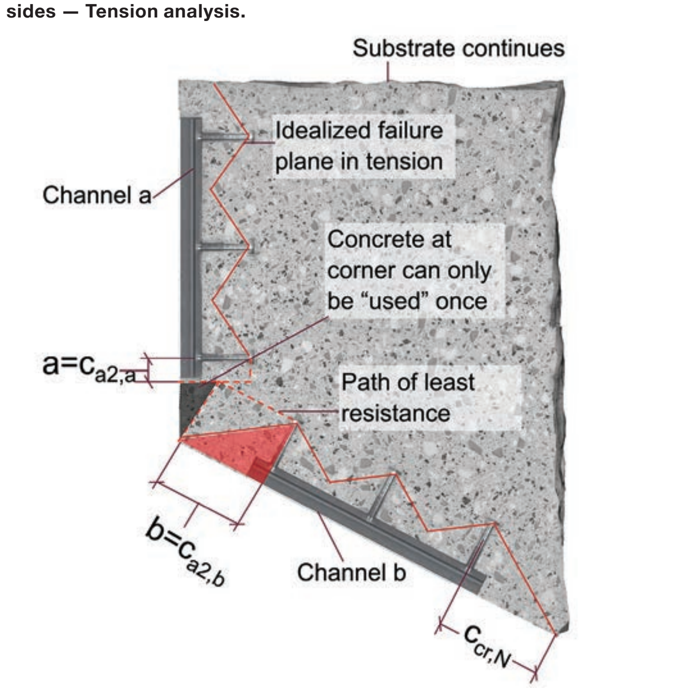



**Figure 9.2.3.16 — Obtuse angle FoS corner with anchor channels on both sides — example of Tension analysis.**

### Longitudinal shear:

Concrete breakout longitudinal shear check for channel a and b, the true side edge is considered for analysis with no added corner reduction factor to the capacity.

### Interaction Equation:

Interacting the concrete utilization in tension, perpendicular shear and longitudinal shear of both channel will include the effect of all of these breakout cones as described below.

3D Load Interaction for Front of Slab solutions (verification for every anchor):

with α=1.67

$$\beta_{N+V,c} = \left(\left(\frac{N^a_{ua}}{\phi \cdot N_{nc}}\right) + \max\left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)_{ch"b"Edb}\right)^{\alpha} + \left(\frac{V^a_{ua,y}}{\phi \cdot V_{nc,y}}\right)^{\alpha} + \left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)^{\alpha} \leq 1.0$$

$\frac{N^a_{ua}}{\phi \cdot N_{nc}}$ : Tension of anchor channel in consideration (channel a)

- Concrete breakout in tension utilization (anchor, including influence of the other channels)
- Pull Out Strength Utilization

$\max\left(\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}\right)_{ch"b"Edi}$ : Longitudinal shear of anchor channel on obtuse edge (channel b)

- Longitudinal concrete edge failure Utilization

$\frac{V^a_{ua,y}}{\phi \cdot V_{nc,y}}$ : Perpendicular shear of anchor channel in consideration ( channel a)

- Maximum Concrete edge breakout utilization for Perpendicular shear

$\frac{V^a_{ua,x}}{\phi \cdot V_{nc,x}}$ : Longitudinal shear of anchor channel in consideration ( channel a)

- Concrete edge (anchor)
- Anchor reinforcement for concrete edge failure

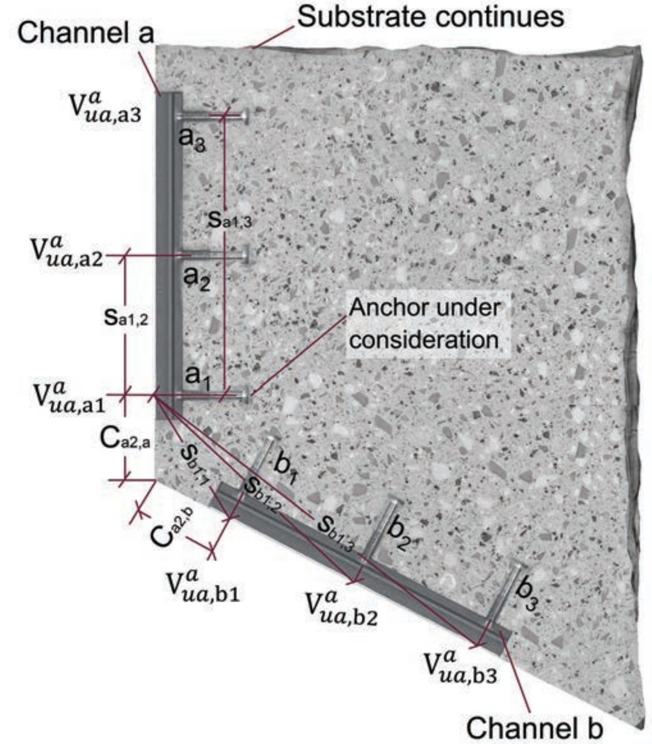



**Figure 9.2.3.16.17— Obtuse FoS corner with anchor channels on both sides —Example of determination of $\psi_{s,v,a1}$.**

## 9.2.4 — HAC AND HAC-T DESIGN: FACE OF SLAB INSIDE CORNER WITH PAIR OF ANCHOR CHANNEL

Inside corners where two anchor channels are present and are loaded simultaneously are outside the scope of AC232. Most of the AC232 provisions can be applied to this type of application. However, the influence of the adjacent anchor channel should be considered, as the concrete strength may be negatively impacted.

**90° Inside Corner**

An Imaginary edge is assumed while analyzing anchor channel b. The side edge distance of $C_{a2,a}$ is taken as shown in figure 9.2.4.1 and Figure 9.2.4.2.

The side edge distance with infinite amount of concrete to the right of the anchor channel a is assumed while analyzing as shown in the figure 9.2.4.1 and figure 9.2.4.2.

**Tension:** Refer Figure 9.2.4.1. This condition can be analyzed by fictitious edge between $c_{a2,b} + c_{cr,N}$ assigning side edge concrete between channel a and b. The total distance of (a+b) can be divided between the two channels, while analysing the individual channels. For example if channel a is loaded more than channel b than side edge distance of 3/4(a+b) can be assumed for channel a and side edge distance 1/4(a+b) can be assumed for channel b.

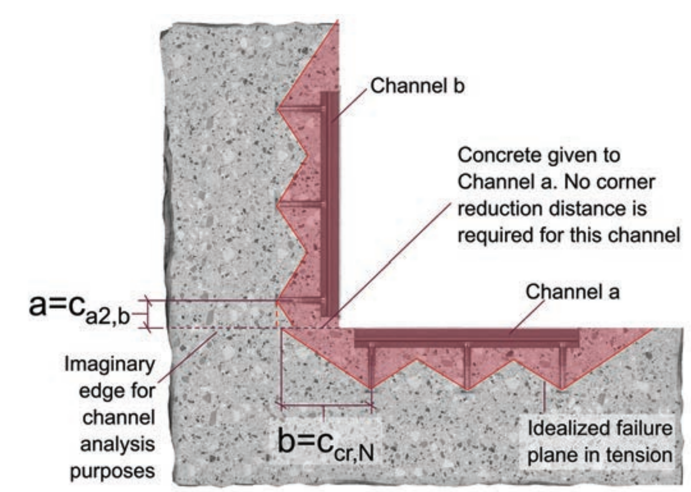



**Figure 9.2.4.1 — 90° interior FoS corner with anchor channels on both sides.**

**Perpendicular shear:** Refer Figure 9.2.4.2. This condition can be analyzed by fictitious edge between $c_{a2,b} + c_{cr,V}$ assigning side edge concrete between channel a and b. The total distance of (a+b) can be divided between the two channels, while analyzing the individual channels. For example if channel a is loaded more than channel b than side edge distance of 3/4(a+b) can be assumed for channel a and side edge distance 1/4(a+b) can be assumed for channel b.

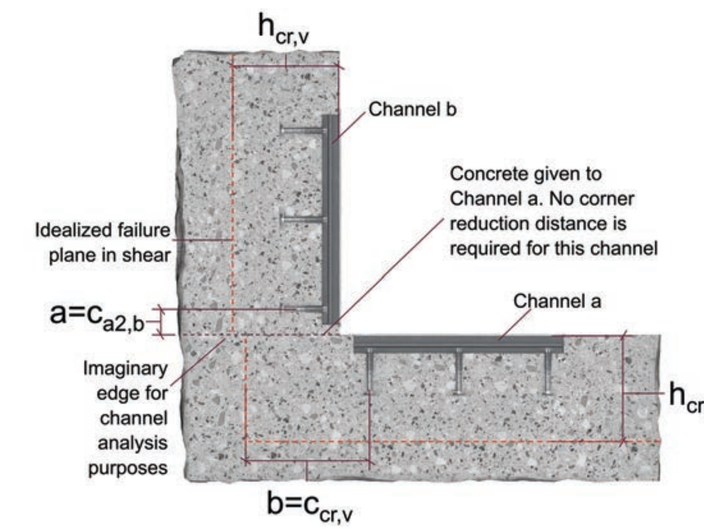



**Figure 9.2.4.2 — Acute angle interior FoS corner with anchor channels on both sides — Perpendicular shear.**

### Acute and obtuse interior corners

**Acute Interior Corner:**

An Imaginary edge is assumed while analyzing anchor channel b. The side edge distance of $C_{a2}$ is taken as shown in the figure to the right figure 9.2.4.3 and figure 9.2.4.4. The concrete shaded in dark color in these Figures is not neglected, while analyzing anchor channel a or b.

The side edge distance with infinite amount of concrete to the right of the anchor channel a is assumed while analyzing as shown in the figure 9.2.4.3 and figure 9.2.4.4.

**Tension:** Refer Figure 9.2.4.3. This condition can be analyzed by fictitious edge between $c_{a2,b} + c_{cr,N}$ assigning side edge concrete between channel a and b. The total distance of (a+b) can be divided between the two channels, while analyzing the individual channels. For example if channel a is loaded more than channel b than side edge distance of 3/4(a+b) can be assumed for channel a and side edge distance 1/4(a+b) can be assumed for channel b.

**Perpendicular shear:** Refer Figure 9.2.4.4. This condition can be analyzed by fictitious edge between $c_{a2,b} + c_{cr,V}$ assigning side edge concrete between channel a and b. The total distance of (a+b) can be divided between the two channels, while analyzing the individual channels. For example if channel a is loaded more than channel b than side edge distance of 3/4(a+b) can be assumed for channel a and side edge distance 1/4(a+b) can be assumed for channel b.

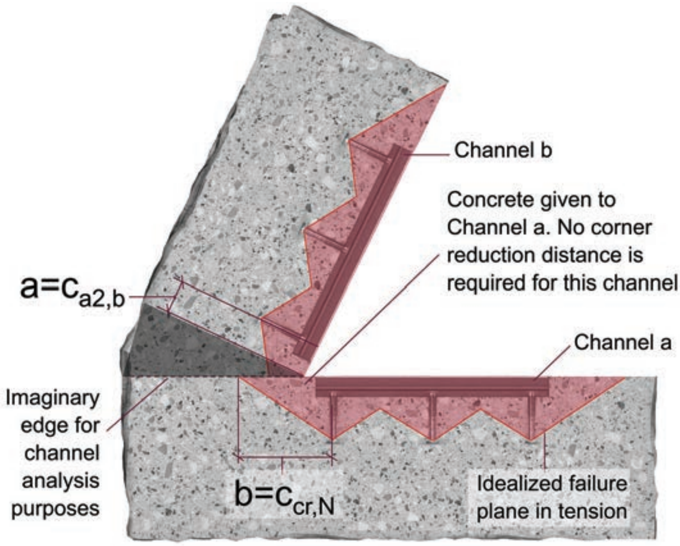



Figure 9.2.4.3— Acute angle interior FoS corner with anchor channels on both sides — Tension

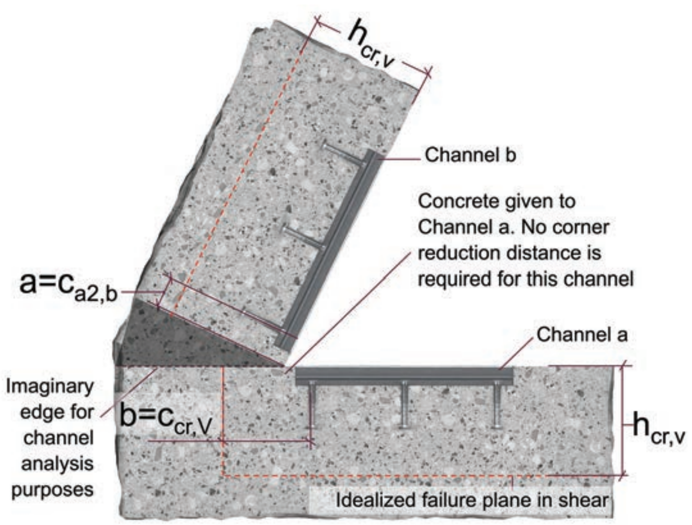



Figure 9.2.4.4 — Acute interior FoS corner with anchor channels on both sides — Perpendicular shear

## Obtuse Interior Corner

**Tension:** The anchor channels installed at an obtuse angle interior corner will generate the overlapping concrete breakout cones in tension as seen in Figure 9.2.4.5. The portion of the concrete shaded in dark should be neglected in order to replicate the real condition. A side edge of $c_{a2,b}$ should be consider in analysis of channel b and side edge of $c_{a2,a}$ should be consider in the analysis of channel a.

**Perpendicular shear:** The anchor channels installed at an obtuse angle interior corner will generate the overlapping concrete breakout planes in perpendicular shear as seen in Figure 9.2.4.6. The portion of the concrete shaded in dark should be neglected in order to replicate the real condition. A side edge of $c_{a2,b}$ should be consider in analysis of channel b and side edge of $c_{a2,a}$ should be consider in the analysis of channel a.

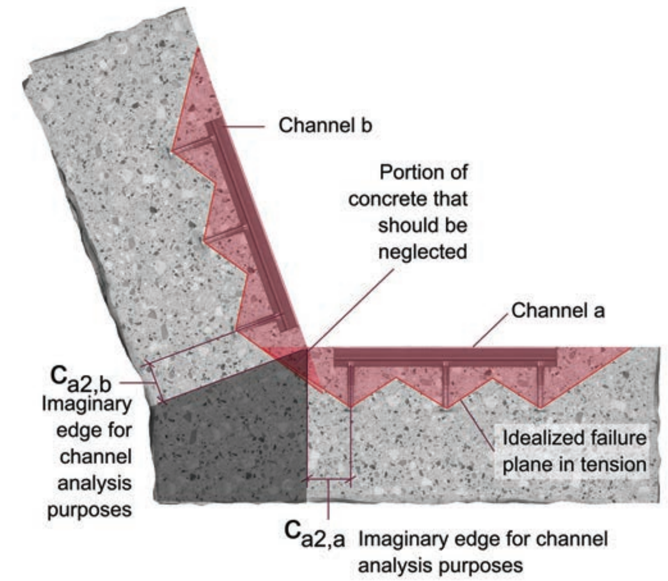



Figure 9.2.4.5 — Obtuse angle interior FoS corner with anchor channels on both sides.

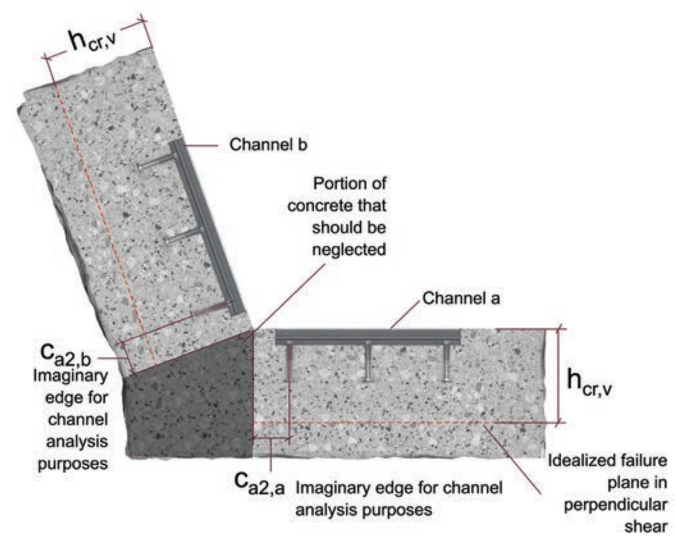



Figure 9.2.4.6 — Obtuse angle interior FoS corner with anchor channels on both sides —perpendicular shear

## 9.2.5 — HAC AND HAC-T DESIGN: FACE OF SLAB THE MINIMUM DISTANCE THAT WILL ASSURE THAT THE CONCRETE CONE DOES NOT INTERSECT BOTH IN SHEAR AND TENSION

Tension: The amount of concrete that is needed to assure that the tension concrete breakout cones do not overlap should be as shown in Figure 9.2.5.1. The corner distance required should be sum of effective embedment (heff) and critical spacing ($c_{cr,N}$) for any one of the two channels. With that distance the channel perpendicular to the edge can be installed at critical distance $c_{cr,N}$ away from the corner. In Figure 9.2.4.7 the channel b is installed at corner distance of ($h_{eff}$ + $c_{cr,}$N) on edge 2, then the channel a can be installed at the corner distance of $c_{cr,N}$ on edge 1.

$$h_{cr,V} = 2c_{a1} + 2h_{ch}$$

$$s_{cr,N} = 2\left(2.8 - \frac{1.3h_{ef}}{7.1}\right)h_{ef} \geq 3h_{ef}$$

$$c_{cr,N} = 0.5s_{cr,N} \geq 1.5h_{ef}$$

$$S_{cr,V} = 4c_{a1} + 2b_{ch} \; in.(mm)$$

$$c_{cr,V} = 0.5 \cdot s_{cr,V} = 2c_{a1} + b_{ch} \; in.(mm)$$

Perpendicular shear: The amount of concrete that is needed to assure that the concrete breakout planes in perpendicular shear do not overlap should be as shown in Figure 9.2.5.2. The corner distance required should be sum of critical height ($h_{cr,V}$) and critical spacing ($c_{cr,V}$) for any one of the two channels. With that distance the channel perpendicular to the edge can be installed at critical distance $c_{cr,V}$ away from the corner. In Figure 9.2.4.8 the channel b is installed at corner distance of ($h_{cr,V}$ + $c_{cr,V}$) on edge 2, then the channel a can be installed at the corner distance of $c_{cr,V}$ on edge 1.

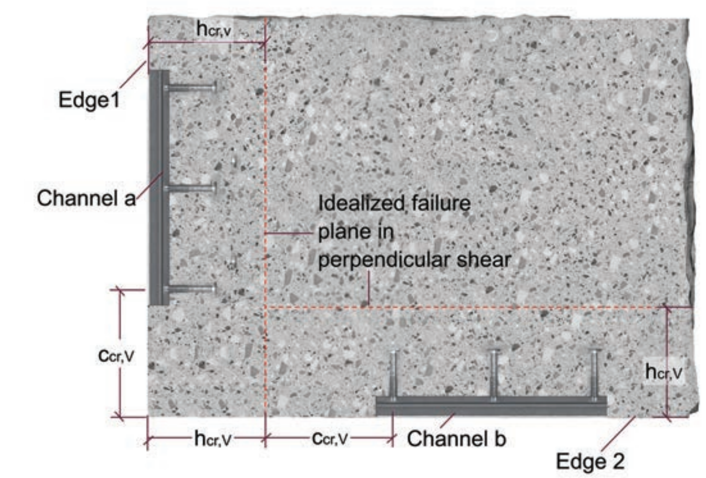



Figure 9.2.5.1— Minimum distance between anchor channels at the corner to assure the breakout cones do not intersect — Tension

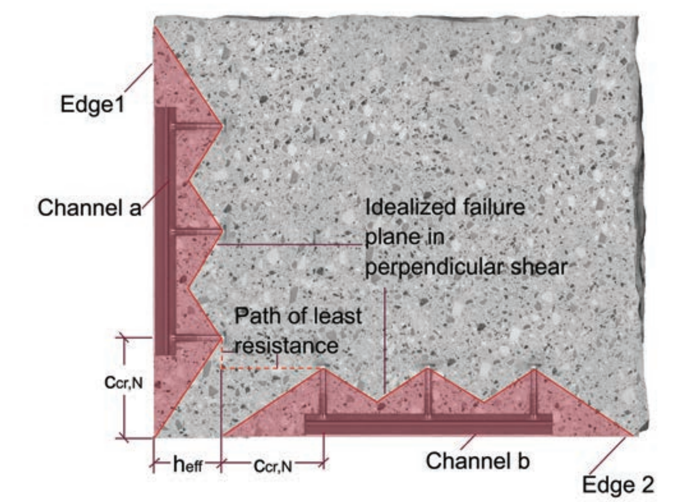



Figure 9.2.5.2— Minimum distance between anchor channels at the corner to assure the breakout cones do not intersect — Tension

# 9.2.6 — HAC AND HAC-T DESIGN: EXAMPLE OF DESIGN OF FACE OF SLAB OUTSIDE CORNER WHERE THE ANCHOR CHANNELS ARE LOCATED AT A CERTAIN DISTANCE

Quick conservative check can be done by using the method described in this section. For concrete breakout, in tension and concrete breakout, and pryout in shear, the imaginary concrete side edge of "(x/2)-1" is considered. This is done in order to take into account the overlapping of the failure planes.

The example is modeled as shown in the Figure 9.2.6.1 and Figure 9.2.6.2. Having the true edge distance yields unconservative results.

Alternatively the detailed method described section 9.2.3 can be applied in analyzing the anchor channels.

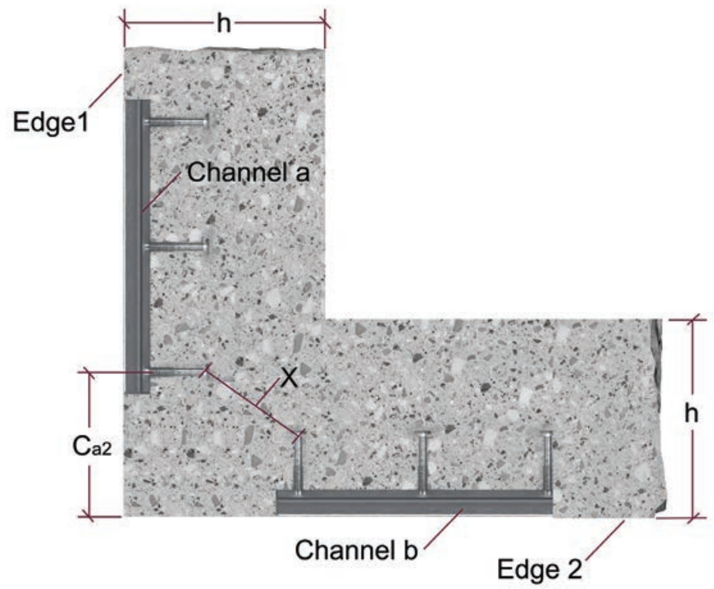



Figure 9.2.6.1 — Example of design of FOS outside corner.

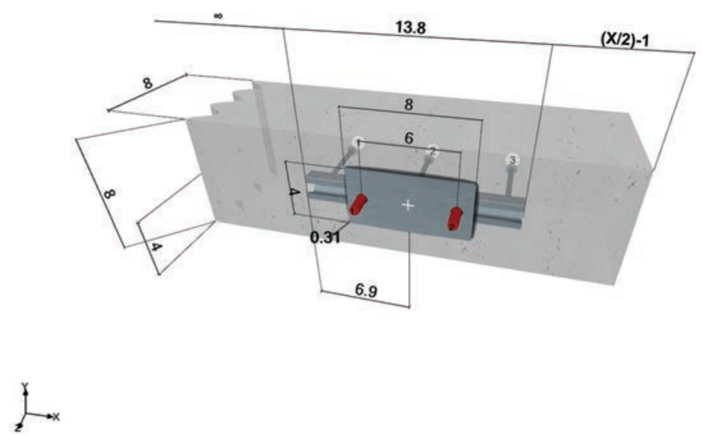



Figure 9.2.6.2 — E xample of use of HAC-40 91/300 F on a curb installing the anchor channel Face of curb.

# 9.2.7 — HAC AND HAC-T DESIGN: TOP OR BOTTOM OF SLAB OUTSIDE CORNER SINGLE ANCHOR CHANNEL

## 90° corners

Outside corners where only one anchor channel is present are fully covered by
ESR-3520. The design methodology is fully in accordance with the anchor channel Design Code presented in Chapter 7.

AC232 includes design provisions to account for the influence of a corner. The concrete strengths in tension and shear of the anchor channel may be reduced (depending on how far the anchor channel is away from the corner) since the concrete cones may not be fully developed. See chapter 7 for design provisions for corners. In PROFIS Anchor Channel, these conditions can be simply modeled by reducing the corner distance.

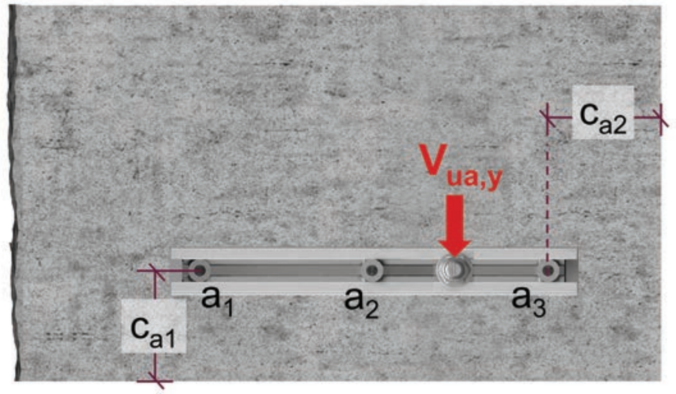



Figure 9.2.7.1 — TOS or BOS single channel at certain distance.

## Acute and obtuse corners

Although AC232 does not specifically address acute and obtuse corners, by not following the idealized failure planes but the path of least resistance, AC232 provisions can be used to analyze this type of corners.

In order to avoid calculating unconservative concrete strength, the path of least resistance for the crack should be always considered.

## Obtuse corners

**Perpendicular Shear:** The line is drawn originating from the corner of the obtuse corner. The $C_{a2}$ is measured from the corner to the anchor. Not using the darkened shaded region of concrete in analysis as illustrated in Figure 9.2.7.2. This is done to make sure the concrete edge of $C_{a1}$ width is available through out for $C_{a2}$ side edge.

**Tension:** Similar to the perpendicular shear in tension analysis the line is drawn originating from the corner of the obtuse angle corner case with one channel. The $C_{a2}$ is measured from the anchor $a_3$ to the line. The darkened shaded region of concrete is not used in analysis as illustrated in Figure 9.2.7.3.

**Longitudinal Shear:** Similar to the perpendicular shear again in longitudinal analysis the line is drawn originating from the corner of the obtuse corner. The $C_{a1}$ is measured from the corner to the anchor. The darkened shaded region of concrete is not used in analysis as illustrated in Figure 9.2.7.4. This is done to make sure the concrete edge of $C_{a2}$ width is available through out for $C_{a1}$.

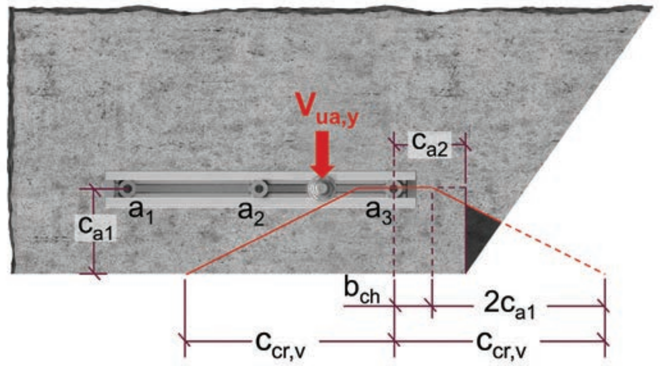



Figure 9.2.7.2 — Obtuse angle corner — TOS or BOS single channel at certain distance — Perpendicular Shear.

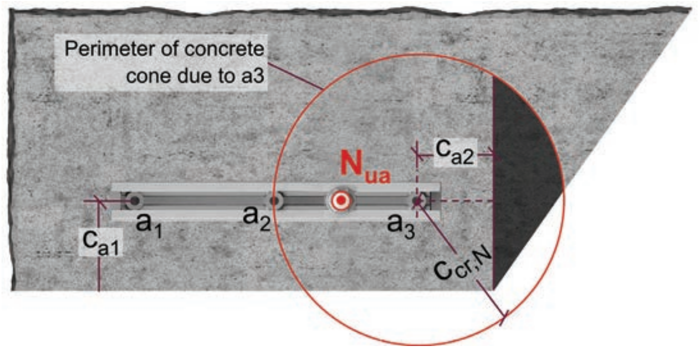



Figure 9.2.7.3 — Obtuse angle corner — TOS or BOS single channel at certain distance — Tension.

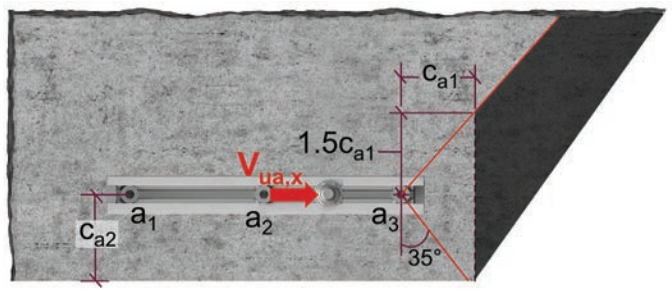



Figure 9.2.7.4 — Obtuse angle corner — TOS or BOS single channel at certain distance — Longitudinal Shear.

## Acute corners

**Perpendicular Shear:** Corner distance shall be considered as the shortest distance between the intersection of the formation of failure planes using $C_{cr,V}$ as shown in the Figure 9.2.4.5. The straight line is drawn (representing path of least resistance) extending out straight until it intersects the inclined slab edge. Which is then extended back on to the perpendicular edge. The $C_{a2}$ is measured from that point onwards to the closest anchor.

**Tension:** Corner distance shall be considered as the shortest distance between the intersection of the formation of failure cones $C_{cr,N}$ as shown in the Figure 9.2.4.6. The circle with radius of $C_{cr,n}$ and the shortest intersection of that circle with the edge is $C_{a2}$ distance.

**Longitudinal Shear:** Corner distance shall be considered as the shortest distance between the intersection of the formation of failure cones using 1.5 $C_{a1}$ as shown in the Figure 9.2.4.7. The $C_{a1}$ distance is assumed, where the 35° line intersects the inclined portion of the slab.

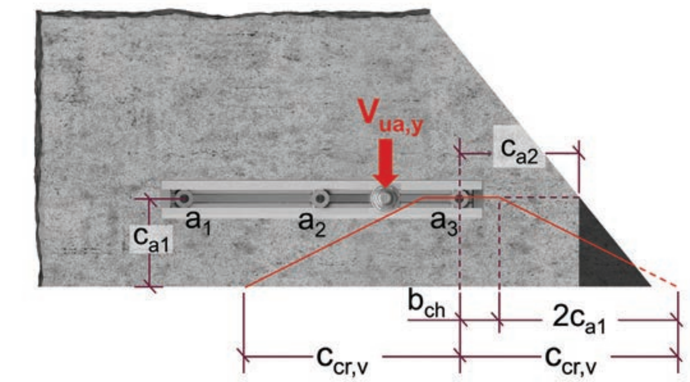



**Figure 9.2.7.5 — Acute angle ToS corner with anchor channels on one sides — Perpendicular shear.**

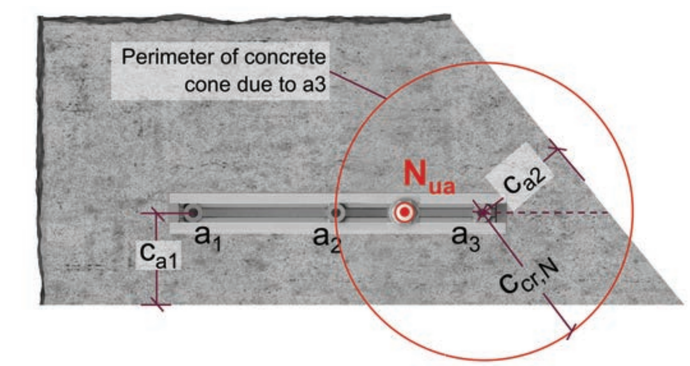



**Figure 9.2.7.6 — Acute angle ToS corner with**

**anchor channels on one sides — Tension.**

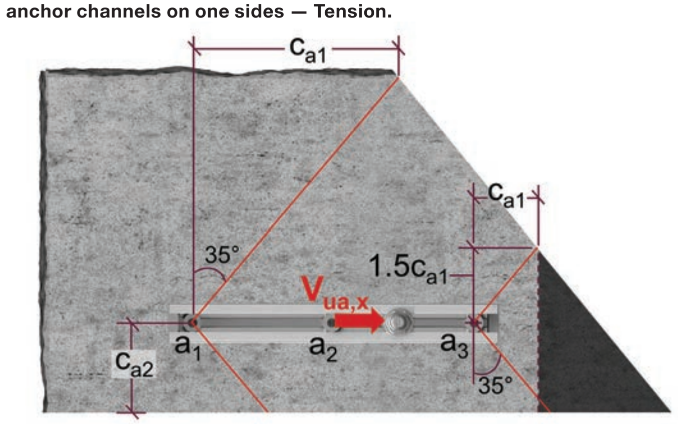



**Figure 9.2.7.7 — Acute angle ToS corner with anchor channels on one sides — Longitudinal shear.**

## 9.2.8 — HAC AND HAC-T DESIGN: TOP OR BOTTOM OF SLAB WITH PAIR OF ANCHOR CHANNEL ADJACENT TO EACH OTHER

**Minimum distance that does not reduce the concrete capacity in tension and perpendicular shear:** The capacity of anchor channel should be reduced because of the presence of the adjacent anchor channel. The anchor channels installed next to each other and subjected to perpendicular shear and tension as seen in Figure 9.2.8.1 does not require the reduction. The reason for this is that the breakout failure plane in shear and breakout failure cones in tension has been completely developed on the left side of channel a and right side of channel b. There is no overlapping of the breakout cones from the adjacent anchor channel. The shear breakout planes as represented by the red shaded area and breakout failure cone in tension as represented by brown circle are completely developed.

In order to make sure that there is no influence of the adjacent anchor channel on the concrete capacity, it is recommended to have them installed at least at a distance 2*Max($C_{cr,v}$ ; $C_{cr,N}$).

Please refer to anchor channel theory for detailed instruction on the factor $C_{cr,v}$ and $C_{cr,N}$. Below are the equation defining these variables.

$$s_{cr,N} = 2\left(2.8 - \frac{1.3h_{ef}}{7.1}\right)h_{ef} \geq 3h_{ef}$$

$$c_{cr,N} = 0.5 s_{cr,N} \geq 1.5h_{ef}$$

$$c_{cr,V} = 0.5 \cdot s_{cr,V} = 2c_{a1} + b_{ch} \; in.(mm)$$

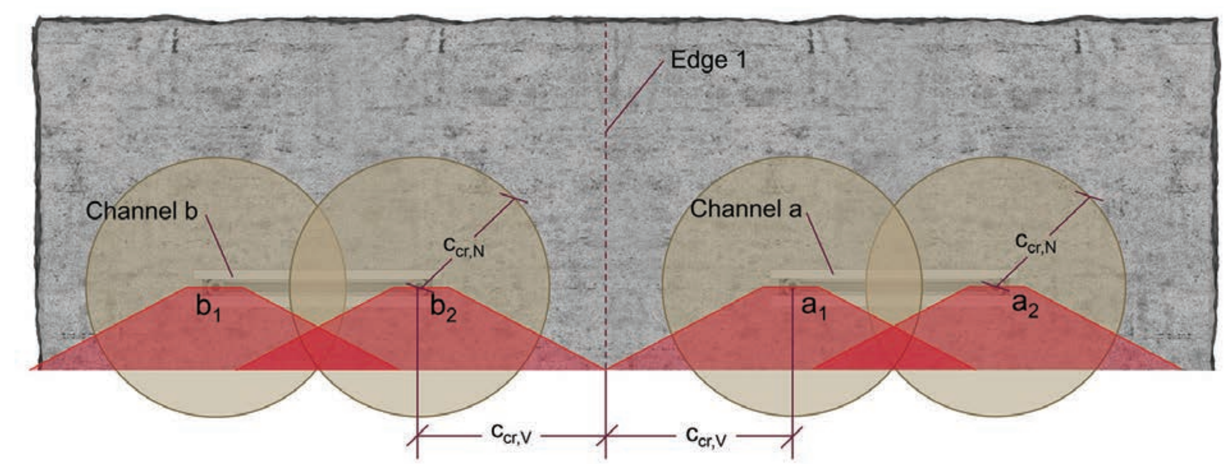



**Figure 9.2.8.1 — TOS and BOS with pair of anchor channel adjacent to each other — Tension and perpendicular capacity doesnot get reduced.**

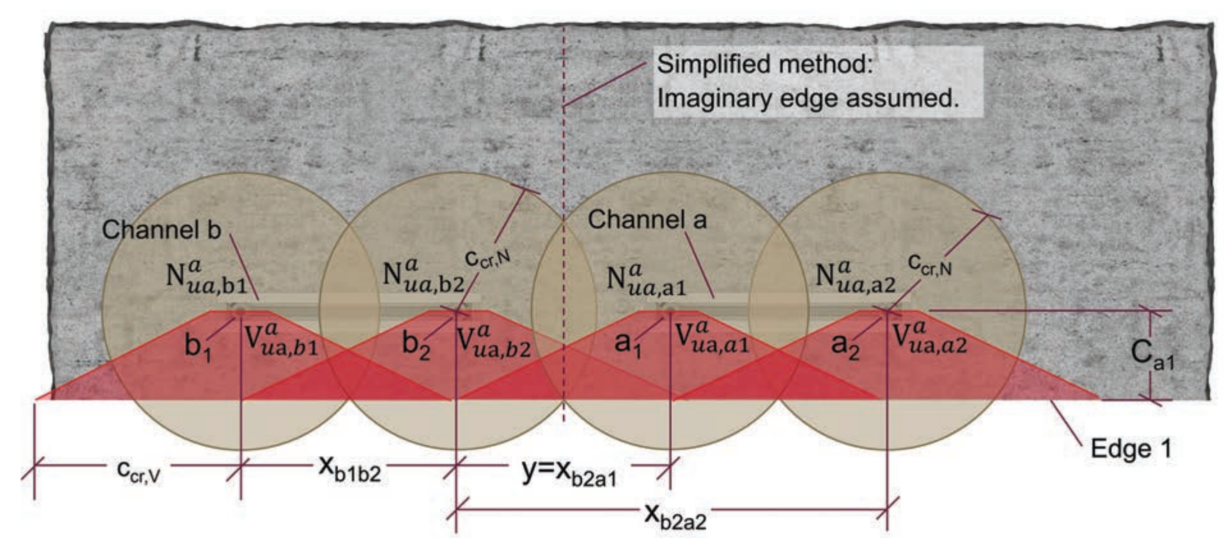



**Figure 9.2.8.2 — TOS and BOS with pair of anchor channel adjacent to each other — Overlapping tension and perpendicular shear concrete cones.**

**Design method for analyzing channels besides each other with concrete cones in tension and perpendicular shear intersecting each other:** This method is based AC232 principles. The capacity of anchor channel should be reduced because of the presence of the adjacent anchor channel. The anchor channels installed next to each other and subjected to perpendicular shear and tension as seen in Figure 9.2.8.2 requires the reduction in the concrete capacities. The reason for this is that the breakout failure plane in shear has not been completely developed as represented by the red shaded area and breakout failure cone in tension is also not been able to completely developed as represented by brown circle. These failure planes intersect as seen in the detail.

Having anchor channel "a" closer to anchor channel "b" has influence on the concrete breakout capacities. In order to incorporate the influence, the $\psi_{s,N}$ and $\psi_{s,V}$ the modification factor influencing location of adjacent anchors should be modified following the concept in AC232. Anchor channel a and b are modelled in profis anchor channel software individually with infinite edges to the sides and then incorporating the modification factor $\psi_{s,N}$ and $\psi_{s,V}$ using the method described below later by hand calculation. Please note that there will not be any imaginary corner influence taken into consideration when the method described below is used. The influence of the neighboring anchor channel is incorporated into the design by incorporating the influence in the spacing modification factor.

**Example:**

Lets consider the anchor $b_2$ with shear $V^a_{au,b2}$ and tension $N^a_{au,b2}$ of channel b. To find the modification factor $\psi_s$ used in determining concrete breakout capacity in tension and shear of $b_2$.

$\psi_{s,N,b2}$ **:** Tension modification is factor for spacing of $b_2$ the case shown in Figure 9.2.8.2 should be found out using the Equation 9.2.8-a. The tension concrete breakout capacity of anchor $b_2$ gets reduced because of presence of anchor $a_1$ and $b_1$. The $a_2$ has no effect on tension concrete breakout capacity of $b_2$, since the concrete breakout tension failure cone generated by $a_2$ does not coincides with breakout cone generated by anchor $b_2$. Please refer to the equation below for calculating the modification factor for $b_2$.

Equation 9.2.8-a

$$\psi_{s,N,b2} = \frac{1}{1+\left[\left(1-\frac{x_{b1,b2}}{s_{cr,N}}\right)^{1.5}\cdot\frac{N^a_{ua,b1}}{N^a_{ua,b2}}\right]+\left[\left(1-\frac{x_{b2,a1}}{s_{cr,N}}\right)^{1.5}\cdot\frac{N^a_{ua,a1}}{N^a_{ua,b2}}\right]}$$

$\psi_{s,V,2}$ **:** Shear modification is factor for spacing of $b_2$ the case shown in Figure 9.2.8.2 should be found out using the Equation 9.2.8-b as shown below. The shear concrete breakout capacity of anchor $b_2$ gets reduced because of presence of anchor $b_1$, $a_2$ and $a_1$. The $a_2$ has effect on shear concrete breakout capacity of b2, since the concrete breakout failure shear cone generated by $b_2$ coincides with breakout cone generated by anchor $a_2$. Please refer to the equation below for calculating the modification factor.

Equation 9.2.8-b

$$\psi_{s,V,b2} = \frac{1}{1+\left[\left(1-\frac{x_{b1,b2}}{s_{cr,V}}\right)^{1.5}\cdot\frac{V^a_{ua,b1}}{V^a_{ua,b2}}\right]+\left[\left(1-\frac{x_{b2,a1}}{s_{cr,V}}\right)^{1.5}\cdot\frac{V^a_{ua,a1}}{V^a_{ua,b2}}\right]+\left[\left(1-\frac{x_{b2,a2}}{s_{cr,V}}\right)^{1.5}\cdot\frac{V^a_{ua,a2}}{V^a_{ua,b2}}\right]}$$

$\psi_{co,N}$ **and** $\psi_{co,V}$ **:** modification factor for corner influence when using the method described above should be considered as 1. This is because here in this method the influence of adjacent anchor channel is incorporated in spacing modification factor $\psi_{s,V,b2}$ and $\psi_{s,N,b2}$. Hence there is no fictitious edge consideration required here in this method.

On other hand, anchor channel can be analyzed using a simplified method as described below. Here anchor channel a and b are analyzed individually limiting the side edge distance as described below.

**Simplified method:** An imaginary edge is assumed in between the channels. The distance between channels is y as seen in the Figure 9.2.8.2. The anchor channel is modelled with the side edge distance of the ratio of the distance y to optimize the concrete in between the channels and to make sure that the concrete is not being utilized twice. For example channel b can be modelled to have a right side edge of ¾ y and channel a can be modeled separately with left side edge distance of ¼ y. Or imaginary edge is assumed to be at ½ y for both anchor channel a and b. This approach will lead to conservative results because concrete breakout capacity is reduced in tension and shear with modification factor $\psi_{co,N}$ and $\psi_{co,V}$ for corner influence respectively. Please refer equation 9.2.8-c and 9.2.8-d. This approach assumes a real edge which in turn leads to higher utilization by reducing the capacity tremendously.

$$\text{If } C_{a2} \le C_{Cr,v} \text{ then } \Psi_{co,v} = \left(\frac{C_{a2}}{C_{cr,v}}\right)^{0.5}$$ Equation 9.2.8-c

$$\text{If } C_{a2} < C_{cr,N} \text{ then } \psi_{co,N} = \left(\frac{C_{a2}}{C_{cr,N}}\right)^{0.5}$$ Equation 9.2.8-d



# 9.2.9 — HAC AND HAC-T DESIGN: TOP OR BOTTOM OF SLAB MINIMUM DISTANCE THAT WILL ASSURE THAT THE CONCRETE CONE DOES NOT INTERSECT BOTH IN SHEAR AND TENSION

If we have 2 times the maximum of $C_{crN}$ and $C_{crV}$ distance between the two anchors closest to the edge of an anchor channel, we can say that there will not be any influence of the anchor channel at the other side of the outside corner as shown in the figure. Please refer to anchor channel theory for more information on this topic. A similar concept can be applied for inside corners as well.

In this case the real side distance can be used to analyze each anchor channel. The example illustrated in Figure 9.2.9.1, $C_{cr,N}$ critical edge distance in tension controls the x dimension.

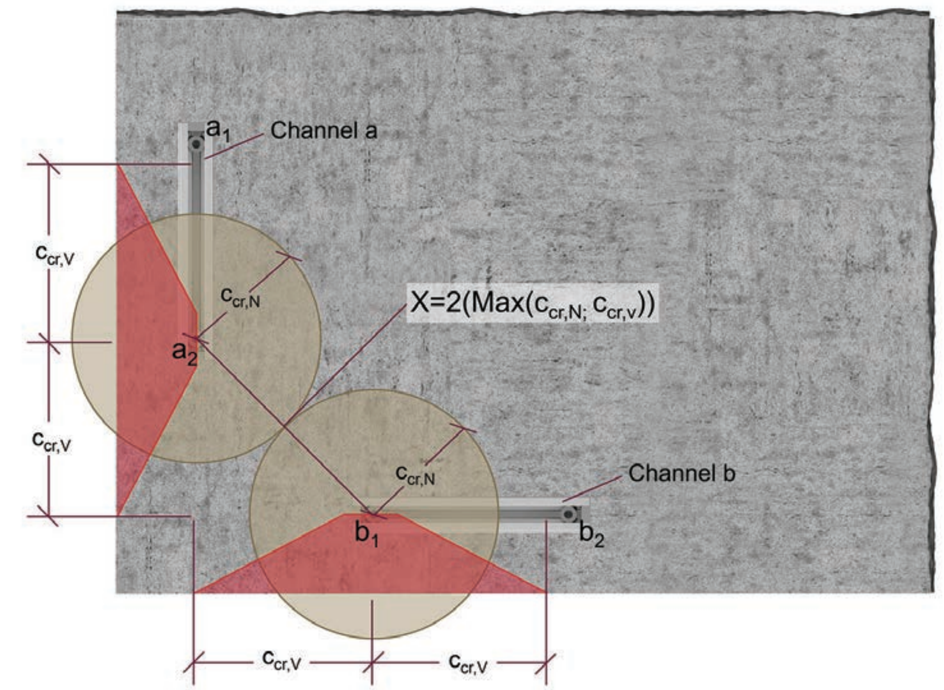



**Figure 9.2.9.1 — TOS and BOS outside corner — Tension and perpendicular shear concrete cones does not intersect.**

The critical spacing for anchors is given as $3h_{ef}$, as described in the following Figure 9.2.9.2. For anchor channels the equation 9.2.9.1 is used for $S_{cr,N}$. Figure 9.2.9.3 shows the comparison of $c_{cr,N}$ for anchors and anchor channels. For effective embedment depth smaller than 180 mm the anchor channels have a larger $c_{cr,N}$ than anchors.

$$s_{cr,N} = 2\left(2.8-\frac{1.3h_{ef}}{7.1}\right)h_{ef} \ge 3h_{ef}$$ Eqn 9.2.9.1

$$c_{cr,N} = 0.5s_{cr,N} \ge 1.5h_{ef}$$

$$S_{cr,V} = 4c_{a1} + 2b_{ch}\ in.(mm)$$

$$c_{cr,V} = 0.5\cdot s_{cr,V} = 2c_{a1} + b_{ch}\ in.(mm)$$

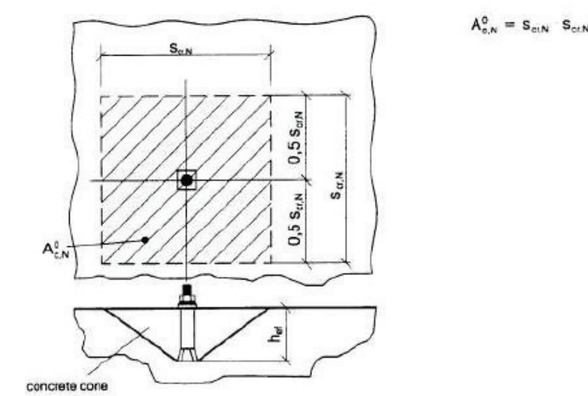



**Figure 9.2.9.2 —ACI 318-14 -Fig. R17.4.2.1—(a) Calculation of $A_{Nco}$ per ACI318-14**

The proposed expression of $s_i$ assumes a circular area of the influence areas of each anchor. In Figure 9.2.9.3 the circular area, for the proposed model for anchor channels is represented, together with the squared one used for anchors. For $h_{ef}$ smaller than 6.10 in. (155 mm) the influence area of the anchor of an anchor channel is larger than those of a single anchor. Therefore, for embedment depths smaller than 6.10 in. (155 mm) the method can be applied without any modification. In order to use this concept also for embedment depth larger than 6.10 in. (155 mm) the following increase for $s_{cr,N,corner}$ equation 9.2.9.2 is proposed:

$$s_{cr,N,corner} = 2\left(2.8-\frac{1.3h_{ef}}{7.1}\right)h_{ef} \ge 3.4h_{ef}$$

Eqn 9.2.9.2

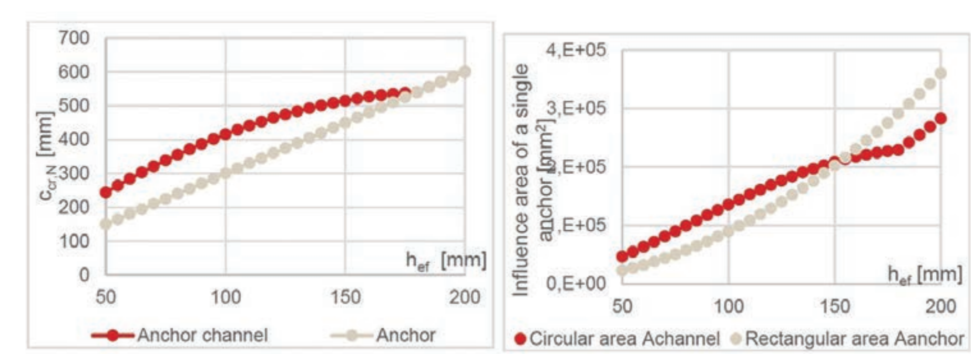



**Figure 9.2.9.3 — Comparison of $c_{cr,N}$ for anchors and for an anchor channels (left), Comparison of the idealized breakout area for anchors and for an anchor channel (right)**

# 9.2.10 — HAC AND HAC-T DESIGN: TOP OR BOTTOM OF SLAB OUTSIDE CORNER WITH PAIR OF ANCHOR CHANNEL

Outside corners where two anchor channels are present and are loaded simultaneously are outside the scope of AC232. Most of the AC232 provisions can be applied to this type of application. However, the influence of the adjacent anchor channel should be consider, as the concrete strength may be negatively impacted.

In this section an extension for the design AC232 to a group of channels and to channels close to a corner is presented. The method is valid for standard anchor channels.

The loads are distributed on each channel independently, according ESR3520 the steel verifications are not affected by the neighbored channels, some considerations should be done for the concrete failure modes.

According to ESR-3520 the minimum distance between the two anchors is 2" 100mm, hence Profis anchor channel software follows the rule stated in the Figure 9.2.10.1.a and Figure 9.2.10.1.b. The software has to be activated for corner in order to design the outside corner with two anchor channels.

When two HAC channels are placed close to each other or to a corner only the concrete verifications needed modifications. The calculation of the anchor loads and of the steel failure modes is calculated independently for the two different channels. The method applies in general to a group of channels with the same edge distance $c_{a1}$ in profis anchor channel software.

When the second element is enabled the following condition must be fulfilled (Figure 9.2.10.1.a, Figure 9.2.10.1.b and Figure 9.2.10.1.c):

$(d_1) + (d_2) \geq 100\text{mm}$

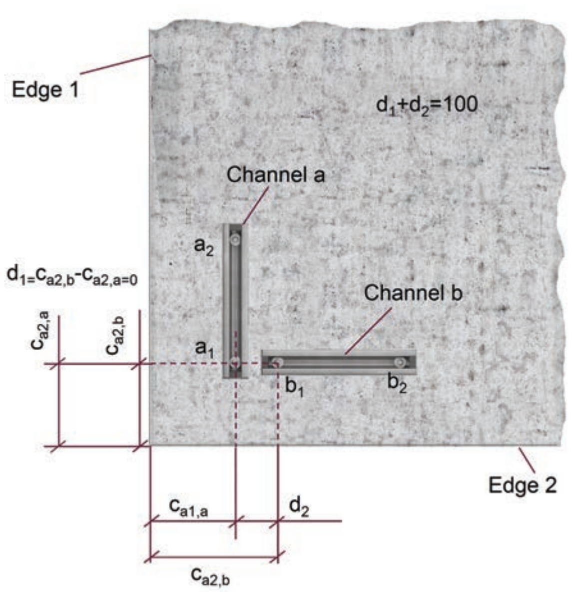



Figure 9.2.10.1.a.

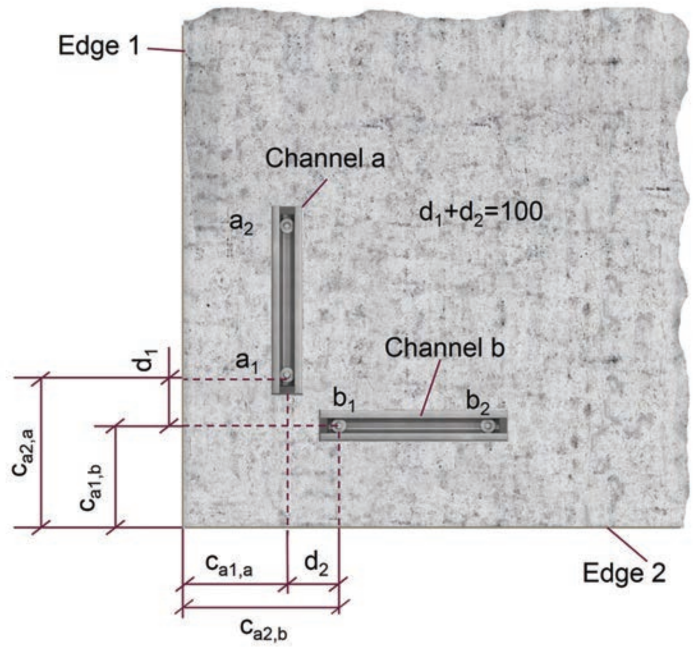



Figure 9.2.10.1.b.

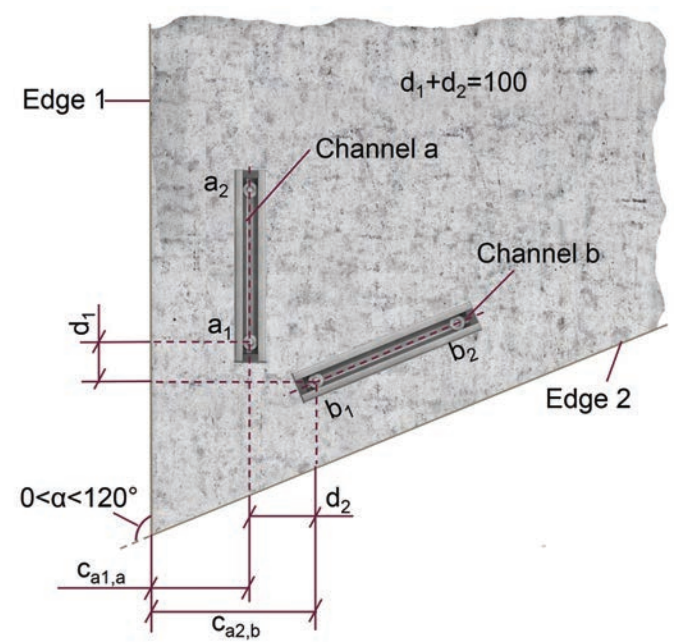



Figure 9.2.10.1.c.

Figure 9.2.10.1: Geometric condition for the second channel after the activation of the second element at the corner.



## Concrete breakout strength in tension

The main difference in the calculation of the concrete cone capacity is the modification factor to account for influence of location and loading of neighboring anchors $\psi_{s,N}$.

Verification: $\varphi \ N_{cb} \geq N^a_{ua}$

$$N_{cb} = N_b \cdot \psi_{s,N} \cdot \psi_{ed,N} \cdot \psi_{co,N} \cdot \psi_{cp,N} \cdot \psi_{c,N}$$

The modification factor for spacing $\psi_{s,N}$ is adjusted to take the loading of the adjacent anchors into account.

Given an anchor channel with only two anchors equally loaded $\psi_{s,N}$ varies from 0.5 to 1, if the relative spacing varies from $s_i = 0$ to $s_i = s_{cr,N}$ respectively. In practice, if $s_i = 0$ the capacity of each anchor is the half, both together have the same capacity of 1 anchor. The equation of $\psi_{s,N}$ limits the maximum capacity of the concrete for each anchor due to the presence of the other cone. Figure 9.2.10.3 shows $\psi_{s,N}$ for two anchors symmetrically loaded increasing the spacing from 0 to $s_i = s_{cr,N}$.

The relative concrete utilization of each anchor is considered with the ratio $N^a_{ua,i} / N^a_{ua,1}$. In this way if the load on the second anchor is much higher than that on the first, it results in a lower $\psi_{s,N,1}$ for the first anchor. Figure 9.2.10.4 shows the variation of $\psi_{s,N}$ for two anchors with a spacing of $0.5s_{cr,N}$ varying the load ratio between the two anchors. The concrete cone capacity is almost proportional to $A_{c,N} / A^0_{c,N}$ like in the CC Method (Concrete Capacity design method for anchors).

The same considerations are valid as well also for more than two anchors and a linear superposition applies.

In Figure 9.2.10.3 standard anchor channel with 2 anchors is represented, where the red rectangle areas are the "influence areas" or idealized breakout surface of each anchor. Since the anchor spacing is smaller than the critical one there are several intersections represented by darker shaded area of cone projection. These intersections are considered with the $\psi_{s,N}$.

If second anchor channel is placed at a distance $s_{a1\,bi} < s_{cr,N}$ (Figure 9.2.10.8), further intersections would be generated between the influence areas of the anchors of first and of the second channel. In the calculation of the concrete cone failure, these intersections can be considered with the factor $\psi_{s,N}$ including in sum also for the anchors of the second channel. In this way, the capacity of each anchors is additionally reduced due to the presence and utilization of second channel and varies smoothly with the relative distance.

The same considerations are valid as well also for more than two anchors and a linear superposition applies.

$$n = n_{ch1} + n_{ch2} \qquad s_i = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

Moreover, considering the spacing of each single anchor in two dimensions, it is possible to consider even more anchor channels, and each possible relative position.

The critical spacing for anchors is $3xh_{eff}$ based on idealized rectangular concrete cone area. For anchor channels the following equation is in accordance to AC232:

$$s_{cr,N} = 2\left(2.8 - \frac{1.3h_{ef}}{180}\right)h_{ef} \geq 3h_{ef}$$

Comparison of $c_{cr,N}$ for anchors and for an anchor channels and comparison of the idealized breakout area for anchors and for an anchor channel of various embedment depths shows for effective embedment depth smaller than 7.1" (180 mm) the anchor channels have a larger $c_{cr,N}$ than anchors. The proposed expression assumes a circular area of the influence areas of each anchor.

The influence area of the anchor of an anchor channel is larger than those of a single anchor, hence the following equation of $s_{cr,N,corner}$ is proposed:

$$s_{cr,N,corner} = 2\left(2.8 - \frac{1.3h_{ef}}{180}\right)h_{ef} \geq 3.4h_{ef}$$

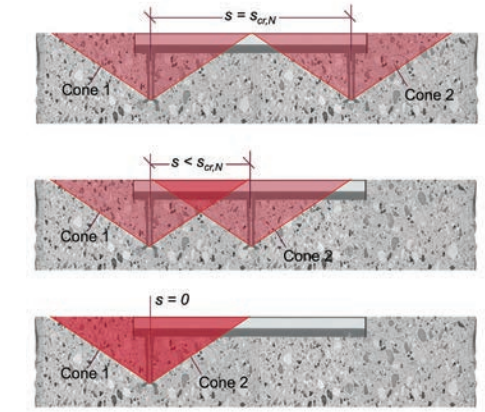



Figure 9.2.10.3 — $\psi_{s,N}$ for two anchors symmetrically loaded.

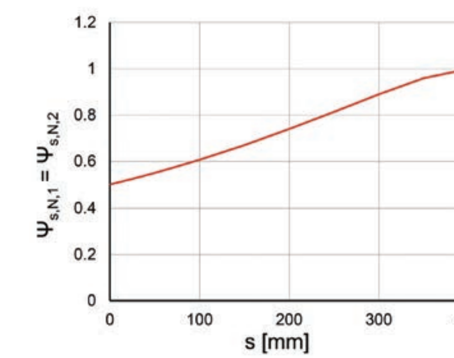



Figure 9.2.10.4 — Graph s vs $\psi_{s,N}$.

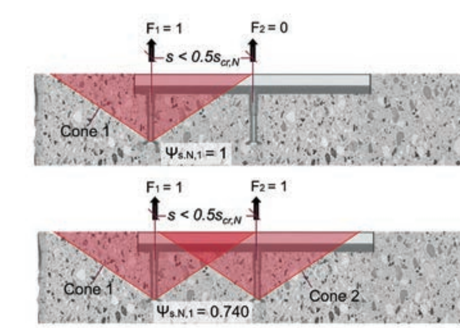



Figure 9.2.10.5 — Influence on $\psi_{s,N}$,1 (of the anchor 1) of the relative load on the anchors.

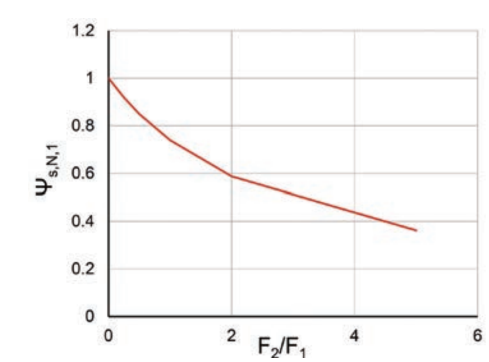



Figure 9.2.10.6 — Graph $\psi_{s,N}$ vs $F_2/F_1$.

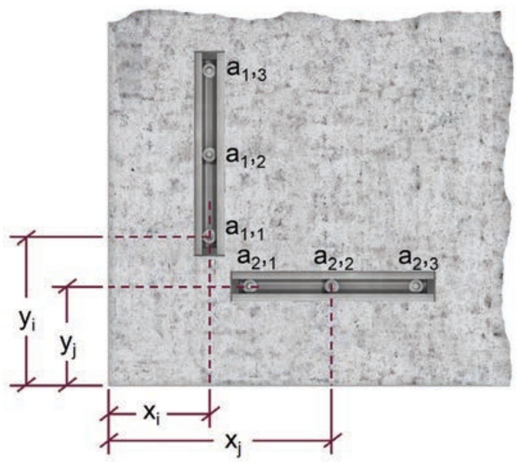



Figure 9.2.10.7 — definition of the relative distance of the anchors in a anchor channels group.

The concrete cone verification remains the same:

Verification: $\phi \cdot N_{cb} \geq N^a_{ua}$

$$N_{cb} = N_{cb} \cdot \psi_{s,N} \cdot \psi_{ed,N} \cdot \psi_{co,N} \cdot \psi_{c,N} \cdot \psi_{cp,N}$$

The only parameter which is adjusted is the modification factor to take the loading of the adjacent anchors $\psi_{s,N}$ into account:

$$\psi_{s,N} = \frac{1}{1+\sum_{i=2}^{n+1}\left[\left(1-\frac{s_i}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,j}}{N^a_{ua,1}}\right]} \qquad \text{Equation 9.2.10.7}$$

Where

$n = n_{ch1} + n_{ch2}$ is the number of all the anchors of the two channels

$s_i$ is the relative distance of two anchors

$s_{cr,N,corne}$ critical anchor spacing for tension

xi, xj, yi, yj coordinate of the anchors from the corner (Figure 9.2.10.7)

**90°Corner:** Lets consider the anchor $a_1$ of anchor channel a with tension $N^a_{ua,a1}$ of channel a. To find the modification factor $\psi_N$ used in determining concrete breakout capacity in tension and shear of $a_1$. Please refer Figure 9.2.10.8.

$$s_{a1,b1} = \sqrt{(x_{b,1}-x_a)^2 + (y_{a,1}-y_b)^2} \qquad \text{Equation 9.2.10.7 a}$$

$$s_{a1,b2} = \sqrt{(x_{b,2}-x_a)^2 + (y_{a,1}-y_b)^2} \qquad \text{Equation 9.2.10.7 b}$$

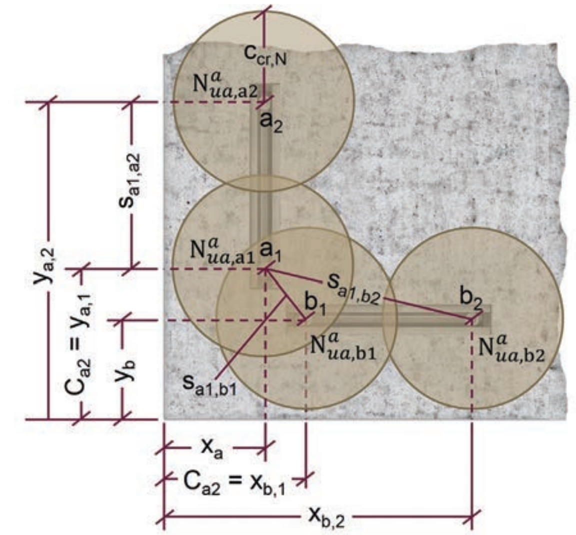



Figure 9.2.10.8 — 90° Corner.

$\psi_{s,N,a1}$ **:** Tension modification is factor for spacing of a1 the case shown in Figure 9.2.10.8 should be found out using the Equation 9.2.10.7 c. The tension concrete breakout capacity of anchor $a_1$ gets reduced because of presence of anchor $a_2$, $b_2$ and $b_1$. Please refer to the Equation 9.2.10.7 c for calculating the modification factor for $a_1$. The $s_{a1,b1}$ and $s_{a1,b2}$ distances are evaluated by using Equation 9.2.10.7 a and Equation 9.2.10.7 b. $\psi_{s,N,a1}$ is evaluated using Equation 9.2.10.7 c.

$$\psi_{s,N,a1} = \frac{1}{1+\left[\left(1-\frac{s_{a1,b1}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,b1}}{N^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a1,b2}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,b2}}{N^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a1,a2}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,a2}}{N^a_{ua,a1}}\right]}$$

Equation 9.2.10.7 c

$\psi_{co,N}$ **:** (modification factor for corner influence) The true edge distance is taken into consideration as shown in the Figure 9.2.10.8 for 90° corner to determine reduction factor for corner distance $c_{a2}$. Please refer to Equation 9.2.10.7 d for $\psi_{co,N}$.

$$c_{cr,N} = 0.5 s_{cr,N} \geq 1.5 h_{ef}$$

If $c_{a2} \geq c_{cr,N}$

then $\psi_{co,N} = 1.0$ — Equation 9.2.10.7 d

If $c_{a2} < c_{cr,N}$

then $\psi_{co,N} = \left(\frac{c_{a2}}{c_{cr,N}}\right)^{0.5} \leq 1.0$

$c_{a2}$ = distance of the anchor under consideration to the corner refer Figure 9.2.10.8 .



**Acute angle Corner:** Lets consider the anchor $a_1$ of anchor channel a with tension $N^a_{ua,a1}$ of channel a. To find the modification factor $\psi_N$ used in determining concrete breakout capacity in tension of $a_1$. Please refer Figure 9.2.10.9.

$$s_{a1,b1} = \sqrt{(x_{b1}-x_a)^2 + (y_{a1}-y_{b1})^2} \qquad \text{Equation 9.2.10.7 f}$$

$$s_{a1,b2} = \sqrt{(x_{b2}-x_a)^2 + (y_{b2}-y_{a1})^2} \qquad \text{Equation 9.2.10.7 g}$$

$\psi_{s,N,a1}$ **:** Tension modification is factor for spacing of $a_1$ the case shown in Figure 9.2.10.9 should be found out using the Equation 9.2.10.7 h. The tension concrete breakout capacity of anchor $a_1$ gets reduced because of presence of anchor $a_2$, $b_2$ and $b_1$. Please refer to the Equation 9.2.10.7 h for calculating the modification factor for $a_1$. The $s_{a1,b1}$ and $s_{a1,b2}$ distances are evaluated by using Equation 9.2.10.7 f and Equation 9.2.10.7 g.

$$\psi_{s,N,a1} = \frac{1}{1+\left[\left(1-\frac{s_{a1,b1}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,b1}}{N^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a1,b2}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,b2}}{N^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a1,a2}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,a2}}{N^a_{ua,a1}}\right]}$$

Equation 9.2.10.7 h

$\psi_{co,N}$ **:** (modification factor for corner influence) The true edge distance is taken into consideration as shown in the Figure 9.2.10.9 for Acute angle corner to determine of reduction factor for corner distance $c_{a2}$. The perpendicular line is drawn from $a_1$ of anchor channel a on to edge 2 to get the side edge distance $c_{a2}$. Please refer to Equation 9.2.10.7 i for $\psi_{co,N}$.

$c_{cr,N} = 0.5 s_{cr,N} \geq 1.5 h_{ef}$

If $c_{a2} \geq c_{cr,N}$

then $\psi_{co,N} = 1.0$

If $c_{a2} < c_{cr,N}$ — Equation 9.2.10.7 i

then $\psi_{co,N} = \left(\frac{c_{a2}}{c_{cr,N}}\right)^{0.5} \leq 1.0$

**Obtuse angle Corner:** Lets consider the anchor $a_1$ of anchor channel a with tension $N^a_{ua,a1}$ of channel a. To find the modification factor $\psi_N$ used in determining concrete breakout capacity in tension of $a_1$.

$$s_{a1,b1} = \sqrt{(x_{b1}-x_a)^2 + (y_{a1}-y_{b1})^2} \qquad \text{Equation 9.2.10.7 j}$$

$$s_{a1,b2} = \sqrt{(x_{b2}-x_a)^2 + (y_{b2}+y_{a1})^2} \qquad \text{Equation 9.2.10.7 k}$$

$\psi_{s,N,a1}$ **:** Tension modification is factor for spacing of $a_1$ the case shown in Figure 9.2.10.10 should be found out using the Equation 9.2.10.7 l. The tension concrete breakout capacity of anchor $a_1$ gets reduced because of presence of anchor $a_2$, $b_2$ and $b_1$. Please refer to the Equation 9.2.10.7 l for calculating the modification factor for a1. The $s_{a1,b1}$ and $s_{a1,b2}$ distances are evaluated by using Equation 9.2.10.7 j and Equation 9.2.10.7 k.

$$\psi_{s,N,a1} = \frac{1}{1+\left[\left(1-\frac{s_{a1,b1}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,b1}}{N^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a1,b2}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,b2}}{N^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a1,a2}}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,a2}}{N^a_{ua,a1}}\right]}$$

Equation 9.2.10.7 l

$\psi_{co,N}$ **:** (modification factor for corner influence) The true edge distance is taken into consideration as shown in the Figure 9.2.10.10 for obtuse angle corner to determine of reduction factor for corner distance $c_{a2}$. Please refer to Equation 9.2.10.7 m for $\psi_{co,N}$.

$$c_{cr,N} = 0.5 s_{cr,N} \geq 1.5 h_{ef}$$

$c_{cr,N} = 0.5 s_{cr,N} \geq 1.5 h_{ef}$

If $c_{a2} \geq c_{cr,N}$

then $\psi_{co,N} = 1.0$ — Equation 9.2.10.7 m

If $c_{a2} < c_{cr,N}$

then $\psi_{co,N} = \left(\frac{c_{a2}}{c_{cr,N}}\right)^{0.5} \leq 1.0$

$C_{a2}$ = distance of the anchor under consideration to the corner refer Figure 9.2.10.10

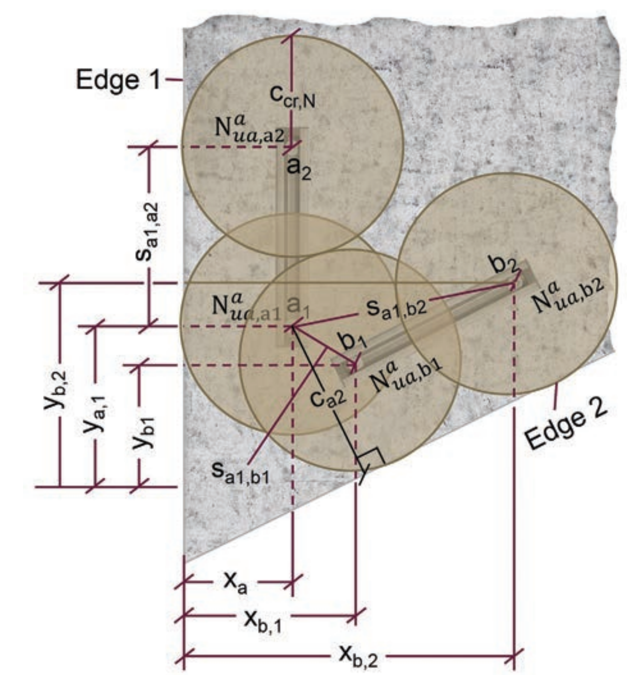



Figure 9.2.10.9 — Acute Corner.

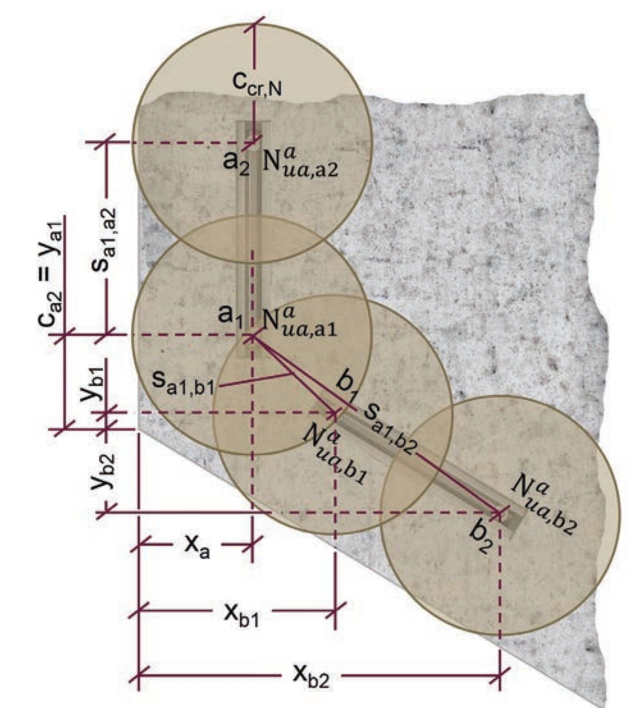



Figure 9.2.10.10 — Obtuse Corner.

## Concrete Pryout for perpendicular and longitudinal load failure

The pryout failure is calculated based on the $N_{cb}$ as indicated above both for longitudinal and perpendicular shear. Test restults show that two anchor channels that are located at the corner $k_{cp}$ for pry out check can be used as 3. $k_{cp}$ =3 is used for two corner anchors located at the corner edge.

## Concrete breakout strength for perpendicular shear

A similar consideration on the modification factor for the anchor spacing can be done for the concrete edge failure for perpendicular shear. Figure 9.2.10.11 shows a similar approach to that proposed for the concrete cone for the concrete edge breakout for perpendicular shear. If two channels are located at a distance $d_{a1,b1}$ smaller than $C_{cr,V}$ (Figure 9.2.10.11 b) the concrete edge failure of the two channels would intersect and the capacity of the system will be reduced. In this case, all the anchors of both channels are considered for the calculation of the modification factor $\Psi_{s,V}$.

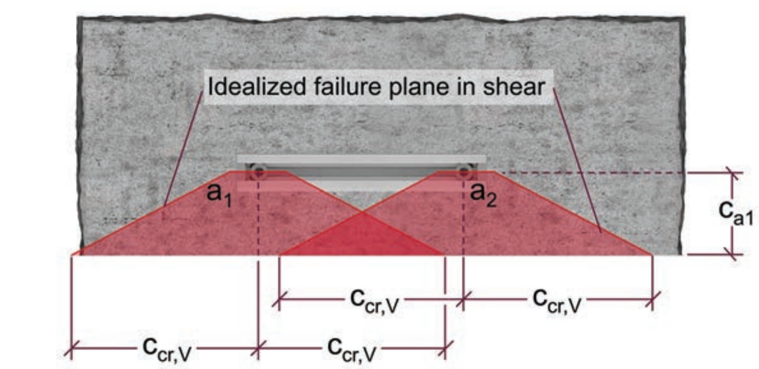



Figure 9.2.10.11a — Single anchor channel in shear.

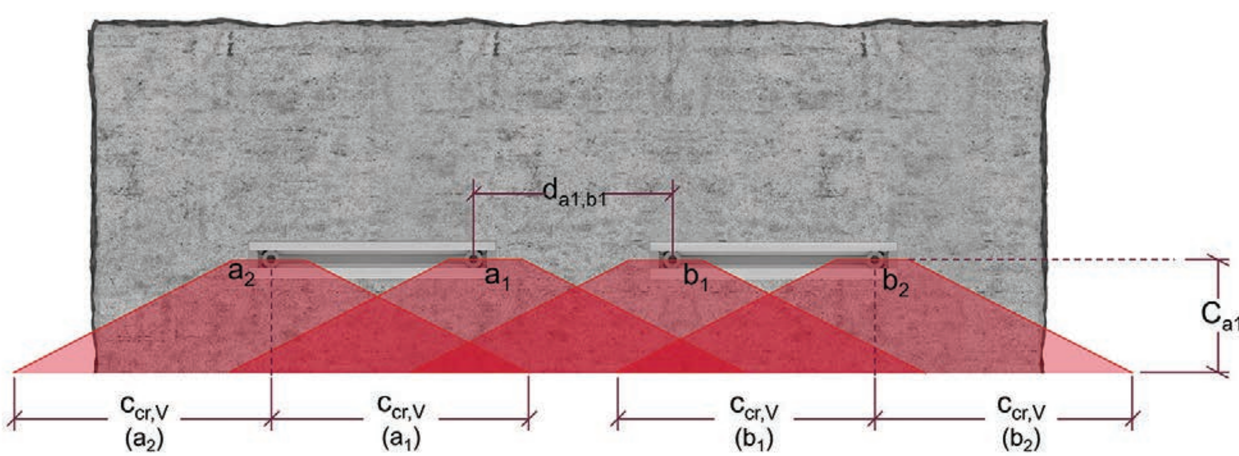



Figure 9.2.10.11b — anchor channels adjacent to each other.

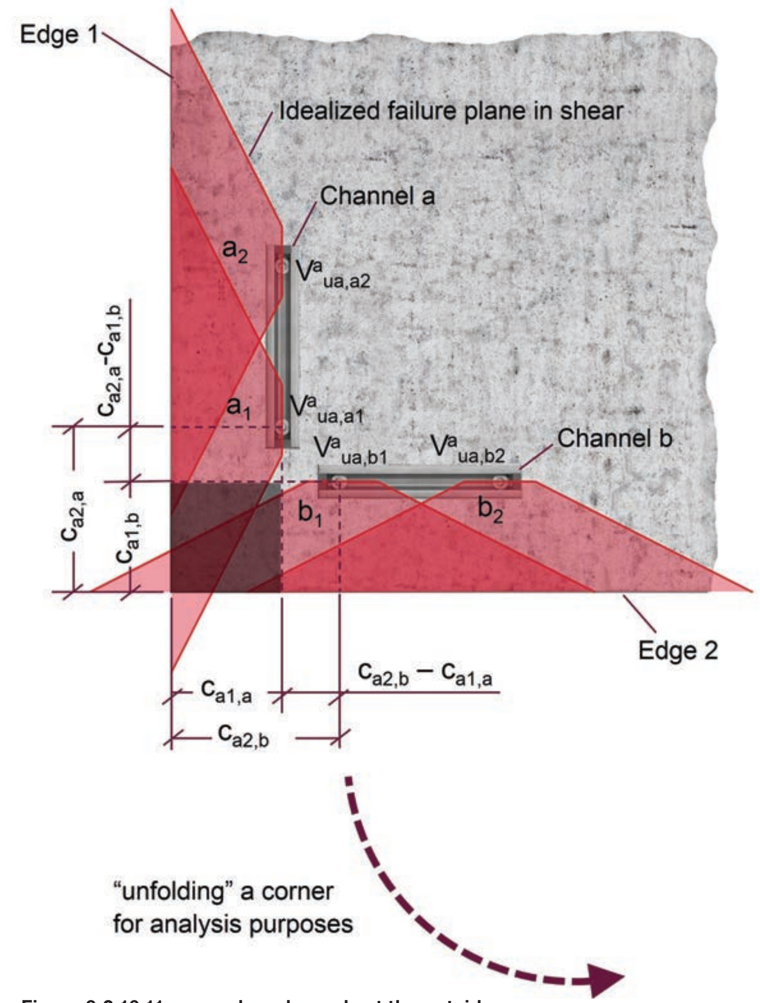



Figure 9.2.10.11c — anchor channels at the outside corner.

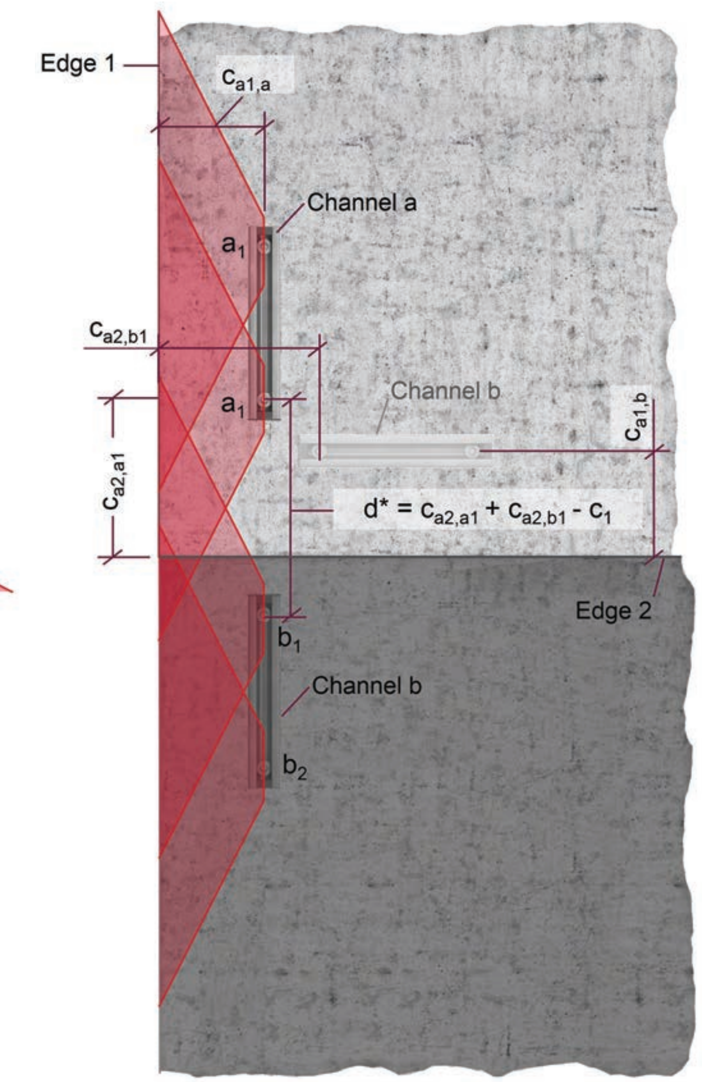



Figure 9.2.10.11d — Unfolding of the corner.

Placing two channels close to a corner (Figure 9.2.10.11 c), it is possible to calculate the channels with the method of "unfolding" the edge (Figure 9.2.10.11 d). Doing this operation, a fictitious distance between the two channels has to be defined and it is important to make sure that the corner area is used only once. In the case of Figure 9.2.10.11 c the area which can be considered only once is represented with black rectangle. If the channel a collapses under shear load, then the area in black would also collapse. The channel b would be left only with the area up to the black rectangle to resist shear loads. The same consideration is made for the channel b.

Therefore, it is proposed to calculate the factor $\Psi_{s,V}$ with the two anchor channels placed in a row with the edge of "fictitious" edge distance d*:

$$d^* = c_{a2,a1} + c_{a2,b1} - c_1$$

Where $c_1$ is the minimum edge distance of channel a and channel b. In case that $c_{a1,a}$ and $c_{a1,b}$ are different, the minimum will be assumed for the calculation of both channels.

$s_i$ is calculated with $d^* = c_{a2,a} + (c_{a2,b} - c_i)$ fictitious distance between channel a and b.

If $c_{a1,a} \neq c_{a1,b}$ both channel will be considered as with

$c_1 = \min(c_{a1,a}; c_{a1,b})$

Verification

$$\phi \; V_{cb,y} \geq V^a_{ua,y}$$

With:

$$V_{cb,y} = V_b \cdot \psi_{s,V} \cdot \psi_{co,V} \cdot \psi_{h,V} \cdot \psi_{c,V}$$

$$\psi_{s,V} = \frac{1}{1+\sum_{i=2}^{n+1}\left[\left(1-\frac{s_i}{s_{cr,V}}\right)^{1.5}\cdot\frac{V^a_{ua,i}}{V^a_{ua,1}}\right]}$$

$$s_{cr,V} = 4c_{a1} + 2b_{ch} \; in.(mm)$$

$n = n_{cha} + n_{chb}$ is the number of all the anchors of the two channels

$s_i$ is the relative distance of two anchors, considering all the anchor on an imaginary "unfolded" channel, where the first anchor of the second channel, is located at a distance $d^*$ from the last anchor of the first (Figure 9.2.10.11d)

$$d^* = c_{a2,a1} + c_{a2,b1} - c_1$$

**90° angle Corner:** 90° angle cases of corner has been drawn in Figure 9.2.10.12a. The corner is unfolded in Figure 9.2.10.12b. Please refer to the distance marked on the detail for 90° angle corner case. The variable a and b has been defined and marked up on figure representing 90° corner condition. While unfolding the corner for this case the fictitious distance of (a+b) is taken into consideration while placing them (a+b) apart as shown in Figure 9.2.10.12b. Lets take into consideration anchor $b_1$ of anchor channel b with shear $V_{a\ ua,b1}$. Please refer Figure 9.2.10.12b. The following equation modification factor for spacing is used.

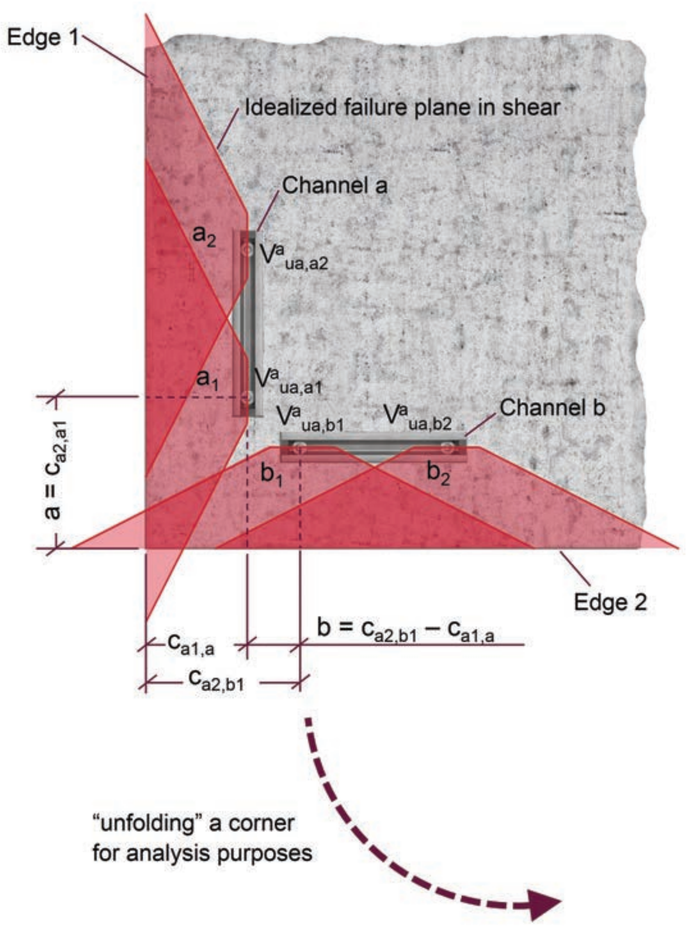



Figure 9.2.10.12a — 90° Corner.

$$\psi_{s,v,b1} = \frac{1}{1+\left[\left(1-\frac{(a+b)}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,a1}}{V^a_{ua,b1}}\right]+\left[\left(1-\frac{(a+b+a_{a1;a2})}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,a2}}{V^a_{ua,b1}}\right]+\left[\left(1-\frac{a_{b1;b2}}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,b2}}{V^a_{ua,b1}}\right]}$$

For the condition illustrated below in Figure 9.2.10.12b the shear breakout plane emitting from anchor $b_1$ overlaps shear plane emitting from anchor $a_1$, $b_2$ and $a_2$. Therefore the spacing modification factor will be the equation above including the effects of anchors $a_1$, $b_2$ and $a_2$ on anchor $b_1$.

$\psi_{co,V}$ modification factor for corner influence for 90° angle corner:

The true edge distance is taken into consideration for determination of reduction factor for corner distance. The corner distance $c_{a2,a1}$ or $c_{a2,b1}$, is into consideration respectively depending on the anchor in consideration.

If $c_{a2} \geq c_{cr,V}$

then $\psi_{co,V} = 1.0$

If $c_{a2} < c_{cr,V}$

then $\psi_{co,V} = \left(\frac{c_{a2}}{c_{cr,V}}\right)^{0.5} \leq 1.0$

$C_{a2}$=($C_{a2,a1}$ or $C_{a2,b1}$) distance of the anchor under consideration to the corner (see Figure 9.2.10.12a).

$$s_{cr,V} = 2b_{ch} + 4C_{a1}$$
$$c_{cr,V} = 0.5s_{cr,N} = b_{ch} + 2c_{a1}$$

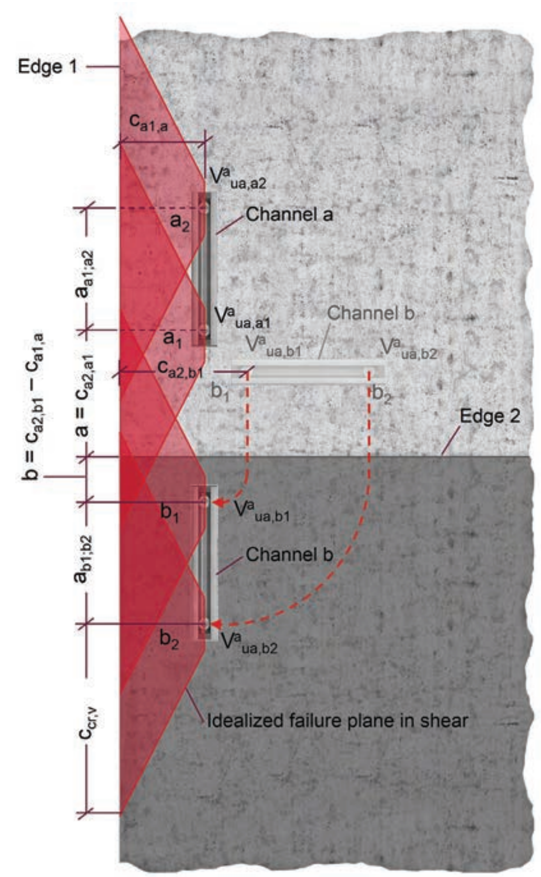



Figure 9.2.10.12b — Unfolding of 90°Corner.

**Acute angle Corner:** Acute corner has been drawn in Figure 9.2.10.13a. The corner is unfolded in Figure 9.2.10.13b. Please refer to the distance marked on the detail for acute angle corner case. The variable a and b has been defined and marked up on figure representing acute angle corner condition. The line is drawn perpendicular to edge 2 emitting from anchor $a_1$ of anchor channel. The intersection point of this line with edge 2 is extended perpendicular to edge 1. The distance between intersection point of this line with edge 1 and $a_1$ of anchor channel a is $c_{a2,a1}$. $c_{a2,a1}$ is taken as "a". In order to get the dimension b, $c_{a2,a;b1}$ is calculated and is deducted from $c_{a2,b1}$ to get b. $c_{a2,a;b1}$ is distance between anchor $b_1$ and intersection of perpendicular line emitting from $a_1$ perpendicular to edge 2 and line emitting $b_1$ perpendicular to edge 1. Refer Figure 9.2.10.13b. While unfolding the corner for this case the fictitious distance of (a+b) is taken into consideration while placing them (a+b) apart as shown in Figure 9.2.10.13b.

Let's take into consideration anchor $b_1$ of anchor channel b with shear $V^a_{ua,b1}$. Please refer Figure 9.2.10.13b. The following equation modification factor for spacing is used.

$$\psi_{s,v,b1} = \frac{1}{1+\left[\left(1-\frac{(a+b)}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,a1}}{V^a_{ua,b1}}\right]+\left[\left(1-\frac{(a+b+a_{a1;a2})}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,a2}}{V^a_{ua,b1}}\right]+\left[\left(1-\frac{a_{b1;b2}}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,b2}}{V^a_{ua,b1}}\right]}$$

For the condition illustrated below in Figure 9.2.10.13b the shear breakout plane emitting from anchor $b_1$ overlaps shear plane emitting from anchor $a_1$, $a_2$ and $b_2$, hence the spacing modification factor will be the equation above for the example in the Figure 9.2.10.13b.

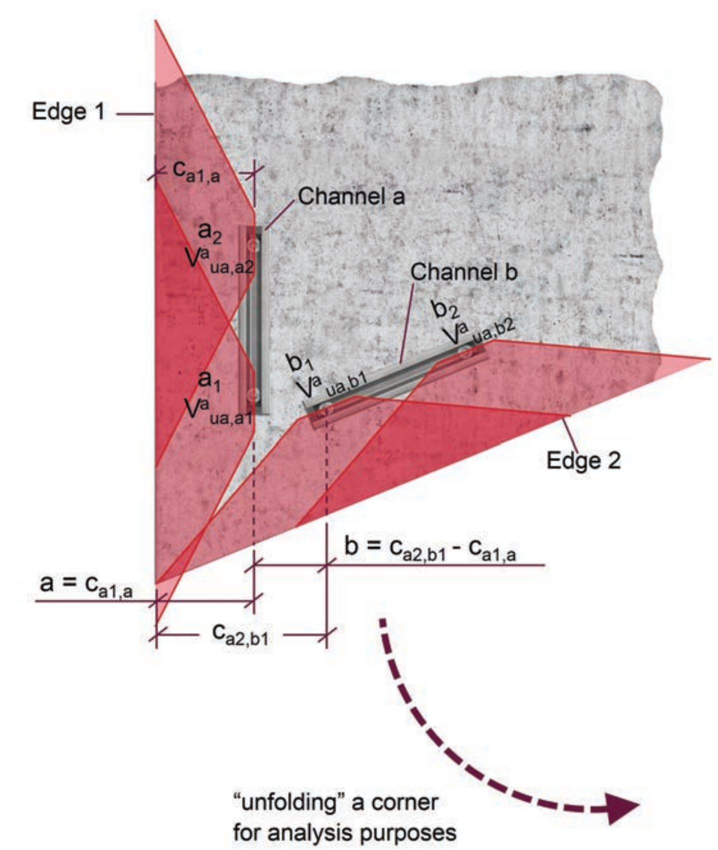



Figure 9.2.10.13a — Acute angle Corner.

$\psi_{co,V}$ modification factor for corner influence for Acute angle corner:

The side edge distance is taken into consideration for determination of reduction factor for corner distance $c_{a2}$. The $c_{a2,a1}$ is taken as distance "a" in case of a acute degree angle corner.

$c_{a2}$=$c_{a2,a1}$ side distance of the anchor $a_1$ to the corner (see Figure 9.2.10.13b). The side edge distance $c_{a2,a1}$ as shown in Figure 9.2.10.13b is used in the corner modification factor for anchor $a_1$of anchor channel a. The side edge distance for anchor $b_1$ of anchor channel b is $c_{a2,b1}$ is used in the corner modification factor.

If $c_{a2} \geq c_{cr,V}$

then $\psi_{co,V} = 1.0$

If $c_{a2} < c_{cr,V}$

then $\psi_{co,V} = \left(\frac{c_{a2}}{c_{cr,V}}\right)^{0.5} \leq 1.0$

$$s_{cr,V} = 2b_{ch} + 4C_{a1}$$
$$c_{cr,V} = 0.5s_{cr,N} = b_{ch} + 2c_{a1}$$

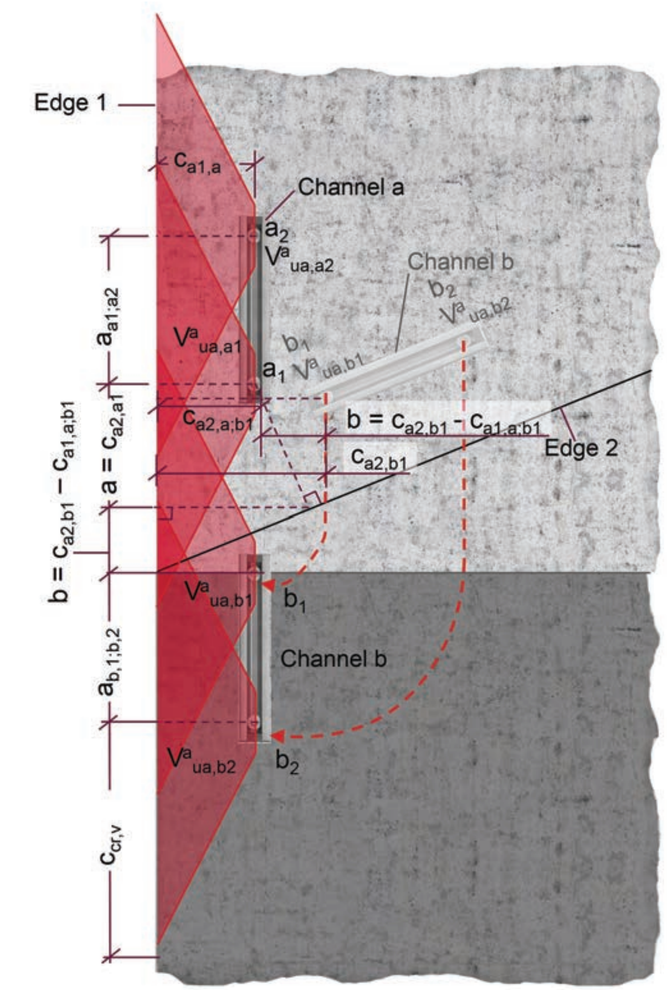



Figure 9.2.10.13b — Unfolding of Acute angle Corner.

**Obtuse angle Corner:** Obtuse corner has been drawn in Figure 9.2.10.14a. The corner is unfolded in Figure 9.2.10.14b. Please refer to the distance marked on the detail for obtuse angle corner case. The variable a and b has been defined and marked up on figure representing obtuse angle corner condition. The dimension b is evaluated by measuring a line emitting from anchor $b_1$ and having it perpendicularly intersect edge 1, this distance is $c_{a2,b1}$. The dimension b is evaluated by taking difference between $c_{a2,b1}$ and $c_{a1,a}$. The side edge distance $c_{a2,b1}$ or $c_{a2,a1}$ is used as side edge distance. While unfolding the corner for this case the fictitious distance of (a+b) is taken into consideration while placing them (a+b) apart as shown in Figure 9.2.10.14b.

Lets take into consideration anchor $b_1$ of anchor channel b with shear $V^a_{ua,b1}$. Please refer Figure 9.2.10.14b. The following equation modification factor for spacing is used.

$$\psi_{s,v,b1} = \frac{1}{1+\left[\left(1-\frac{(a+b)}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,a1}}{V^a_{ua,b1}}\right]+\left[\left(1-\frac{(a+b+a_{a1;a2})}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,a2}}{V^a_{ua,b1}}\right]+\left[\left(1-\frac{a_{b1;b2}}{s_{cr,v}}\right)^{1.5}\cdot\frac{V^a_{ua,b2}}{V^a_{ua,b1}}\right]}$$

For the condition illustrated below in Figure 9.2.10.14b the shear breakout plane emitting from anchor $b_1$ overlaps shear plane emitting from anchor $a_1$, $a_2$ and $b_2$, hence the spacing modification factor will be the equation above for the example in the Figure 9.2.10.14b.

$\psi_{co,V}$ modification factor for corner influence for obtuse angle corner:

The side edge distance is taken into consideration for determination of reduction factor for corner distance $c_{a2}$. The $c_{a2,b1}$ or $c_{a2,a1}$ is taken as side edge distance.

$c_{a2} = c_{a2,b1}$ or $c_{a2,a1}$ side distance of the anchor $b_1$ or $a_1$ to the corner respectively (see Figure 9.2.10.14b).

$$\text{If } c_{a2} \geq c_{cr,V}$$

$$\text{then } \psi_{co,V} = 1.0$$

$$\text{If } c_{a2} < c_{cr,V}$$

$$\text{then } \psi_{co,V} = \left(\frac{c_{a2}}{c_{cr,V}}\right)^{0.5} \leq 1.0$$

$$s_{cr,V} = 2b_{ch} + 4C_{a1}$$

$$c_{cr,V} = 0.5s_{cr,N} = b_{ch} + 2c_{a1}$$

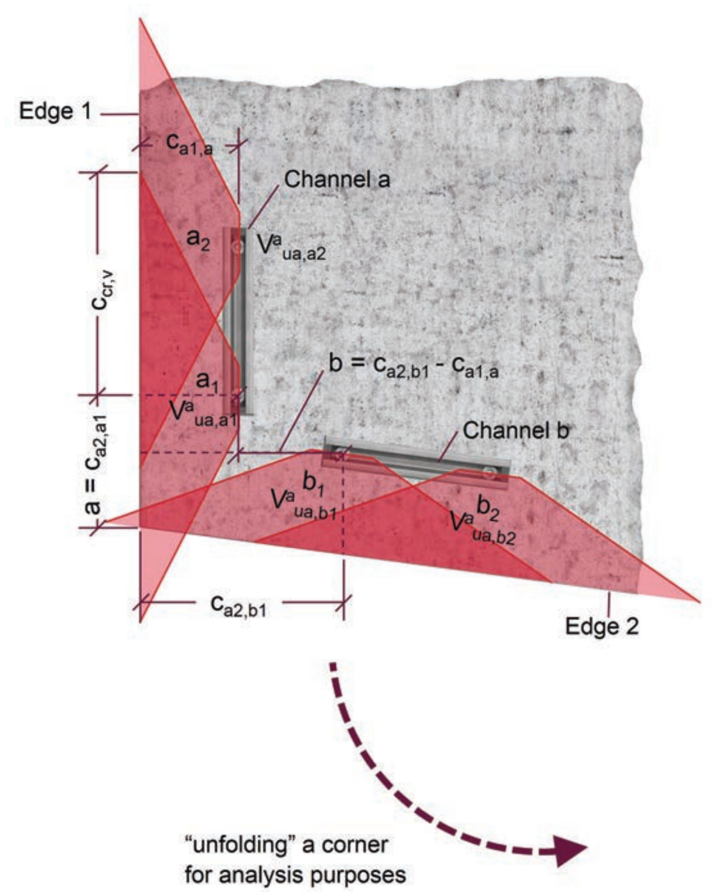



Figure 9.2.10.14a — Obtuse angle Corner.

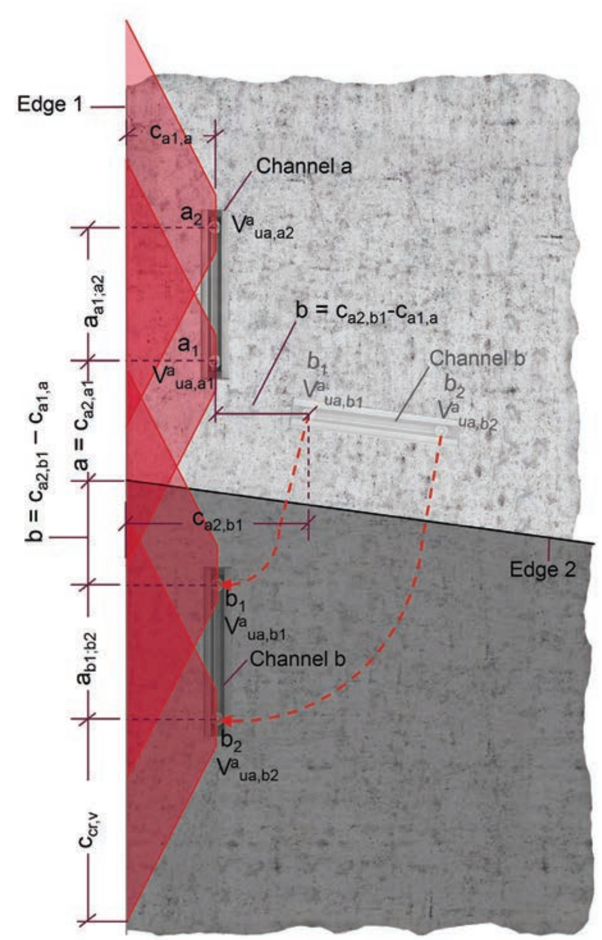



Figure 9.2.10.14b — Unfolding of Obtuse angle Corner.

## Concrete side-face blow out

The concrete side blowout is calculated with the same verification of ESR3520:

$$\phi \; N_{sb} \geq N^a_{ua}$$

$$N_{sb} = N^0_{sb} \cdot \Psi_{g,Nb} \cdot \Psi_{co1,Nb} \cdot \Psi_{co2,Nb} \cdot \Psi_{h,Nb} \cdot \Psi_{c,Nb}$$

With the only differences:

$\psi_{co2,Nb} = 1$ Since the second corner is not available

$$\psi_{s,Nb} = \frac{1}{1+\sum_{i=2}^{n+1}\left[\left(1-\frac{s_i}{s_{cr,Nb}}\right)^{1.5}\cdot\frac{N^a_{ua,i}}{N^a_{ua,1}}\right]} \leq 1.0$$

$n = n_{ch1} + n_{ch2}$ is the number of all the anchors of the two channels

$s_i$ is the relative distance of two anchors, considering all the anchor on an imaginary "unfolded" channel, where the first anchor of the second channel, is located at a distance d* from the last anchor of the first (Figure 9.2.10.11)

## Concrete breakout strength for parallel shear

The concrete breakout strength for parallel shear is calculated according ESR for both channels are verified independently. The concrete utilization of both edges is then combined in conservative way as described in the next paragraph.

## Concrete failure, load interaction

Every anchor already considers the second channel for tension and perpendicular shear. The governing failure modes in the three directions are combined according to the following method. Refer Figure 9.210.15.

A verification for each anchor of both anchor channel is needed.

ch, a is the channel of the considered anchor

ch, b indicate the other channel

Ed, i is the edge parallel to the channel of the considered anchor

Ed, j indicate the edge parallel to the other channel

Considering the channel b, tension and perpendicular shear of the channel b are considered "precisely" as described. Longitudinal shear of the channel itself is considered according to ESR3520. The effects of the channel a due to longitudinal shear on the channel b is difficult to consider. Therefore, on the safe side, the highest utilization for longitudinal shear of channel b on the edge i is added linearly to the utilization of perpendicular shear of the considered anchor. Longitudinal shear on the channel b is calculated according to ESR3520.

Verification of the anchors of the channel b.

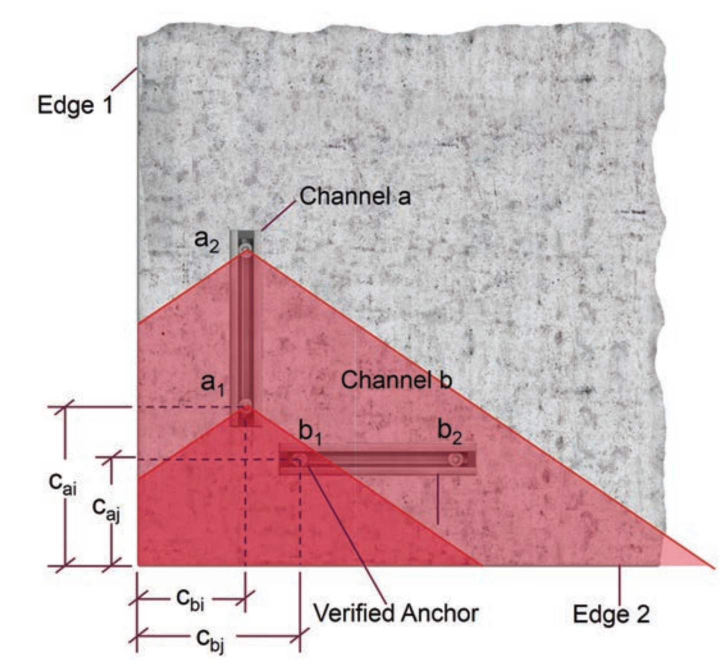



**Figure 9.2.10.15 — Interacting tension with perpendicular shear and longitudinal shear.**

$$\beta_{N+V,c,b1}=\left(\frac{N^a_{ua}}{\phi N_{nc}}\right)^{\alpha}_{chb1}+\left(\left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right)_{chb1}+\left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right)_{cha,Edi}\right)^{\alpha}+\left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right)^{\alpha}_{chb1}\leq 1.0$$

$$\beta_{Nc,b1}=\left(\frac{N^a_{ua}}{\phi N_{nc}}\right)_{chb1}\leq 1.0$$

$\beta_{N,c}$ highest anchor utilization for tension loading between anchor $b_1$ of anchor channel b :

- blow out ($N_{sb}$)
- anchor pull-out ($N_{pn}$)
- concrete breakout ($N_{cb}$)
- anchor reinforcement (if available $N_{ca,s}$, $N_{ca}$)

$$\beta_{Vc,y,b1}=\left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right)_{chb1}\leq 1.0$$

$\beta_{V,c,y}$ highest utilization under shear loading (perpendicular) $b_1$ of anchor channel b:

- pryout for perpendicular shear ($V_{cp,y}$),
- concrete edge failure ($V_{cb,y}$)

$$\beta_{Vc,x,b1}=\left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right)_{chb1}\leq 1.0$$

$\beta_{V,c,x}$ highest utilization under shear loading (parallel) $b_1$ of anchor channel b:

- concrete breakout ($V_{cb,x}$)
- pryout for parallel shear ($V_{cp,x}$).

$$\beta_{V,c,xa}=\left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right)_{cha,Edi}\leq 1.0$$

$\beta_{V,c,x,chj}$ highest utilization for longitudinal shear of channel j for concrete failure involving the edge i.

- concrete breakout ($V_{cb,x}$)
- concrete breakout for shear parallel to on edge i due to perpendicular shear on edge j

$\alpha = 1$ with anchor reinforcement to take up tension and parallel shear loads

$\alpha = 5/3$ for channels without reinforcement



On other hand, anchor channel can be analyzed using a simplified method as described below. Here anchor channel a and b is analyzed individually limiting the side edge distance as described below.

## Simplified method

The concrete at the corner is shared by the two anchor channels and therefore, using the AC232 provisions with the actual corner distance for analysis purposes can yield very unconservative concrete strengths. Moreover, if the idealized failure plane is followed and the corner distance is taken to the point where the two idealized failure planes overlap. this may still create unconservative concrete strengths, as the concrete crack will follow the path of least resistance. Therefore, this model is only applicable for applications loaded in tension and/or perpendicular shear.

## 90° Corner

**Tension:** To account for the influence of the adjacent corner anchor channel, the corner distance is reduced by assuming the concrete crack follows the path of least resistance and considering the corner distance where the "crack" of each anchor channel overlaps. For the concrete failure modes in tension, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner generates a concrete cone with the radius of $c_{cr,N}$. The distance between the closest anchor heads is defined as x, as shown in the Figure 9.2.10.16-a. These channels should be analyzed using a fictitious $c_{a2}$ of (x/2). To evaluate channel a and b the anchor channel is modelled in Profis anchor channel software with $c_{a2}$ of x/2. With limiting the edge the concrete breakout strength in tension is reduced by the modification factor for corner effect $\Psi_{co,N}$.

**Perpendicular shear:** For the concrete failure modes in shear, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner change the concrete behavior. The concrete crack does not follow the idealized failure plane ($c_{cr,V}$) but the path of least resistance. This concept is illustrated in Figure 9.2.10.16-b. The fictitious edge can be taken in between the distance (a+b) for analyzing the anchor channel a and b depending on whichever anchor channel needed more concrete. To evaluate channel a and b the anchor channel is modelled with $c_{a2}$ distance of in between distance (a+b). With limiting the edge the concrete breakout strength in shear is reduced by the modification factor for corner effect $\Psi_{co,V}$.

Perpendicular outside corners with headed stud HAC channel loaded only in tension or in all three directions: The distance between the closest anchor heads is defined as x, as shown in the Figure 9.2.10.16-a. These channels should be analyzed using a fictitious $c_{a2}$ of (x/2).

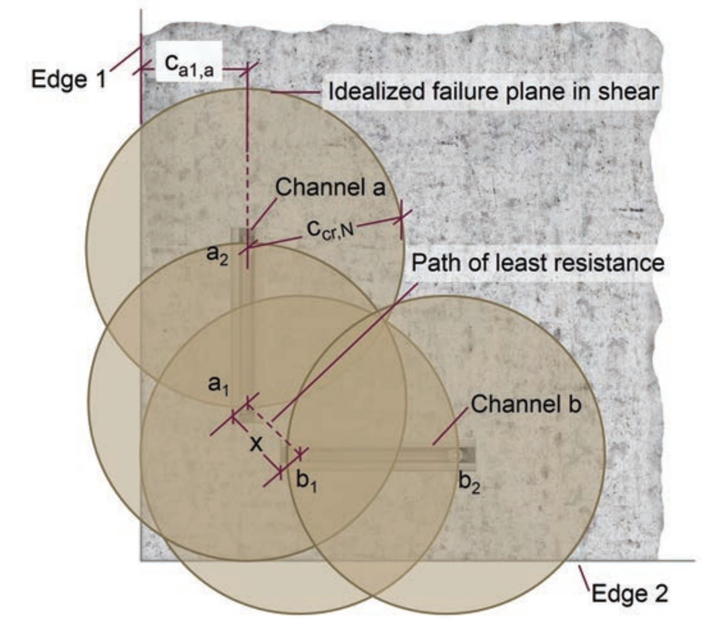



**Figure 9.2.10.16-a— Simplified Method-90° Corner — Tension.**

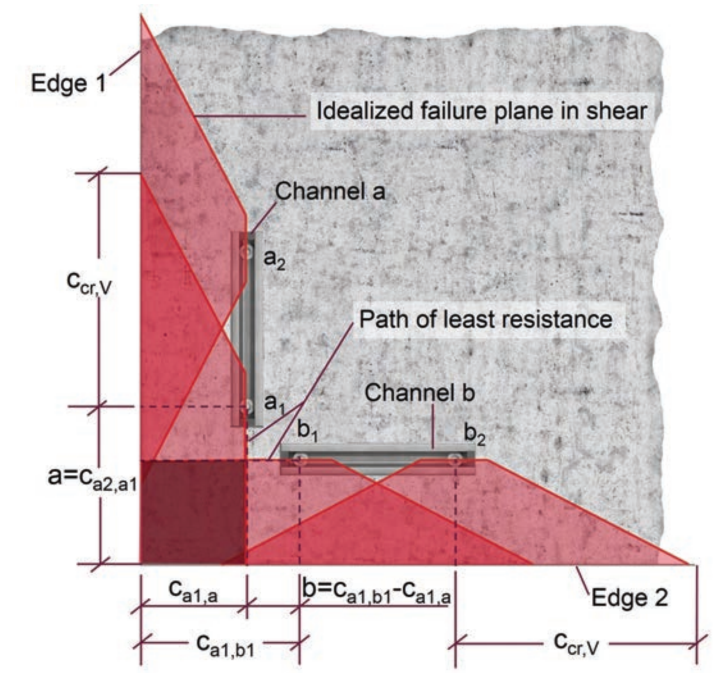



**Figure 9.2.10.16-b— Simplified Method-90° Corner — Perpendicular Shear.**

## Acute and obtuse corners

### Acute Corner:

**Tension:** To account for the influence of the adjacent corner anchor channel, the corner distance is reduced by assuming the concrete crack follows the path of least resistance and considering the corner distance where the "crack" of each anchor channel overlaps. For the concrete failure modes in tension, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner generates a concrete cone with the radius of $c_{cr,N}$. The distance between the closest anchor heads is defined as x, as shown in the Figure 9.2.10.17-a. These channels should be analyzed using a fictitious $c_{a2}$ of (x/2). To evaluate channel a and b the anchor channel is modelled in Profis anchor channel software with $c_{a2}$ of x/2. With limiting the edge the concrete breakout strength in tension is reduced by the modification factor for corner effect $\psi_{co,N}$.

**Perpendicular shear:** For the concrete failure modes in shear, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner change the concrete behavior. The concrete crack does not follow the idealized failure plane ($c_{cr,V}$) but the path of least resistance. This concept is illustrated in Figure 9.2.10.17-b. The fictitious edge can be taken in between the distance (a+b) for analyzing the anchor channel a and b depending on whichever anchor channel needed more concrete. To evaluate channel a and b the anchor channel is modelled with $c_{a2}$ distance of in between distance (a+b). With limiting the edge the concrete breakout strength in shear is reduced by the modification factor for corner effect $\psi_{co,V}$. Channel a is evaluated using $c_{a2,a1}$ and channel b can be evaluated using $c_{a2,b1}$.

Acute outside corners with headed stud HAC channel loaded only in tension or in all three directions: The distance between the closest anchor heads is defined as x, as shown in the Figure 9.2.10.17-a. These channels should be analyzed using a fictitious $c_{a2}$ of (x/2).

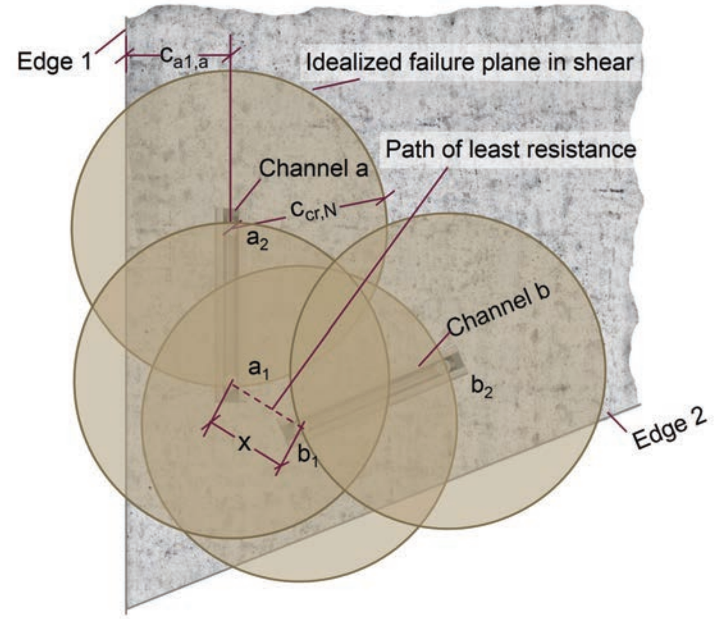



**Figure 9.2.10.17-a — Simplified Method — Acute Corner — Tension.**

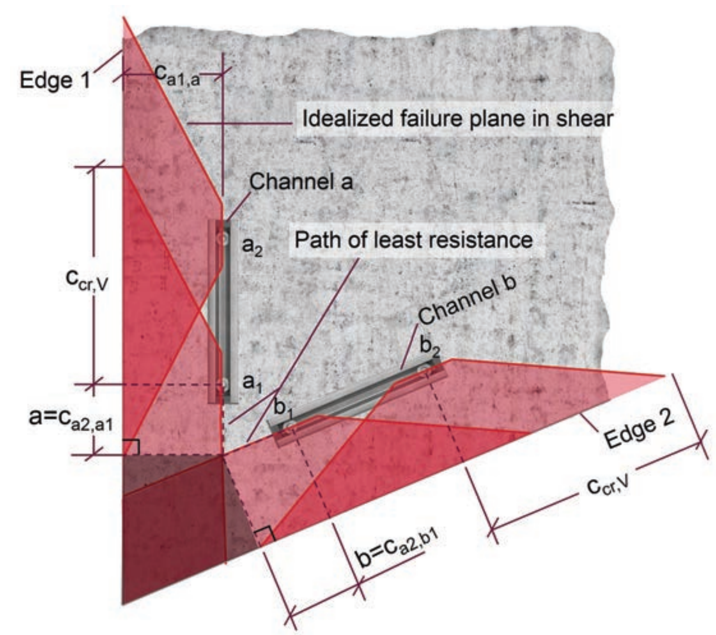



**Figure 9.2.10.17-b — Simplified Method — Acute Corner — Perpendicular Shear.**

### Obtuse Corner:

**Tension:** To account for the influence of the adjacent corner anchor channel, the corner distance is reduced by assuming the concrete crack follows the path of least resistance and considering the corner distance where the "crack" of each anchor channel overlaps. For the concrete failure modes in tension, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner generates a concrete cone with the radius of $c_{cr,N}$. The distance between the closest anchor heads is defined as x, as shown in the Figure 9.2.10.18-a. These channels should be analyzed using a fictitious $c_{a2}$ of (x/2). To evaluate channel a and b the anchor channel is modelled in Profis anchor channel software with $c_{a2}$ of x/2. With limiting the edge the concrete breakout strength in tension is reduced by the modification factor for corner effect $\psi_{co,N}$.

**Perpendicular shear:** For the concrete failure modes in shear, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner change the concrete behavior. The concrete crack does not follow the idealized failure plane ($c_{cr,V}$) but the path of least resistance. This concept is illustrated in Figure 9.2.10.18-b. The fictitious edge can be taken in between the distance (a+b) for analyzing the anchor channel a and b depending on whichever anchor channel needed more concrete. To evaluate channel a and b the anchor channel is modelled with $c_{a2}$ distance of in between distance (a+b). With limiting the edge the concrete breakout strength in shear is reduced by the modification factor for corner effect $\psi_{co,V}$. Channel a is evaluated using $c_{a2,a1}$ and channel b can be evaluated using $c_{a2,b1}$.

Obtuse angle corners with headed stud HAC channel loaded only in tension or forces in all three directions: The distance between the closest anchor heads is defined as x, as shown in Figure 9.2.10.18-a. These channels should be analyzed using a fictitious $c_{a2}$ of (x/2).

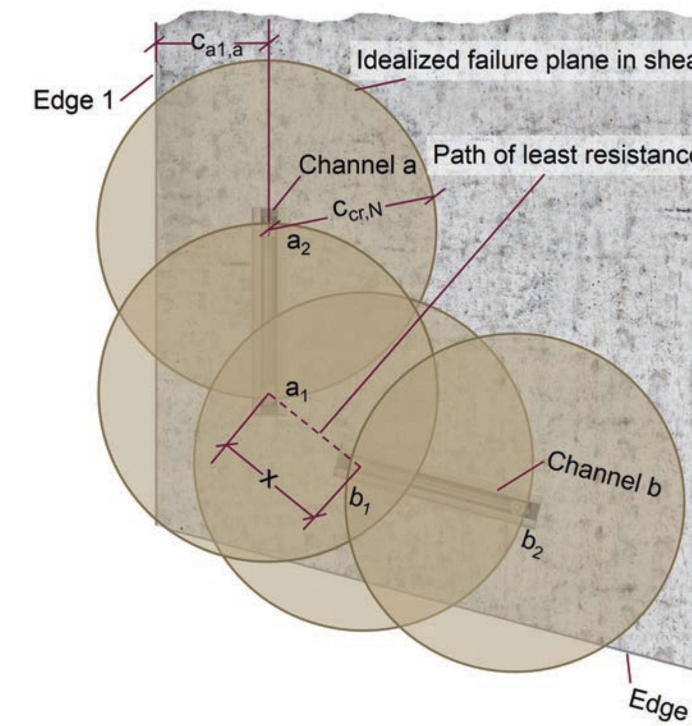



**Figure 9.2.10.18-a — Simplified Method — Obtuse Corner — Tension .**

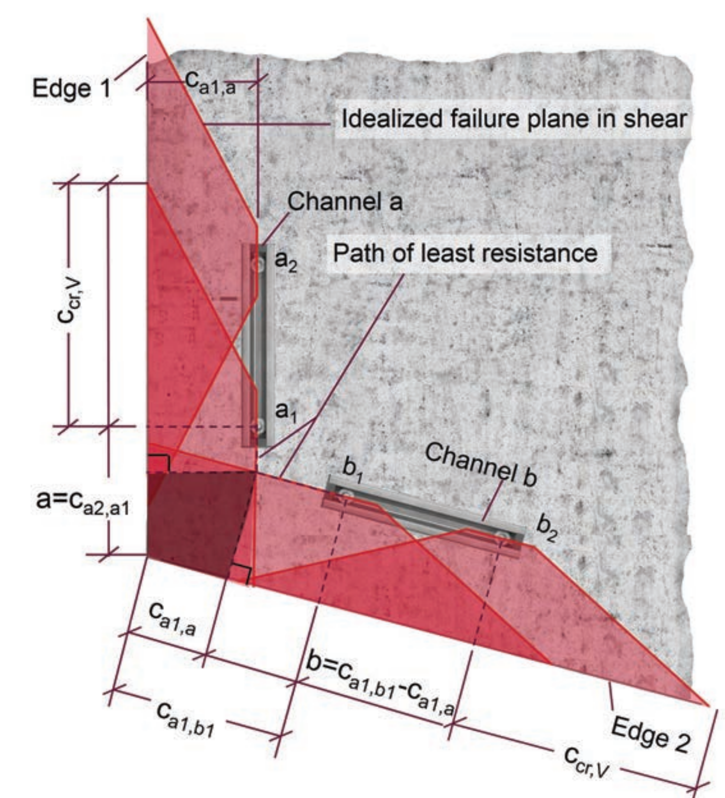



**Figure 9.2.10.18-b — Simplified Method — Obtuse Corner — Perpendicular Shear**

## 9.2.11 — HAC AND HAC-T DESIGN: EXAMPLE OF DESIGN OF TOP OF SLAB OUTSIDE CORNER

The distance between the closest anchor heads is defined as x, as shown in the Figure 9.2.11.1. For concrete breakout in tension, concrete breakout and pryout in shear the imaginary concrete side edge distance of (x"/2) is considered. The side edge distance of (x"/2)-(1") can be used while modeling in Hilti PROFIS Anchor Channel software as shown in Figure 9.2.11.2. 1" is anchor channel's overhang that is needed to be deducted from side edge when modelling it in profis.

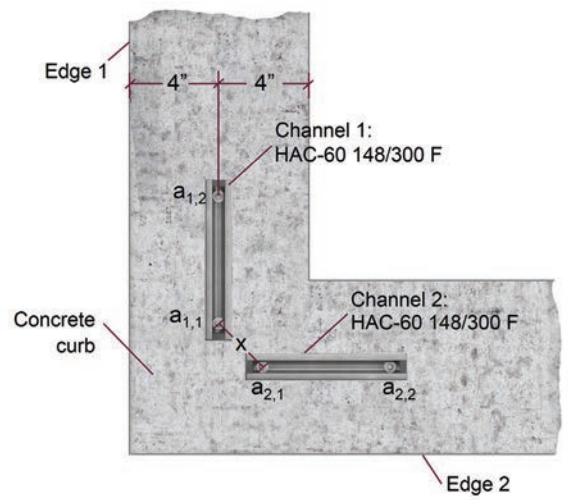



Figure 9.2.11.1 — Example of simplified method of HAC in a top of curb corner.

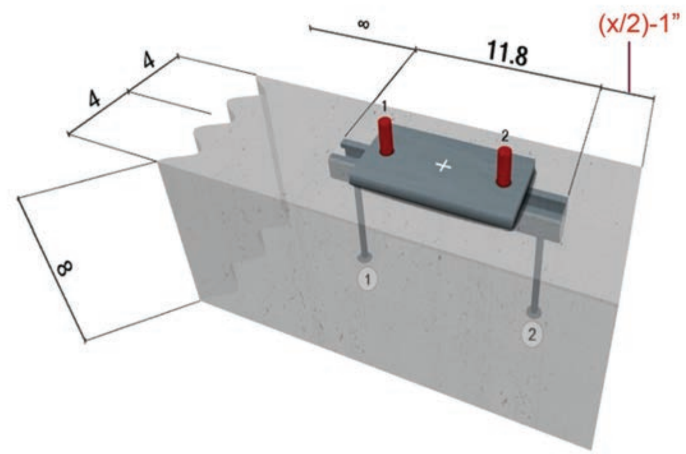



Figure 9.2.11.2 — Analysis of channel 1 using the simplified method in PROFIS Anchor Channel.

## 9.2.12 — HAC AND HAC-T DESIGN: TOP OF SLAB INSIDE CORNER WITH PAIR OF ANCHOR CHANNEL

**Tension:** To account for the influence of the adjacent corner anchor channel, the corner distance is reduced by assuming the concrete crack follows the path of least resistance and considering the corner distance where the "crack" of each anchor channel overlaps. For the concrete failure modes in tension, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner generates a concrete cone with the radius of $c_{cr,N}$. The distance between the closest anchor heads is defined as x, as shown in the Figure 9.2.12.1-a. These channels should be analyzed using a fictitious $c_{a2}$ of (x/2). To evaluate channel a and b the anchor channel is modelled in Profis anchor channel software with $c_{a2}$ of x/2. With limiting the edge the concrete breakout strength in tension is reduced by the modification factor for corner effect $\psi_{co,N}$.

**Perpendicular shear:** For the concrete failure modes in shear, the stresses in the concrete induced by the two anchors of the anchor channels closer to the corner change the concrete behavior. The concrete crack does not follow the idealized failure plane ($c_{cr,V}$) but the path of least resistance. This concept is illustrated in Figure 9.2.12.1-b. The fictitious edge can be taken in between the distance (a+b) for analyzing the anchor channel a and b depending on whichever anchor channel needed more concrete. To evaluate channel a and b the anchor channel is modelled with $c_{a2}$ distance in between distance (a+b). With limiting the edge, the concrete breakout strength in shear is reduced by the modification factor for corner effect $\psi_{co,V}$.

Interior angle corners with headed stud HAC channel loaded only in tension or forces in all three directions: The distance between the closest anchor heads is defined as x, as shown in Figure 9.2.12.1-a. These channels should be analyzed using a fictitious $c_{a2}$ of (x/2).

Same concept can be used for analyzing acute and obtuse degree inside corners with headed studs anchor channel.

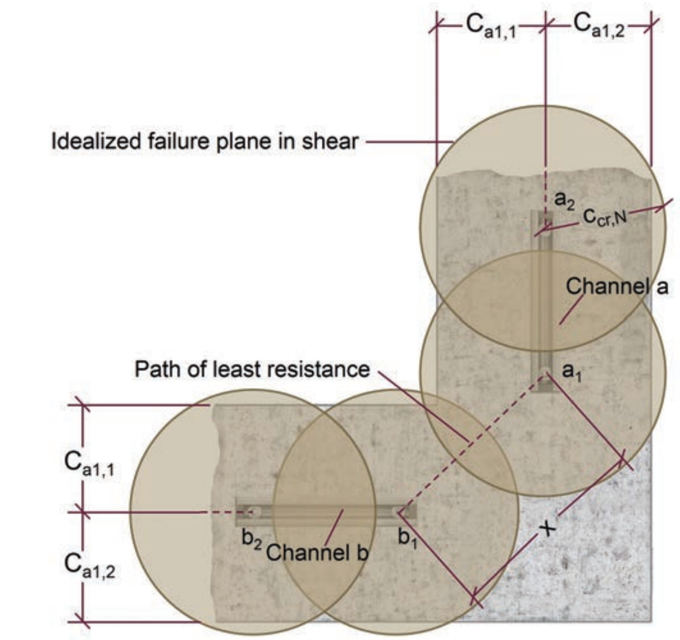



Figure 9.2.12.1-a — Inside Corner — Tension.

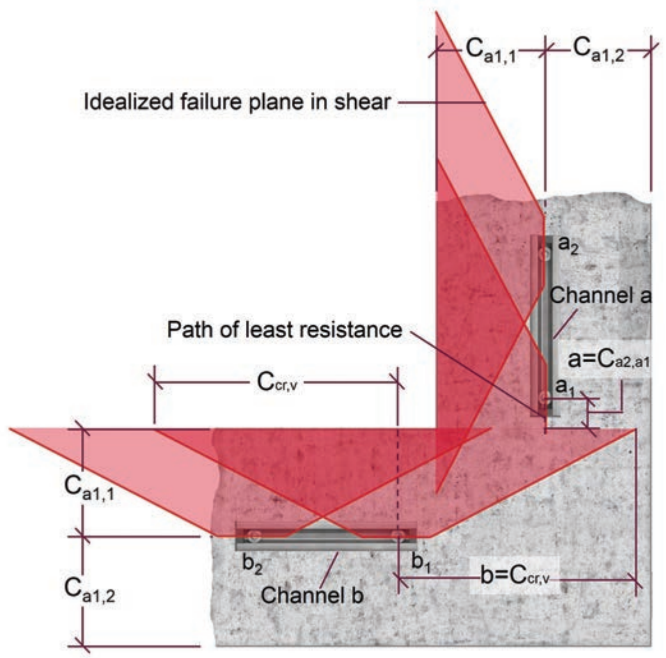



Figure 9.2.12.1-b — Inside Corner — Shear Perpendicular

# 9.2.13 — HAC AND HAC-T DESIGN: PARALLEL CHANNELS

## Two TOS or BOS channels:

Currently, AC232 excludes parallel anchor channels. Hilti anchor channel analysis of parallel anchor channels are based on ACI 318 provisions. The analysis of the concrete breakout strength in shear is based on ACI 318 principles in conjunction with AC232 design methodology.

All steel failure modes are in accordance to ESR-3520.

Concrete breakout strength in shear of parallel anchor channels is per ACI 318 concepts pertaining to dividing the concrete between the two channels.

**Perpendicular Shear**

**Case 1:** One assumption of the distribution of forces indicates that half of the shear force would be critical on the front anchor and the projected area. For the calculation of concrete breakout, $c_{a1}$ is taken as $c_{a1,a}$.

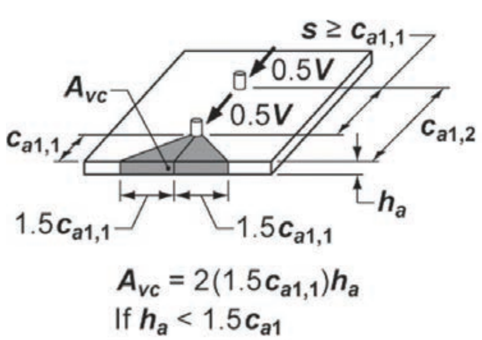



Figure 9.2.13.1— ACI-Fig. R17.5.2.1b—Calculation of $A_{vc}$ for single anchors and groups of anchors per ACI 318-14..

**Front anchor channel analysis:** Refer Figure 9.2.13.2 and 9.2.13.3. The perpendicular concrete breakout strength of front channel should be evaluated using the concrete edge distance of $c_{a1,a}$. The front anchor channel should be loaded with half of the total shear force acting on the double anchor channel system. This is required to be checked following ACI 318-14 chapter 17 section commentary Fig17.5.2.1b case I. This is shown in Figure 9.2.13.1.

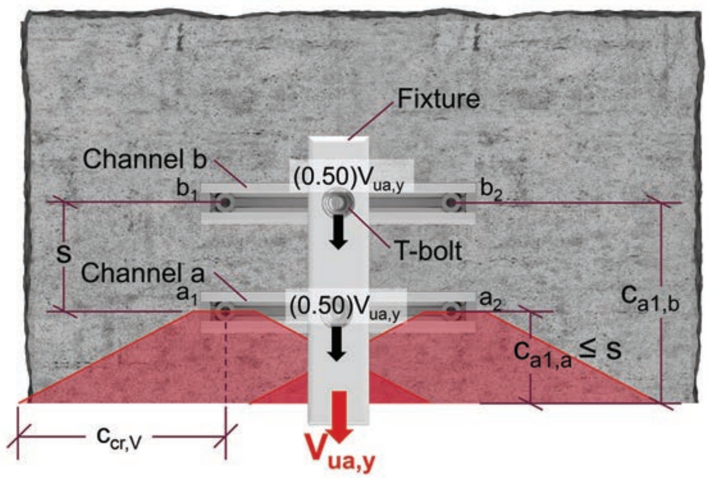
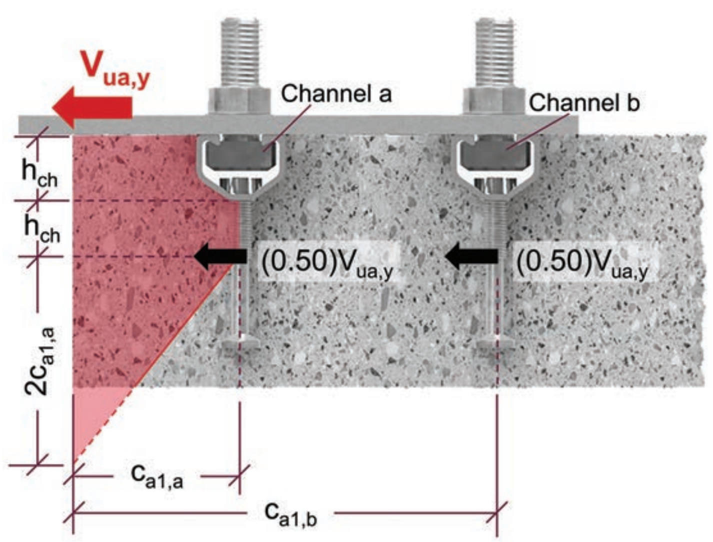



Figure 9.2.13.2 — Parallel Channels-Perpendicular Shear CaseI-Plan.




FFigure 9.2.13.3 — Parallel Channels — Shear CaseI-Section view.

**Case 2:** Another assumption of the distribution of forces indicates that the total shear force would be critical on the rear anchor and its projected area. This assumption needs to be considered only when anchors are welded to a common plate independent of "s". In the case of anchor channels, this condition is applicable for "filled" holes conditions.

This provision is checked for parallel double channels in order to confirm that the total available concrete between the back channel of the parallel channels and the front edge has sufficient capacity to take the total shear force experiencing by the system.

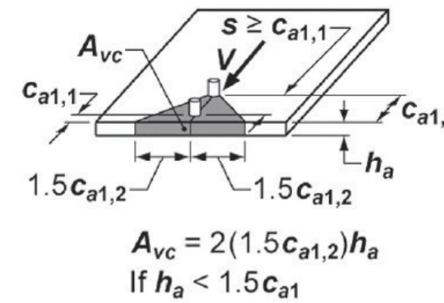



Figure 9.2.13.4 — Fig. R17.5.2.1b — Calculation of $A_{vc}$ for single anchors and groups of anchors per ACI 318-14..

**Back anchor channel analysis:** Refer Figure 9.2.13.5 and 9.2.13.6. The perpendicular concrete breakout strength of the back channel should be evaluated using the concrete edge distance of $c_{a1,b}$. The back anchor channel should be loaded with the total shear force acting on the double anchor channel system. This is required to be checked following ACI 318-14 chapter 17 section commentary Fig17.5.2.1b case II. This is shown in Figure 9.2.13.4.

Both Case 1 and Case 2 should be evaluated to determine which controls for design.

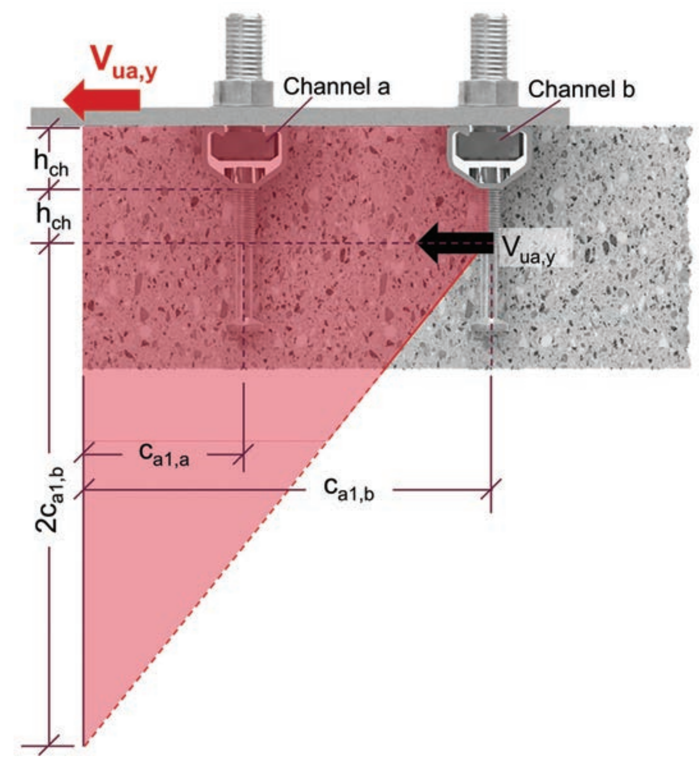



Figure 9.2.13.6 — Parallel Channels-Shear Case II-Section view.

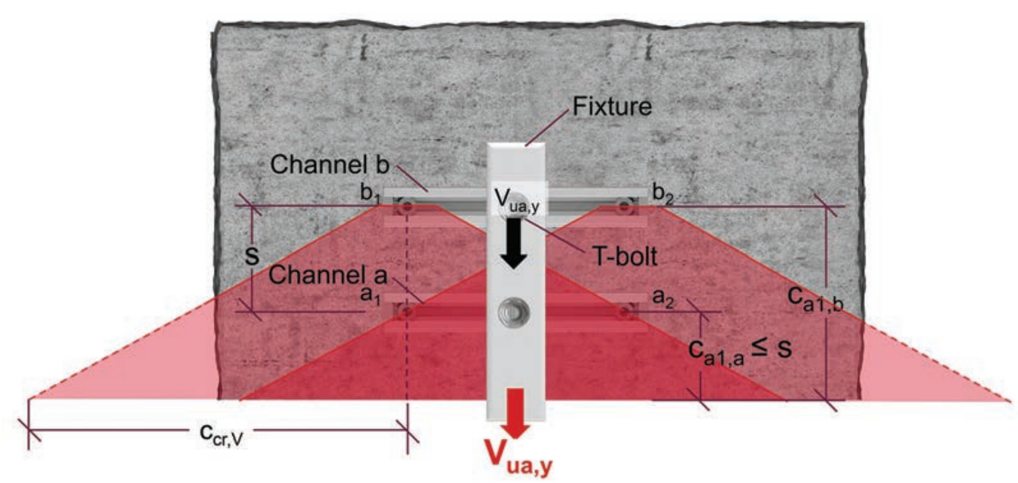



Figure 9.2.13.5 — Parallel Channels-Shear CaseII-Plan view.

## Tension

Both the front and back anchor channels are analyzed in tension using an imaginary concrete edge of x/2 as shown in Figure 9.2.13.7, if both anchor channels are equally loaded.

Please note that the location of imaginary concrete edge can be optimized according to the magnitude of tensile forces each anchor channel is experiencing as shown in Figure 9.2.13.8. The imaginary edge is assumed at a distance of (3/4)x from the back channel, if the back channel is experiencing a larger tension force.

Alternatively, the spacing method can be used to determine the spacing modification factor $\psi_{s,N}$ for the anchor in consideration, considering the effect of the anchors of the channel parallel to the one in consideration. Please note that there is no need to assume the imaginary edge in between the channel when spacing method is used. The actual perpendicular edge distance of the channel has to be consider, while calculating the edge modification factor $\psi_{ed,N}$. Refer Figure 9.2.13.8.

Please refer to the formula below for finding the spacing modification factor for anchor $a_1$ of channel a.

$$\psi_{s,N,a1} = \frac{1}{1+\left[\left(1-\frac{s_{a1,a2}}{s_{cr,N}}\right)^{1.5}\cdot\frac{N^a_{ua,a2}}{N^a_{ua,a1}}\right]+\left[\left(1-\frac{s_{a1,b1}}{s_{cr,N}}\right)^{1.5}\cdot\frac{N^a_{ua,b1}}{N^a_{ua,a1}}\right]\left[\left(1-\frac{s_{a1,b2}}{s_{cr,N}}\right)^{1.5}\cdot\frac{N^a_{ua,b2}}{N^a_{ua,a1}}\right]}$$

The edge modification factor for anchor channel a is given below.

$$c_{a1,a} \le C_{cr,N} \text{ then } \Psi_{ed,N} = \left(\frac{c_{a1,a}}{C_{cr,N}}\right)^{0.5}$$

The edge modification factor for anchor channel b is given below.

$$c_{a1,b} \le C_{cr,N} \text{ then } \Psi_{ed,N} = \left(\frac{c_{a1,b}}{C_{cr,N}}\right)^{0.5}$$

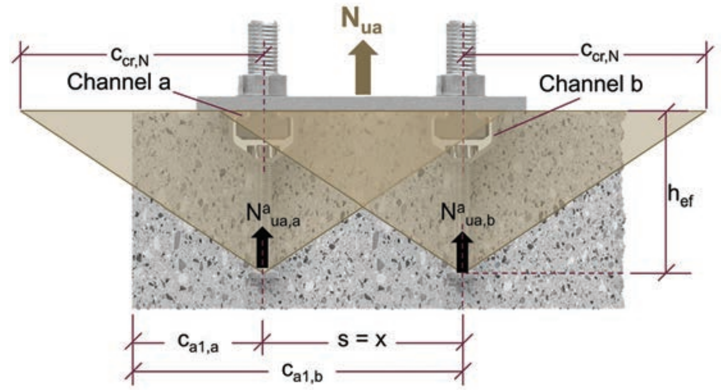



Figure 9.2.13.7 — Tension -Equal tension force-Section view.

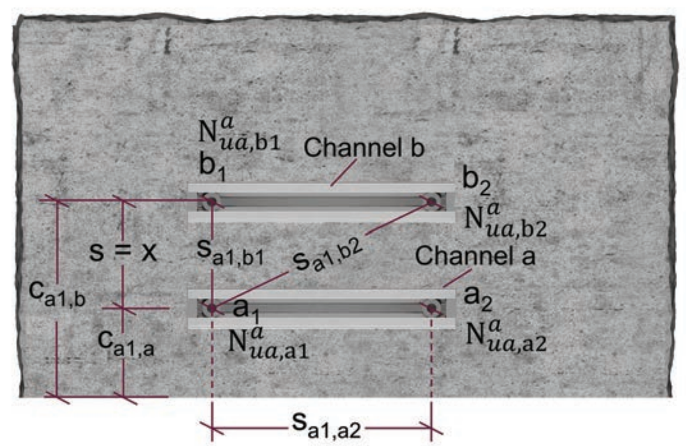



Figure 9.2.13.8 — Tension — unequal tension force-Section view.

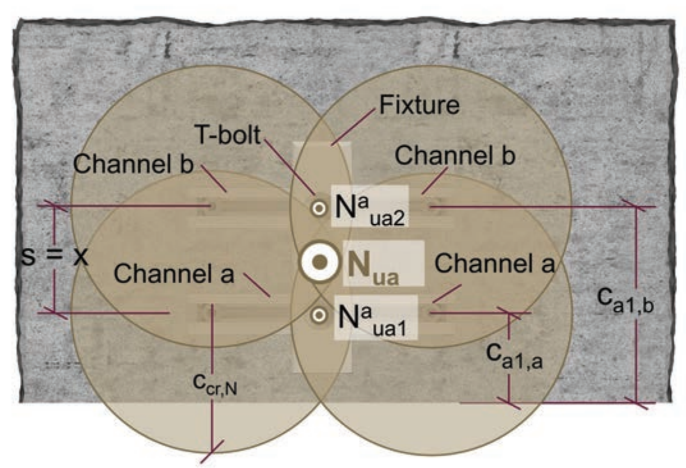



Figure 9.2.13.9 — Tension — Equal tension force-Plan`` view.

## Longitudinal shear

The longitudinal shear force $V_{ua,x}$ is applied at an eccentricity, as shown in Figure 9.2.13.10. This eccentricity creates the force $V_{uax,b}$ on anchor channel b in opposite to the direction of $V_{ua,x}$. Where as anchor channel a experiences the longitudinal force in the direction of $V_{ua,x}$. Having infinite sides edges on both sides will create breakout planes perpendicular to the edge as seen in the Figure 9.2.13.10. For analyzing anchor channel a the front edge of $c_{a1}$,a is considered. For analyzing anchor channel b the edge available in between the two channels is used, which is x $(c_{a1,b} - c_{a1,a})$ as shown in Figure 9.2.13.10.

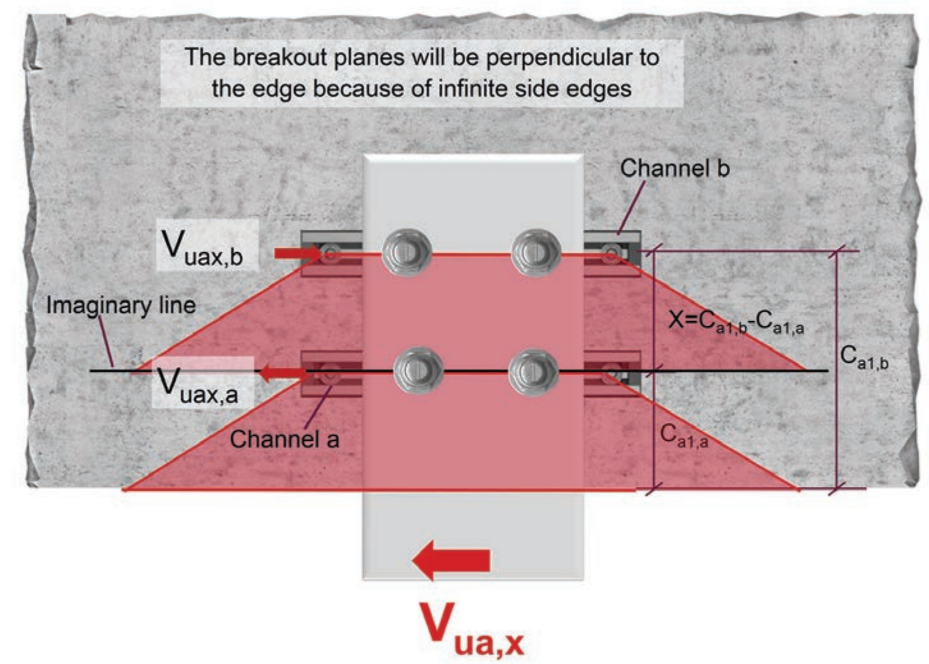



Figure 9.2.13.10 — Longitudinal Shear — Plan view.

# 9.2.14 — HAC AND HAC-T DESIGN: PARALLEL CHANNELS TOP AND BOTTOM

## One BOS and another TOS channels: BOS away from TOS

Current AC232 excluded parallel anchor channels. Hilti anchor channel analysis of parallel anchor channels is based on ACI 318 provisions. The analysis of the concrete breakout strength in shear is based on ACI 318 principles in conjunction with AC232 design methodology.

All steel failure modes are in accordance to ESR-3520.

One can use the principles of to use ACI 318-14 provision to evaluate top and bottom.

Concrete breakout strength in shear of parallel anchors is per ACI 318 concepts pertaining to dividing the concrete between the two channels. Principles of AC232 should be used while evaluating the concrete breakout capacity of all the concrete failure modes.

**Perpendicular Shear**

**TOP OF SLAB embed:** Shear forces on TOS and BOS are $V_{uay,a}$ and $V_{uay,b}$ respectively. The front edge of the ToS embed is checked against the $V_{uay,a}$ force. For the calculation of concrete breakout, $c_{a1}$, is taken as $c_{a1,a}$.

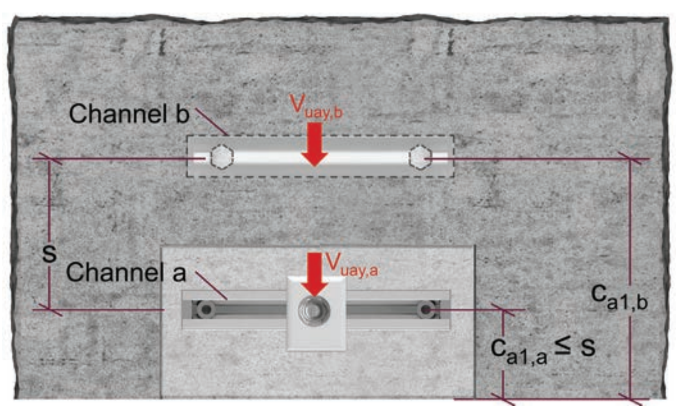



Figure 9.2.14.1 — Parallel Channels Top and Bottom: BOS away from TOS - Plan View.

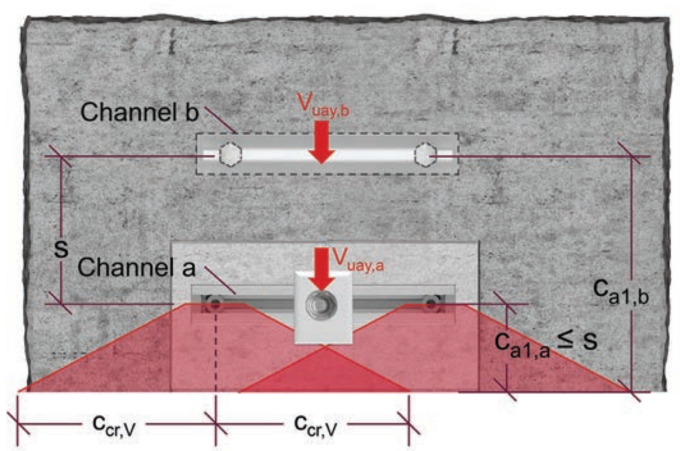



Figure 9.2.14.3 — Parallel Channels Top and Bottom: BOS away from TOS-Perpendicular Shear TOS-Plan View.

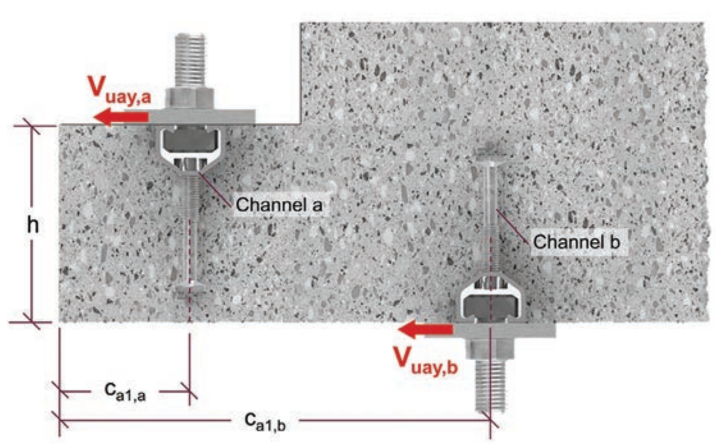



Figure 9.2.14.2 — Parallel Channels Top and Bottom: BOS away from TOS - Section View.

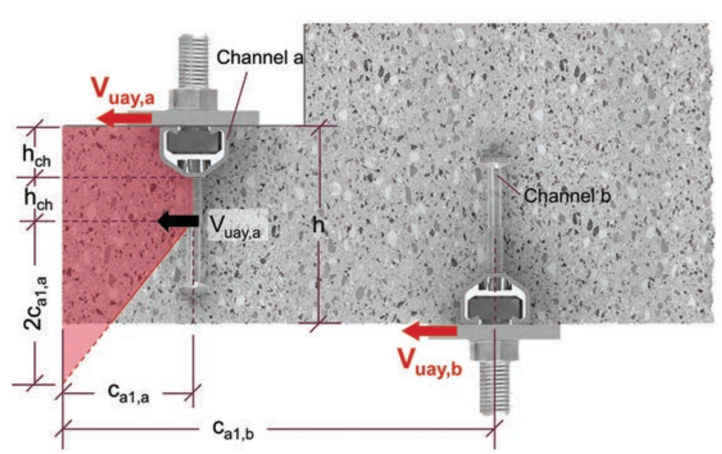



Figure 9.2.14.4— Parallel Channels Top and Bottom-BOS away from TOS: Perpendicular Shear TOS-Section View.

Another assumption of the distribution of forces indicates that the total shear force would be critical on the rear anchor and its projected area.

This provision is checked for parallel double channels in order to confirm that the total available concrete between the BOS channel and the front edge has sufficient capacity to take the total shear force experienced by both channels.

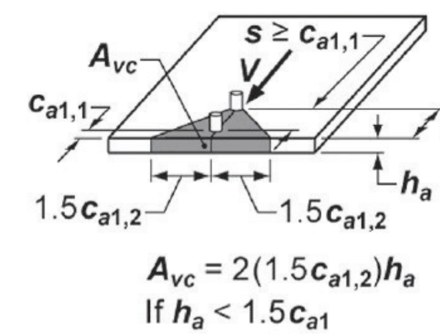



Figure 9.2.14.5—Calculation of $A_{vc}$ for single anchors and groups of anchors per ACI 318-14.

**BOTTOM OF SLAB:** The perpendicular concrete breakout strength of the BOS channel should be evaluated using $c_{a1}$ as the concrete edge distance of $c_{a1,b}$. The BOS anchor channel should be loaded with the total shear force ($V_{uay,a}$+$V_{uay,b}$) acting on both anchor channels. The height (h) used in the analysis is h as shown in Figure 9.2.14.6.

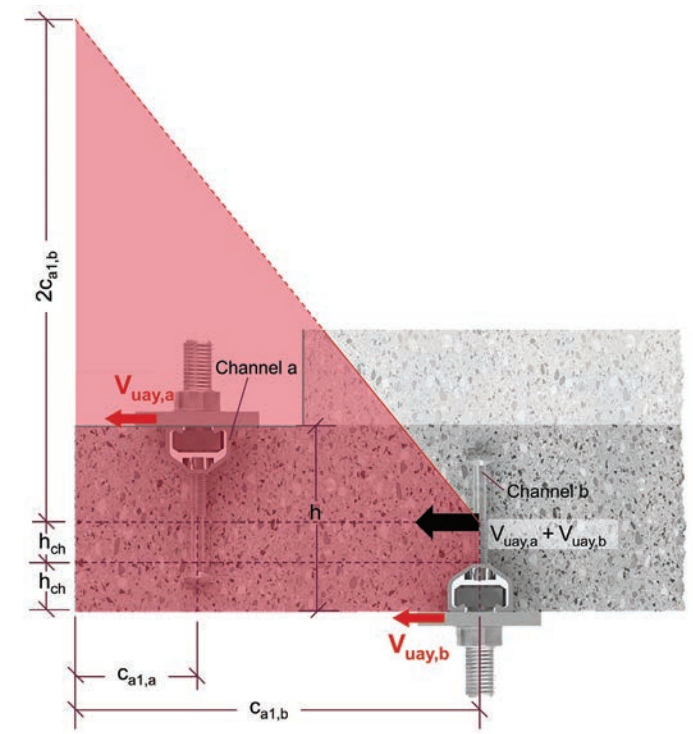



Figure 9.2.14.6 — Parallel Channels Top and Bottom: BOS away from TOS-Perpendicular Shear BOS Section View.

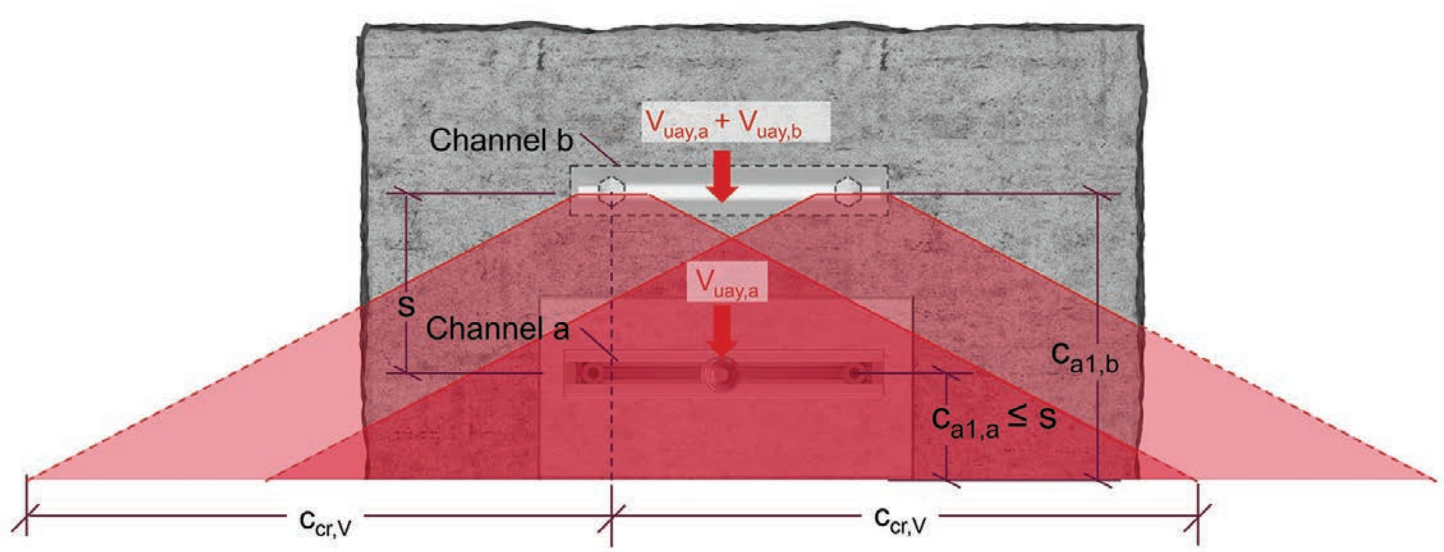



Figure 9.2.14.7 — Parallel Channels Top and Bottom: BOS away from TOS-Perpendicular Shear BOS-Plan View.

## Tension

**TOS and BOS:** In the case shown in figure 9.2.14.8 the two anchor channels are drifted apart so much so that the failure planes in tension do not intersect. The idealized failure plane is represented by brown line while the red line represents the path of least resistance. For the concrete failure modes in tension, the stresses in the concrete induced by the two anchors of the anchor channels closer to each other change the concrete behavior. The concrete crack does not follow the idealized failure plane ($C_{cr,N}$) but the path of least resistance. This concept is illustrated in Figure 9.2.14.8 and Figure 9.2.14.9.

The front edge concrete for the BOS anchor channel is as taken as 0.5x in the analysis. The ToS channel is modeled as having a back edge of 0.5x. The distance x is defined as the shortest straight line connecting one anchor stud to another as shown in the Figure 9.2.14.8 and Figure 9.2.14.9.

Please note that the location of the imaginary line in between channel a and b can be optimized in accordance to the amount of tension experienced by each channel as needed.

## Longitudinal shear

**TOS and BOS anchor channels**

The longitudinal shear force $V_{uax,a}$ and $V_{uax,b}$ is applied at the center line of the anchor channel, as shown in Figure 9.2.14.10-a and Figure 9.2.14.10-b. Having infinite sides edges on both sides will create breakout planes perpendicular to the edge as seen in the Figure 9.2.14.10-a and Figure 9.2.14.10-b. For analyzing anchor channel "a" the front edge of $c_{a1,a}$ is considered subjecting it to shear force of $V_{ua,xa}$. For analyzing anchor channel "b" the edge of $c_{a1,b}$ is used against the total shear force ($V_T = V_{uax,a} + V_{uax,b}$) following the ACI 318-14 provision as shown in Figure 9.2.14.10-b.

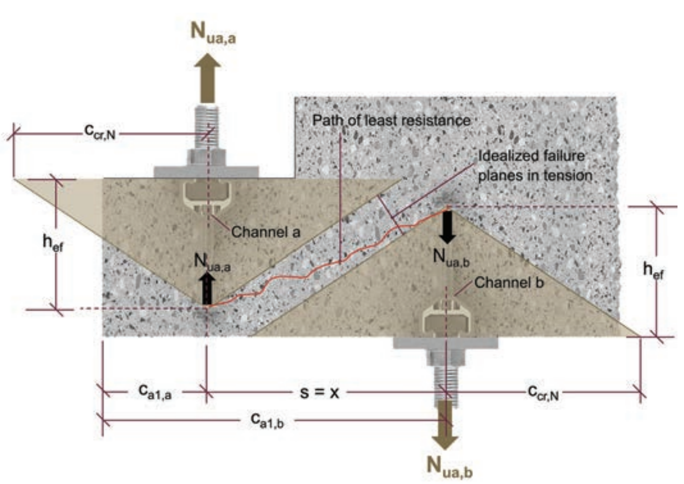



**Figure 9.2.14.8 — Parallel Channels Top and Bottom-BOS away from TOS: Tension- TOS and BOS Section View.**

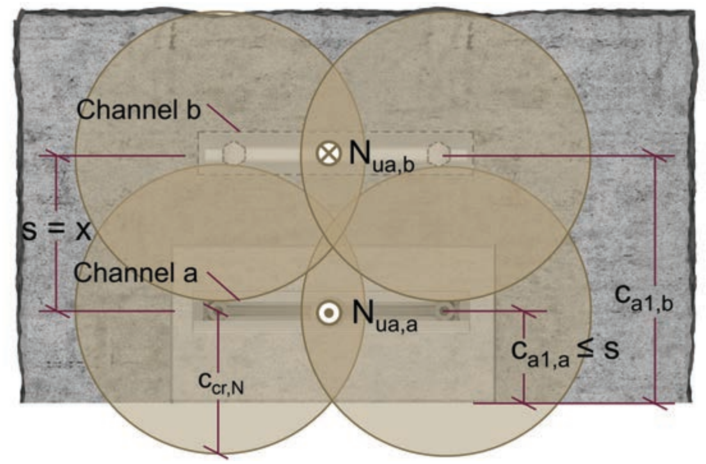



**Figure 9.2.14.9 — Parallel Channels Top and Bottom-BOS away from TOS: Tension — TOS and BOS Plan View.**

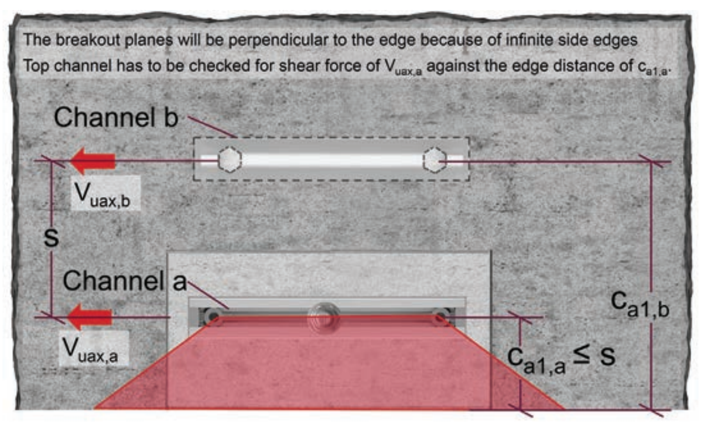



**Figure 9.2.14.10-a — Longitudinal Shear — Plan view-Top anchor channel.**

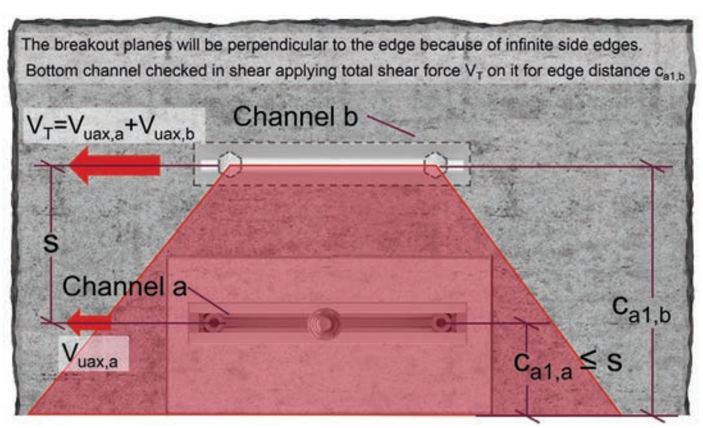



**Figure 9.2.14.10-b add the figure name.**

## BOS and TOS channels: BOS under from TOS

**TOS and BOS:** This section describes the conditions where two anchor channels are placed one on top of the other, facilitating the connection above and below the slab. For analyzing these condition it is recommended to assign half of the concrete height to the TOS channel and half to the BOS channel.

In Figure 9.2.14.11 the failure planes are drawn in tension and in Figure 9.2.14.12: failure planes are drawn for perpendicular shear. An imaginary line is drawn at the intersection of these failure planes limiting the height of the slab to h/2 for each anchor channel analysis.

The location of the imaginary line can be optimized. More concrete in height can be assigned to the channel subjected to more shear force.

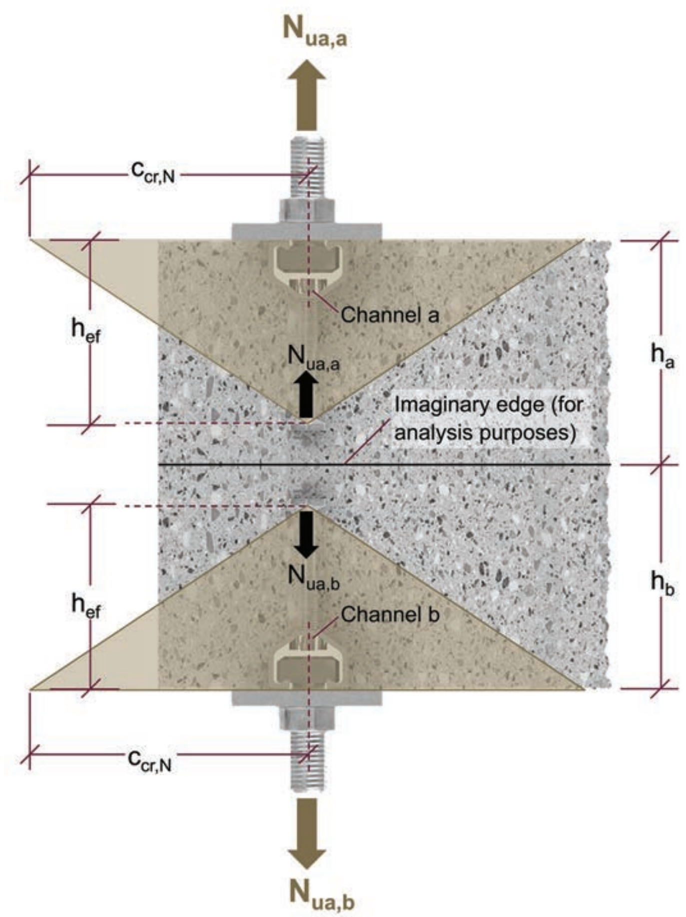



**Figure 9.2.14.11 — Top and Bottom Channel: TOS under BOS -Tension — Section View.**

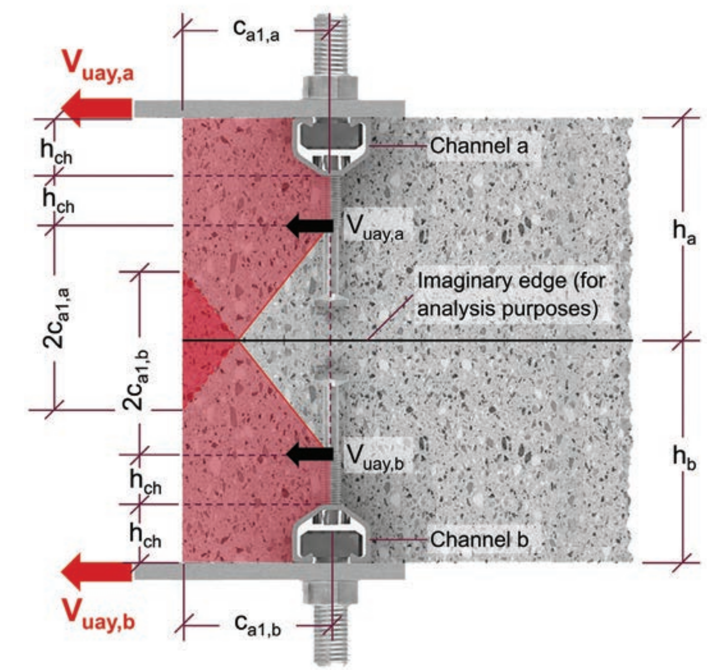



**Figure 9.2.14.12 — Top and Bottom Channel: TOS under BOS -Perpendicular Shear — Section View.**

## BOS and TOS Channel intersecting

The two channels may be installed at top and bottom of slab as seen in the Figure 9.2.14.13. The simulations were performed at the University of Rijeka with configuration as seen in Figure 9.2.14.14, Figure 9.2.14.15, and Figure 9.2.14.16. With these simulations following design procedure has been concluded.

Top channel and bottom channel should be analyzed separately considering the total height of the substrate. The interaction of the breakout planes of the two top and bottom channels are taken into account by using the interaction equation below. This interaction equation combines the concrete breakout utilizations of top and bottom channels, hence including the effect of the two overlapping concrete breakout planes into the design.

$$\beta_{N+V,c} = \left(\frac{N^a_{ua}}{\phi N_{nc}}\right)^{1.67}_{ch\ a} + \left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right)^{1.67}_{ch\ a} + \left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right)^{1.67}_{ch\ a} + \left(\frac{N^a_{ua}}{\phi N_{nc}}\right)^{1.67}_{ch\ b} + \left(\frac{V^a_{ua,y}}{\phi V_{nc,y}}\right)^{1.67}_{ch\ b} + \left(\frac{V^a_{ua,x}}{\phi V_{nc,x}}\right)^{1.67}_{ch\ b} \leq 1.0$$

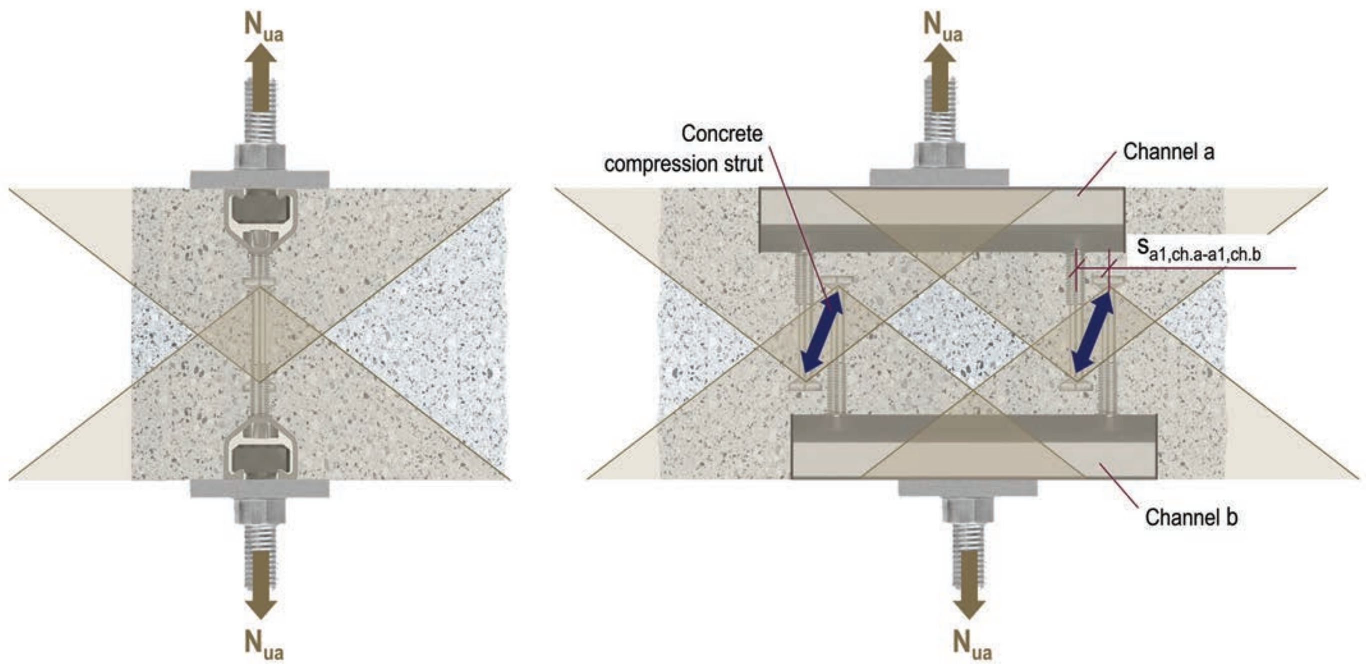



**Figure 9.2.14.13 — Intersecting Top and Bottom Channel; tension loading**

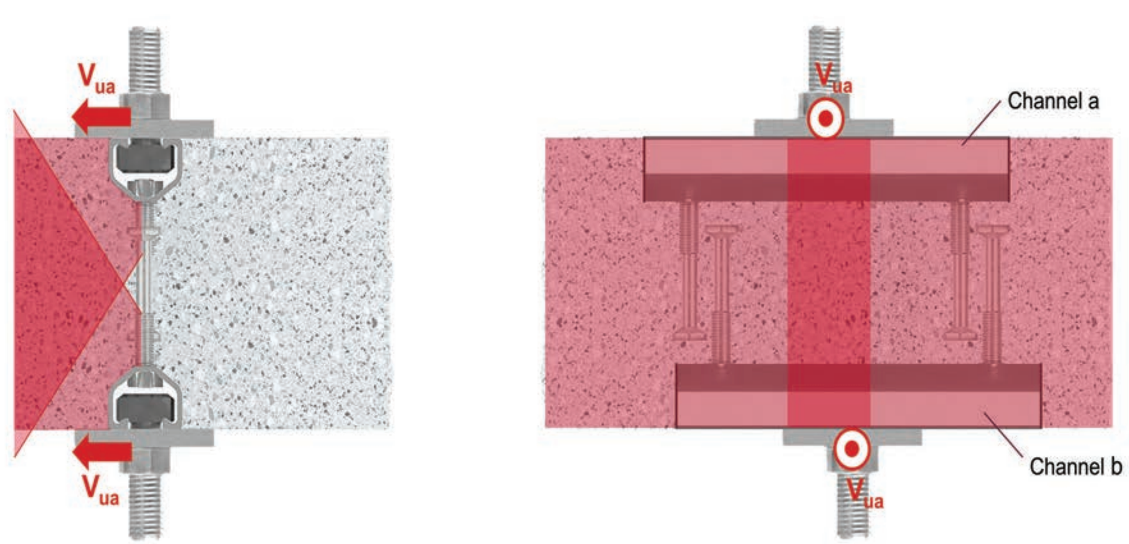



**Figure 9.2.14.14 — Intersecting Top and Bottom Channel; shear loading**

# 9.2.15 — HAC AND HAC-T DESIGN: COMPOSITE SLABS

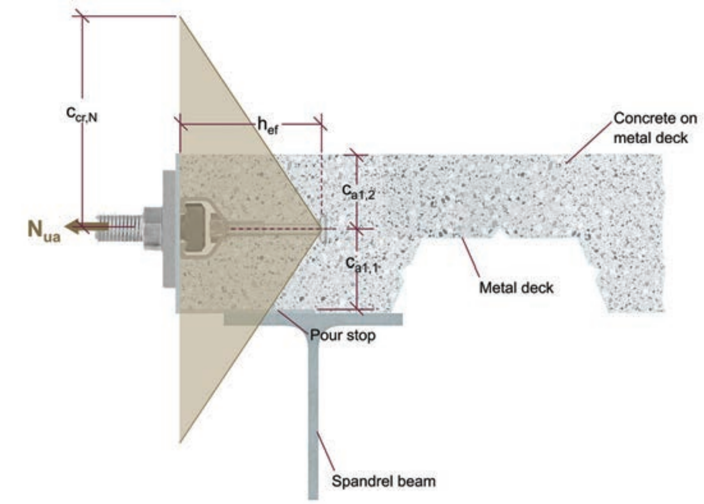



**Figure 9.2.15.1 — FOS: Composite Slab — Tension — Section View.**

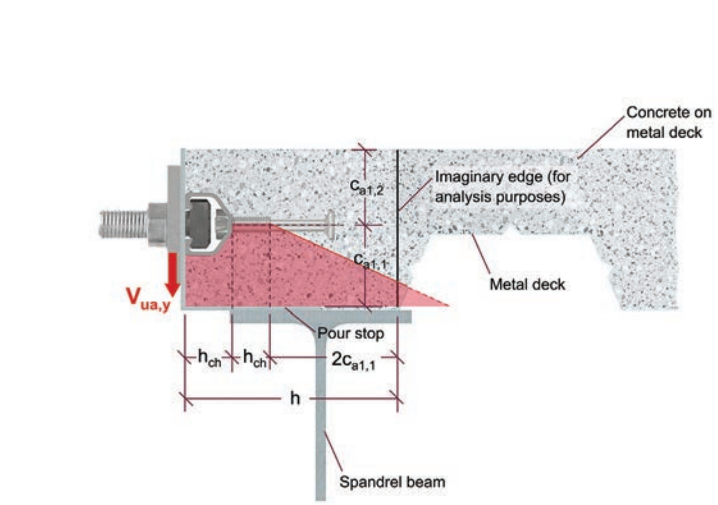



**Figure 9.2.15.1-b — FOS: Composite Slab — Perpendicular Shear — Section View.**

The concrete breakout in shear failure modes needs to be modified in order to take into account of metal deck when HAC or HAC-T anchor channels are used:

**Concrete breakout strength in shear**

This dimension h effects concrete breakout strength in perpendicular shear. This will change the factor $\Psi_{h,V}$.

The dimension h in the formula below for $\Psi_{h,V}$ factor should be taken as h as shown in Figure 9.2.15.1-b and Figure 9.2.15.2-b.

Please refer to anchor channel theory for more information on concrete breakout in shear.

$$h_{cr,V} = 2c_{a1} + 2h_{ch}$$

$$\psi_{h,V} = \left(\frac{h}{h_{cr,V}}\right)^{\beta_1} \leq 1.0$$

**Concrete Breakout in tension**

The concrete breakout capacity in tension will get reduced with having the $c_{a1,2}$ is less than $c_{a1,1}$ as seen in Figure 9.2.15.1-a Figure 9.2.15.2-a. The imaginary line is drawn to simulate the effect of metal deck It is recommended to limit the available concrete for tension to be $c_{a1,2}$. The following modification should be incorporated in the design by modelling the edge $c_{a1,2}$, or manually changing the reduction factor in report if profis does not allow modelling at edge $c_{a1,2}$ because of minimum edge requirement. Reduction factor for edge is as seen below. In this equation minimum of $c_{a1,1}$ or $c_{a1,2}$ is used.

$$C_{a1} \leq C_{Cr,N} \text{ then } \Psi_{ed,N} = \left(\frac{C_{a1}}{C_{cr,N}}\right)^{0.5}$$

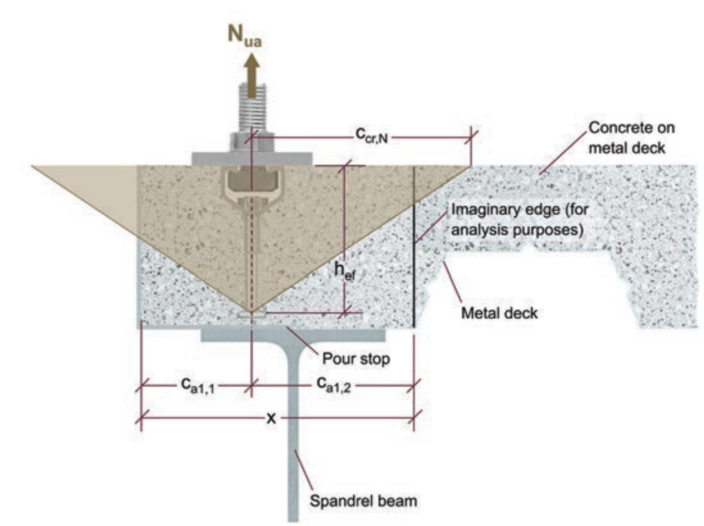



**Figure 9.2.15.2 — TOS: Composite Slab — Tension — Section View.**

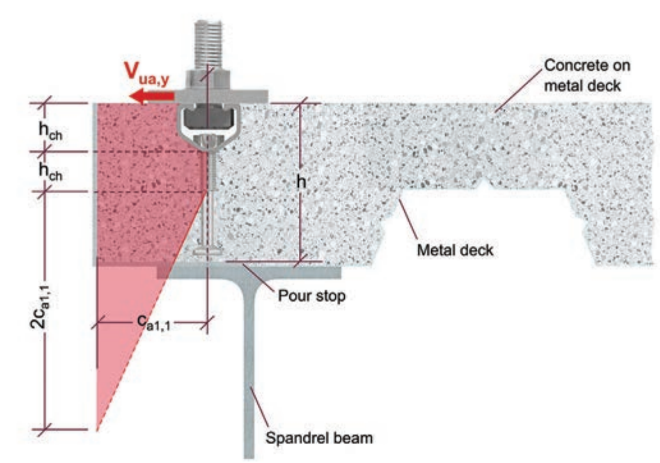



**Figure 9.2.15.2-b — TOS: Composite Slab — Perpendicular Shear — Section View.**

## 9.2.16 — HAC AND HAC-T DESIGN: INTERMEDIATE FACE OF SLAB ANCHOR CHANNEL WITH COLUMN CONFLICT

When there is a column conflict in an intermediate condition. It is recommended to have the bracket extended and determine the bolt forces. The anchor channel is analyzed using a side distance of x. This side edge is used since the concrete breakout plane gets interrupted by the presence of column.

The concrete breakout in tension, concrete breakout in shear, and concrete pryout strength are analyzed using the side edge distance of x. Please refer Figure 9.2.16.1.

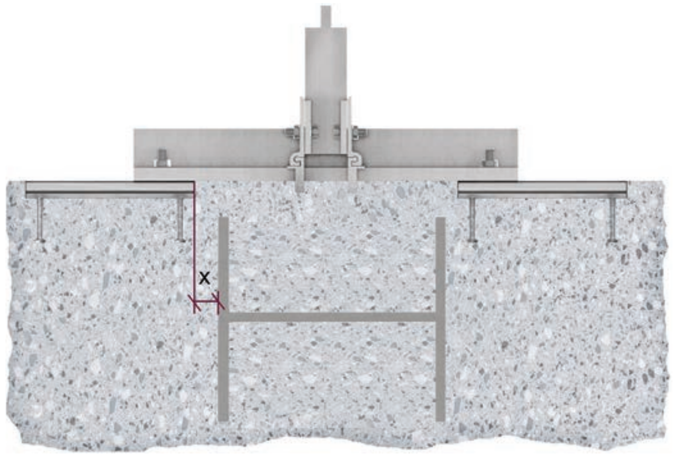



**Figure 9.2.16.1 — FOS With Column Conflict — Section View.**

## 9.2.17 — CASE II: PERPENDICULAR SHEAR

The method described in sections 9.2.2 to 9.2.16 for shear force perpendicular is the case I of the perpendicular shear. The case II of the perpendicular shear should also be checked, where the concrete breakout planes are in longitudinal direction due to perpendicular shear. The worst results of the two cases should be taken into consideration. This will be the controlling load case, where the side edge distance is small and perpendicular shear capacity is more than longitudinal capacity due perpendicular shear. We will see this case to be the controlling one, when HAC Edge anchor channel is used at a small side edge. Refer section 9.6 for more information on HAC Edge.

For a shear force parallel to an edge, $V_{cb,y}$ shall be permitted to be 2.5 times the value of the shear capacity determined from ESR-3520 equation 30 with the shear force assumed to act perpendicular to the edge.

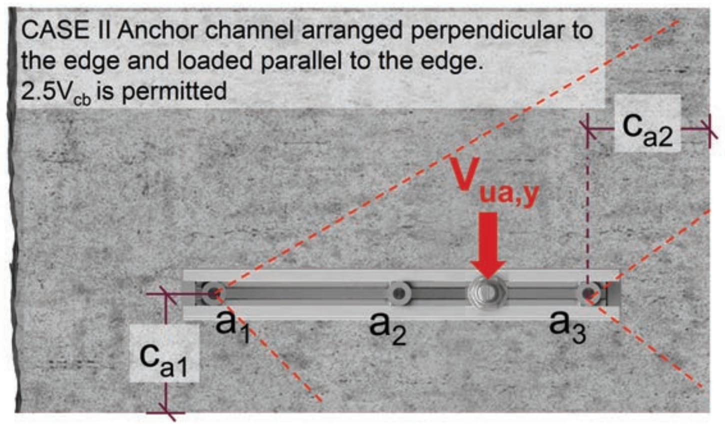



**Figure 9.2.17— Anchor channel arranged perpendicular to the edge and loaded parallel to the edge.**



# 9.3 — HAC CRFOS U DESIGN

International Council Code Acceptance Criteria 232 (AC232) only covers anchor channel with rounded headed anchors, I-anchors and straight deformed reinforcing bars. Historically, the verification of the pull-out strength of the reinforcing bar has been based on the development length. Therefore, the pullout strength is calculated in accordance with ACI 318. ACI 318 requires a minimum reinforcing bar length of 12 in. AC232 requires anchor channels with reinforcing bars that meet splice length requirements.

HAC CRFoS U come with predetermined reinforcing bar lengths that comply with the development length requirements of ACI 318. Moreover, its design model ensures that the pullout strength of the reinforcing bar is not exceeded and the combined shear and tension concrete utilization meets the required concrete interaction equation. However, there may be applications such as lightweight concrete where the splice lengths may not be met.

Additional testing conducted by Hilti validates the similarities in the behavior of an anchor channel with rounded headed anchors and reinforcing bar anchors. Naturally, there are differences in some specific failure modes. Hence, the design of HAC CRFoS U follows the principles of AC232 and ACI 318. For further code compliance, the steel strengths of HAC CRFoS U are based on testing protocols of AC232.

The published steel strength of HAC CRFoS U were derived based on testing protocols of AC232. The overall anchor channel design (i.e. failure modes, load distribution, and concrete and steel assessment) is in accordance with AC232. The main differences between HAC and HAC CRFoS U design models are in the concrete breakout in tension, pull-out, and pry-out.

As is the case with HAC, the design of corners with a pair of channels loaded simultaneously is excluded from AC232. This section provides information about the overall HAC CRFoS U design. Moreover, design guidelines for failure modes not covered by AC232 but applicable to HAC CRFoS U and design guidelines for corners with a pair of channels loaded simultaneously are given in this chapter.

In contrast to anchor channels with rounded head anchors, anchor channels with reinforcing bars with configurations such as HAC CRFoS U do not require the verification of the concrete breakout strength in tension.

### Typical concrete tensile failure mode of HAC

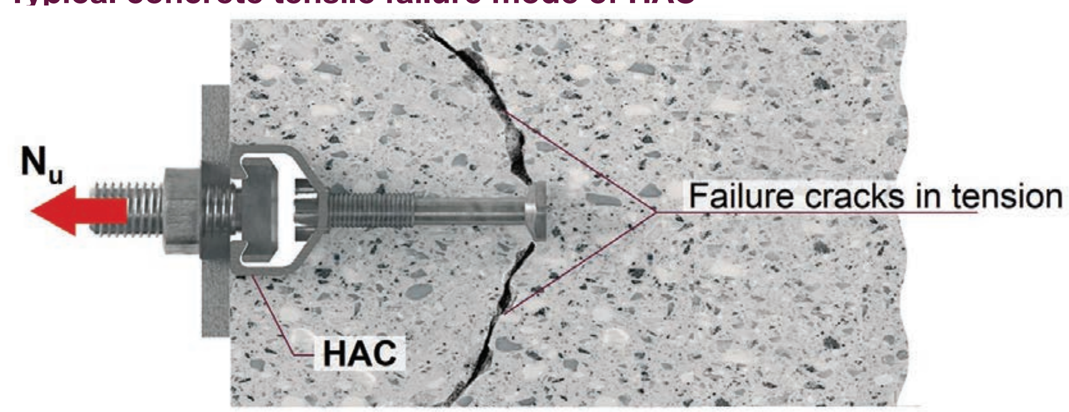



**Figure 9.3.1 — Concrete breakout in tension of a cast-in anchor channel with rounded stud head anchors (HAC) — Section View.**

### HAC CRFoS U loaded in tension

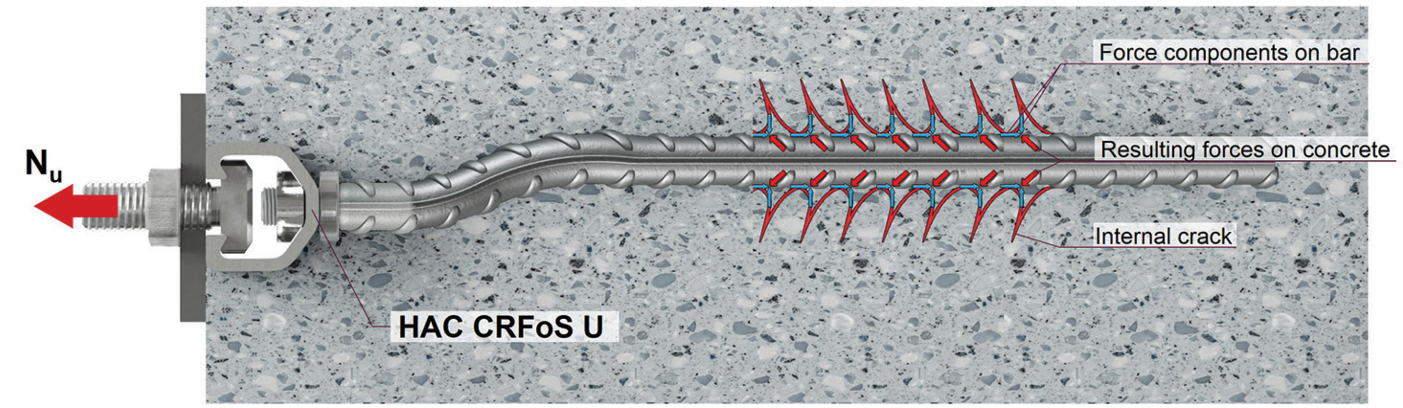
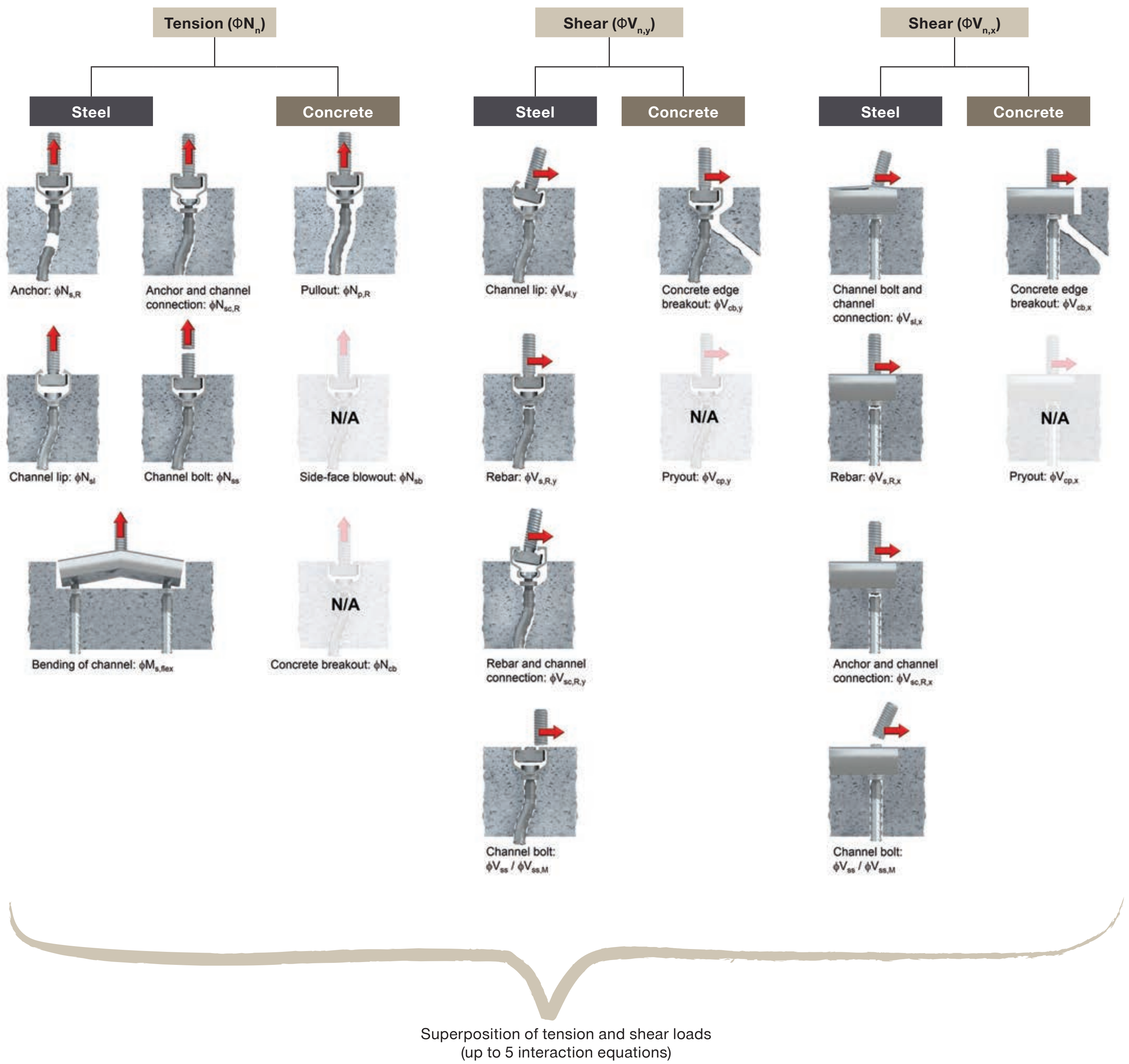


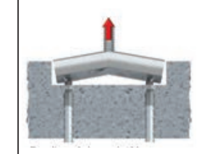
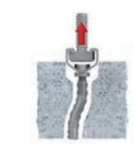

**Figure 9.3.2 — Concrete failure mode of Cast-in anchor channel with rebar anchors (HAC CRFoS U) — Section View.**




**IMPORTANT! Failure analysis modes evaluated follow ACI 318-14, chapter 17. This DOES NOT include evaluating the base material (e.g. edge-of-slab) capacity to resist compressive forces generated by the fixture. The engineer must ALWAYS verify the base material (e.g. edge-of-slab) design is capable of resisting the applied loading.**

For additional information, please contact Hilti at US+CA.HAC@Hilti.com

**Figure 9.3.3 — Failure modes for HAC CRFOS U.**

| Tension | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Steel Failure Modes** | | | | | **Concrete Failure Modes** | | |
| Channel bolt: $\Phi N_{ss}$ | Channel lip: $\Phi N_{sl}$ | Bending of channel: $\Phi M_{s,flex}$ | Connection: $\Phi N_{sc}$ | Anchor: $\Phi N_{sa}$ | Concrete breakout: $\Phi N_{cb}$ | Pullout: $\Phi N_{pn}$ | Side-face Blow-out: $\Phi N_{sb}$ |
|  |  |  |  |  |  N/A |  |  N/A |
| ESR-3520 Sec. 4.1.3.2.2 Refer anchor channel theory | Hilti Method based on AC232 testing guidelines | ESR-3520 Sec. 4.1.3.2.2 Refer anchor channel theory | Hilti Method based on AC232 testing guidelines | Hilti Method based on AC232 testing guidelines | N/A | ACI 318-11 Ch. 12.2 | N/A |

## Channel lip: $\Phi N_{sl}$

$\Phi N_{sl} > N_{bua}$

The tests follow AC232 testing guidelines. Refer to anchor channel theory for further clarification. Please refer table 2.3.3.1 for strength values.

**Channel lip: $\Phi N_{sl}$**

## Connection Anchor and Channel: $\Phi N_{sc}$

$\Phi N_{sc} > N_{aua}$

The tests follow AC232 testing guidelines. Refer to anchor channel theory for further clarification. Please refer table 2.3.3.1 for strength values.

**Anchor and channel connection: $\Phi N_{sc}$**

## Anchor: $\Phi N_{sa}$

$\Phi N_{sa} > N_{aua}$

The tests follow AC232 testing guidelines. Refer to anchor channel theory for further clarification. Please refer table 2.3.3.1 for strength values.

**Anchor: $\Phi N_{sa}$**

## Pullout: $\Phi N_{pn}$

$\Phi N_{pn} > N_{aua}$

$l_d$ is in accordance ACI318-11; chapter 12.2 is used. The stress in rebar is found by isolating ($f_y$ =) $\sigma_d$ in the equation as shown below.

**Pullout: $\Phi N_{pn}$**

The ACI concept of development length is based on the attainable average bond stress over the length of embedment of the reinforcement.

If a rebar provides the required development length, the rebar will yield before it is pulled-out of the concrete. In situations where the force at the rebar is less than its yield strength, ACI 318 allows reduction the excess reinforcement.

In cases where $\ell_d$ is provided ($\ell_{d,prov}$), the nominal pull-out strength of the rebar ($N_{p,R}$) is as follows:

$$l_{d,prov} \geq l_d = \left( \frac{3}{40} \cdot \frac{f_y}{\lambda \cdot \sqrt{f'_c}} \cdot \frac{\psi_t \psi_e \psi_s}{\frac{c_d + K_{tr}}{d_b}} \right) . d_b \geq 12in$$

$$Ktr = 0$$

$$\frac{cd}{db} \leq 2.5$$

$$(f_y =)\sigma_d = l_{d,prov} . \pi . d_b . \frac{10}{3} . \lambda . \sqrt{f'_c} . \min\left(\frac{c_d}{d_b}, 2.5\right) . \frac{1}{\psi_t \psi_e \psi_s}$$

$$N_{P,R} = \frac{\pi . d^2_{s,R}}{4} . \sigma_d = l_{d,prov} . \pi . d_b . \frac{10}{3} . \lambda . \sqrt{f'_c} . \min\left(\frac{c_d}{d_b}, 2.5\right) . \frac{1}{\psi_t \psi_e \psi_s}$$

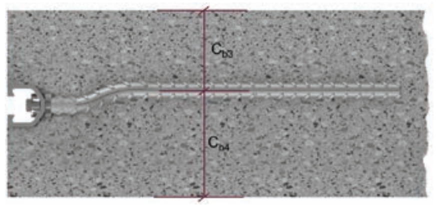
$\ell_d$ = development length, in.

$\ell_d \geq 12$ in.

$f_y$ = yield strength of bar

Rebar cover factor is:
a) the least of the side cover
b) the concrete cover to the bar or wire
c) One-half the center-to-center spacing of the bars.

In all cases, $c_b$ is measured from the center of the bar.




$c_b$ minimum of:
a) $c_{b1}$
b) $c_{b2/2}$
c) $c_{b3}$
d) $c_{b4}$

**Figure 9.3.4 — Rebar Cover — HAC CRFOS U — Section View**

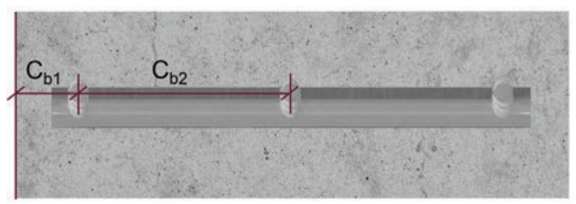



**Figure 9.3.5 — Rebar Cover — HAC CRFOS U — Plan View**

Hilti offers a special anchor channel with rebars for front of slab applications. The rebar which is connected to the channel profile is kinked in order to also allow the installation of two anchor channels in a corner (see Figure 9.3.5). This product is called CRFoS U (U = universal installation close to an edge or in a corner).

**Figure 9.3.5 — HAC CRFOS U.**

**Figure 9.3.6-b — Tension test setup universal testing machine.**

Tests have been performed on CRFoS (U) to demonstrate that, in front of slab applications no hairline cracks or spalling in the most critical condition ( corner condition and minimum slab thickness) are observed due to the kinked rebar before steel failure of the anchor channel occurs.

The steel strength of the channel lips ($N_{sl}$), connection between anchor/rebar and channel profile ($N_{sc}$) and anchor ($N_{sa}$) is derived from a tension test in a universal testing machine without being cast into concrete (test series 1 in AC232). In this test series one anchor is fixed to the testing frame (see Figure 9.3.6-b).

A channel bolt is inserted directly over the anchor and loaded without a fixture.

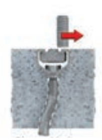
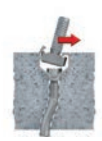
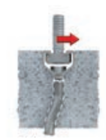
The test setup is shown in Figure 9.3.7.

**Figure 9.3.7 — Tension test setup for testing anchor channels under static and simulated seismic conditions.**

**Evaluation of test results:**

The test results shows that no hairline cracks were observed under static and simulated seismic conditions prior to failing the connection between rebar and channel profile.

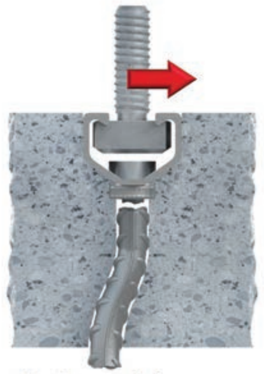
The one diameter kink is provided in CRFoS U anchor channel. Hence in the PROFIS report there will be a k value of a diameter representing the kink in the rebar.

| Perpendicular Shear | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | | Concrete Failure Modes | |
| Channel bolt: $\Phi V_{ss}$ | Channel Lip $\Phi V_{sl,y}$ | connection : $\Phi V_{sc,R,y}$ | Rebar $\Phi V_{s,R,y}$ | Concrete Breakout $\Phi_{Vcb,y}$ | Concrete Pryout |
|  |  |  |  |  |  N/A |
| ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 Refer to anchor channel theory | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 Refer to anchor channel theory | Hilti Method based on AC232 testing protocols | Hilti Method based on AC232 testing guidelines | ESR-3520 Sec. 4.1.3.3.3 Refer anchor channel theory | N/A |

## Rebar strength: $\Phi V_{s,R,y}$

$\Phi V_{s,R,y} > V^a_{ua}$

The tests follow AC232 testing guidelines. Refer to anchor channel theory for further clarification. Please refer to table 2.3.4.1 for strength values.

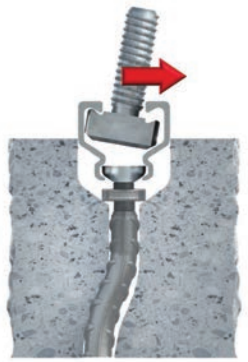


**Rebar: $\Phi V_{s,R,y}$**

## Connection Anchor and Channel : $\Phi V_{s,R,y}$

$\Phi V_{s,R,y} > V^a_{ua}$

The tests follow AC232 testing guidelines. Refer to anchor channel theory for further clarification. Please refer to table 2.3.4.1 for strength values.

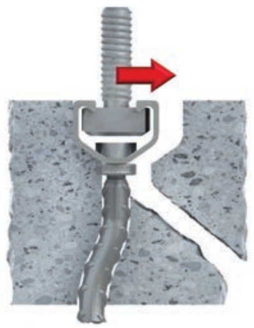


**Rebar and channel connection: $\Phi V_{s,R,y}$**

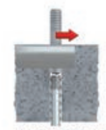
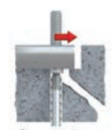
## Concrete breakout in perpendicular shear: $\Phi V_{cb,y}$

$\Phi V_{cb,y} > V^a_{ua}$

Please refer to anchor channel theory for more information on this failure mode. The design methodology is the same as that of headed stud anchor channel. This check is compliant with ESR 3520.



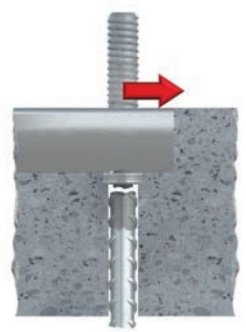
**Concrete edge breakout: $\Phi V_{cb,y}$**

| Longitudinal Shear | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | | Concrete Failure Modes | |
| Channel bolt: $\Phi V_{ss}$ | Channel Lip $\Phi V_{sl,y}$ | connection : $\Phi V_{sc,R,y}$ | Rebar $\Phi V_{s,R,y}$ | Concrete Breakout $\Phi_{Vcb,y}$ | Concrete Pryout |
|  |  |  |  |  |  N/A |
| ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | Hilti Method based on AC232 testing guidelines | Hilti Method based on AC232 testing guidelines | ESR-3520 Sec. 4.1.3.4.3 | N/A |

### Rebar strength: $\Phi V_{s,R,x}$

$\Phi V_{s,R,x} > V^{a}_{ua}$

The tests follow AC232 testing guidelines. Refer to anchor channel theory for further clarification. Please refer table 2.3.4.3 for strength values.

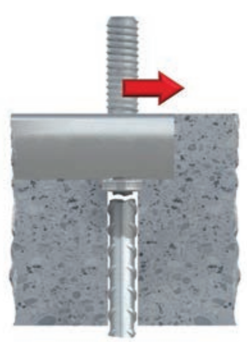


Rebar: $\Phi V_{s,R,x}$

### Connection Anchor and Channel : $\Phi V_{sc,R,x}$

$\Phi V_{sc,R,x} > V^{a}_{ua}$

The tests follow AC232 testing guidelines. Refer to anchor channel theory for further clarification. Please refer to table 2.3.4.3 for strength values.

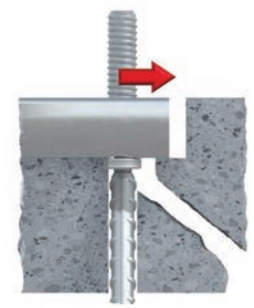


Anchor and Channel Connection: $\Phi V_{sc,R,x}$

### Concrete breakout in perpendicular shear: $\Phi V_{cb,x}$

$\Phi V_{cb,x} > V^{a}_{ua}$

Please refer to anchor channel theory for more information on this failure mode. The design methodology is the same as that of headed stud anchor channel. This check is compliant with ESR 3520.



Concrete edge breakout: ΦVcb,x



## 9.3.1 — HAC CRFOS U DESIGN: INTERMEDIATE FACE OF SLAB ANCHOR CHANNEL

**Cast-in anchor channels with rebar anchors for face of slab applications**

The overall design of HAC CRFoS U follows the principles described in chapter 7 with some modifications to the verification of some failure modes. Table 9.3.1.1, 9.3.1.2, 9.3.1.3, Figures 9.3.1.1 and 9.3.1.2 illustrate the main differences in the possible failures modes of HAC and HAC CRFoS U.

Concrete breakout in tension and pry-out failure modes were not observed in testing, and therefore, they are excluded from the possible failure modes of HAC CRFoS U. The verification of the adequacy of the pull-out strength of the rebar anchors is based on ACI 318. The design ensures the applied rebar forces do not exceed the bond stresses between the rebar and the concrete.

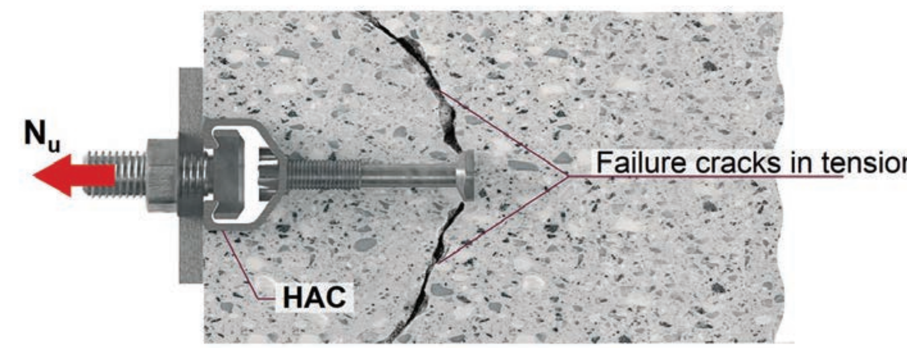



**Figure 9.3.1.1 — Cast-in anchor channel with rounded stud anchors (HAC) loaded in tension.**

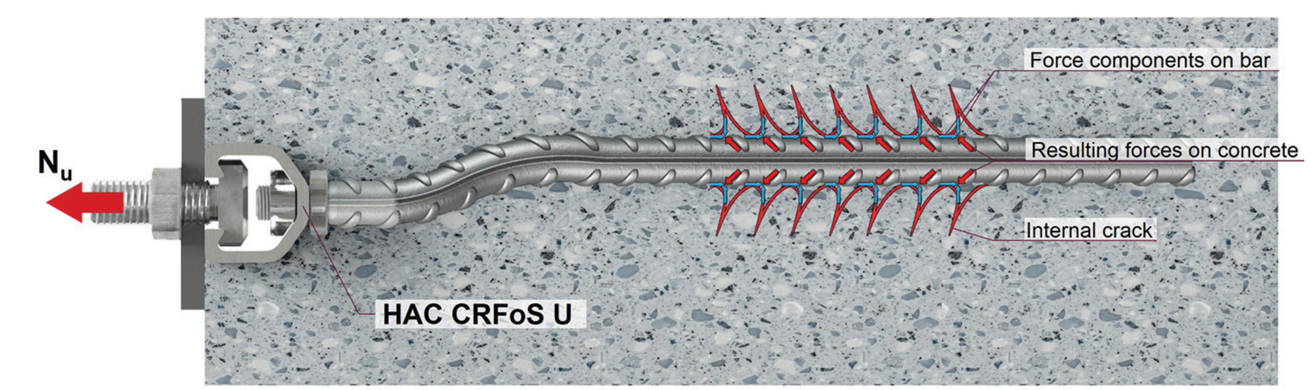



**Figure 9.3.1.2 — Cast-in anchor channel with reinforcing bar anchors (HAC CRFoS U) loaded in tension.**

**Table 9.3.1.1 — Comparison of Tension Failure modes of HAC and HAC CRFOSU**

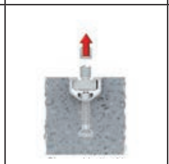
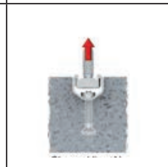
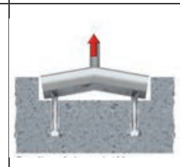
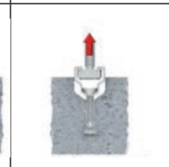
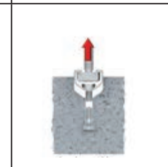
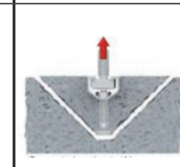
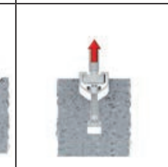
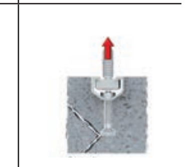
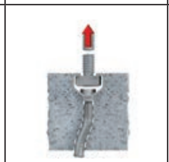
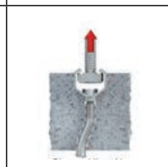
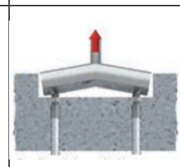
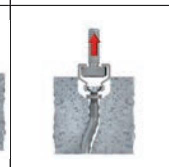
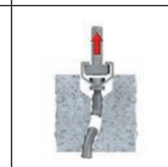
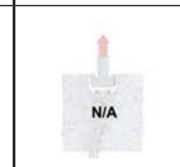
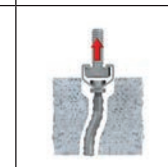
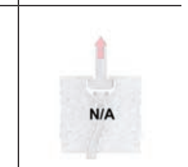
| | Tension | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Steel Failure Modes | | | | | Concrete Failure Modes | | |
| | Channel Bolt | Channel Lip | Bending of channel | Connection | Anchor | Concrete Breakout | Concrete Pullout | Concrete Blowout |
| HAC |  |  |  |  |  |  |  |  |
| | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.3 | ESR-3520 Sec. 4.1.3.2.4 | ESR-3520 Sec. 4.1.3.2.5 |
| HAC CRFoS U |  |  |  |  |  |   |  |   |
| | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | Hilti Method based on AC232 testing guidelines | Hilti Method based on AC232 testing guidelines | N/A | ACI 318-11 Ch. 12.2 | N/A |

**Table 9.3.1.2 — Comparison of Perpendicular shear Failure modes of HAC and HAC CRFOSU**

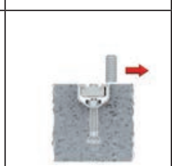
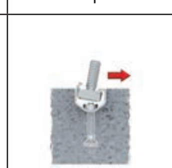
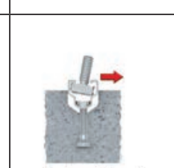
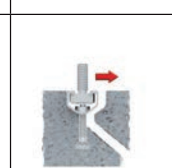
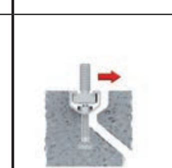
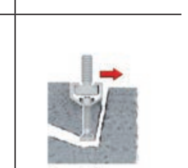
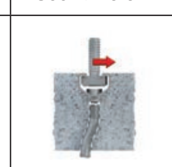
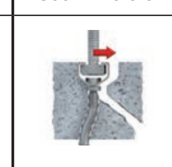
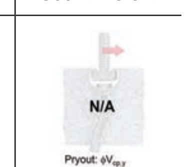
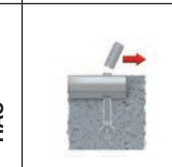
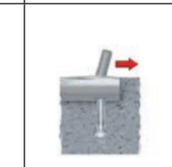
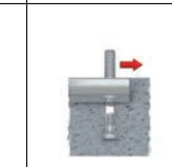
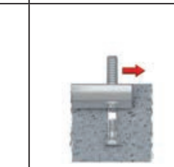
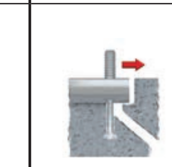
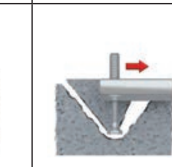
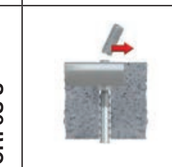
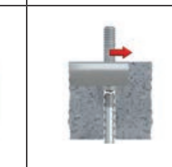
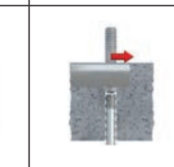
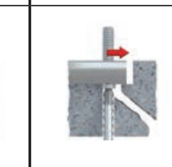
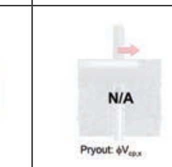
| | Perpendicular Shear | | | | | |
|---|---|---|---|---|---|---|
| | Steel Failure Modes | | | Concrete Failure Modes | | |
| | Channel Bolt | Channel Lip | Connection | Anchor | Concrete Breakout | Concrete Pryout |
| HAC |  |  |  |  |  |  |
| | ESR-3520 Sec. 4.1.3.3.2 | ESR-3520 Sec. 4.1.3.3.2 | ESR-3520 Sec. 4.1.3.3.2 | ESR-3520 Sec. 4.1.3.3.2 | ESR-3520 Sec. 4.1.3.3.3 | ESR-3520 Sec. 4.1.3.3.4 |
| HAC CRFoS U |  |  |  |  |  |   |
| | ESR-3520 Sec. 4.1.3.3.2 | ESR-3520 Sec. 4.1.3.3.2 | Hilti Method based on AC232 testing guidelines | Hilti Method based on AC232 testing guidelines | ESR-3520 Sec. 4.1.3.4.3 | N/A |



**Table 9.3.1.3 — Comparison of Longitudinal shear Failure modes of HAC & HAC CRFOSU**

| | Longitudinal Shear | | | | | |
|---|---|---|---|---|---|---|
| | Steel Failure Modes | | | | Concrete Failure Modes | |
| | Channel Bolt | Channel Lip | Connection | Anchor | Concrete Breakout | Concrete Pryout |
| HAC |  |  |  |  |  |  |
| | ESR-3520 Sec. 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2 | ESR-3520 Sec. 4.1.3.4.3 | ESR-3520 Sec. 4.1.3.4.4 |
| HAC CRFoS U |  |  |  |  |  |   |
| | ESR-3520 Sec. 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.4.2 | Hilti Method based on AC232 testing guidelines | Hilti Method based on AC232 testing guidelines | ESR-3520 Sec. 4.1.3.4.3 | N/A |

# 9.3.2 — HAC CRFOS U DESIGN: FACE OF SLAB OUTSIDE CORNER WITH A SINGLE ANCHOR CHANNEL

## 90 Degree Corner

Tension breakout cone formation is precluded because of having rebars instead of headed studs. Therefore to determine the available concrete for the analysis depends on formation of projected areas due to the concrete breakout cone in shear.

The effect of the reduced side edge distance can also effect the pullout strength of rebar if the cover is so small that it yields the $c_b/d_b$ value less than 2.5. The value of $c_b$ is equal to $c_{a2}$.

Please refer to the Figure 9.3.2.1.

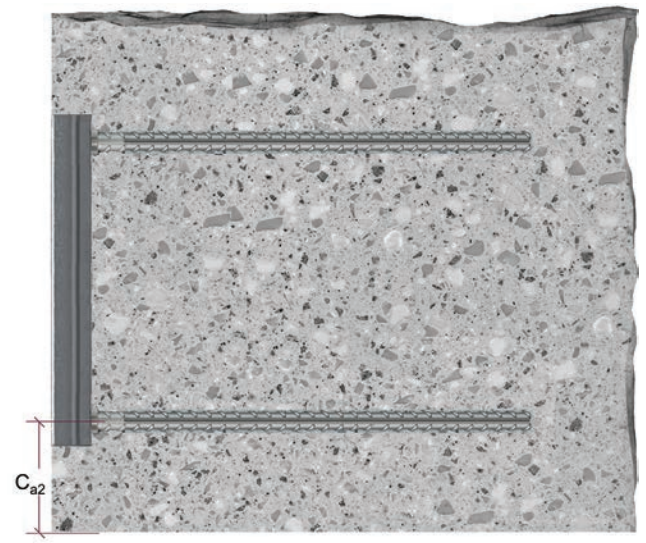



Figure 9.3.2.1 — HAC CRFOS U — Single anchor channel — 90 degree Corner.

## Acute Angle Corner

**Tension:** Acute angle corners do not have the same amount of concrete throughout as 90 degree corners. The rebar can be bend having at least 12" in accordance to ACI-318 as shown in Figure 9.3.2.2. The pullout strength should be calculated by hand using 12" development length. The $c_b$ concrete cover is taken as minimum of the four s/2, $c_{b1}$, $c_{b2}$ and $c_{b3}$ dimensions. (s=spacing between rebars). Refer Figure 9.3.2.2 and Figure 9.3.2.3.

**Shear:** To determine the $c_{a2}$ dimension while analyzing a acute corner, it is recommended to draw the projected area in perpendicular shear as shown in Figure 9.3.2.2. The darkened portion of the concrete is not utilized in the analysis, hence limiting to a shorter $c_{a2}$ dimension. This is achieved by projecting the intersection of the concrete plane back to other side of the corner. Please refer to Figure 9.3.2.2 and Figure 9.3.2.3 covering the perpendicular shear analysis at acute degree corner. Please refer section 9.2.2 for Longitudinal shear method of analysis for acute angle corner for detail analysis of face of slab.

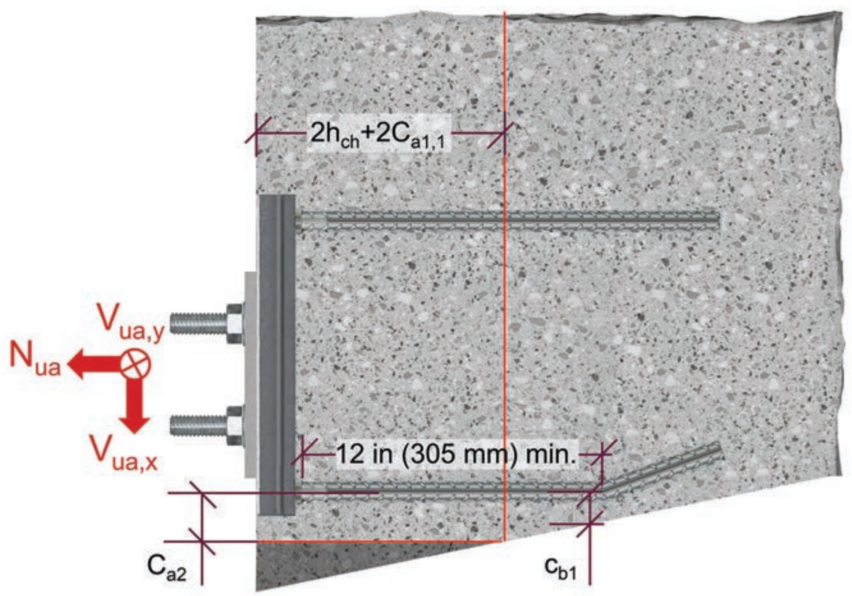



Figure 9.3.2.2 — HAC CRFOS U — Single anchor channel — Acute angle Corner — Plan View.

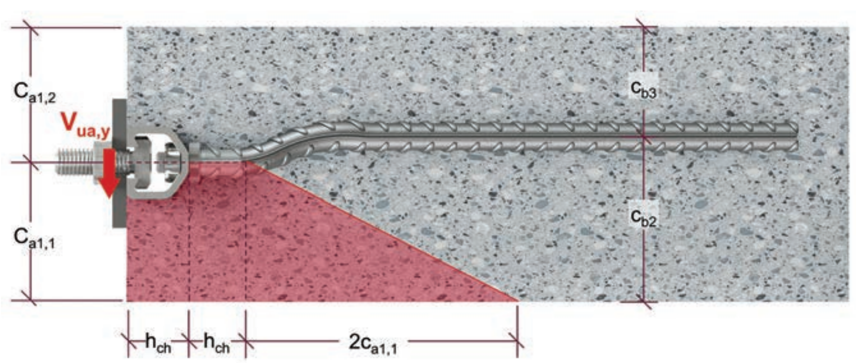



Figure 9.3.2.3 — HAC CRFOS U — Single anchor channel — Acute angle Corner — Section View.

## Obtuse Angle Corner

**Shear:** Obtuse angle corners have a greater amount of concrete than in 90 degree corners. The determination of $c_{a2}$ dimension for perpendicular shear analysis is conservatively assumed as shown in Figure 9.3.2.4. Please refer to Figure 9.3.2.4 covering the perpendicular shear analysis at obtuse degree corner. Please refer section 9.2.2 for analysis of anchor channel subjected to longitudinal shear for obtuse angle corner with single anchor channel on face of slab.

**Tension:** For Tension analysis refer section 9.3.1 pull out in tension. There will not be the concrete breakout cone development in tension. The cb concrete cover is taken as minimum of the four s/2, $c_{b1}$, $c_{b2}$ and $c_{b3}$ dimensions.(s=spacing between rebars). Refer Figure 9.3.2.4 and Figure 9.3.2.5.

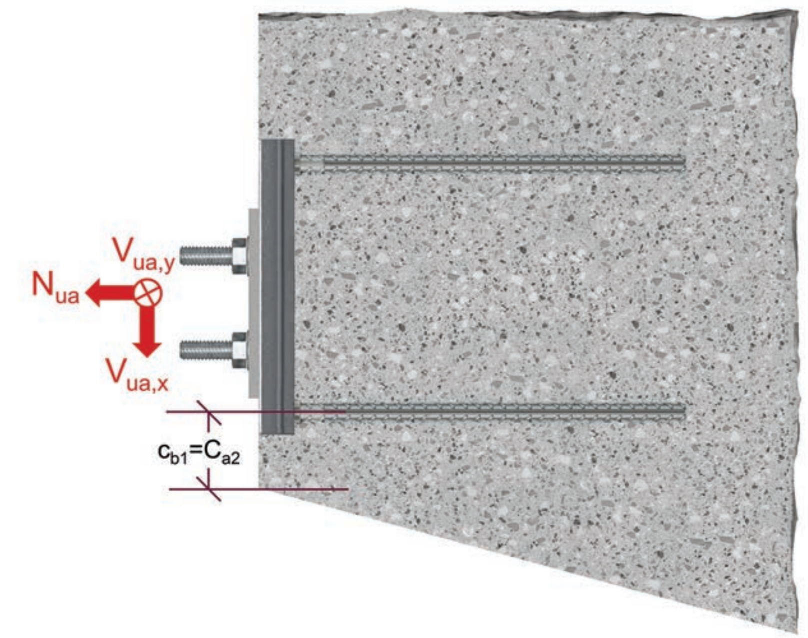



Figure 9.3.2.4 — HAC CRFOS U — Single anchor channel — Obtuse angle Corner — Plan View.

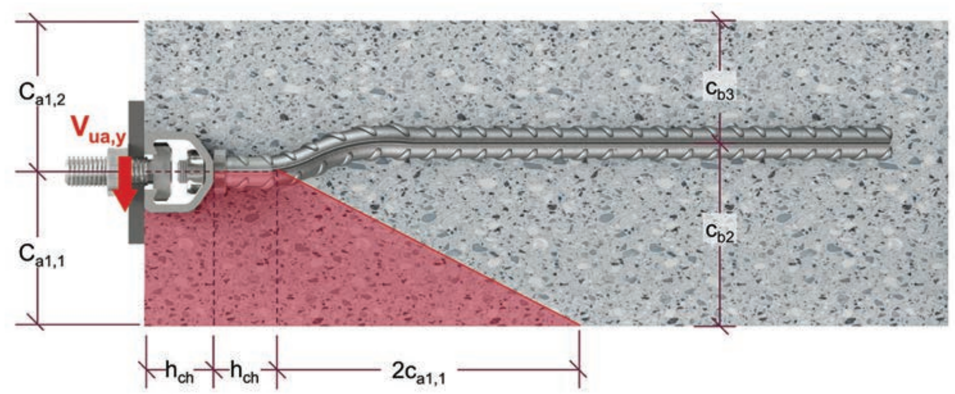



Figure 9.3.2.5 — HAC CRFOS U — Single anchor channel — Obtuse angle Corner — Section View.

# 9.3.3 — HAC CRFOS U DESIGN: FACE OF SLAB OUTSIDE CORNER WITH PAIR OF ANCHOR CHANNEL


Figure 9.3.3.1 — HAC CRFOS U — Anchor channels on both sides — 90 degree angle Corner — Plan View.

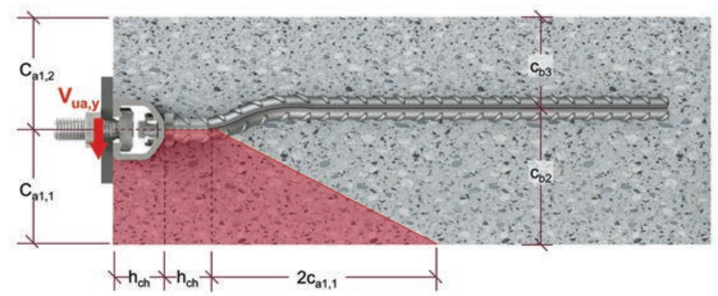



Figure 9.3.3.2 — HAC CRFOS U — Anchor channels on both sides — 90 degree angle Corner — Section View.

## 90 Degree Corner

Hilti HAC CRFoS U has a one diameter kink to help facilitate installing the anchor channels as close possible to the corner. This helps the installation of t-bolts close to the corner and hence reduces the length of the bracket used. The anchor channel is pushed away from the corner edge so that the rebars do not intersect at the corner. Please refer to chapter 2 Table 2.2.5.3 for the minimum side edge distance of various CRFoS U channels.

By replacing the headed stud anchors with rebars, the concrete breakout in tension is precluded. The rebar transfers the loads to the concrete via interlock.

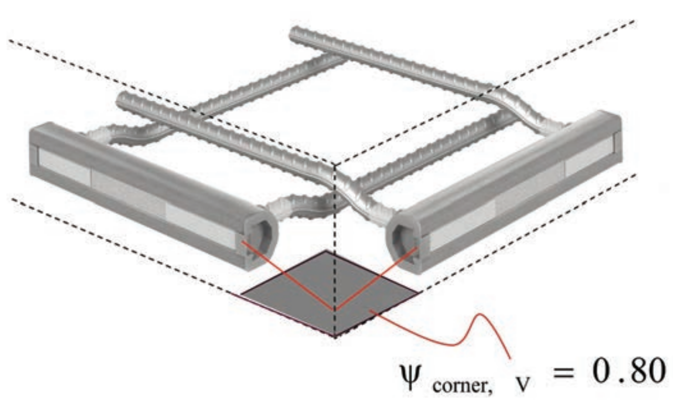



Figure 9.3.3.3 — HAC CRFOS U — Anchor channels on both sides — 90 degree angle Corner — Reduction factor.

$$V_{cb} = V_b \cdot \psi_{s,V} \cdot \psi_{co,V} \cdot \psi_{h,V} \cdot \psi_{c,V} \cdot \psi_{corner,V}$$

**Shear:** PROFIS Anchor Channel has the "activate corner" option which gives us an opportunity to design the corner. The difference between the design of anchor channels at the corner is that when it comes to the concrete breakout check in perpendicular shear, the capacity is reduced by 20% because of overlapping of the concrete breakout failure planes in perpendicular shear as shown Figure 9.3.3.3. Not multiplying by the corner factor will result in unconservative results for the breakout capacity in perpendicular shear. Please refer Anchor channel theory for more information on concrete breakout in shear.

Please refer section 9.2.3 for detail method of analyzing perpendicular and longitudinal shear for a face of slab 90 degree angle corner with anchor channels on both sides. The section 9.2.3 describes method that includes the influence of the anchor channel on the other side of the corner.

**Tension:** The tension analysis will follow the section 9.3.1 in determining pullout capacity $\Phi N_{pn}$. The $c_b$ concrete cover is taken as minimum of the four s/2, $c_{b1}$, $c_{b2}$ and $c_{b3}$ dimensions. (s=spacing between rebars) Refer Figure 9.3.3.1 and Figure 9.3.3.2.

## Acute Angle Corner

The difference between the behavior of headed stud anchor channel and anchor channel with rebar anchors is that having rebars precludes the concrete breakout cone in tension and pryout. The only determining factor of the side edge distance $C_{a2}$ is the concrete breakout in shear.

**Shear:** In order to the determine $c_{a2}$ dimension it is recommended to have a line drawn parallel to edge at a distance $h_{cr,V}$, the intersection point of this line is projected back to the edge as illustrated in Figure 9.3.3.4. The shaded concrete region of the Figure 9.3.3.4 is neglected in analysis in order to take into account the effect of the acute angle corner. Model the 90 degree corner with $c_{a2}$ as the side edge distance to the closest anchor in the PROFIS Anchor Channel software. The concrete breakout strength in shear is reduced by 20% to take into account the utilization of concrete twice in shear following the simplified method of analysis. Please refer section 9.2.3 for detail method of analyzing perpendicular and longitudinal shear for a face of slab acute degree angle corner with anchor channels on both sides. The section 9.2.3 describes method that includes the influence of the anchor channel on the other side of the corner.

**Tension:** It is made sure that the available rebar length is 12" following the ACI provisions for minimum length in order to rely on rebar theory for transfer of tensile force. The tension analysis will follow the section 9.3.1 without having any reduction in anchorage tension pullout capacity $\Phi N_{pn}$ because of the influence of the other anchor channel. The cb concrete cover is taken as minimum of the four s/2, $c_{b1}$, $c_{b2}$ and $c_{b3}$ dimensions.(s=spacing between rebars) Refer Figure 9.3.3.4 and Figure 9.3.3.5.

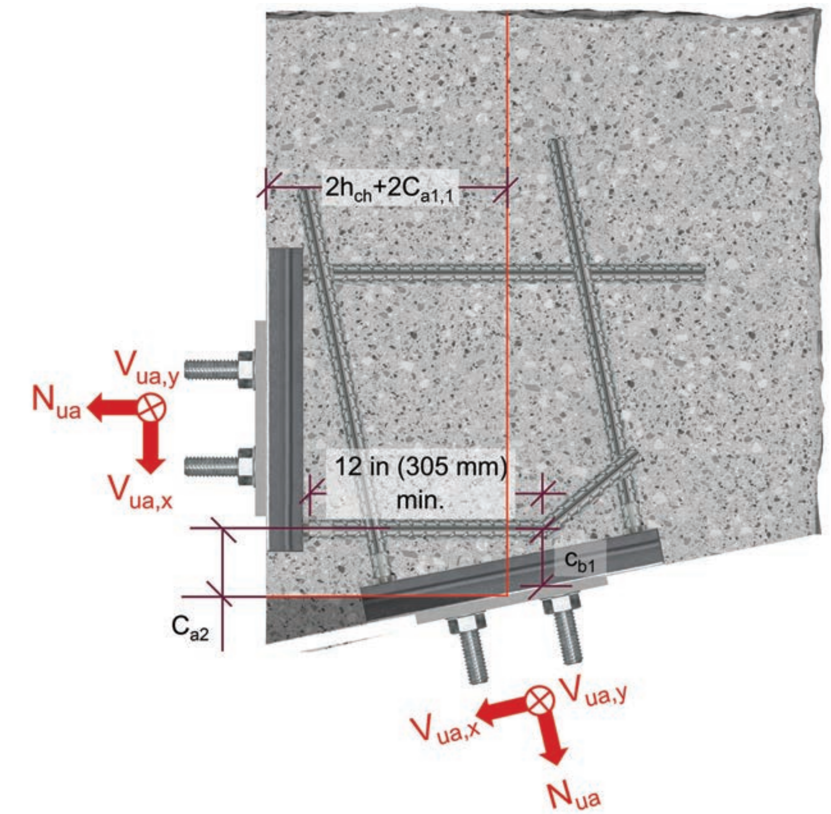



Figure 9.3.3.4 — HAC CRFOS U — Anchor channels on both sides — Acute angle Corner — Plan View.

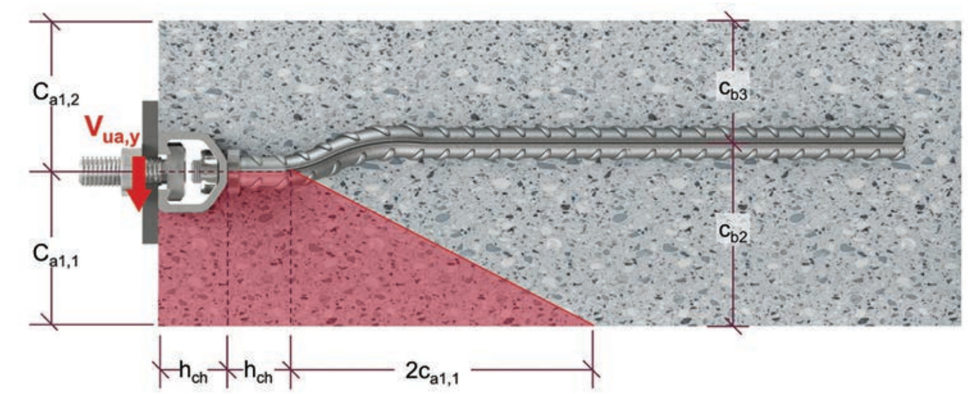



Figure 9.3.3.5 — HAC CRFOS U — Anchor channels on both sides — Acute angle Corner — Section View.

## Obtuse Angle Corner

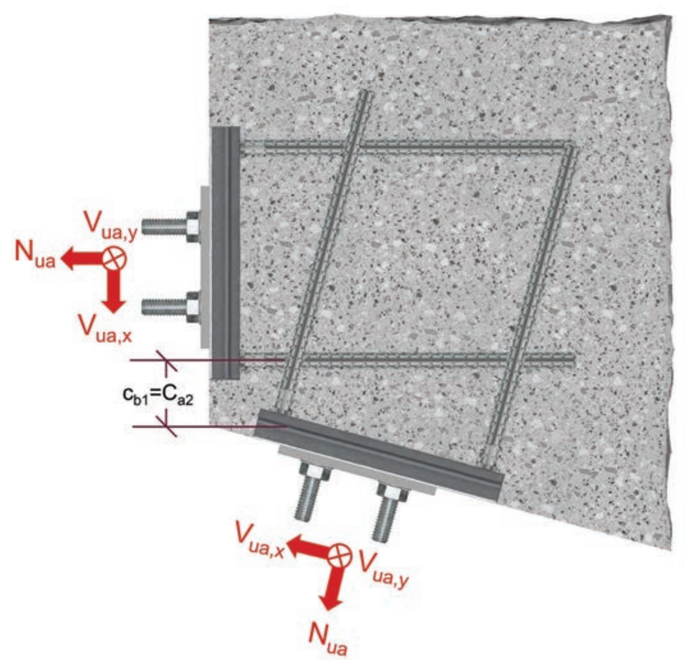



Figure 9.3.3.6 — HAC CRFOS U — Anchor channels on both sides - O btuse angle Corner — Plan View.

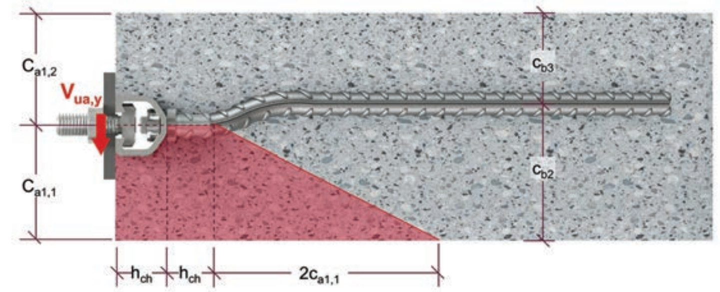



Figure 9.3.3.7 — HAC CRFOS U — Anchor channels on both sides — Obtuse angle Corner —Section View.

**Shear:** Obtuse angle corners with HAC CRFOS U channels: The side edge distance used in the analysis should be as shown in the Figure 9.3.3.6. Analysis is done using the design methodology of 90 degree corners. Conservatively, the concrete breakout strength in shear is reduced by 20% similar to 90 degree corners. Please refer the section for 90 degree corner. However, in reality corner reduction factor should be less 20% because of the availability of more concrete compared to 90 degree corners.

If the obtuse angle corner does not work by modeling it as a 90 degree corner, contact Hilti for further assistance in optimizing the solution.

Please refer section 9.2.3 for detail method of analyzing perpendicular and longitudinal shear for a face of slab obtuse degree angle corner with anchor channels on both sides. The section 9.2.3 describes method that includes the influence of the anchor channel on the other side of the corner.

**Tension:** The tension analysis will follow the section 9.3.1 no reduction in anchorage tension pullout capacity $\Phi N_{pn}$ because of the influence of the other anchor channel. The cb concrete cover is taken as minimum of the four s/2, $c_{b1}$, $c_{b2}$ and $c_{b3}$ dimensions.(s=spacing between rebars) Refer Figure 9.3.3.6 and Figure 9.3.3.7.



# 9.3.4 — HAC CRFOS U DESIGN: FACE OF SLAB INSIDE CORNER WITH PAIR OF ANCHOR CHANNEL

Inside corners where two anchor channels are present and are loaded simultaneously are outside the scope of AC232. Most of the AC232 provisions can be applied to this type of application. However, the influence of the adjacent anchor channel should be considered, as the concrete strength may be negatively impacted.

**Perpendicular Shear:** This condition can be analyzed by fictitious edge between $c_{a2,b}$ + $c_{cr,V}$ assigning side edge concrete between channel a and b. The total distance of (a+b) can be divided between the two channels, while analyzing the individual channels. For example if channel a is loaded more than channel b than side edge distance of 3/4(a+b) can be assumed for channel a and side edge distance 1/4(a+b) can be assumed for channel b. Refer Figure 9.3.4.1.

**Tension:** The tension analysis will follow the section 9.3.1 without having any reduction in anchorage tension pullout capacity $\Phi N_{pn}$ because of the influence of the other anchor channel.

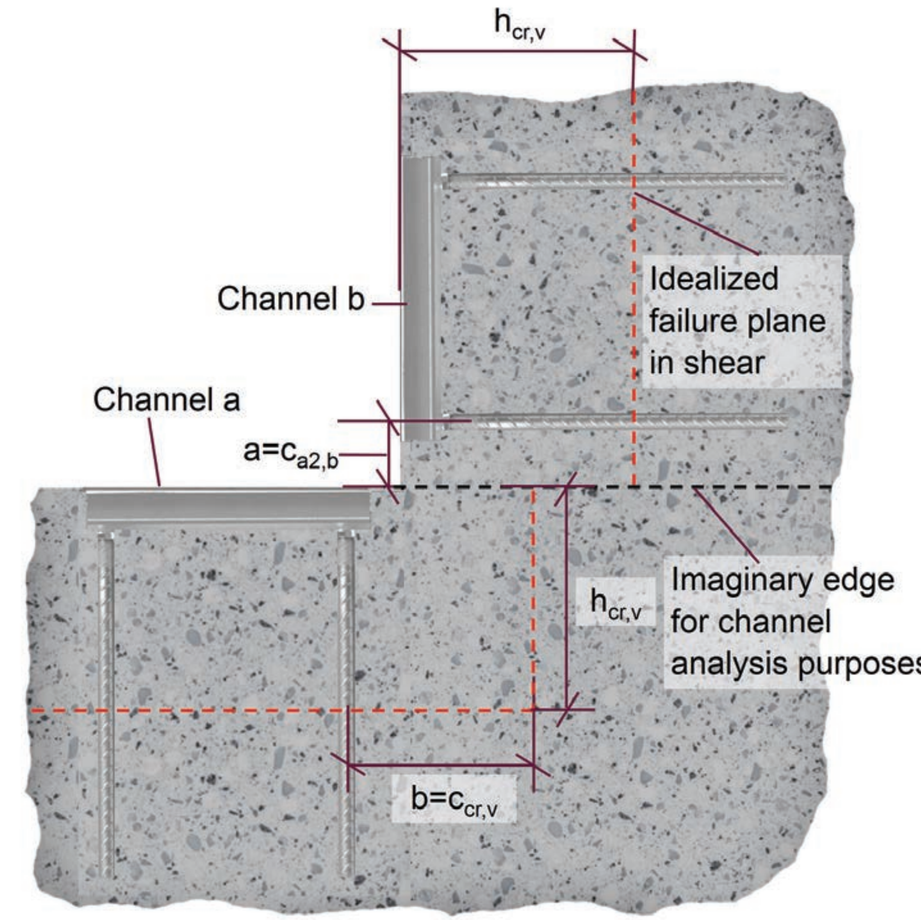



Figure 9.3.4.1 — HAC CRFOS U — Inside Corner.

## 9.3.5 — HAC CRFOS U DESIGN: COMPOSITE SLABS

The following failure modes needs to be modified in order to take account the effect of metal deck:

**Pullout strength in tension**

For FOS anchor channel design on a metal deck, the cover on the rebar where the rebar goes on top of metal deck should be measured from center of rebar to the metal deck. The $c_b$ value is taken as minimum value of $x_1$ and $x_2$ in the development length equation. The pullout strength gets reduced due to the reduced cover if the ratio $c_b/d_b$ is less than 2.5. Please refer to rebar theory chapter 8 and section 9.2.3 chapters for more information on this failure mode.

$$(f_y =)\sigma_d = l_{d,prov} . \pi . d_b . \frac{10}{3} . \lambda . \sqrt{f'_c} . \min\left(\frac{c_d}{d_b}, 2.5\right) . \frac{1}{\psi_t . \psi_e . \psi_s}$$

$$N_{P,R} = \frac{\pi . d^2_{s,R}}{4} . \sigma_d = l_{d,prov} . \pi . d_b . \frac{10}{3} . \lambda . \sqrt{f'_c} . \min\left(\frac{c_d}{d_b}, 2.5\right) . \frac{1}{\psi_t . \psi_e . \psi_s}$$

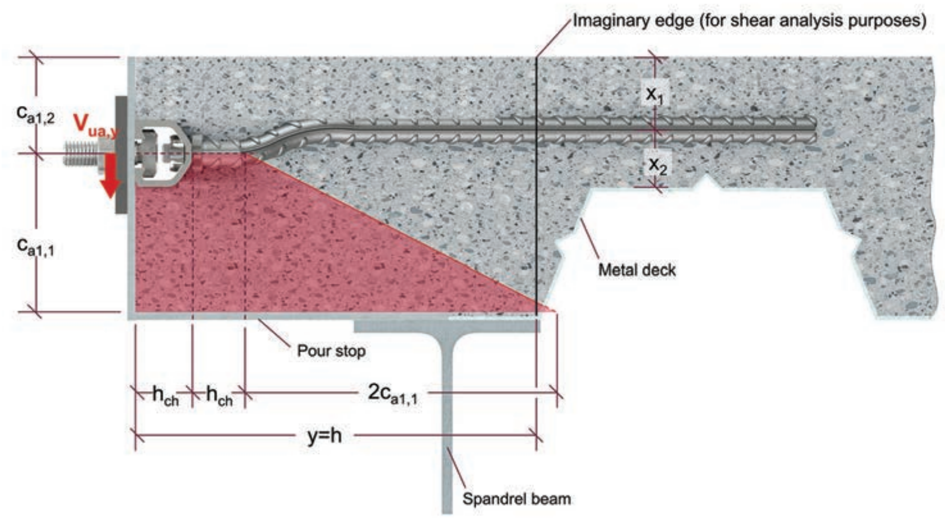



Figure 9.3.5.1 — HAC CRFOS U — FOS — Composite Slabs.

**Concrete breakout strength in shear**

The dimension y” effects concrete breakout strength in perpendicular shear. This will change the factor $\Psi_{h,V}$.

The dimension h in the formula below for the $\Psi_{h,V}$ factor should be taken as h as shown in Figure 9.3.5.1.

Please refer to anchor channel theory for more information on concrete breakout in shear.

$$h_{cr,V} = 2c_{a1} + 2h_{ch}$$

$$\psi_{h,V} = \left(\frac{h}{h_{cr,V}}\right)^{\beta_i} \leq 1.0$$

## 9.3.6 — HAC CRFOS U DESIGN: DESIGN OF ANCHOR CHANNEL FOR OUTSIDE CORNER OF A CURB OR OUTSIDE CORNER WITH COLUMN CONFLICT

Please contact Hilti at US+CA.HAC@Hilti.com for additional information.

## 9.3.7 — HAC CRFOS U DESIGN: DESIGN OF FACE OF SLAB ANCHOR CHANNEL WITH COLUMN CONFLICT AT THE CORNER

When there is a column conflict at the corner, the anchor channel is analyzed using a height of the base material as x” .

This dimension x” effects concrete breakout strength in perpendicular shear $\Psi_{h,V}$.

The dimension h in the formula below for the $\Psi_{h,V}$ factor should be taken as h=x”.

Please refer to anchor channel theory for more information on concrete breakout in shear.

$$h_{cr,V} = 2c_{a1} + 2h_{ch}$$

$$\psi_{h,V} = \left(\frac{h}{h_{cr,V}}\right)^{\beta_i} \leq 1.0$$


Figure 9.3.6.1 — HAC CRFOS U — FOS — Column Conflict at Corner.

## 9.4 — HAC AND HAC-T DESIGN: POST TENSIONED SLABS

See best practices, section 11.5.3

## 9.5 — HAC CRFOS U DESIGN: POST TENSIONED SLABS

See best practices, section 11.5.3

# 9.6 — HAC EDGE DESIGN

## 9.6.1 — HAC (T) EDGE, HAC (T) EDGE LITE AND HAC S (T) EDGE DESIGN: INTRODUCTION

Hilti Anchor Channel with the new rebar edge confinement plate (HAC EDGE or HAC EDGE Lite) is a solution for Curtain Wall applications that offers superior concrete edge breakout performance in shear. HAC EDGE changes the traditional concept of anchoring to concrete. Instead of relying on the low capacity of the concrete in tension, it takes advantage of the tensile strength of the reinforcement attached to the anchor channel. HAC EDGE optimizes the shear load transfer from the channel profile into the reinforcing bars and overcomes the challenges with traditional anchor channels with welded reinforcing bars.

HAC EDGE is a new anchoring system that brings value innovation. It copes with today's fast track construction demands and requirements of the curtain wall industry such as installation tolerance, high wind loads, thin concrete members, pockets, close edge distances, and lightweight concrete. In such adverse conditions, HAC EDGE provides more than 2 times the capacity of traditional top of slab anchor channels where the reinforcing bars are welded to the back of the channel and outperforms standard anchor channels without reinforcing bars by up to a factor of 5.

**Code Compliance of HAC EDGE**

HAC EDGE is a system consisting of a rebar edge confinement plate (EDGE plate) non-structurally attached to a Hilti Anchor Channel (HAC). The anchor channel itself is covered in the ESR-3520. Because the EDGE plate is not structurally connected to the anchor channel, the system is decoupled and the EDGE plate does not change the behavior of the anchor channel. Therefore, the design model and technical data can be taken from ESR-3520 for most of the failure modes.

The scope of the current version of AC232 (June 2017) is limited to anchor channels with round headed anchors or I-anchors. Anchor channels with reinforcing bars attached to the anchor channels are not explicitly covered in the criteria. However, the testing protocols of AC232 were used to determine the resistances of HAC in combination with the EDGE plate. The design provisions of AC232 are valid to design 19 out of the 20 failure modes of an anchor channel required per ESR-3520. Only the verification for concrete edge failure in shear is modified, based on rigorous in-house testing to benefit from the improved load-bearing behavior provided by the confinement plate with reinforcing bars. The anchorage length is designed in accordance with ACI 318.

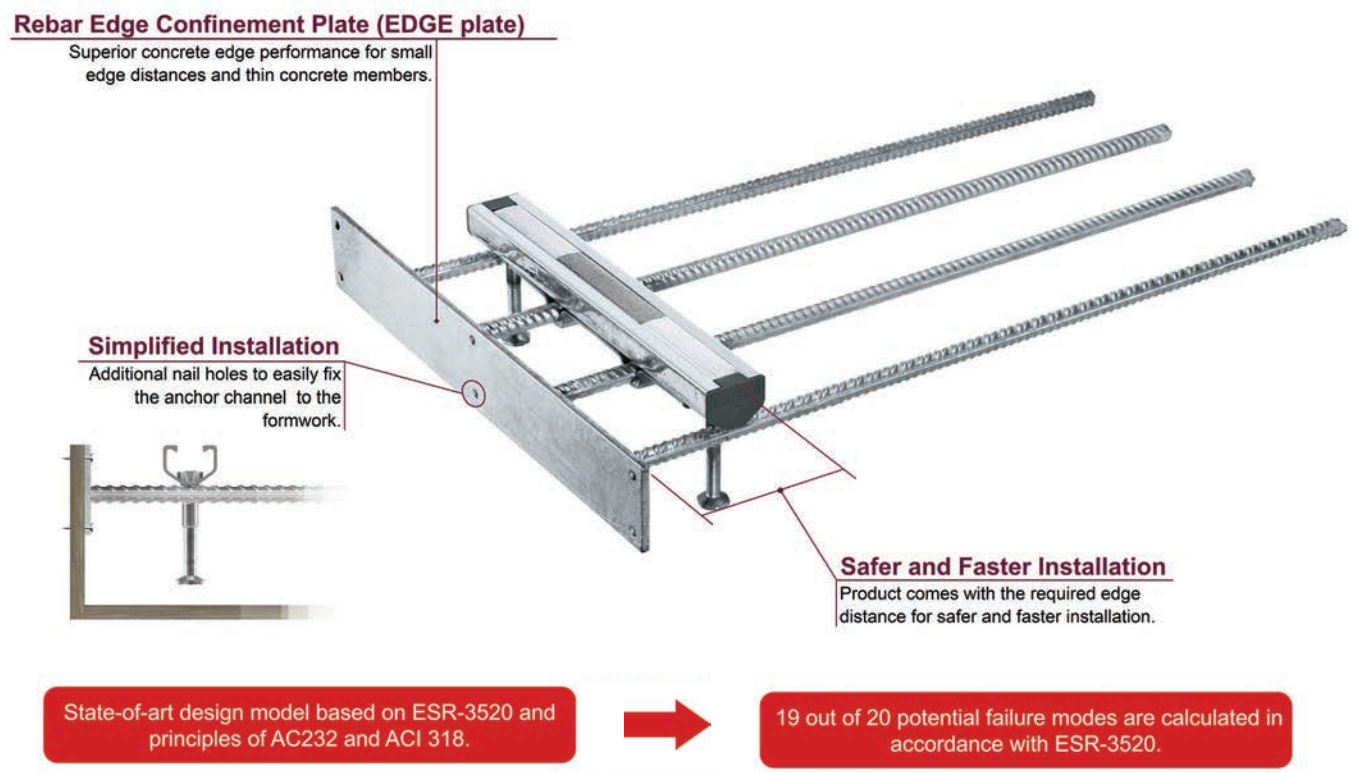



Figure 9.6.1.1 — HAC EDGE or HAC EDGE Lite — Introduction.

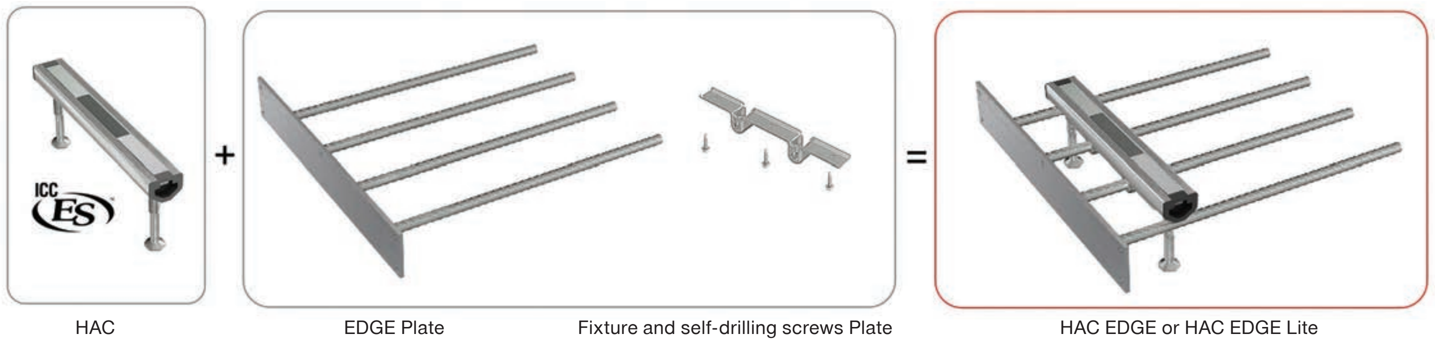



**Figure 9.6.1.2 — HAC EDGE or HAC EDGE Lite — Components.**

**The Weakest Link in Top of Slab Applications**

The design of cast-in anchor channels requires the verification of steel and concrete failure modes for tension, shear and combined tension and shear. An anchor channel is only as strong as its weakest link. For curtain wall applications, the weakest link in shear is typically concrete edge breakout failure. This failure mode is controlled by the geometrical dimensions and material characteristics of the concrete.

**Standard Anchor Channels**

The verification of concrete edge breakout of anchor channels consists of the basic concrete breakout strength of one anchor of the anchor channel multiplied by a series of modification factors that account for the anchor spacing, member thickness, corner effect, state of concrete (cracked or uncracked) and reinforcement in the concrete member.

The basic concrete breakout strength of one anchor without the influence of a corner, member thickness or adjacent anchors in unreinforced concrete is determined as follows:

$$V_b = \lambda . \alpha_{ch,V} . \sqrt{f_c^{'}} . (C_{a1})^{\frac{4}{3}}$$

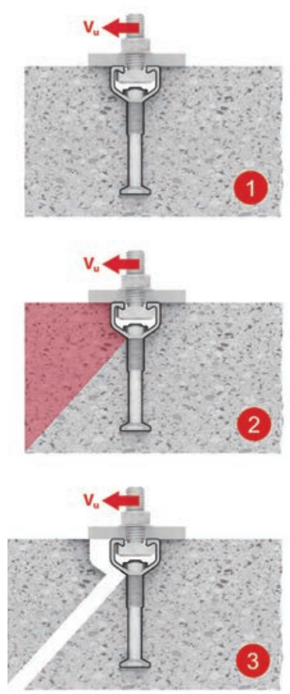
$\lambda$ Modification for lightweight concrete
All-lightweight concrete = 0.75
Sand-lightweight concrete = 0.85

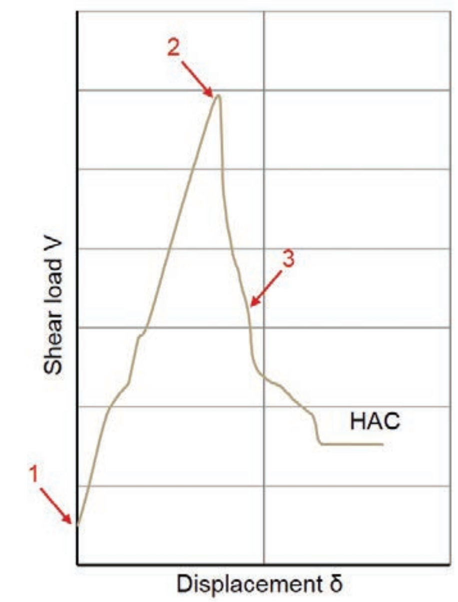
$\alpha_{ch,V}$ Factor to account for the influence of channel on concrete edge breakout strength (10.50, max.)

$f'_c$ Specified concrete compressive strength (psi) (8,500 psi, max)

$c_{a1}$ Edge distance of anchor channel in direction 1 (in.) (edge to center line of anchor)

According to the Figure 9.6.1.3, for standard anchor channels covered in ESR-3520 the shear loads acting on the fixture are transferred through the anchor channel into the concrete via the t-bolts and the anchor elements (1). The failure occurs in front of the channel profile (2). After reaching the ultimate shear load the concrete in front of the channel is completely separated from the rest of the structure. The shear load decreases with increasing deformation of the channel (3).




Anchor channel with rounded head anchors

**Figure 9.6.1.3 — HAC — Headed Studs — Behavior of anchor channels loaded in shear (left). Shear load vs displacement curve (right).**

In curtain wall applications, the design of the anchor channel typically takes place at one of the last stages of the building design. Oftentimes, the design of the anchorage comes as an afterthought. By the time the anchor channel is sized, the variables that can significantly influence the performance of the anchor channel have been defined. The edge distance is the variable that has the largest impact on concrete edge breakout failure. However, even this variable may have already been defined leaving designers with minimal options. Typically, the edge distance can only be varied in a very narrow band due to the size of the bracket.

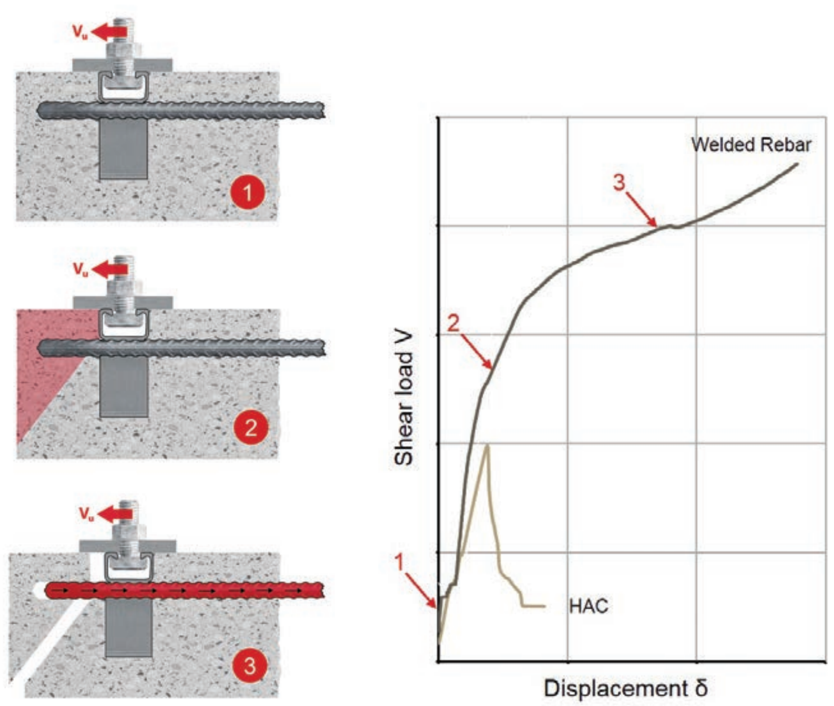
**Overcoming the Limitations of the Concrete Edge Breakout Strength**

**Anchor Channels with Welded Reinforcing Bars**

To overcome the limitations of the relatively low concrete edge breakout strength close to an edge, often anchor channels with reinforcing bars structurally welded to the back of the channel are used.

In analogy to standard anchor channels, the shear loads are transferred into the concrete via the channel profile (1). The failure also occurs in front of the channel profile (2). However, compared to standard anchor channels the shear loads are redistributed to the reinforcing bars. The higher ultimate resistance of the system is reached only with increased deformations and large cracks in front of the channel (3).

Welding reinforcing bars to an anchor channel changes the behavior of the anchor channel in tension and combined tension and shear. When tension forces are applied to the anchor channel, the concrete above the reinforcing bars fails and reduce the concrete cone resistance of the anchor channel. Also, due to the large cracks in front of the anchor channel in case of shear loading, the interaction with concrete cone failure is negatively influenced. These effects are even more pronounced in lightweight concrete structures. Therefore, the negative effect of the welded reinforcing bars should be considered in the design of these types of anchor channels.



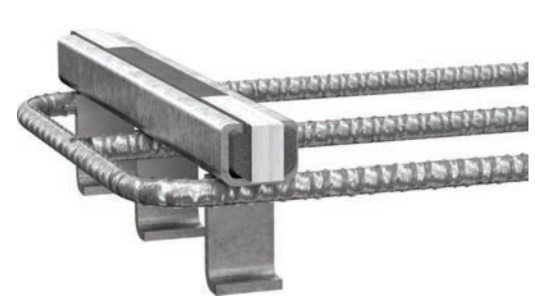


Anchor channel with anchors and welded reinforcing bar

Figure 9.6.1.4 — Welded rebar channel — Behavior of anchor channels with reinforcing bars loaded in shear (left). Shear load vs displacement curve (right).



**HAC EDGE**

Utilizing the basic principles of reinforced concrete structures has lead Hilti to develop a new anchor channel system that copes with the curtain wall market needs. Rather than relying on the relatively low tensile capacity of the concrete for the failure mode “concrete edge breakout”, HAC EDGE brings superior concrete edge performance by optimizing the load transfer for small edge distances, thin concrete members, low concrete compressive strengths, and lightweight concrete.

The first loading stage of HAC EDGE is equal to the one of standard anchor channels and anchor channels with welded reinforcing bars (1). After shear loads are applied to the anchor channel, the loads are first transferred from the channel profile towards the free edge of the concrete. The EDGE plate which is held back by the welded reinforcing bars confines the edge, allowing for the formation of compression struts (2). The shear load is transferred back to the reinforcing bars. The ultimate resistance of the system is reached after the reinforcing bars are fully activated (3).

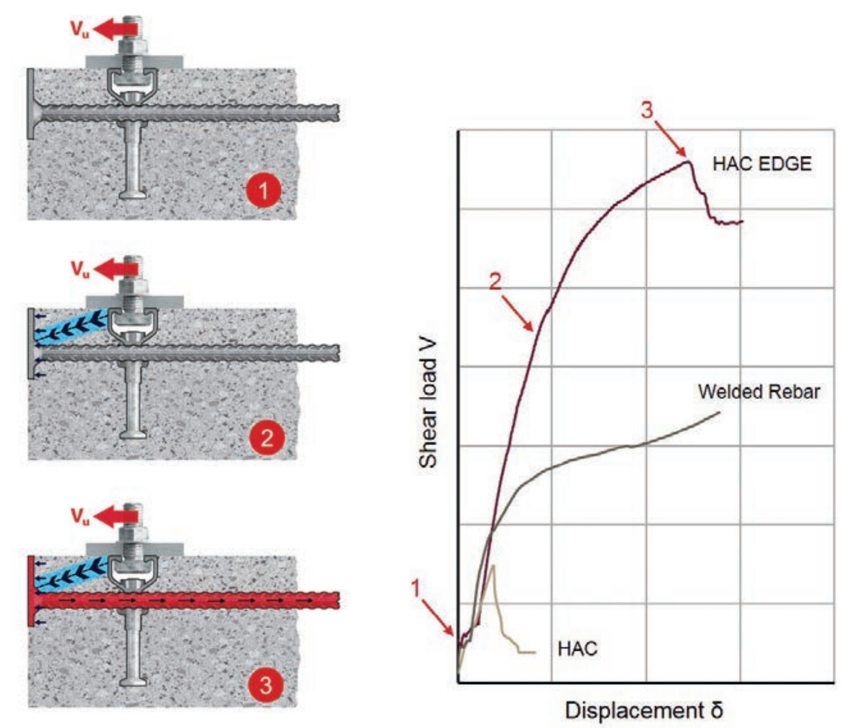
The EDGE plate is not structurally connected to the anchor channel. This allows decoupling of the shear and tension load transfer mechanism. The concrete cone resistance of the anchor channel can be conservatively calculated according to AC232.

For small edge distances HAC EDGE provides more than 2 times the capacity of traditional top of slab anchor channels where the reinforcing bars are welded to the back of the channel. Moreover, depending on the geometry of the concrete member and location of the anchor channel, HAC EDGE can outperform standard anchor channels without reinforcing bars up to a factor of 5.

**Additional Benefits of HAC EDGE**

In addition to the high concrete edge breakout in shear performance, HAC EDGE comes with the specified/ordered edge distance to reduce errors in placement, and provide a safer and quicker installation. This goes in hand with Hilti’s mission of building a better future. HAC EDGE reduces the probability of installing the product at the wrong edge distance. The edge distance is the most sensitive variable that has the highest impact on the concrete edge breakout strength in shear.

Moreover, the installation of the anchor channel is simplified as the product can easily be secured to the formwork by nailing or screwing the EDGE plate to it. Moreover, HAC EDGE brings overall material savings as it allows the use of smaller facade brackets. The superior concrete shear performance for small edge distances allows the curtain wall bracket to be concealed by the stool trim or gypsum wall, if they are at least 4”-5” away from the edge of the building. This eliminates the need of so-called pockets, bringing substantial savings





Anchor channel with anchors and rebar edge confinement plate (EDGE Plate)

Figure 9.6.1.5 — HAC EDGE Behavior of HAC EDGE loaded in shear (left). Shear load vs displacement curve (right).

## 9.6.2 — HAC (T) EDGE, HAC (T) EDGE LITE AND HAC S (T) EDGE: DESIGN

In this section an overview of the verifications is given.

All the actions on the anchors are calculated according to AC232. The action on the rebars are calculated with the model of AC232 with a modification of the influence length. A summary of the applied load distributions is given in Table 9.6.2.1.

In case of two elements close to an edge the actions on the anchors are calculated independently for the two channels resistances.

Following considerations are done for the verifications of the three introduced components:

1) HAC-50 and HAC-T50 with reduced embedment depth: no changes to the design is based on ESR3520 and AC232.

2) Lip strengthening element (Clip): in combination with the clip higher values of $V_{sl,y}$, $V_{sa,y}$ and $V_{sc,y}$ are provided. Seismic design is performed according to the ESR3520: the lip strengthening element is not considered in the seismic calculation nor for load acting towards the slab (wind pressure).

3) With the new Rebar Top of Slab front Plate (EDGE), the rebars and the anchor channel are structurally uncoupled: the connection between the two elements is weak and has no structural function.

For tension loads, the rebars are neglected and all the verifications are performed in the same way as for the standard HAC channels, according ESR3520. The splitting failure (considered in the concrete breakout verification) is not possible when the EDGE front plate is combined ($\Psi_{cp,N}$ = 1.0) and the concrete is always considered as cracked ($\Psi_{c,N}$ = 1.0).

For perpendicular shear a new method for concrete edge failure and an additional reduction for the lip failure are introduced. Additionally, the verification of rebar pull-out and rebar steel strength are performed in the same way as for the CRFOS U. Moreover, two remarks are added in Profis, the first concerning the "concrete cone" for shear load and the second concerning the presence of cracks at the sides of the channel. Supplementary reinforcement for perpendicular or for longitudinal shear is not permitted in combination with the EDGE plate.

For longitudinal shear the rebars are neglected and the concrete failure is calculated according to ESR3520. This assumption is conservative since the capacity of unreinforced concrete is lower than that of the edge with the EDGE reinforcement.

All the verifications under combined loads are performed according to ESR3520.

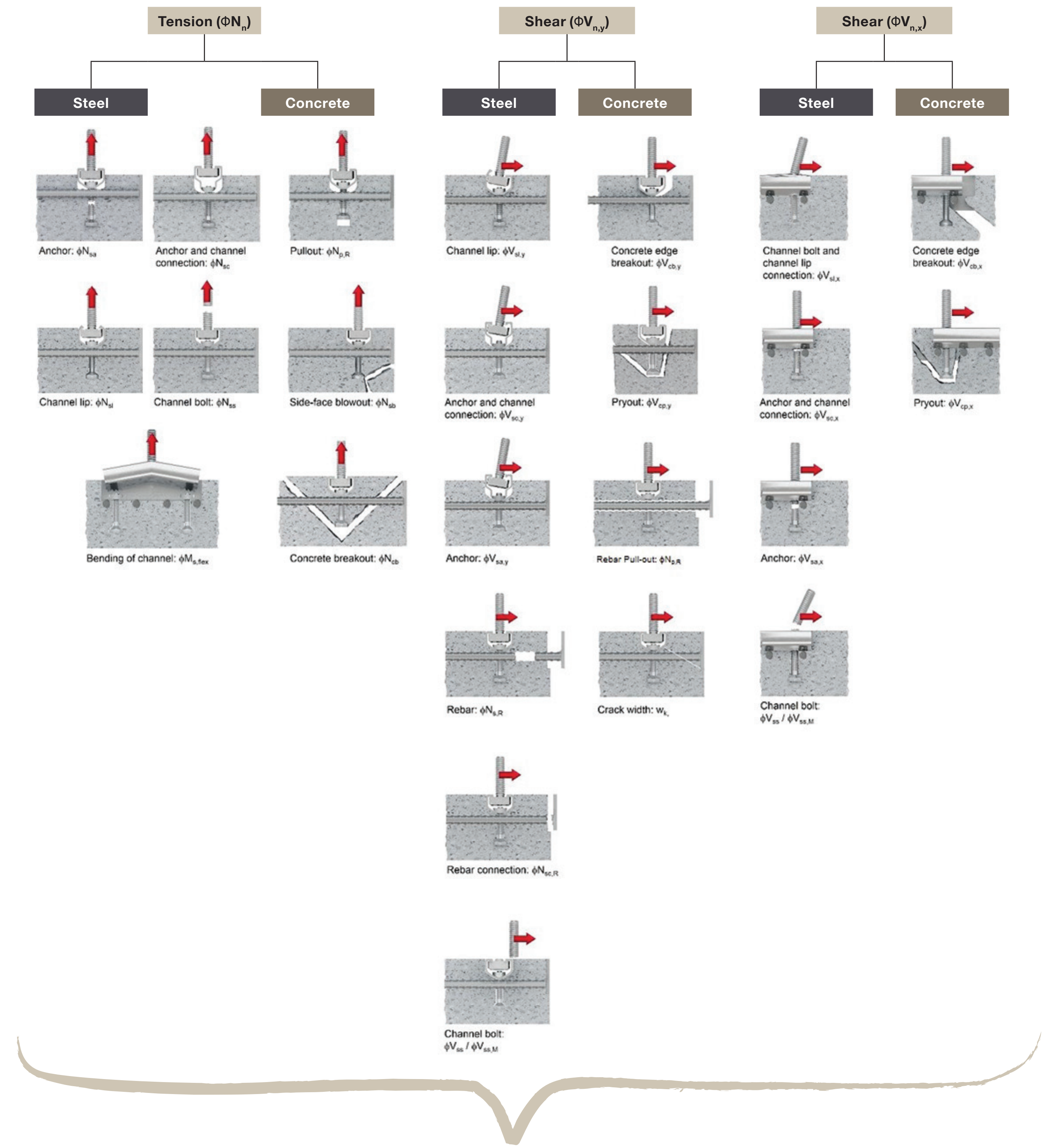
If two anchor channels are placed close to a corner, all the steel verification remain the same. Since the two channels use the same concrete surface, some modification have to be done for all the concrete verifications in order to take the relative influence into account.

An adjustment to the ESR method for the calculation of concrete cone and concrete edge failure in case of two (or more) channels is described in Sections 9.2.7 to 9.2.17. For longitudinal shear the reinforcement bars are neglected and the ESR method is applied.

Conservative assumptions are done for the 3D load interaction.

**Table 9.6.2.1 — Actions on the anchors.**

| Action | HAC-(T)50 with EDGE front Plate | HAC-(T)50 with EDGE front Plate + Clip |
|---|---|---|
| Anchor tension | AC232 | AC232 |
| Anchor shear perpendicular | AC232 | AC232 |
| Anchor shear parallel | AC232 | AC232 |
| Rebar tension | Mod. AC232 | Mod. AC232 |




**IMPORTANT! Failure analysis modes evaluated follow ACI 318-14, chapter 17. This DOES NOT include evaluating the base material (e.g. edge-of-slab) capacity to resist compressive forces generated by the fixture. The engineer must ALWAYS verify the base material (e.g. edge-of-slab) design is capable of resisting the applied loading.**

For additional information, please contact Hilti at US+CA.HAC@Hilti.com

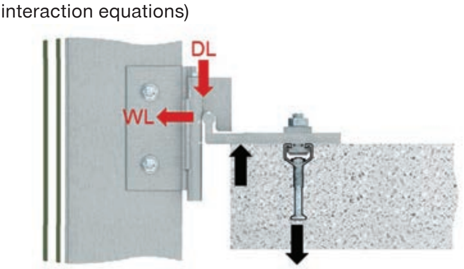



**Figure 9.6.2.1 — HAC (T) EDGE, HAC (T) EDGE Lite — HAC (T) EDGE ( C).**

9.1 Overview of Hilti Anchor Channel Systems Design
9.2 HAC and HAC-T Design
9.3 HAC CRFoS U Design
9.4 & 9.5 Post Tensioned Slabs
9.6 HAC EDGE Design

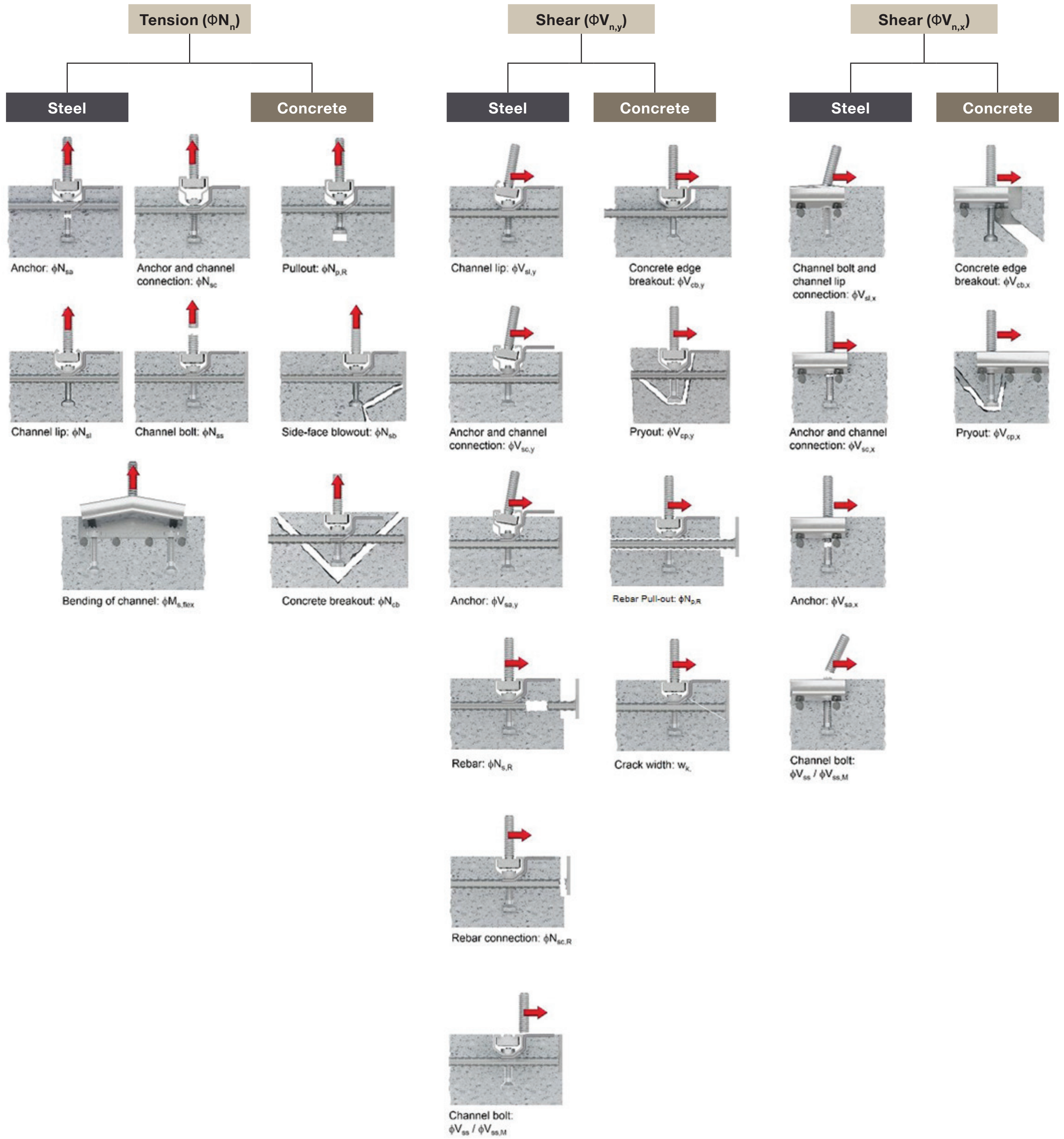
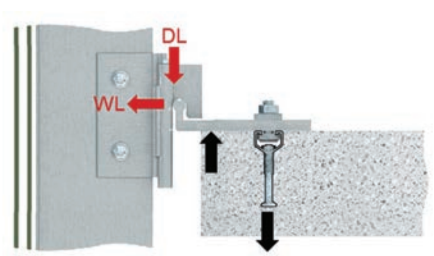



**Figure 9.6.2.2 — HAC S (T) EDGE, — HAC S (T) EDGE ( C).**

**IMPORTANT! Failure analysis modes evaluated follow ACI 318-14, chapter 17. This DOES NOT include evaluating the base material (e.g. edge-of-slab) capacity to resist compressive forces generated by the fixture. The engineer must ALWAYS verify the base material (e.g. edge-of-slab) design is capable of resisting the applied loading.**

For additional information, please contact Hilti at US+CA.HAC@Hilti.com

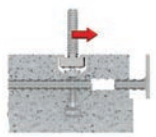
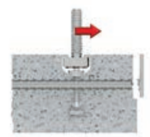
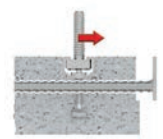
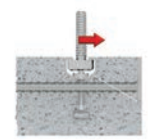


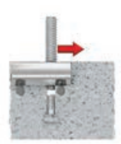
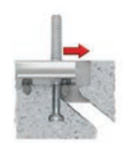
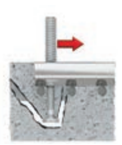

## HAC-(T) EDGE and HAC-(T) EDGE Lite

| TENSION | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Steel Failure Modes** | | | | | **Concrete Failure Modes** | | |
| Channel bolt : $\phi N_{ss}$ | Channel lip : $\phi N_{sl}$ | Bending of channel : $\phi M_{s,flex}$ | Connection : $\phi N_{sc}$ | Anchor: $\phi N_{sa}$ | Concrete breakout : $\phi N_{cb}$ | Pullout : $\phi N_{pn}$ | Side-face blow-out: $\phi N_{sb}$ |
| ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520* Sec. 4.1.3.2.3 | ESR-3520 Sec. 4.1.3.2.4 | ESR-3520 Sec. 4.1.3.2.5 |
| | | | | | **Anchor reinf. steel** | **Anchor reinf. anchorage** | |
| | | | | | ESR-3520 sec 4.1.3.2.3 | ESR-3520 sec 4.1.3.2.3 | |

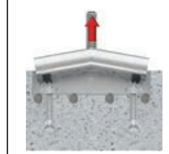
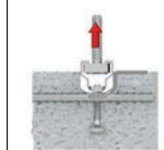
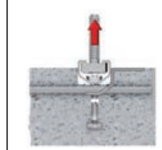
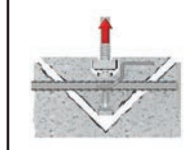
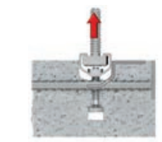
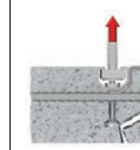
* No splitting possible in combination with the steel plate, concrete always cracked

| PERPENDICULAR SHEAR | | | | | |
|---|---|---|---|---|---|
| **Steel Failure Modes** | | | | **Concrete Failure Modes** | |
| Channel bolt: | Channel Lip | Connection | Anchor | Concrete Breakout | Concrete Pryout |
| ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | Hilti Method | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | Hilti Method | ESR-3520 Sec. 4.1.3.3.4 |

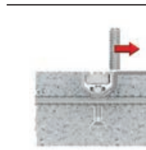
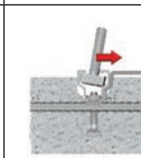
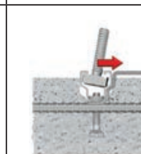
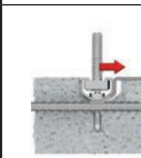
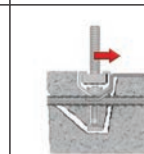
| REBAR FAILURE MODES | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | Concrete Failure Modes | | |
| Rebar in tension | Rebar connection | Anchor reinf. steel | EDGE Rebar pull-out | SLS Concrete edge | Anchor reinf. anchorage |
|  |  | N/A |  |  | N/A |
| Hilti Method (Rebar pull-out and Rebar connection are performed in the same way as for the FoS products.) | No (The rebar welding is specified such as to have an higher strength than the rebar itself ) | Not permitted | Hilti Method based on ACI | Remark in Profis | Not permitted |

| LONGITUDINAL SHEAR | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | | Concrete Failure Modes | |
| Channel bolt: | Channel Lip | Connection | Anchor | Concrete Breakout | Concrete Pryout |
|  |  |  |  |  |  |
| ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.4.3 | ESR-3520 Sec. 4.1.3.4.4 |
| | | | | **Anchor reinf. steel** | **Anchor reinf. anchorage** |
| | | | | Not permitted | Not permitted |

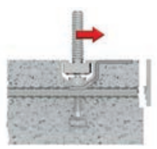
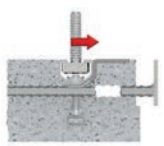
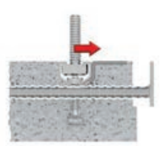
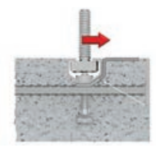
## HAC-(T) S EDGE

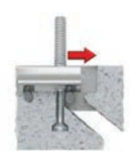
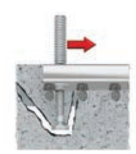
| TENSION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Steel Failure Modes | | | | | Concrete Failure Modes | | |
| Channel bolt : $\phi N_{ss}$ | Channel lip : $\phi N_{sl}$ | Bending of channel : $\phi M_{s,flex}$ | Connection : $\phi N_{sc}$ | Anchor: $\phi N_{sa}$ | Concrete breakout : $\phi N_{cb}$ | Pullout : $\phi N_{pn}$ | Side-face blow-out: $\phi N_{sb}$ |
|  |  |  |  |  |  |  |  |
| ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520* Sec. 4.1.3.2.3 | ESR-3520 Sec. 4.1.3.2.4 | ESR-3520 Sec. 4.1.3.2.5 |
| | | | | | **Anchor reinf. steel** | **Anchor reinf. anchorage** | |
| | | | | | ESR-3520 sec 4.1.3.2.3 | ESR-3520 sec 4.1.3.2.3 | |

* No splitting possible in combination with the steel plate, concrete always cracked

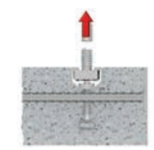
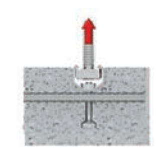
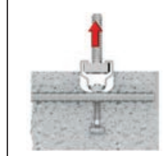
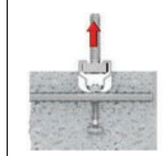
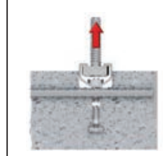
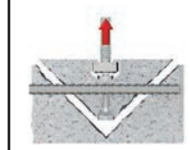
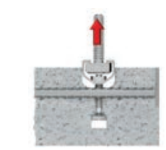
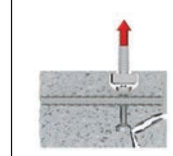
| PERPENDICULAR SHEAR | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | | Concrete Failure Modes | |
| Channel bolt: | Channel Lip | Connection | Anchor | Concrete Breakout | Concrete Pryout |
|  |  |  |  |  |  |
| ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | Hilti Method** | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | Hilti Method | ESR-3520 Sec. 4.1.3.3.4 |

**If the clip is selected $V_{sl,y}$, $V_{sl,y}$, $V_{sc,y}$ are changed in clip direction, and only static

| REBAR FAILURE MODES | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | Concrete Failure Modes | | |
| Rebar connection | Rebar in tension | Anchor reinf. steel | EDGE Rebar pull-out | SLS Concrete edge | Anchor reinf. anchorage |
|  |  | N/A |  |  | N/A |
| No (The rebar welding is specified such as to have an higher strength than the rebar itself ) | Hilti Method (Rebar pull-out and Rebar connection are performed in the same way as for the FoS products.) | Not permitted | Hilti Method based on ACI | Remark in Profis | Not permitted |

| LONGITUDINAL SHEAR | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | | Concrete Failure Modes | |
| Channel bolt: | Channel Lip | Connection | Anchor | Concrete Breakout | Concrete Pryout |
|  |  |  |  |  |  |
| ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.4.3 | ESR-3520 Sec. 4.1.3.4.4 |
| | | | | **Anchor reinf. steel** | **Anchor reinf. anchorage** |
| | | | | Not permitted | Not permitted |

## HAC-(T) EDGE, HAC-(T) S EDGE, HAC-(T) C EDGE and HAC-(T) EDGE Lite

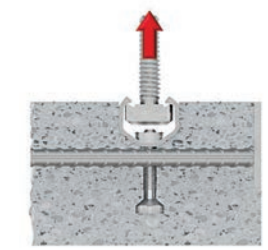
| TENSION | | | | | | | |
|---|---|---|---|---|---|---|---|
| Steel Failure Modes | | | | | Concrete Failure Modes | | |
| Channel bolt : $\phi N_{ss}$ | Channel lip : $\phi N_{sl}$ | Bending of channel : $\phi M_{s,flex}$ | Connection : $\phi N_{sc}$ | Anchor: $\phi N_{sa}$ | Concrete breakout : $\phi N_{cb}$ | Pullout : $\phi N_{pn}$ | Side-face blow-out: $\phi N_{sb}$ |
|  |  |  |  |  |  |  |  |
| ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520 Sec. 4.1.3.2.2 | ESR-3520* Sec. 4.1.3.2.3 | ESR-3520 Sec. 4.1.3.2.4 | ESR-3520 Sec. 4.1.3.2.5 |
| | | | | | **Anchor reinf. steel** | **Anchor reinf. anchorage** | |
| | | | | | ESR-3520 sec 4.1.3.2.3 | ESR-3520 sec 4.1.3.2.3 | |

* No splitting possible in combination with the steel plate, concrete always cracked

### Channel lip: $\Phi N_{sl}$

$\Phi N_{sl} > N^{b}_{ua}$

The capacity of channel lip is in accordance to ESR-3520 Sec. 4.1.3.2.2. Please refer to table 2.3.17 and 2.3.5 of chapter 02.

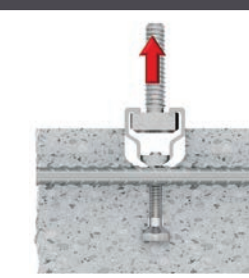


Channel lip: $\Phi N_{sl}$

### Connection Anchor and Channel : $\Phi N_{sc}$

$\Phi N_{sc} > N_{aua}$

The capacity of connection is in accordance to ESR-3520 Sec. 4.1.3.2.2. Please refer to table 2.3.17 and 2.3.5 of chapter 02.

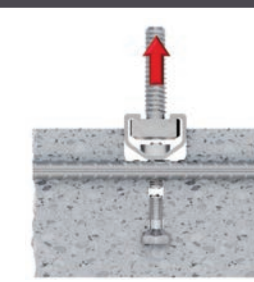


Anchor and channel connection: $\Phi N_{sc}$

### Anchor : $\Phi N_{sa}$

$\Phi N_{sa} > N_{aua}$

The capacity of anchor is in accordance to ESR-3520 Sec. 4.1.3.2.2. Please refer to table 2.3.17 and 2.3.5 of chapter 02.

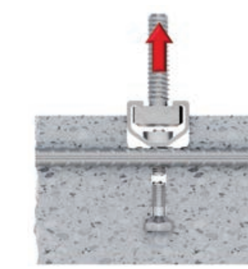


Anchor: $\Phi N_{sa}$

### Bending strength of channel : $\Phi M_{s,flex}$

$\Phi M_{s,flex} \geq M_{u,\,flex}$

The capacity of anchor is in accordance to ESR-3520 Sec. 4.1.3.2.2. Please refer to table 2.3.17 and 2.3.5 of chapter 02.

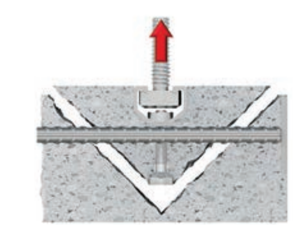


Bending : $\Phi M_{s,flex}$

### Concrete breakout : $\Phi N_{cb}$

$\Phi N_{cb} > N_{aua}$

The concrete breakout capacity of anchor channel is in accordance to ESR-3520 Sec. 4.1.3.2.3. Please refer to table 2.2.7.1, 2.2.7.2, 2.2.7.3, 2.2.16.1, 2.2.16.2 and 2.2.16.3 of chapter 02 for parameters and section 7.3.2 of anchor channel theory chapter 07 for analysis.



Concrete breakout: $\Phi N_{cb}$

$\Psi_{cp,N}$= 1.0 if the EDGE (C) steel plate is activated.

$\Psi_{c,N}$= 1.0 always if the EDGE (C) steel plate is activated: with the EDGE (C) front plate concrete is always considered as cracked.

### Pull out: $\Phi N_{pn}$

$\Phi N_{pn} > N_{aua}$

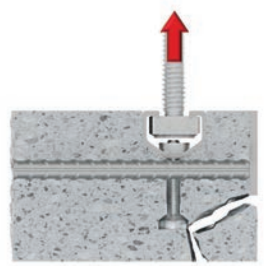
The concrete pull out capacity is in accordance to ESR-3520 Sec. 4.1.3.2.4. Please refer to table 2.2.7.1, 2.2.7.2, 2.2.7.3, 2.2.16.1, 2.2.16.2 and 2.2.16.3 of chapter 02 for parameters and section 7.3.2 of anchor channel theory chapter 07 for analysis.

Pullout: $\Phi N_{pn}$

### Side-face blow-out: $\Phi N_{sb}$

$\Phi N_{sb} > N_{aua}$

The concrete side-face blow-out capacity is in accordance to ESR-3520 Sec. 4.1.3.2.5. Please refer to table 2.2.7.1, 2.2.7.2, 2.2.7.3, 2.2.16.1, 2.2.16.2 and 2.2.16.3 and table 2.2.14.1 of chapter 02 for parameters and section 7.2.2 of anchor channel theory chapter 07 for analysis.

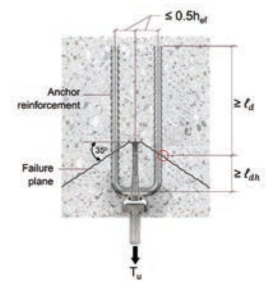


Blow-out: $\Phi N_{sb}$

### Anchor reinforcement steel: $\Phi N_{ca,s}$

$\Phi N_{ca,s} > N_{aua}$

The anchor reinforcement steel capacity is in accordance to ESR-3520 Sec. 4.1.3.2.3. Please refer section 7.2.2 of anchor channel theory chapter 07 for analysis.

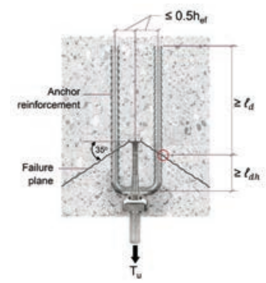



Anchor reinforcement steel: $\Phi N_{ca,s}$

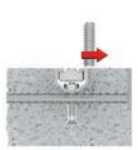
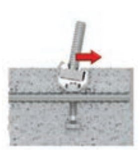
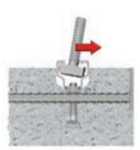
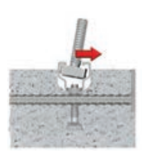
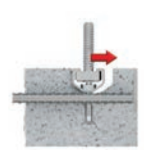
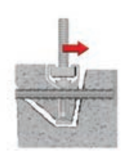
### Anchor reinforcement anchorage: $\Phi N_{ca}$

$\Phi N_{ca} > N_{aua}$

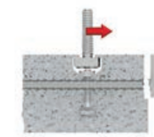
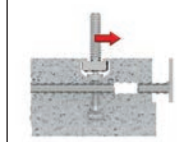
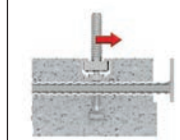
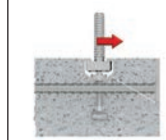
The anchor reinforcement anchorage capacity is in accordance to ESR-3520 Sec. 4.1.3.2.3. Please refer section 7.2.2 of anchor channel theory chapter 07 for analysis.




Anchor reinforcement anchorage: $\Phi N_{ca}$

| PERPENDICULAR SHEAR | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | | Concrete Failure Modes | |
| Channel bolt: | Channel Lip | Connection | Anchor | Concrete Breakout | Concrete Pryout |
|  |  |  |  |  |  |
| ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | Hilti Method** | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | Hilti Method | ESR-3520 Sec. 4.1.3.3.4 |

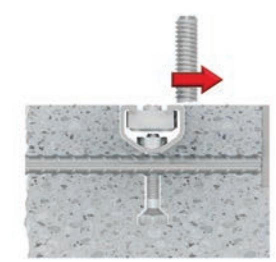
**If the clip is selected $V_{sl,y}$, $V_{sl,y}$, $V_{sc,y}$ are changed in clip direction, and only static

| Rebar Failure Modes | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | Concrete Failure Modes | | |
| Rebar connection | Rebar in tension | Anchor reinf. steel | EDGE Rebar pull-out | SLS Concrete edge | Anchor reinf. anchorage |
|  |  | N/A |  |  | N/A |
| No (The rebar welding is specified such as to have an higher strength than the rebar itself ) | Hilti Method (Rebar pull-out and Rebar connection are performed in the same way as for the FoS products.) | Not permitted | Hilti Method based on ACI | Remark in Profis | Not permitted |

### Channel lip : $\phi V_{sl,y}$

$\phi V_{sl,y} > V^b_{ua}$

The capacity of channel lip is in accordance to ESR-3520 Sec. 4.1.3.2.2. Please refer to table 2.3.22 and 2.3.6 of chapter 02. Anchor channel casted into concrete in combination with the EDGE Plate with two bolts in different positions and with different spacing were tested under shear load. A failure for local bending of the channel lip was observed and the failure load was depending on the bolt spacing. According to AC232, for the chosen spacing of 75 mm and 100 mm, there should be no mutual influence of the two bolts on the lip failure load. The lower observed failure loads are probably caused by the disturbance into concrete introduced by the plate or from the crack which appears with a small edge distance. In order to cover this failure a reduction factor for the channel lip strength is proposed as $\psi_{s,sl}$. The reduction factor is similar to that for the nominal strength of the channel lip to take up tension loads of ESR 3520 [1] (eq. 5 in 4.1.3.2.2).



Channel lip : $\phi V_{sl,y}$

The value of $V_{sl,y}$ is valid only if the center-to-center distance between the channel bolt under consideration and adjacent channel bolts, $s_{bch}$ is at least $s_{chb,cr,V}$. If this requirement is not met then the value of $V_{sl,y}$ must be reduced as follow:

$$V_{sl,y} = \psi_{s,sl} . V_{sl,y,technical\ data}$$

$$\psi_{s,sl} = \frac{1}{1 + \sum_{i=2}^{n+1}\left[\left(1 - \frac{s_{chb,i}}{s_{chb,cr,V}}\right)^{1.5} \cdot \frac{V^b_{ua,j}}{V^b_{ua,a1}}\right]}$$

$$s_{chb,cr,V} = s_{chb,cr,0} - 0.9c_{a1} \geq 3d_s$$

critical bolt spacing for shear load for the HAC-50.

where

$$V^b_{ua,j};\ \ V^b_{ua,1} \rightarrow\ \ +same\ \ dir.$$

in case one bolt is loaded in the opposite direction no positive effect on the factor is considered

The bolt shear forces are considered only if acting in the same direction. If one bolt is loaded in the opposite direction no positive effect on the factor is considered.

$s_{chb,cr,V}$ decreases linearly with the edge distance $c_{a1}$: the influence of the EDGE front plate on the lip strength becomes smaller with the edge distance and from a $c_{a1}$ =200 mm it is assumed that there is no influence anymore on the lip strength. With $s_{chb,cr,0}$ = 240mm the critical spacing at $c_{a1}$ =200 mm becomes 3 times the bolt diameter $d_s$ as specified in ESR3520.

**Figure 9.6.2.2 — Series Zero — Bolt pair.**

**Figure 9.6.2.3— Bolts at one side.**

**Figure 9.6.2.4 — Bolts in the midpoint.**

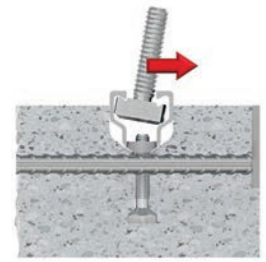
### With lip strengthening element (Clip)

If the clip is selected, $V_{sl,y}$ is increased to $V_{sl,y,clip}$ in direction of the clip according Hilti technical data. The reduction factor $\Psi_{s,sl}$ is applied as above. In the opposite direction, the standard value of $V_{sl,y}$ and when specified the reduction factor $\Psi_{s,sl}$ are applied:

Verifications:
$$\phi V_{sl,y,clip} \geq V^s_{ua,y} \quad \text{(in clip direction)}$$
$$\phi V_{sl,y} \geq V^s_{ua,y}$$

### Connection Anchor and Channel : $\phi V_{sc,y}$

$\phi V_{sc,y} > V_{aua,y}$



**Connection Anchor and Channel: $\phi V_{sc,y}$**

Without Clip: The capacity of connection is in accordance to ESR-3520 Sec. 4.1.3.2.2 and according to Hilti technical data. Please refer to table 2.3.22 and 2.3.6 of chapter 02.

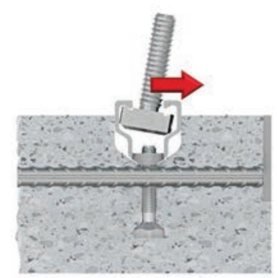
With lip strengthening element (Clip)

If the clip is selected, in direction of the clip $V_{sc,y}$ is increased to $V_{sc,y,clip}$ , according Hilti technical data. In the opposite direction, the standard value of $V_{sc,y}$ are applied:

Verifications:
$$\phi V_{sc,y,clip} \geq V^a_{ua,y}\ y$$
$$\phi V_{sc,y} \geq V^a_{ua,y}$$

### Anchor : $\phi V_{sa,y}$

$\phi V_{sa,y} > V_{aua}$



**Anchor: $\phi V_{sa,y}$**

The capacity of anchor is in accordance to ESR-3520 Sec. 4.1.3.2.2. Please refer to table 2.3.22 and 2.3.6 of chapter 02.

With lip strengthening element (Clip)

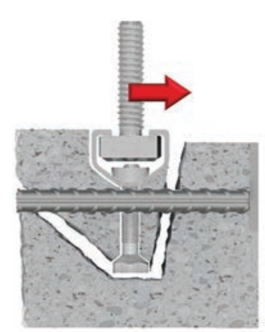
If the clip is selected, in direction of the clip $V_{sa,y}$ is increased to $V_{sa,y,clip}$ , according Hilti technical data. In the opposite direction, the standard value of $V_{sc,y}$ are applied:

Verifications:
$$\phi V_{sc,y,clip} \geq V^a_{ua,y}\ y \quad \text{(in clip direction)}$$
$$\phi V_{sc,y} \geq V^a_{ua,y}$$

### Concrete pryout strength : $\phi V_{cp,y}$

Verifications:

$\phi V_{cp,y} > V_{aua}$



**Concrete pryout strength: $\phi V_{cp,y}$**

The capacity of anchor is in accordance to ESR-3520 Sec. 4.1.3.3.4. Please refer to table 2.2.7.1, 2.2.7.2 and 2.2.7.3 of chapter 02 for parameters and section 7.4.2 of chapter 07 of anchor channel theory for analysis.

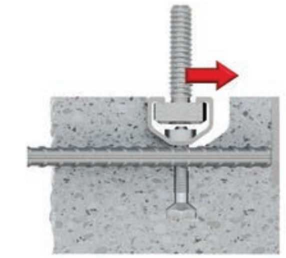


### Concrete breakout strength (shear perpendicular, Hilti method) : $\Phi V_{cb,y}$

Without the EDGE front plate, with and without Clip, the concrete edge verification is performed according to ESR3520. With edge plate following methodolgy is applied.

Verification: $\Phi V_{cb,y} > V_{aua,y}$

With



**Concrete breakout strength: $\Phi V_{cb,y}$**

$$V_{cb,y} = V_b \cdot \Psi_{s,V} \cdot \Psi_{h,V} \cdot \Psi_{co,V} \cdot \Psi_{c,V}$$

$V_b$ : is the basic concrete breakout strength for perpendicular shear of a single anchor in cracked concrete, in combination with the EDGE plate, lbf. (kN):

$$V_b = \lambda_{cb,RToS} \cdot k_{RToS} \cdot c_{a1}^{x1} \cdot f_c'^{x2}$$

$\lambda_{cb,RToS}$ modification factor for lightweight concrete for EDGE concrete edge breakout

$k_{RToS}$ factor to account for the influence of plate size and rebar diameter on concrete edge breakout strength in shear, in case of the EDGE C the verification is the same this the only parameter which is varying (-) Refer Table 2.3.12.1and Table 2.3.8.1 of chapter 02.

$c_{a1}$ edge distance of anchor channel in direction 1

$x_1$ Exponent for the edge distance in the basic value of the concrete edge breakout strength, (-) Refer Table 2.3.12.1 and Table 2.3.8.1 of chapter 02

$f_c'$ specified concrete compressive strength, psi (MPa)

$x_2$ Exponent for the concrete strength in the basic value of the concrete edge breakout, (-) Refer Table 2.3.12.1 and Table 2.3.8.1 of chapter 02

$\Psi_{s,V}$ modification factor to account for influence of location and loading of neighboring anchors on concrete edge breakout strength for anchor channels loaded in shear (-). $\Psi_{s,V}$ takes the position of the load on the neighboring anchors within a distance of $S_{cr,V}$ into account. The ratio $V_{uai}$ / $V_{ua,1}$ the relative load and utilization is considered in reduction factor of capacity.

$$\psi_{s,V} = \frac{1}{1+\sum_{i=2}^{n+1}\left[\left(1-\frac{s_i}{s_{cr,V}}\right)^{1.5}\cdot\frac{V^a_{ua,i}}{V^a_{ua,1}}\right]}$$

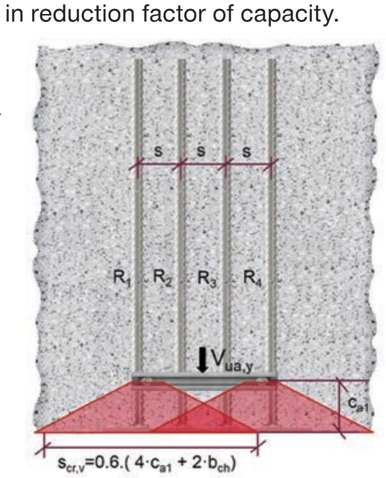



**Figure 9.6.2.5 — Modification of anchor spacing: $\Psi_{s,v}$.**

$s_i$ distance between the anchor under consideration and the adjacent anchors, in. (mm) ≤ $s_{cr,V}$

$$s_{cr,V} = \alpha_{1,V}(4c_{a1} + 2b_{ch})\ in.(mm)$$

$\alpha_{1,v}$ Modification factor for the critical anchor spacing in combination with the EDGE plate refer Table 2.3.8.1 and Table 2.3.12.1

The $\alpha_{1,v}$ leads to smaller value of $s_{cr,v}$, which means that the relative influence on two anchors for shear load is smaller than on a standard channel. This is because the rebars take a large part of the shear load and the concrete failure is "limited" in a smaller influence area. Please note that the consideration of having rebars attached to the edge plate is reflected in the $s_{cr,v}$ expression by the reduction of the critical spacing by 0.6.

$V_{aua,i}$ factored shear load of an influencing anchor, lbf (kN)

$V_{aua,1}$ factored shear load of the anchor under consideration, lbf (kN)

n number of anchors within a distance $s_{cr,V}$ to both sides of the anchor under consideration.

$\Psi_{h,V}$ modification factor to account for influence of member thickness on concrete edge breakout strength for anchors channels loaded in shear [-]:

$$h_{cr,V} = 2c_{a1} \quad in.\ (mm)$$

$$\psi_{h,V} = \left(\frac{h}{h_{cr,V}}\right)^{x3} \leq 1.0$$

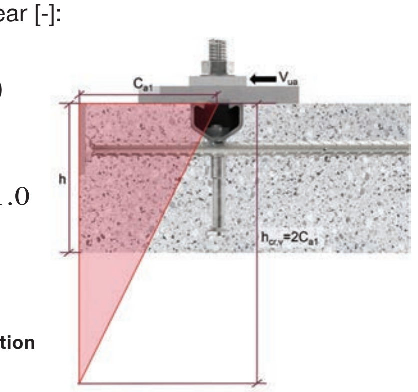



**Figure 9.6.2.6 — Modification of height $\Psi_{h,v}$.**

$x_3$ Exponent for the modification factor to account for influence of member thickness on concrete edge breakout strength for anchors channels loaded in shear Refer Table 2.3.12.1 and Table 2.3.8.1 of chapter 02.

$\Psi_{ca,V}$ modification factor for corner effects on concrete edge breakout strength for anchor channels loaded in shear [-]:

$$\psi_{co,V} = \left(\frac{c_{a2}}{c_{cr,V}}\right)^{x4} \leq 1.0$$

$$c_{cr,V} = 2c_{a1} + b_{ch}, \quad in.\ (mm)$$

$x_4$ Exponent for the modification factor for corner effects on concrete edge breakout strength for anchor channels loaded in shear Refer Table 2.3.12.1 and Table 2.3.8.1 of chapter 02.

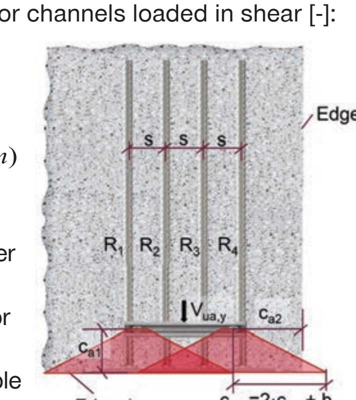



**Figure 9.6.2.7 — Modification of corner effect: $\Psi_{co,v}$.**

If two corners are available, a $\Psi_{co,V}$ for second corner is calculated and multiplied by the first. For narrow members ($c_{a2,max} < c_{cr,V}$) with a thickness $h < h_{cr,V}$ the same prescriptions as in AC232 are adopted and the edge distance $c_{a1}$ in the calculation of $V_b$ shall not exceed the following value of $c_{a1,red}$:

$$c_{a1,red} = \max\left(\frac{c_{a2,max} - b_{ch}}{2}, \frac{h - 2h_{ch}}{2}\right)$$

$\Psi_{c,V}$ = 1.0 modification factor for cracked concrete, always 1.0

## Determination of anchor and rebar forces acting on the channel

In combination with the EDGE front plate all the actions on the anchors (tension, perpendicular and longitudinal shear) are calculated with the method of AC232.

The tension load on the rebars is also calculated with the model of AC232, with a modification of $\ell_{in}$, as specified below.

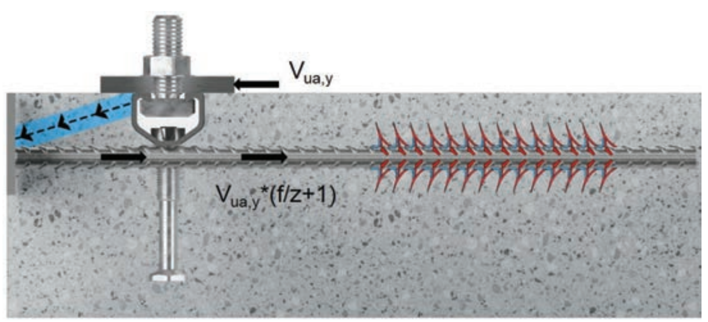



**Figure 9.6.2.8 — Load Path.**

- **Rebar tensile forces (Hilti Method):** The rebar tensile forces $N_{rua,i}$ are calculated with the bolt factored shear load $V^b_{ua,y}$ with the same method, based on a triangular distribution, described in the previous paragraph.
  In this case the base of the triangle $\ell$ in is reduced as specified in eq. (2) and loads are also increased by the ratio (es / z + 1) to take the load eccentricity into account (see in Figure 9.6.2.10).

$$N^r_{ua,i} = k.A'_i.V^b_{ua}((e_s/z)+1);$$

Where:

$A'_{r,i}$ ordinate at the position of the rebar i assuming a triangle with the unit height at the position of load $V_{ua}$ and the base length $2\cdot\ell_{in,r}$ with $\ell_{in,r}$ determined in accordance with (Equation 9.6.2.1). Examples are provided in Figure 9.6.2.9.

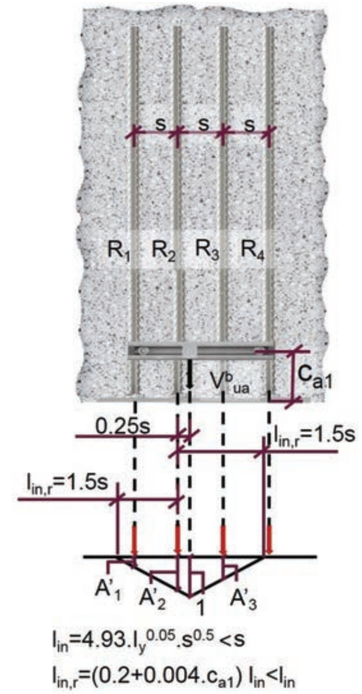



**Figure 9.6.2.9 — Example for the calculation of rebar forces in accordance with the triangular load distribution method for an anchor channel with four rebars. The influence length is assumed as $\ell_{in}$ = 1.5s**

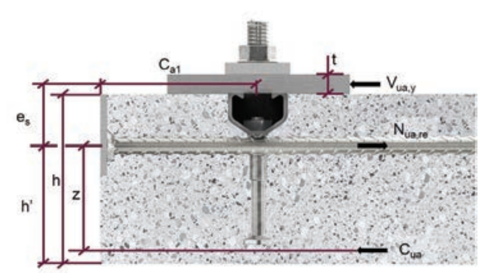



**Figure 9.6.2.10 — Anchor reinforcement to resist shear loads.**

$$k = 1/\sum A'_{r,i}$$
$$l_{in} = 4.93.I_y^{0.05}.s^{0.5} < s$$
$$l_{in,r} = (0.2 + 0.004c_{a1})l_{in} \le l_{in} \quad in \qquad \text{Equation 9.6.2.1}$$

$s = anchor\ spacing,\ in$

$V^b_{ua} = factored\ tension\ load\ on\ channel\ bolt,\ lb$

$t = anchor\ plate\ thickness$

$e_c = dist\ between\ concrete\ top\ surface\ and\ anchor\ plate\ bottom\ surface$

$z = 0.85.h'$

$h' = h - h_{ch} - \frac{d_b}{2} \le \min(2.h_{ef}, 2.c_{a1})$

$h$ = actual member depth

$h_{ch} = height\ of\ anchor\ channel$

$h_{ef} = embedment\ depth\ of\ the\ anchor$ under consideration

$c_{a1} = edge\ distance\ of\ the\ anchor$ under consideration

$$e_s = e_c + \frac{t}{2} + h_{ch} + \frac{d_b}{2} + 0.0394 \quad for\ EDGE,\ in$$
$$e_s = e_c + \frac{t}{2} + h_{ch} + \frac{3d_b}{2} + 0.0787 \quad for\ EDGE\ C,\ in$$

$$A'_1 = \frac{0.25\cdot s}{l_{in}} = \frac{1}{6}$$
$$A'_2 = \frac{1.25\cdot s}{l_{in}} = \frac{5}{6}$$
$$A'_3 = \frac{0.75\cdot s}{l_{in}} = \frac{1}{2}$$
$$k = \frac{1}{A'_1 + A'_2 + A'_3} = \frac{2}{3}$$
$$N^r_{ua,1} = \left(\frac{1}{6}\right).\left(\frac{2}{3}\right).V^b_{ua}.\left(\frac{e_s}{z}+1\right) = \left(\frac{1}{9}\right).V^b_{ua}.\left(\frac{e_s}{z}+1\right)$$
$$N^r_{ua,2} = \left(\frac{5}{6}\right).\left(\frac{2}{3}\right).V^b_{ua}.\left(\frac{e_s}{z}+1\right) = \left(\frac{5}{9}\right).V^b_{ua}.\left(\frac{e_s}{z}+1\right)$$
$$N^r_{ua,3} = \left(\frac{1}{2}\right).\left(\frac{2}{3}\right).V^b_{ua}.\left(\frac{e_s}{z}+1\right) = \left(\frac{1}{3}\right).V^b_{ua}.\left(\frac{e_s}{z}+1\right)$$

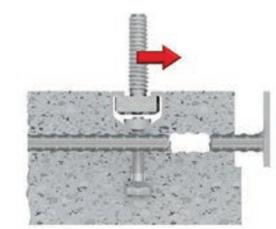
If several tension or shear loads are acting on the channel a linear superimposition of the rebar forces for all shear loads is assumed.

In case of forces acting toward the inside of the slab, rebars forces are added in a similar way as for the anchors. Negative resulting forces on the rebars are neglected.

## EDGE Steel strength of rebar : $\Phi N_{s,R}$

$\Phi N_{s,R} > N^b_{ua}$

The capacity of steel rebar Hilti Method is in accordance to ESR-3520 Sec. 4.1.3.3.3. Please refer to table 2.3.23.1 of chapter 02.



**Rebar: $\Phi N_{s,R}$**

$$N_{s,R} = \frac{\pi.d^2}{4}.f_y$$

$f_y = nominal\ yield\ strength\ of\ the\ EDGE\ reinforcement$

$d = diameter\ of\ the\ EDGE\ reinforcement$

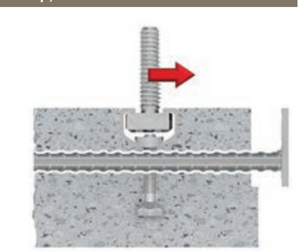
$N^r_{ua} = diameter\ of\ the\ EDGE\ reinforcement$

$\phi = 0.75$

## EDGE pull-out strength of rebar : $\Phi N_{p,R}$

$\Phi N_{p,R} > N_{rua}$

In general an verification acc. to ACI 318-11 is performed by comparing a development length with a provided length. Due to the fact that the provided length as well as the diameter of the rebar is fixed a possible (virtual) "anchorable" force (stress) in the rebar is "back"-calculated. For the verification this "anchorable" force $N_{p,R}$ will be compared with the acting force $N_{rua}$ on the rebar.



**Pullout: $\Phi N_{p,R}$**

$$l_{d,prov} \ge l_d = \left(\frac{3}{40}.\frac{f_y}{\lambda.\sqrt{f'_c}}.\frac{\psi_t.\psi_e.\psi_s}{\left(\frac{c_d + K_{tr}}{d_b}\right)}\right).d_b \ge 12in$$

$f_y = yield\ strength\ of - reinforcement\ [psi]$

$\lambda = 1.0\ for\ normal-weight\ concrete$

$\lambda = 0.75\ for\ all-lightweight\ concrete$

$f_c = concrete\ cylinder\ compressive\ strength\ [psi]$

$K_{tr} = 0 - no - transverse - reinforcement - is - taken - into - account$

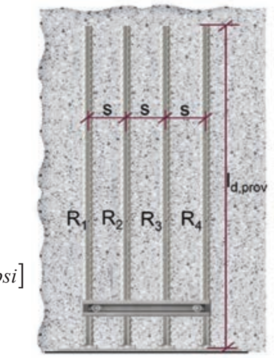



**Figure 9.6.2.11 — Developement**

$\frac{c_b}{d_b} \le 2.5$ – influence of concrete cover

$c_b$ = to be determined taking into account the rebar position and the member geometry

$\Psi t = 1.3$ – where horizontal reinforcement is placed such that more than 12 in. of fresh concrete is cast below the development length - > to be determined taking into account the rebar position and the member geometry

$\Psi_t = 1.0$ for other situations

$\Psi_e = 1.0$ for uncoated reinforcement

$\Psi_s = 0.8$ for No. 6 and smaller bars (db ≤ 0.75in.)

$\Psi_s = 1.0$ for No. 7 and larger bars (db ≥ 0.875in.)

db = reinforcement diameter [in.]

$l_{d,prov} = l_R - c_{a1}$ provided length

$\phi = 0.75$ reduction factor

$\phi_{seismic} = 0.75$ additional reduction factor for seismic

Anchorable force:

$l_{d,prov} = 12$ in

$$(f_y =)\sigma_d = l_{d,prov}.\pi.d_b.\frac{10}{3}.\lambda.\sqrt{f'_c}.\min\left(\frac{c_d}{d_b}, 2.5\right).\frac{1}{\psi_t.\psi_e.\psi_s}$$

$$N_{P,R} = \frac{\pi.d^2_{s,R}}{4}.\sigma_d = l_{d,prov}.\pi.d_b.\frac{10}{3}.\lambda.\sqrt{f'_c}.\min\left(\frac{c_d}{d_b}, 2.5\right).\frac{1}{\psi_t.\psi_e.\psi_s}$$

## Anchor reinforcement anchorage: $\Phi V_{ca}$

**$\Phi V_{ca} > V_{aua}$**

In combination with the EDGE front In combination with the EDGE front plate, it is not allowed to consider also the supplementary reinforcement.

Without the EDGE front plate, with and without lip strengthening element (clip), ESR-3520 applies

Not Permitted

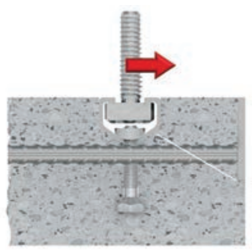
**Anchor reinforcement anchorage: $\Phi V_{ca}$**

## Concrete breakout in shear

"Reinforcing bars comprising part of the Hilti Anchor Channel (HAC) system are proportioned to meet the development length provisions of the code as they apply to cases where anchorage development for fully $f_y$ is not required. The concrete member in which the anchor channel is installed shall be in conformance with the requirements of the code for reinforced concrete and designed for the load introduced by the anchor channel."

## Remark for SLS crack width

The characteristic crack width at the side of the channel is calculated based on empirical equation.



Crack width: $w_k$

$N^r_{serv}$ (KN) is the force on the rebar at the serviceability level and is obtained with the safety factor for serviceability:

$$N^r{}_{serv} = \frac{N^r{}_{ua}}{\gamma_{SLS}} \ (KN)$$

$N^r_{ua}$ is the maximum of the factored shear load of the first and the last rebar (R1 and R4 in Figure 9.6.2.9)

$\gamma_{SLS}$ reduces the shear loads which are defined for strength verification to a service level and should be selected by the user in Profis >Options >Project options>safety factors. The current "safety factor for 1st crack in SLS check" should be renamed in "Shear factor for serviceability crack width check" (Figure 9.6.2.12), $\gamma_{SLS}$ will be assumed 1 as default.

Remark in Profis:

If the calculated $w_k$ < 0.3 mm: Cracking of the concrete may occur at service load levels. The characteristic crack width is less than 0.3 mm (0.012 in.). This value is calculated based on experimental investigations on anchor channels loaded in shear in unreinforced concrete slabs.

If $w_k$ ≥ 0.3 mm: Cracking of the concrete may occur at service load levels. The characteristic crack width is x mm (x in.). This value is calculated based on experimental investigations on anchor channels loaded in shear in unreinforced concrete slabs. The crack widths are smaller in case of reinforcement in the slab. The data obtained with experimental program performed for the development and qualification of HAC EDGE.

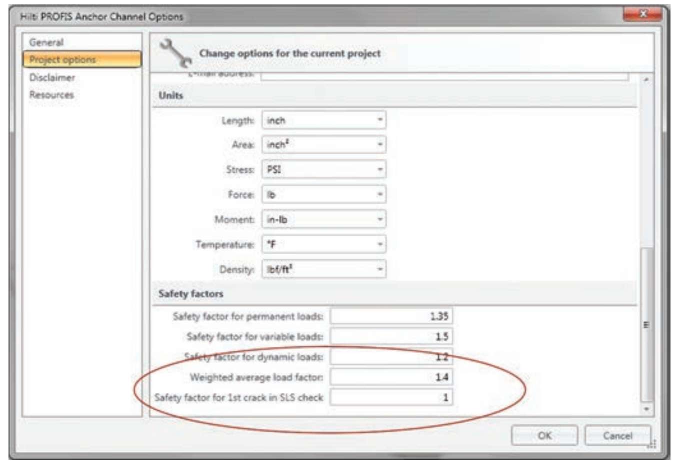



Figure 9.6.2.12 — Hilti Profis Anchor Channel Options.

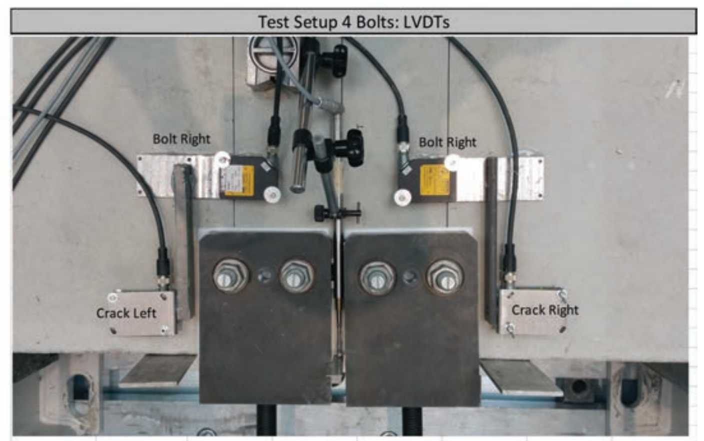



Figure 9.6.2.13 — Test Setup 4 Bolts: LVDTs.

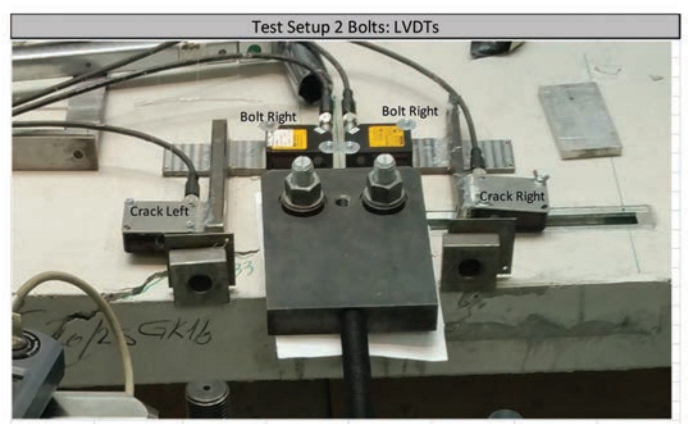
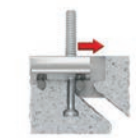
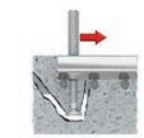



Figure 9.6.2.14 — Test Setup 2 Bolts: LVDTs.

| LONGITUDINAL SHEAR | | | | | |
|---|---|---|---|---|---|
| Steel Failure Modes | | | | Concrete Failure Modes | |
| Channel bolt: | Channel Lip | Connection | Anchor | Concrete Breakout | Concrete Pryout |
|  |  |  |  |  |  |
| ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2 | ESR-3520 Sec. 4.1.3.4.3 | ESR-3520 Sec. 4.1.3.4.4 |
| | | | | **Anchor reinf. steel** | **Anchor reinf. anchorage** |
| | | | | Not permitted | Not permitted |

Concrete breakout strength for parallel shear: The concrete breakout strength for parallel shear is calculated according ESR for both channels are verified independently and neglecting the EDGE front plate. The concrete utilization of both edges is then combined in conservative way as described in the next paragraph.

### Channel Lip strength: $\Phi V_{s,l,x}$

$\Phi V_{s,l,x} > V_{aua,x}$

This check is in accordance to ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2

Please refer table 2.3.18.3 and 2.3.22.3 for strength values.

Channel bolt and channel lip connection: $\Phi V_{s,l,x}$

### Anchor strength: $\Phi V_{sa,x}$

$\Phi V_{sa,x} > V_{aua,x}$

This check is in accordance to ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2

Please refer table 2.3.18.1 and 2.3.10.1 for strength values.

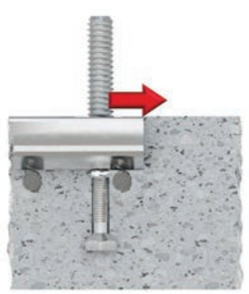
Anchor reinforcement anchorage: $\Phi V_{ca}$

### Connection Anchor and Channel : $\Phi V_{sc,x}$

$\Phi V_{sc,x} > V_{aua}$

This check is in accordance to ESR-3520 Sec. 4.1.3.3.2, 4.1.3.4.2

Please refer table 2.3.18.1 and 2.3.10.1 for strength values.

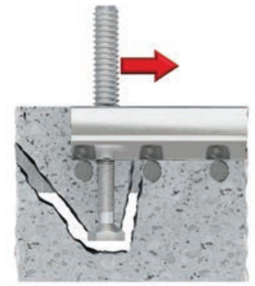


Anchor reinforcement anchorage: $\Phi V_{ca}$

### Concrete pryout strength for shear parallel: $\Phi V_{cp,x}$

$\Phi V_{cp,x} > V_{aua,x}$

Please refer to anchor channel theory for more information on this failure mode. The design methodology is same as of headed stud anchor channel. This check is compliant with ESR 3520 section 4.1.3.4.4. Refer Anchor channel theory Section 7.4.4

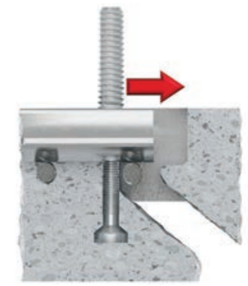


Anchor reinforcement anchorage: $\Phi V_{ca}$

### Concrete breakout strength for shear parallel: $\Phi V_{cb,x}$

$\Phi V_{cb,x} > V_{aua,x}$

Please refer to anchor channel theory for more information on this failure mode. The design methodology is same as of headed stud anchor channel. This check is compliant with ESR 3520 section 4.1.3.4.3. Refer Anchor channel theory Section 7.4.4.



Anchor reinforcement anchorage: $\Phi V_{ca}$



## Required verifications under combined tension and shear loading

If forces act in more than one direction the combination of loads has to be verified. Anchor channels subjected to combined axial and shear loads shall be designed to satisfy the following requirements by distinguishing between steel failure of the channel bolt, steel failure modes of the channel and concrete failure modes.

Steel failure of channel bolts under combined loads (ESR-3520)

$$\beta_{N+V,s} = \left(\frac{N^s_{ua}}{\phi.N_{ss}}\right)^2 + \left(\frac{\sqrt{V^s_{ua,y}{}^2 + V^s_{ua,x}{}^2}}{\phi.Vss}\right) \leq 1.0$$

$$\beta_{Ns} = \left(\frac{N^s_{ua}}{\phi.N_{ss}}\right)^2 \leq 1.0$$ highest utlization under tension loading per channel bolt

$$\beta_{V,s} = \left(\frac{\sqrt{V^s_{ua,y}{}^2 + V^s_{ua,x}{}^2}}{\phi.Vss}\right) \leq 1.0$$ highest utlization under shear loading per channel bolt

Steel failure modes of rebar channels under combined loads (ESR-3520)

a) For connection between anchor and channel

$$\beta_{N+V,ac} = \max\left(\frac{N^a_{ua}}{\phi N_{sa}}, \frac{N^a_{ua}}{\phi N_{sc}}\right)^\alpha + \max\left(\frac{V^a_{ua,y}}{\phi V_{sa,y}}, \frac{V^a_{ua,y}}{\phi V_{sc,y}}\right)^\alpha + \max\left(\frac{V^a_{ua,x}}{\phi V_{sa,x}}, \frac{V^a_{ua,x}}{\phi V_{sc,x}}\right)^2 \leq 1.0$$

$$\beta_{N,ac} = \max\left(\frac{N^a_{ua}}{\phi N_{sa}}, \frac{N^a_{ua}}{\phi N_{sc}}\right) \leq 1.0$$ highest utlization under tension loading per rebar

$$\beta_{V,ac,y} = \max\left(\frac{V^a_{ua,y}}{\phi V_{sa,y}}, \frac{V^a_{ua,y}}{\phi V_{sc,y}}\right) \leq 1.0$$ highest utlization under shear loading (perpendicular) per rebar

$$\beta_{V,ac,x} = \max\left(\frac{V^a_{ua,x}}{\phi V_{sa,x}}, \frac{V^a_{ua,x}}{\phi V_{sc,x}}\right) \leq 1.0$$ highest utlization under shear loading (perpendicular) per rebar

$\alpha = 2.0$ for rebar channels with $\max(V_{sa,y}, V_{sc,y}) \leq \min(N_{sa}, N_{sc})$

$\alpha = 1.0$ for rebar channels with $\max(V_{sa,y}, V_{sc,y}) > \min(N_{sa}, N_{sc})$

It is permitted to assume reduced values for $V_{sa,y}$ and $V_{sc,y}$ corresponding to the use of an exponent α = 2. In this case the reduced values for $V_{sa,y}$ and $V_{sc,y}$ shall also be used

b) At the point of load application

$$\beta_{N+V,lac} = \left(\frac{N^s_{ua}}{\phi N_{sl}}\right)^{\alpha} + \left(\frac{V^s_{ua,y}}{\phi V_{sl,y}}\right)^{\alpha} + \left(\frac{V^s_{ua,x}}{\phi V_{sl,x}}\right)^{2} \leq 1.0$$

$$\beta_{N+V,la,m-c} = \left(\frac{M_{u,flex}}{\phi M_{s,flex}}\right)^{\alpha} + \left(\frac{V^s_{ua,y}}{\phi V_{sl,y}}\right)^{\alpha} + \left(\frac{V^s_{ua,x}}{\phi V_{sl,x}}\right)^{2} \leq 1.0$$

$\beta_{N,la,c} = \left(\frac{N^s{}_{ua}}{\varphi . N_{sl}}\right) \leq 1.0$ highest utlization under tension loading per per t-bolt

$\beta_{V,la,c,y} = \left(\frac{V^s{}_{ua,y}}{\varphi . V_{sl,y}}\right) \leq 1.0$ highest utilization under shear loading ⊥ per t-bolt

$\beta_{V,la,c,x} = \left(\frac{V^s{}_{ua,x}}{\varphi . V_{sl,x}}\right) \leq 1.0$ highest utilization under shear loading parallel per t-bolt

$\beta_{V,la,m} = \left(\frac{M_{u,flex}}{\varphi . M_{s,flex}}\right) \leq 1.0$ highest utilization under tension loading per t-bolt

$\alpha = 2.0$ for rebar channels with $V_{sl,y} \leq N_{sl}$

$\alpha = 1.0$ for rebar channels with $V_{sl,y} > N_{sl}$

It is permitted to assume reduced values for $V_{sl,y}$ corresponding to the use of an exponent α = 2. In this case the reduced values for $V_{sl,y}$ shall also be used.

**Concrete failure modes of anchor channels under combined loads**

A verification for each anchor is needed:

$$\beta_{N+V,c} = \left(\frac{N^a{}_{ua}}{\varphi . N_{sc}}\right)^{\alpha} + \left(\frac{V^a{}_{ua,y}}{\varphi . V_{nc,y}}\right)^{\alpha} + \left(\frac{V^a{}_{ua,x}}{\varphi . V_{nc,x}}\right)^{\alpha} \leq 1.0$$

$\beta_{N,c} = \left(\frac{N^a{}_{ua}}{\varphi . N_{sc}}\right) \leq 1.0$  $\beta_{N,c}$ highest anchor utilization for tension loading between:

- blow out ($N_{sb}$)
- anchor pull-out ($N_{pn}$)
- concrete breakout ($N_{cb}$)
- anchor reinforcement (if available $N_{ca,s}$, $N_{ca}$)

$\beta_{V,c,y} = \left(\frac{V^a{}_{ua,y}}{\varphi . V_{nc,y}}\right) \leq 1.0$  $\beta_{V,c,y}$ highest utilization under shear loading (perpendicular):

- EDGE rebar steel in tension ($N_{s,R}$)[1)]
- pull-out of EDGE reinforcement ($N_{p,R}$)[1)]
- pryout for perpendicular shear ($V_{cp,y}$)
- concrete edge failure ($V_{cb,y}$)

[1)] the rebar with higher tension load of the whole connection governs

$\beta_{V,c,x} = \left(\frac{V^a{}_{ua,x}}{\varphi . V_{nc,x}}\right) \leq 1.0$  $\beta_{V,c,x}$ highest utilization under shear loading (parallel):

- concrete breakout ($V_{cb,x}$)
- pryout for parallel shear ($V_{cp,y}$)

$\alpha = \frac{5}{3}$ for rebar channels without anchor reinforcement and in combination with the EDGE front Plate

$\alpha = 1.0$ with anchor reinforcement to take up tension and parallel shear loads

## 9.6.3 — HAC (T) EDGE, HAC (T) EDGE LITE AND HAC S (T) EDGE DESIGN: IN METAL DECK APPLICATIONS

The capacity of anchor channel should be reduced because of the presence of a metal deck. The following failure modes should be modified:

- **EDGE pull-out strength of rebar:** In general an verification according to ACI 318-11 is performed by comparing a development length with a provided length. Due to the fact that the provided length as well as the diameter of the rebar is fixed a possible (virtual) "anchorage" force (stress) in the rebar is "back"-calculated. For the verification this "anchorage" force $N_{p,R}$ will be compared with the acting force $N^r_{ua}$ on the rebar.

Please refer to the section: 9.6.2 of this chapter for the method of calculating the forces at the rebar $N^r_{ua}$.

$\phi N_{p,R} \geq N^r_{ua}$

$$(f_y =)\sigma_d = l_{d,\,prov} . \pi . d_b . \frac{10}{3} . \lambda . \sqrt{f'_c} . \min\left(\frac{c_d}{d_b}, 2.5\right) . \frac{1}{\psi_t . \psi_e . \psi_s}$$

$$N_{P,R} = \frac{\pi . d^2{}_{s,R}}{4} . \sigma_d = l_{d,\,prov} . \pi . d_b . \frac{10}{3} . \lambda . \sqrt{f'_c} . \min\left(\frac{c_d}{d_b}, 2.5\right) . \frac{1}{\psi_t . \psi_e . \psi_s}$$

$f_y$ = yield strength of reinforcement [psi]

λ=1.0 for normal-weight concrete

λ=0.75 for all-lightweight concrete

λ=0.75 for sand-lightweight concrete

$f_c$ concrete cylinder compressive strength [psi]

$K_{tr}$ = 0 no transverse reinforcement is taken into account

$c_b$ / $d_b$ ≤ 2.5 influence of concrete cover

The $c_b$ cover on the rebar where the rebar goes on top of metal deck should be measured from center of rebar to the metal deck. The $c_b$ value is taken as minimum value of $x_1$ and $x_2$ in the development length equation. The pullout strength gets reduced due to the reduced cover if the ratio $c_b/d_b$ is less than 2.5. Please refer to rebar theory and design of anchor channel design code chapters 7 and 8 for more information on this failure mode.

The concrete cover gets affected when the anchor channel is in a metal deck. This affect cannot be modelled in PROFIS. PROFIS anchor channel software takes the $c_b$ as the $c_{b1}$ which is $h_{ch}$+0.5$d_b$. For the available product this $x_1/d_b$ ($c_b/d_b$) value is greater than 2.5, hence the capacity is not reduced because of the cover effect. Therefore check needs to be reevaluated by measuring the $c_{b2}$ as seen in Figure 9.6.3.1 and Figure 9.6.3.2. The ratio $x_2/d_b$ ($c_b/d_b$) is determined and if it is less than 2.5 then the capacity needs to be reduced. If value of the ratio is y=$x_2/d_b$ ($c_b/d_b$), then the capacity is reduced by the ratio of y/2.5. Refer Figure 9.6.3.1

**Concrete breakout strength in shear**

This dimension of height of substrate effects concrete breakout strength in perpendicular shear check. This will change the factor $\Psi_{h,V}$. It is recommended to model the concrete thickness h as seen in the Figure 9.6.3.1.

The dimension h in the formula below for $\Psi_{h,V}$ factor should be taken as h as shown in Figure 9.6.3.1.

Please refer to anchor channel design code for more information on concrete breakout in shear.

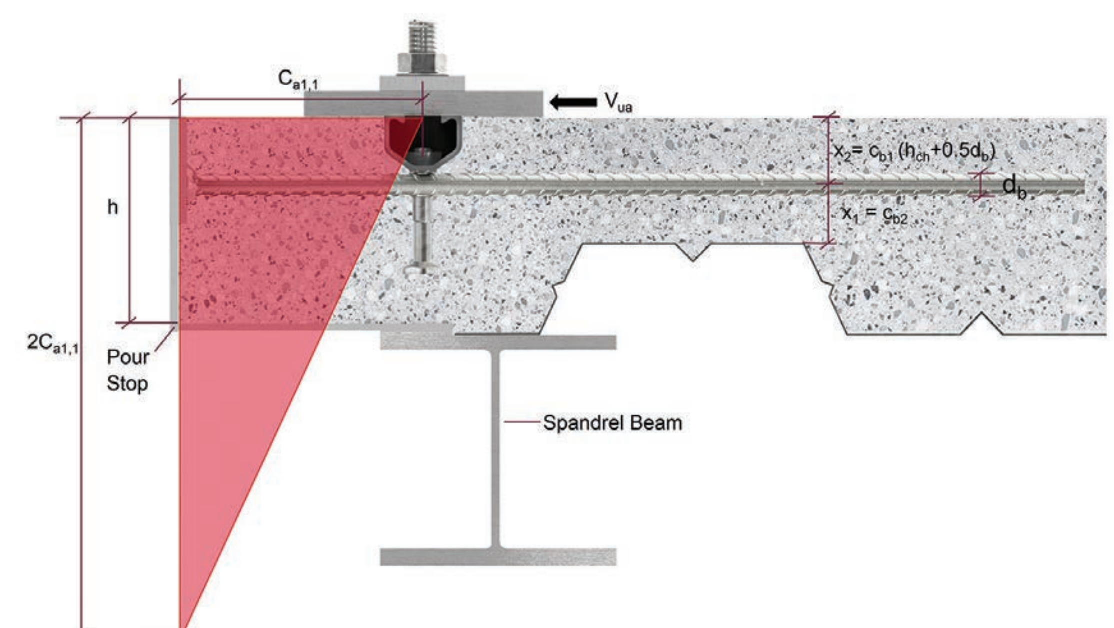



**Figure 9.6.3.1 — HAC EDGE, HAC EDGE Lite and HAC S EDGE — Composite slab — Shear out.**

**Concrete breakout strength in tension:**

An imaginary line is drawn to simulate the effect of metal deck by drawing the breakout cone in tension. It is recommended to limit the available concrete for tension to be $C_{a1,2}$, if $C_{a1,1}$ is more than $C_{a1,2}$. The following modification should be incorporated by modelling edge $C_{a1,2}$ as the edge or manually changing the reduction factor in the report, if profis does not allow modelling the edge because of minimum edge requirement. Reduction factor for edge is as seen below. Please refer to the section 7.2.3 of anchor channel theory for more information in regards to variable $C_{cr,N}$ Refer Figure 9.6.3.2.

$$\psi_{ed,N} = \left(\frac{C'_{a1}}{C_{cr,N}}\right)^{0.5} \leq 1.0$$

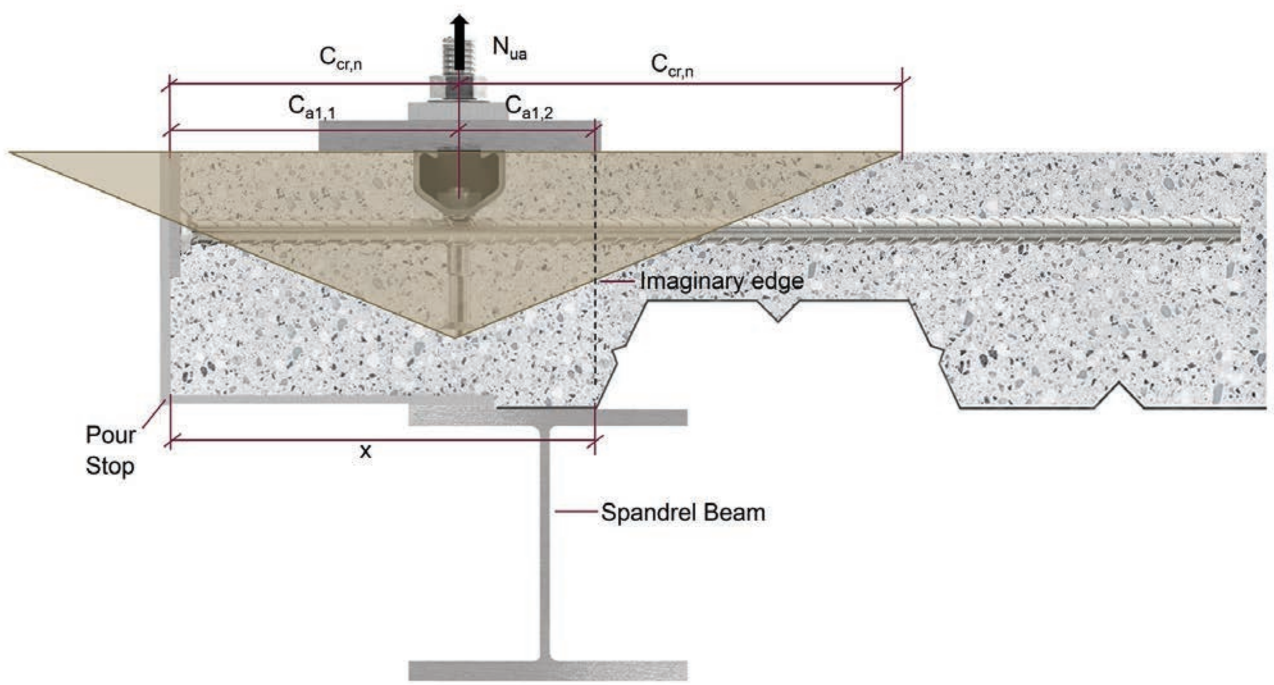



Figure 9.6.3.2 — HAC EDGE, HAC EDGE Lite and HAC S EDGE — Composite slab — Shear In.

# 9.6.4 — HAC (T) EDGE, HAC (T) EDGE LITE AND HAC S (T) EDGE DESIGN: TOP AND BOTTOM OF SLAB OUTSIDE CORNER SINGLE ANCHOR CHANNEL

## 90° corners

The concrete strengths in tension and shear of the anchor channel may be reduced (depending on how far the anchor channel is away from the corner) since the concrete cones may not be fully developed.

The design methodology is fully in accordance with the previous sub-chapter section 9.6.3 of Design of Anchor channel, only difference additional check described below.

Following concrete breakout in perpendicular shear is evaluated:

Concrete breakout strength — perpendicular shear, direction, y + accordance to Hilti method section 9.6.3 of Design of Anchor channel chapter

Concrete edge breakout strength — perpendicular shear, direction, x+ along longitudinal axis accordance to acc. to ESR-3520 section 4.1.3.3

It has been observed during testing of HAC (T) EDGE, HAC (T) EDGE Lite or HAC S (T) EDGE that concrete tends to break towards the side edge as seen in Figure 9.6.4.1, introducing the need to check the concrete breakout in perpendicular shear direction x+ along the longitudinal axis of the anchor channel. Having small side edge to the Concrete edge breakout strength — perpendicular shear, direction, x+ along longitudinal axis is checked and gets compared to the concrete breakout strength — perpendicular shear, direction, y +, which ever controls gets printed in the profis calculation report. The concrete shear strength in +y (perpendicular to channel axis) is not the controlling failure mode when anchor channel is installed at the corner because of the edge plate confinement.

**Concrete edge breakout strength — perpendicular shear, direction, x+ along longitudinal axis:**

Refer to the equation below

$$\phi V_{cb,y} \geq V^a_{ua,y}$$

$$V_{cb} = V_b . \psi_{s,v} . \psi_{co1,v} . \psi_{co2,v} . \psi_{c,v} . \psi_{h,v} . \psi_{parallel,v}$$

$$V_b = \lambda . \alpha_{ch} . \sqrt{f'_c} . c_{a1}^{\frac{4}{3}}$$

$$\psi_{s,v} = \frac{1}{1 + \sum_{i=2}^{n+1} \left(1 - \frac{s_i}{s_{cr,v}}\right)^{1.5} \cdot \frac{V^a_{ua,i}}{V^a_{ua,1}}} \leq 1.0$$

$$s_{cr,v} = 4C_{a1} + 2b_{ch}$$

$$\psi_{co1,v} = \left(\frac{c_{a2,1}}{c_{cr,v}}\right)^{1.5} \leq 1.0$$

$$\psi_{co2,v} = \left(\frac{c_{a2,2}}{c_{cr,v}}\right)^{1.5} \leq 1.0$$

$$c_{cr,v} = 0.5 . s_{cr,v} = 2c_{a1} + b_{ch}$$

$$\psi_{h,v} = \left(\frac{h}{h_{cr,v}}\right)^{0.5} \leq 1.0$$

$$h_{cr,v} = 2C_{a1} + 2h_{ch}$$

$$\psi_{parallel,v} = 3.5$$

Figure 9.6.4.1 — HAC (T) EDGE, HAC (T) EDGE Lite or HAC S (T) EDGE — Side breakout in perpendicular shear when Achor channel is installed at the corner.

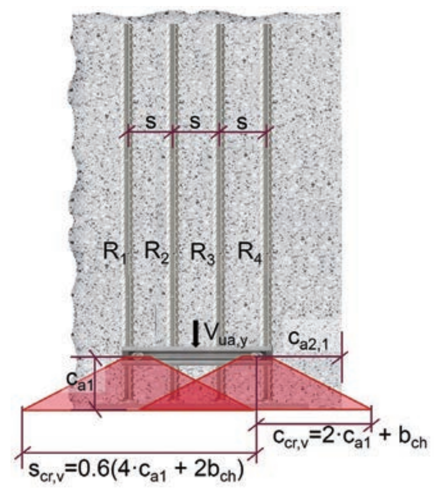



Figure 9.6.4.2 — TOS or BOS HAC EDGE single channel — Shear along perpendicular to axis y+.

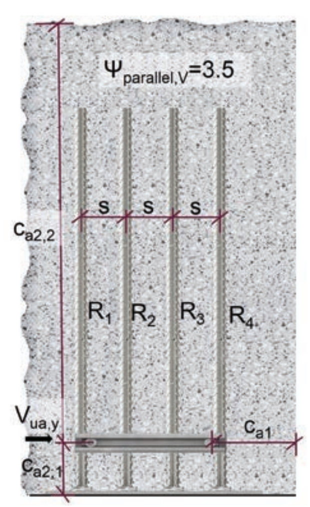



Figure 9.6.4.3 — TOS or BOS HAC EDGE single channel at certain distance – Shear along longitudinal axis x+.

### Acute and obtuse corners

Please refer section 9.2.7 for details on analyzing the obtuse and acute angle corner with single anchor HAC EDGE channel at the corner. Also refer 9.6.3 and 9.6.4 on details for analyzes and all the failure modes and interaction that needed to be taken into consideration.

## 9.6.5 — HAC (T) EDGE, HAC (T) EDGE LITE AND HAC S (T) EDGE DESIGN: TOP AND BOTTOM OF SLAB OUTSIDE CORNER WITH PAIR OF ANCHOR CHANNELS

### Corner Rebar Top of Slab (EDGE C)

In order to install two EDGE front plates close to an edge some modifications to the geometry of the product are needed. Indeed, the rebar location of one EDGE Plate (EDGE C) needs to be lower, in order to avoid clashing with the rebars of the adjacnet corner channel. This is illustrated in Figure 9.6.5.1.

For this application, one element is a standard EDGE and the second is the so-called Corner Rebar Top of Slab (EDGE C) front plate.

The EDGE C front plate is 20 mm higher and has the rebar 14 mm deeper in order to cross those of the other EDGE element. The thickness of the plate is increased to 6 mm instead of 5, in order to resist the bending moment due to the larger lever arm. The other geometrical dimensions, as well as the position and number of the rebars remains the same as described in chapter 02.

The vertical distance of the rebar center point from the concrete surface is for the EDGE C: $e_r = h_{ch} + 3d/2 + 2$ [mm]

Refer Figure 9.6.5.1 for the description. This $e_R$ will effect the magnitude of tension force that the rebars will experience as described below. Refer Figure 9.6.5.2 for the example of determining the rebar forces

It will not be possible to select a EDGE C front plate as stand-alone in Profis. A EDGE C will be automatically adopted when the corner is activated on the second edge.

$$k = 1 / \sum A'_{r,i}$$

$$l_{in} = 4.93 . I_y^{0.05} . s^{0.5}$$

$$l_{in,r} = (0.2 + 0.004 c_{a1}) l_{in} \le l_{in} \quad in$$

$s$ = anchor spacing, in

$V^b_{ua}$ = factored tension load on channel bolt, lb

$t$ = anchor plate thickness

$e_c$ = dist between concrete top surface and anchor plate bottom surface

$$z = 0.85 . h'$$

$$h' = h - h_{ch} - \frac{d_b}{2} \le \min(2.h_{ef}, 2.c_{a1})$$

$h$ = actual member depth

$h_{ch}$ = height of anchor channel

$h_{ef}$ = embedment depth of the anchor under consideration

$c_{a1}$ = edge distance of the anchor under consideration

$$e_s = e_c + \frac{t}{2} + h_{ch} + \frac{3d_b}{2} + 0.0787 \quad \text{for EDGE C, in}$$

### 90°, Acute and obtuse corners

Please refer section 9.2.10 for details on analyzing the obtuse and acute angle corner with pair HAC (T) EDGE or HAC S (T) EDGE anchor channel at the outside corner. Also refer 9.6.3 and 9.6.4 on details for analyzes and all the failure modes and interaction that needed to be taken into consideration.

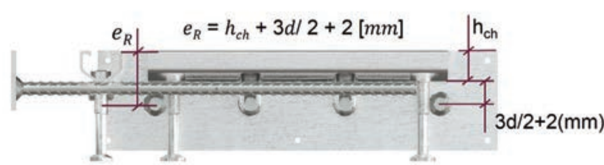



Figure 9.6.5.1 — TOS or BOS HAC (T) EDGE C anchor channel — $e_R$.

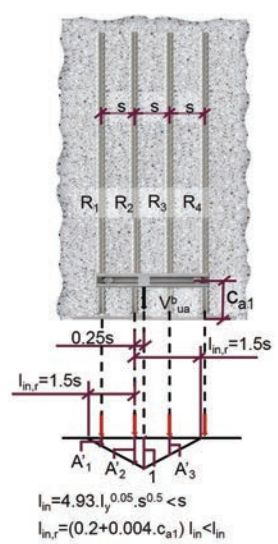



Figure 9.6.5.2 — Example for the calculation of rebar forces in accordance with the triangular load distribution method for an anchor channel with four rebars. The influence length is assumed as ℓin = 1.5s.

$$A'_1 = \frac{0.25 \cdot s}{l_{in}} = \frac{1}{6}$$

$$A'_2 = \frac{1.25 \cdot s}{l_{in}} = \frac{5}{6}$$

$$A'_3 = \frac{0.75 \cdot s}{l_{in}} = \frac{1}{2}$$

$$k = \frac{1}{A'_1 + A'_2 + A'_3} = \frac{2}{3}$$

$$N^r_{ua,1} = \left(\frac{1}{6}\right) \cdot \left(\frac{2}{3}\right) . V^b_{ua} \cdot \left(\frac{e_s}{z} + 1\right) = \left(\frac{1}{9}\right) . V^b_{ua} \cdot \left(\frac{e_s}{z} + 1\right)$$

$$N^r_{ua,2} = \left(\frac{5}{6}\right) \cdot \left(\frac{2}{3}\right) . V^b_{ua} \cdot \left(\frac{e_s}{z} + 1\right) = \left(\frac{5}{9}\right) . V^b_{ua} \cdot \left(\frac{e_s}{z} + 1\right)$$

$$N^r_{ua,3} = \left(\frac{1}{2}\right) \cdot \left(\frac{2}{3}\right) . V^b_{ua} \cdot \left(\frac{e_s}{z} + 1\right) = \left(\frac{1}{3}\right) . V^b_{ua} \cdot \left(\frac{e_s}{z} + 1\right)$$

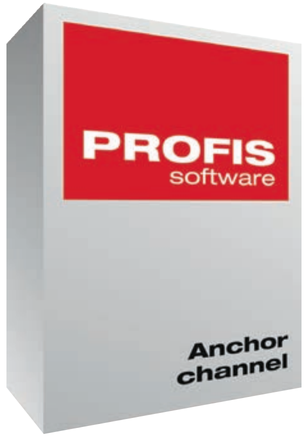


# 10. DESIGN SOFTWARE

PROFIS Anchor Channel allows users to quickly and accurately model anchor channel system applications. Through a simple, user-friendly interface, the verification of 20 anchor channel failure modes and 5 interaction equations can be done in seconds.

PROFIS Anchor Channel allows users to design anchor channels with anchor reinforcement. Moreover, the so called anchor channels with “rebars” (HAC CRFoS U and HAC EDGE) are available. The software also allows users to design even the most complex applications such as seismic, corners, and applications in lightweight concrete and thin slabs.

# PROFIS ANCHOR CHANNEL




The introduction of a design methodology for cast-in anchor channels brought significant benefits to the cast-in industry. Two major examples are the ability to optimize and confidently design an anchor channel system without relying on engineering judgment. On the other hand, it brought two major drawbacks; the design is highly complex and very time consuming.

Hand calculations for up to 25 failure modes, up to 5 interaction equations, different load combinations, varying t-bolt position along the anchor channel, bracket tolerance, substrate geometry, etc. becomes quite unpractical.

Moreover, designing via Excel spreadsheets or Mathcad sheets becomes risky and time consuming. Its programming complexity increases the probability of errors.

To cope with such drawbacks, Hilti developed PROFIS Anchor Channel software. It is design technology that allows users to quickly and accurately model anchor channel systems.

Through a simple, user-friendly interface, PROFIS Anchor Channel designs anchor fastenings for static and seismic applications in concrete, according to the most current building codes, approvals, and standards.

## WELCOME TO THE NEW ERA — PROFIS ANCHOR CHANNEL

### Innovate

- Portfolio of solutions for the most challenging applications.
- User-friendly interface to explore different design options.
- State of the art calculations.
- No design boundaries.

### Optimize

- Find the most cost-effective solution for your project.
- Productivity increase; all failure modes checks in real time at the click of a button.
- Explore different bracket geometries for an optimum fixture and anchor channel design.

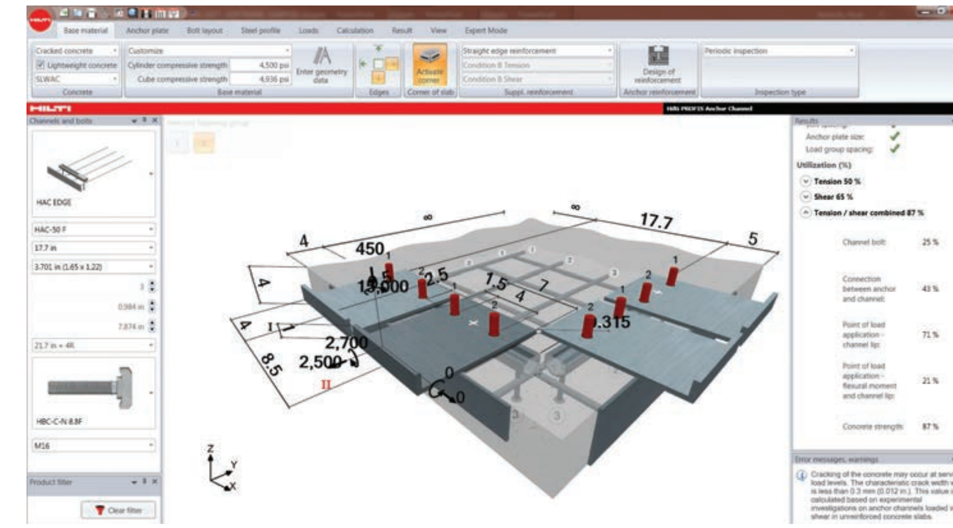
### Comply

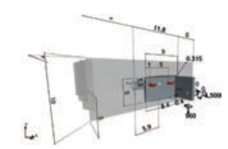
- Design models based on ICC ESR-3520, ACI 318, and/or AC232.
- Anchor channels tested according to AC232.
- Ensure general welfare.
- No more engineering judgments backed up by your P.E. license.

## 10.1 PROFIS ANCHOR CHANNEL SOFTWARE AT A GLANCE

Hilti has continuously invested in PROFIS Anchor Channel over the last 8 years. It is an ever improving software for an ever changing market. PROFIS Anchor Channel is the simplest and safest way to design Hilti Anchor Channel Systems. Similar to the product, the software brings added value to the design community. The software is available for free and can be downloaded from Hilti's website. and link below:

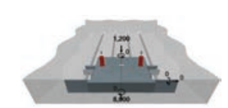
https://www.hilti.com/content/hilti/W1/US/en/engineering/software/profis/profischannel.html



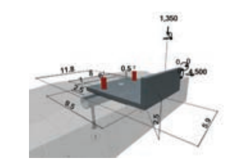


**3D graphics interface**

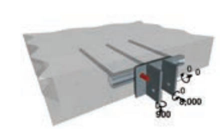

**Anchor channels in seismic design category C,D, E, or F**



**HAC EDGE**
top of slab anchor channels with shear confinement plate

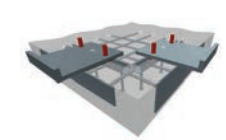


**Load resolution at bolts and Torsional moments**

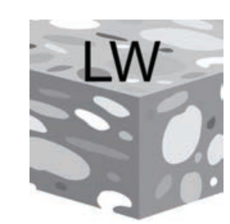


**HAC CRFoS U**

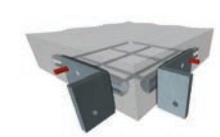

**Instantly and automatically utilization updates**



**Top of slab corners**




**Lightweight concrete**

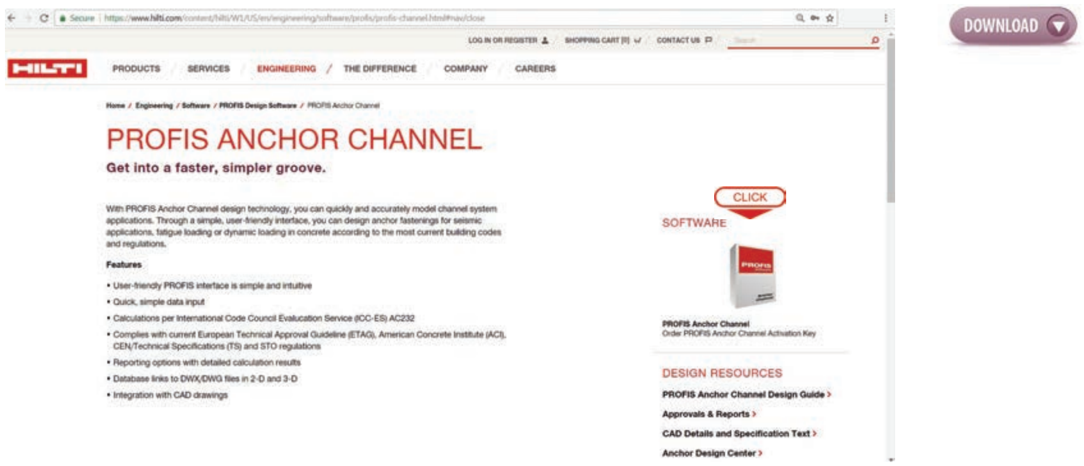


**Face of slab corners**

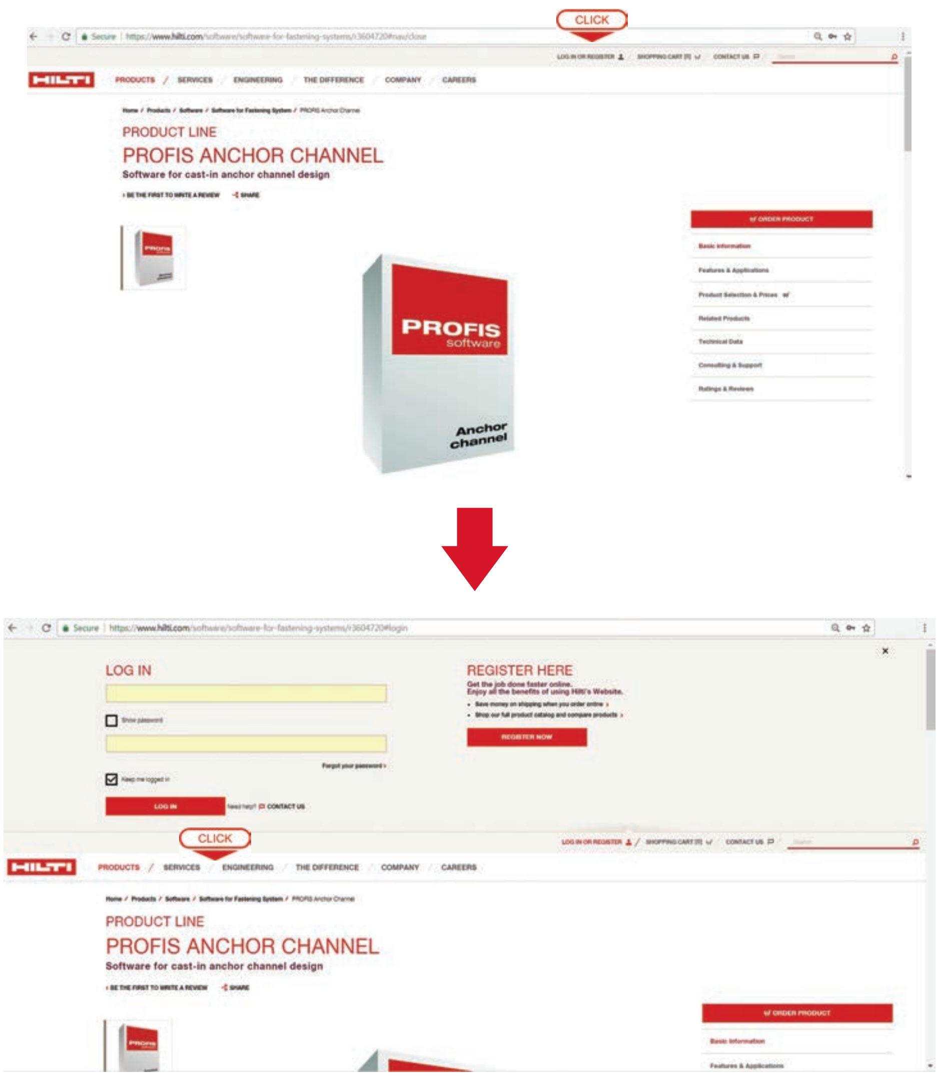
**Detailed analysis report**

# 10.2 DOWNLOAD THE SOFTWARE

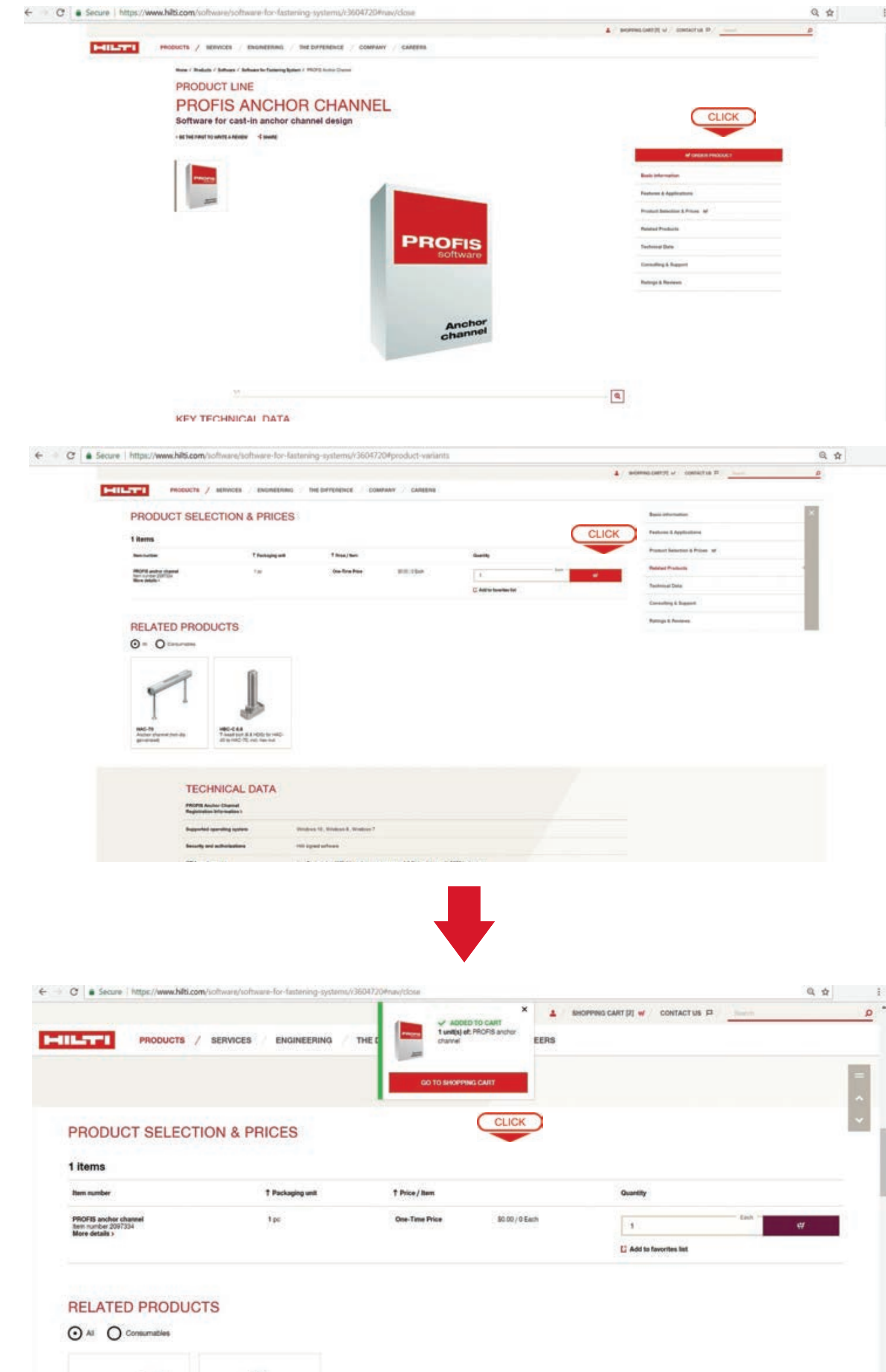
## ❶ Open website and click on PROFIS Anchor Channel Software



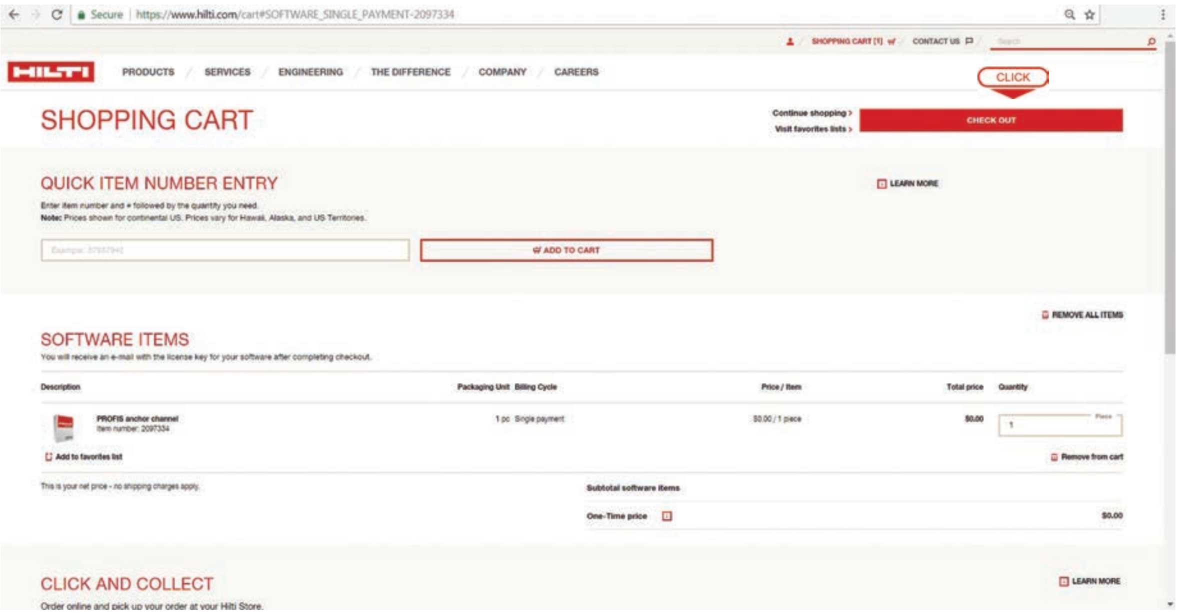

## ❷ Log in or register



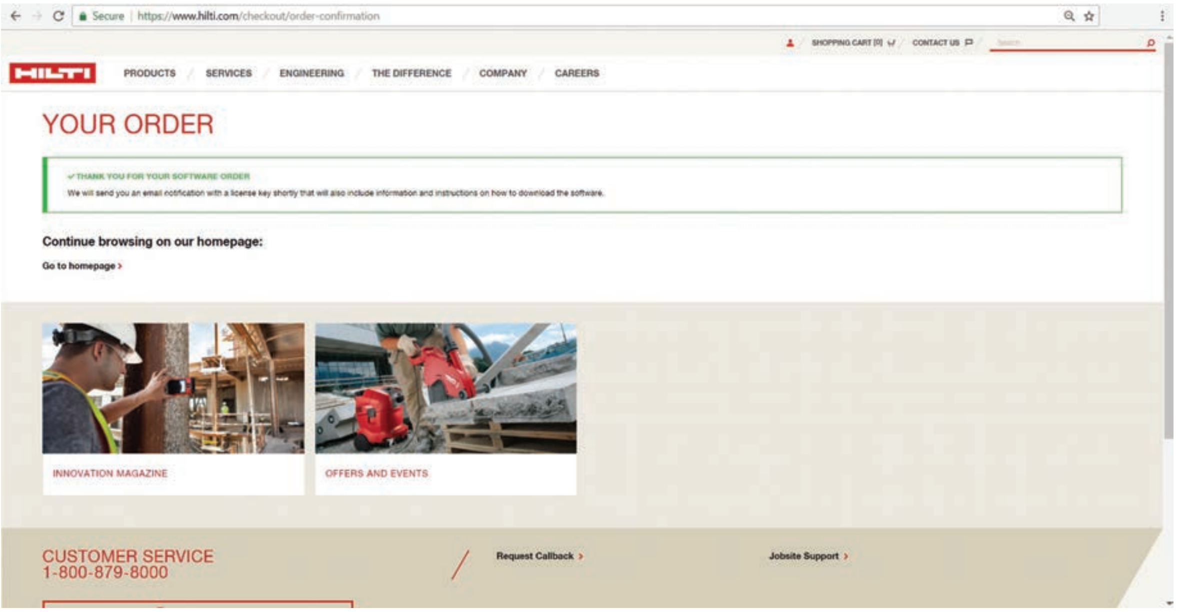

## ❸ Add to Cart



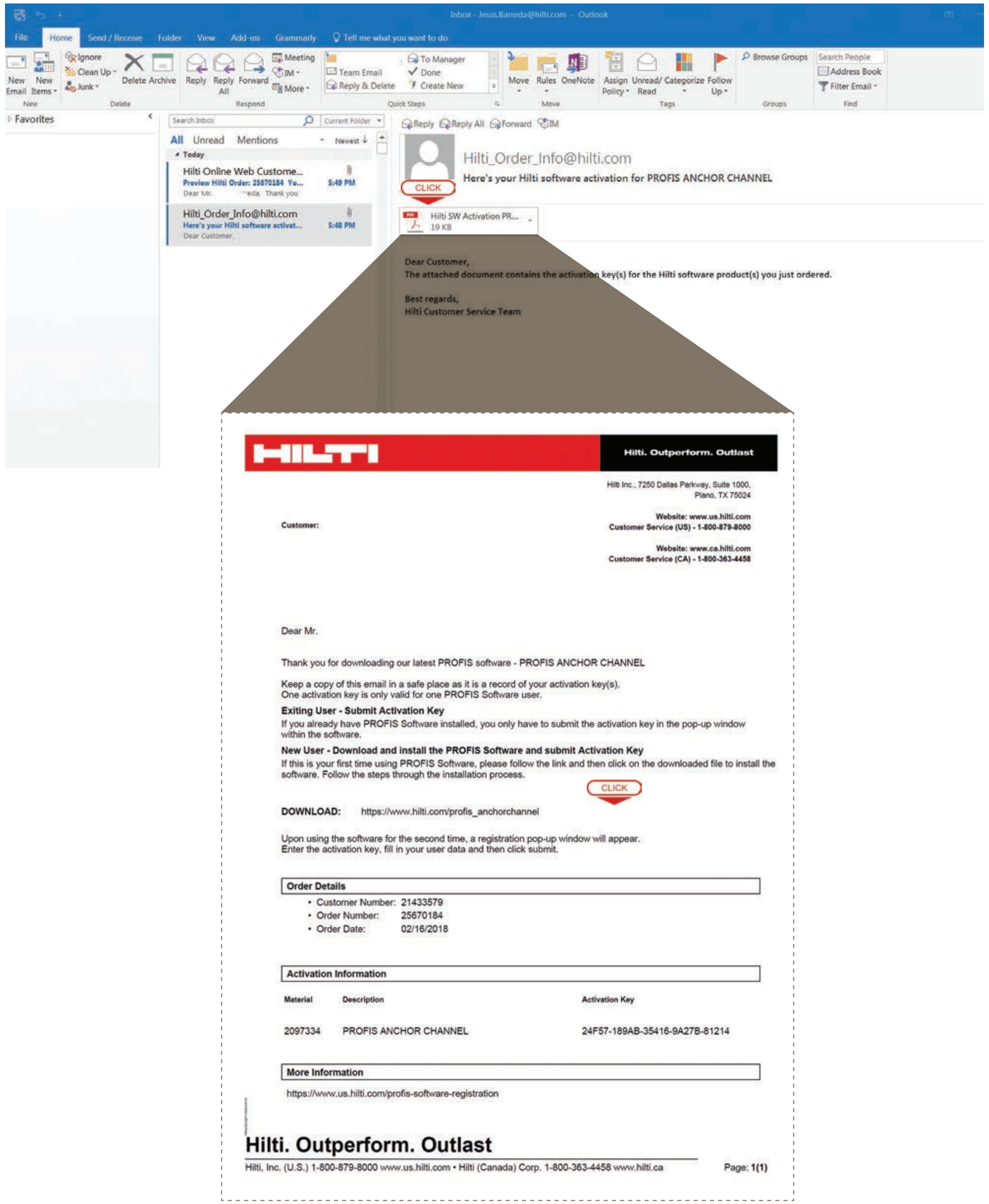
## ❹ Check out




## ❺ Order confirmation




## ❻ Check email and download PROFIS Anchor Channel




Hilti. Outperform. Outlast

Hilti Inc., 7250 Dallas Parkway, Suite 1000, Plano, TX 75024

Customer:

Website: www.us.hilti.com
Customer Service (US) - 1-800-879-8000

Website: www.ca.hilti.com
Customer Service (CA) - 1-800-363-4458

Dear Mr.

Thank you for downloading our latest PROFIS software - PROFIS ANCHOR CHANNEL

Keep a copy of this email in a safe place as it is a record of your activation key(s).
One activation key is only valid for one PROFIS Software user.

**Exiting User - Submit Activation Key**
If you already have PROFIS Software installed, you only have to submit the activation key in the pop-up window within the software.

**New User - Download and install the PROFIS Software and submit Activation Key**
If this is your first time using PROFIS Software, please follow the link and then click on the downloaded file to install the software. Follow the steps through the installation process.

CLICK

**DOWNLOAD:** https://www.hilti.com/profis_anchorchannel

Upon using the software for the second time, a registration pop-up window will appear.
Enter the activation key, fill in your user data and then click submit.

**Order Details**
- Customer Number: 21433579
- Order Number: 25670184
- Order Date: 02/16/2018

**Activation Information**

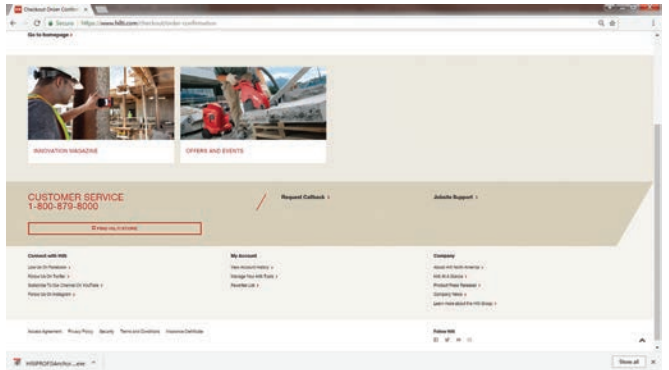
| Material | Description | Activation Key |
|---|---|---|
| 2097334 | PROFIS ANCHOR CHANNEL | 24F57-189AB-35416-9A27B-81214 |

**More Information**
https://www.us.hilti.com/profis-software-registration

**Hilti. Outperform. Outlast**
Hilti, Inc. (U.S.) 1-800-879-8000 www.us.hilti.com • Hilti (Canada) Corp. 1-800-363-4458 www.hilti.ca
Page: 1(1)

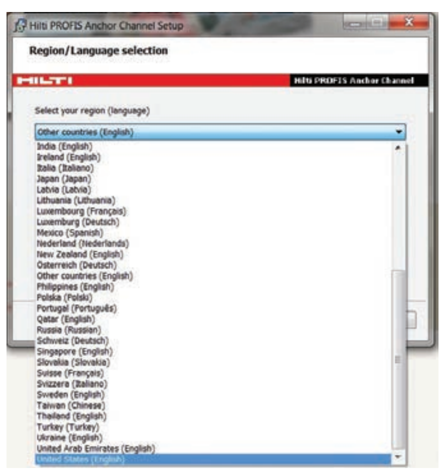
## ❼ Install PROFIS Anchor Channel

**Open HiltiPROFISAnchorChannel.exe**

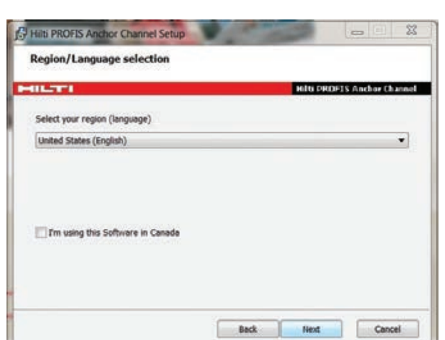


**Setup Wizard, click Next**


**Select your region (language)**

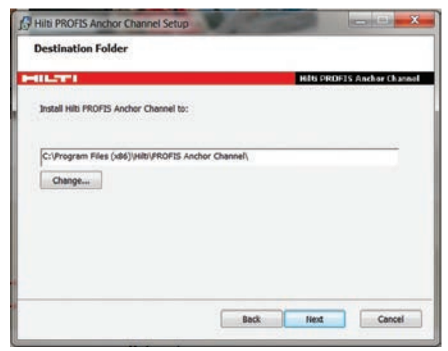



**Confirm and Next**




**Review terms and conditions**


**Select Destination Folder**




**Install PROFIS Anchor Channel**


# 10.3 PROFIS ANCHOR CHANNEL TUTORIAL

## 10.3.1 CREATE A NEW PROJECT IN PROFIS ANCHOR CHANNEL

### Region

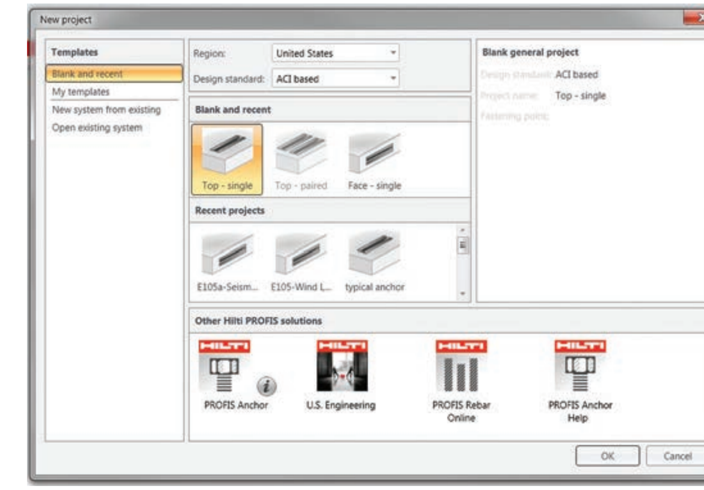
Select the region to reflect the Imperial or Metric system and display available products in your region.

### Design Standard

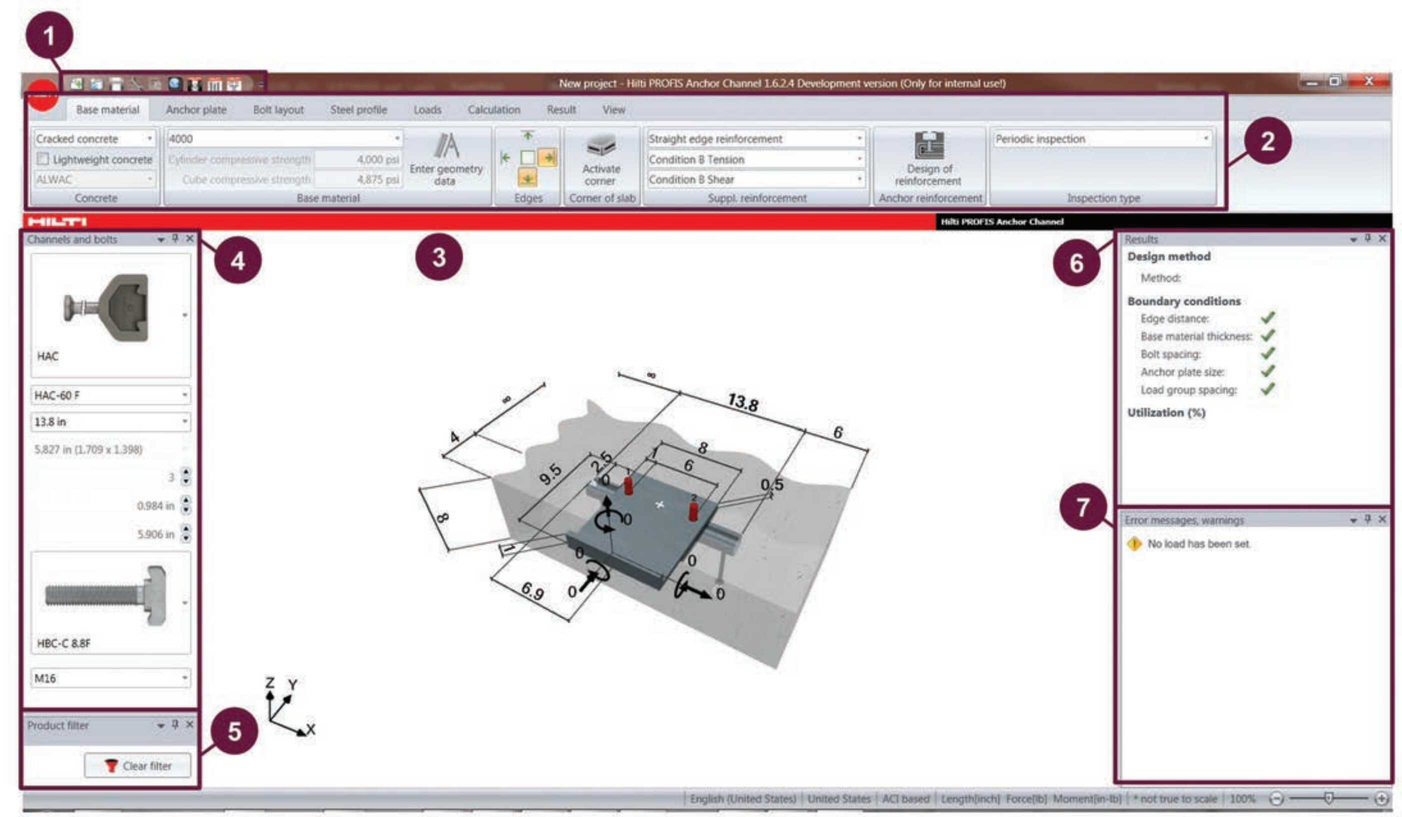
The software selects the default design standard of the selected region. The design standard can be changed depending on project's requirements.

Choose a blank top or face of slab project, open an existing file, or open a saved template based on your most common conditions.

Select the appropriate design standard for your project.




## 10.3.2 PROFIS ANCHOR CHANNEL OVERVIEW




❶ QUICK ACCESS TOOLBAR

❷ RIBBON

❸ GRAPHICS/MODEL WINDOW

❹ ANCHOR CHANNEL AND T-BOLT SELECTION WINDOWS

❺ PRODUCT FILTER

❻ REULTS WINDOWS

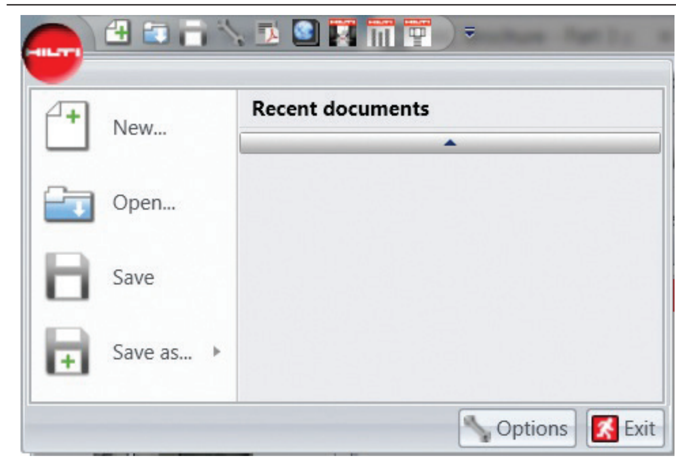
❼ ERROR MESSAGES, WARNINGS WINDOW

## 10.3.2.1 QUICK ACCESS TOOLBAR

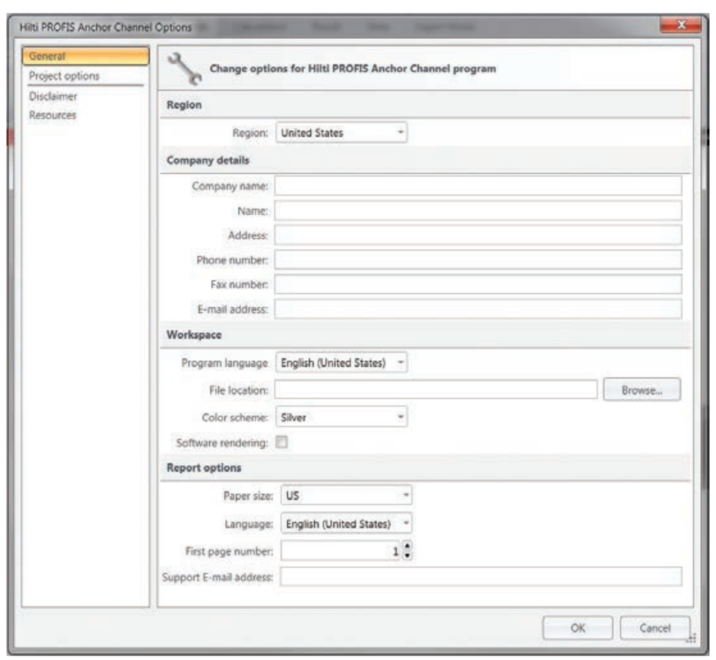
b c d e f g h i
a

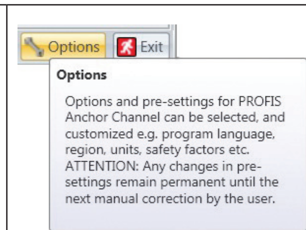
**a** Start window
**b** New project
**c** Open existing project
**d** Save
**e** Project Options
**f** Design Report
**g** Online Technical Library
**h** PROFIS Rebar Online
**i** PROFIS Anchor Software

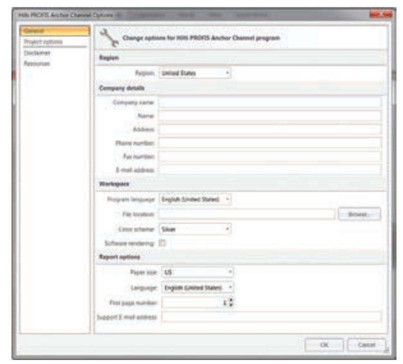
## Start window









## General

**Region**

- Allows changing the region without having to start a new project.

**Company details**

- Specifier information can be added. This information will be displayed in the final report.

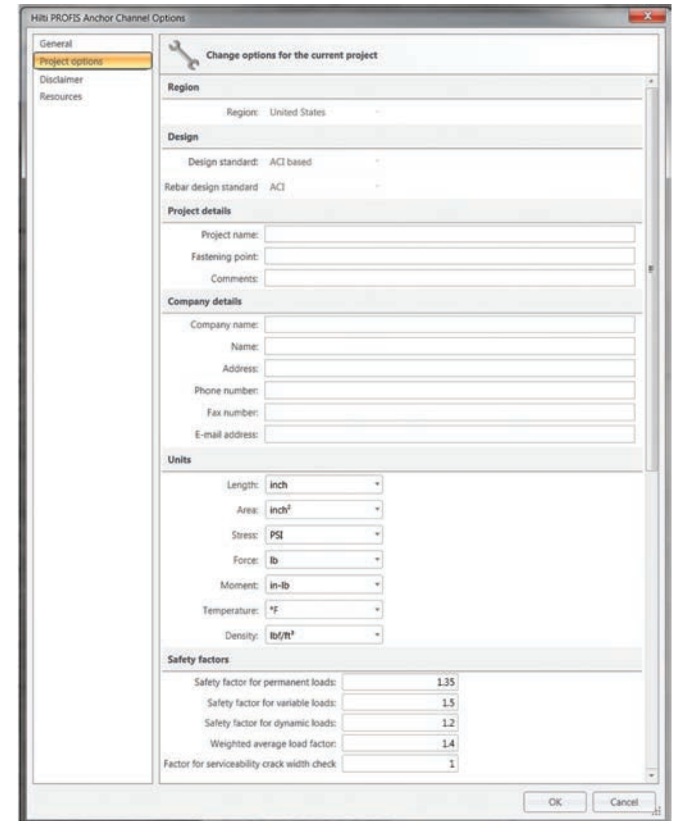
**Workspace**

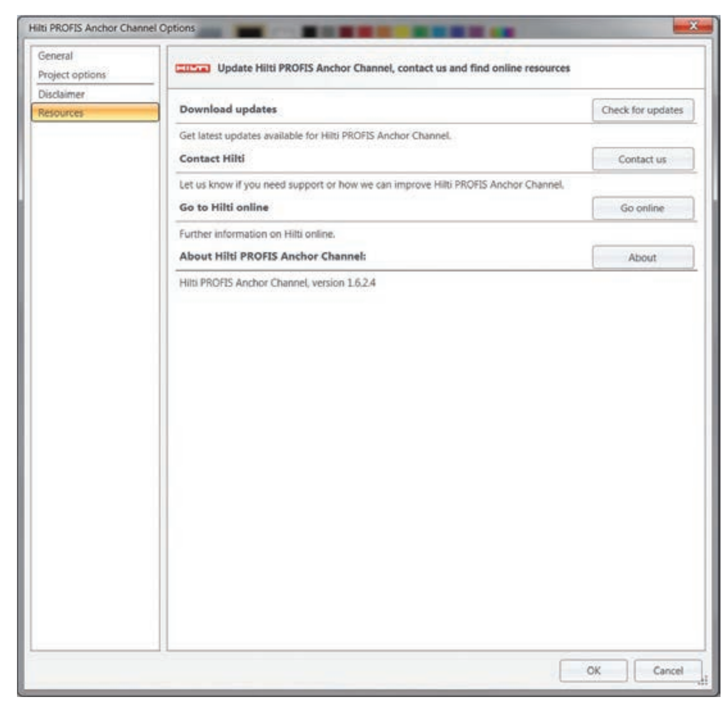
- Change program language
- Change PROFIS Anchor Channel Scheme

**Report options**

- Select report paper size of report- Select report language

## Start window

## Project options

**Project details**

- Project information can be added. This information will be displayed in the final report.

**Company details**

- Specifier information can be added. This information will be displayed in the final report.

**Units**

- Select preferred units. The work space will be updated accordingly.

**Safety factors**

- For ACI based, the only two relevant fields are “weighted average load factor” and “Factor for serviceability crack width check”

**Weighted average load factor**

- Only applicable when HAC EDGE is used. Software checks if cracking of the concrete occurs at service levels and used this factor to unfactor the shear force.
- This factor shall be equal to the shear load factor. For instance, if ASCE 7-05 is used, this factor shall be equal to 1.6. If ASCE 7-10 is used, this factor shall be equal to 1/0.6 = 1.667

**Factor for serviceability crack width check**

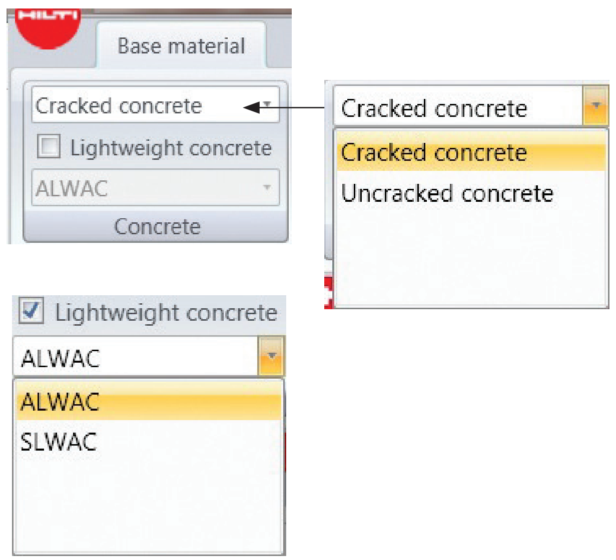
- Select the required safety factor for serviceability crack width. Serviceability is typically checked using nominal strengths (1.0) at service loads. See section 9.6.2 for additional information.

**Always check for updates**

- Hilti is continuously adding new features to the software. Keeping the software updated allows you to take advantage of all the features the software has to offer.

## 10.3.2.2 BASE MATERIAL TAB


### Concrete




**Uncracked concrete**

If analysis indicates no cracking at service load levels, the use of uncracked concrete can be justified.

**Cracked concrete**

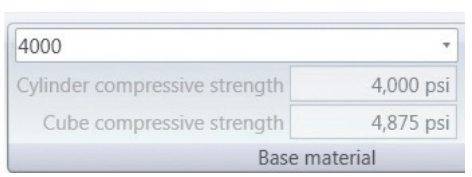
If analysis indicates cracking at service load levels.

All-lightweight concrete (ALWAC) λ = 0.75

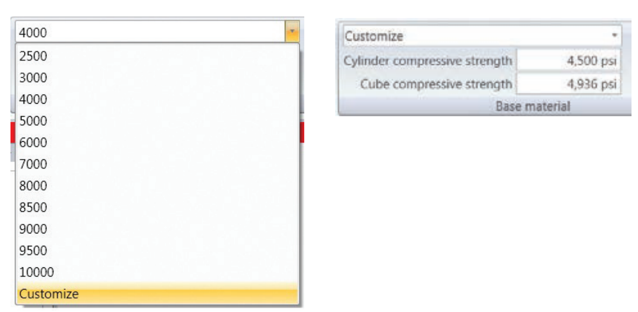
San lightweight concrete (SLWC) λ = 0.85

See section 5.1.2 for additional information.

### Base material

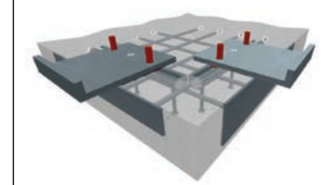



Select the concrete cylinder compressive strength of the substrate. Drop menu provides incremental of 1000 psi. For a specific cylinder compressive strength, click on "Customize" option and input the specific value.

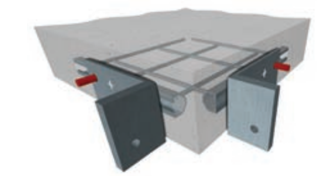



### Corner of Slab


- Activates pair of channels in a corner.
- Only symmetric corners are allows. For unsymmetrical corners, use the highest loads.
- Analysis assumes both corner channels are loaded simultaneously.

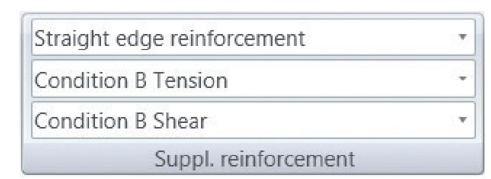


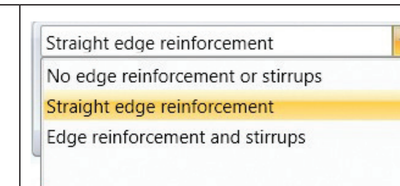
Top of slab corner

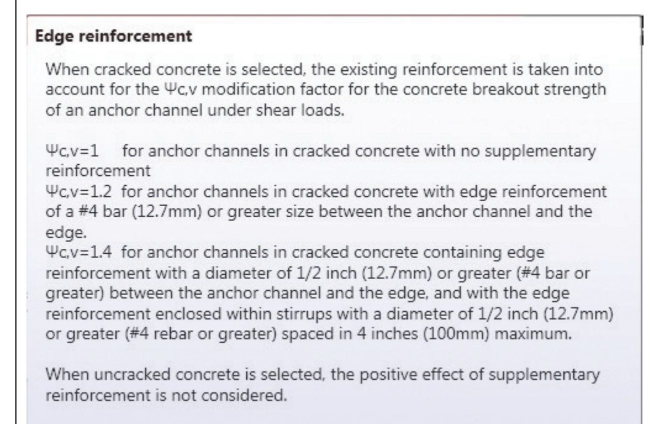


Face of slab corner

### Supplementary reinforcement



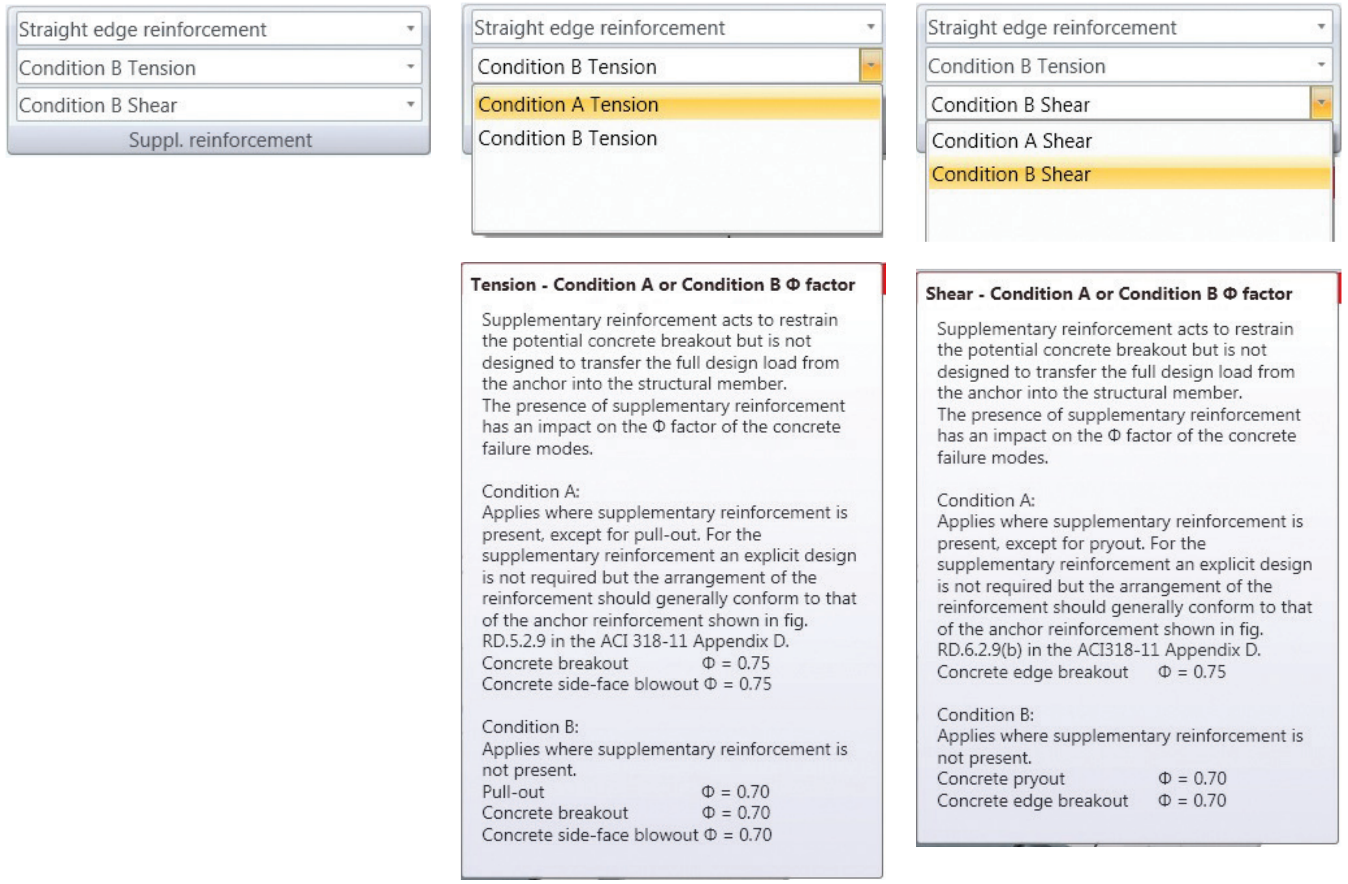
**Edge reinforcement**

When cracked concrete is selected, the existing reinforcement is taken into account for the Ψc,v modification factor for the concrete breakout strength of an anchor channel under shear loads.

Ψc,v=1 for anchor channels in cracked concrete with no supplementary reinforcement
Ψc,v=1.2 for anchor channels in cracked concrete with edge reinforcement of a #4 bar (12.7mm) or greater size between the anchor channel and the edge.
Ψc,v=1.4 for anchor channels in cracked concrete containing edge reinforcement with a diameter of 1/2 inch (12.7mm) or greater (#4 bar or greater) between the anchor channel and the edge, and with the edge reinforcement enclosed within stirrups with a diameter of 1/2 inch (12.7mm) or greater (#4 rebar or greater) spaced in 4 inches (100mm) maximum.

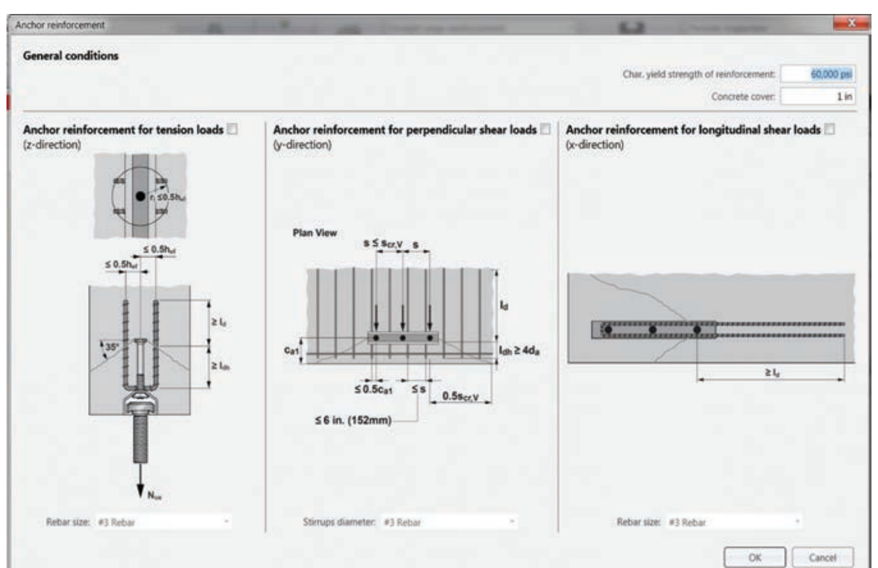
When uncracked concrete is selected, the positive effect of supplementary reinforcement is not considered.

## Supplementary reinforcement




## Anchor reinforcement


Anchor reinforcement precluded concrete breakout. See sections 7.3 and 7.4 for additional information




## Inspection Type

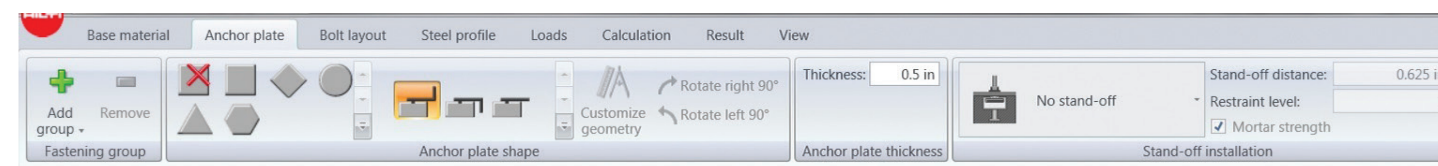

This tab only impacts the Φ factor for the shear steel strength of connection between channel lips and channel bolts $V_{sl,x}$

Periodic inspection
HBC-C-N → Φ = 0.55
HBC-T → Φ = 0.65

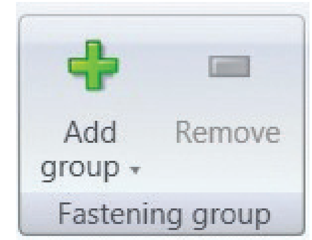
Continuous inspection
HBC-C-N → Φ = 0.65
HBC-T → Φ = 0.75

In case of continuous inspection the value for $V_{sl,x}$ for the size M12 can be taken for all channel sizes HAC-40F through HAC-70 F as $V_{sl,x}$ = 2,021 lb (9.0 kN).

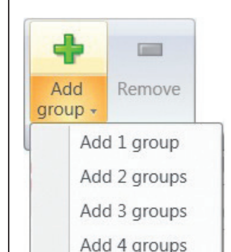
### 10.3.2.3 ANCHOR PLATE

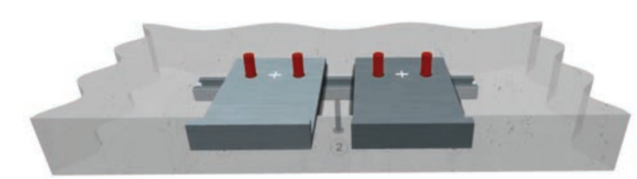



## Fastening group




This feature adds another bracket to the anchor channel. Although the analysis assumes the brackets are loaded simultaneously, the configuration and loads can be different.

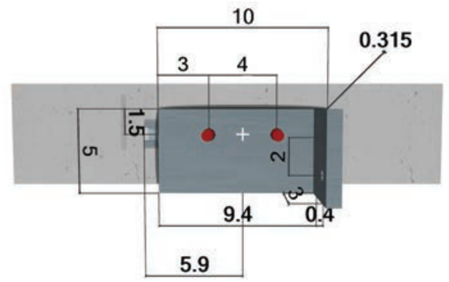


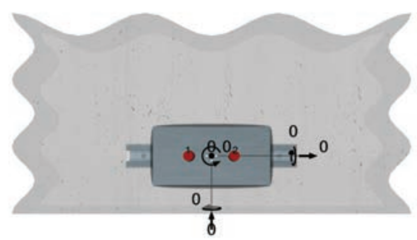
## Anchor reinforcement

Top and face of slab brackets

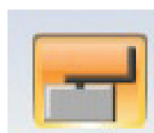
Removes bracket; allows to input loads on the t-bolt(s)

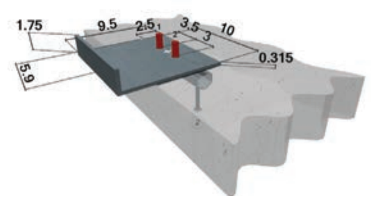


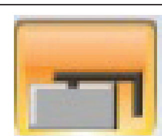

Inserts flat plate

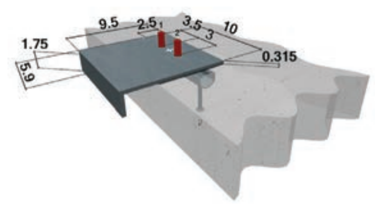


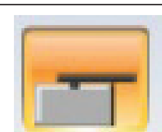
Top of slab brackets

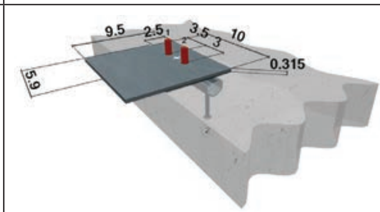




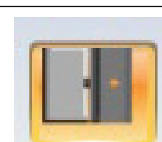



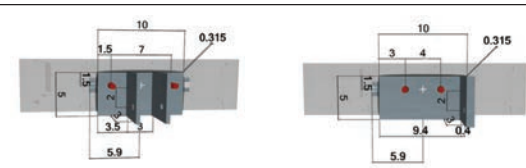


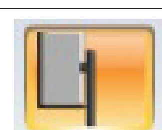



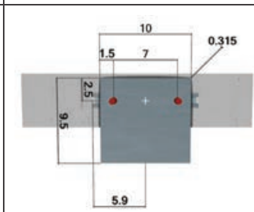


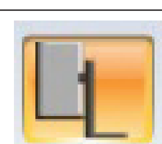

Face of slab brackets

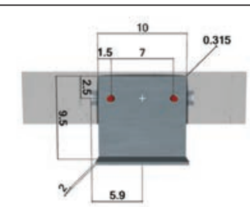




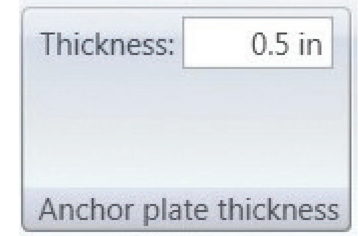





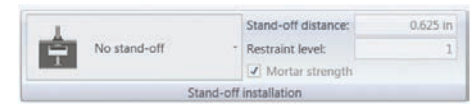


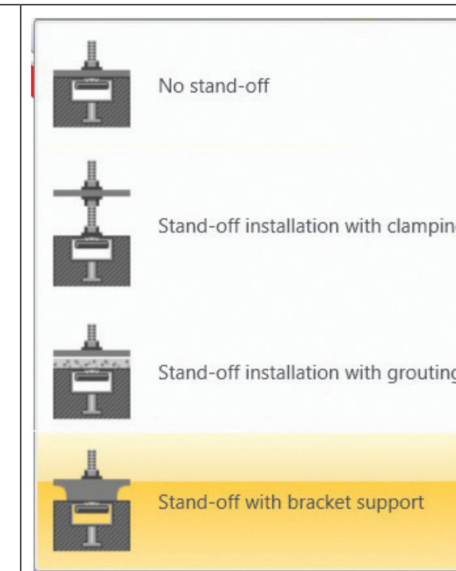

## Anchor plate thickness

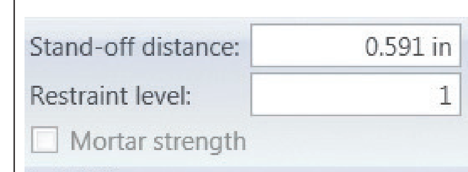



Select plate/bracket thickness

## Stand-off installation

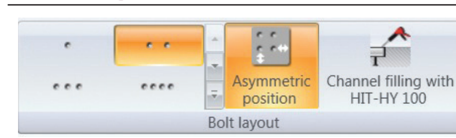



### 10.3.2.4 BOLT LAYOUT

## Bolt layout



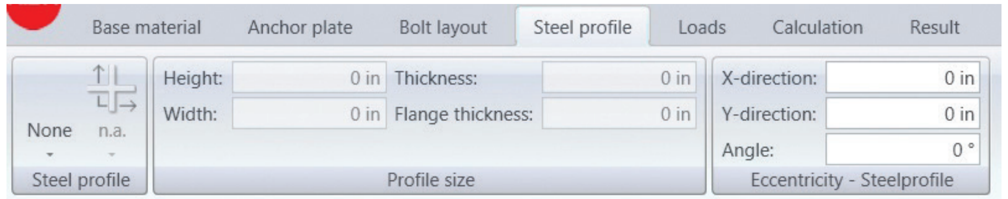

Select number of t-bolts (8 maximum per bracket)

Asymmetric position of bracket and t-bolts

Channel filling with HIT-HY 100 allows to “lock” the t-bolts in position and transfer longitudinal forces.

Filling of the channel with HI-HY 100 is NOT needed to transfer longitudinal forces if HBC-C-N or HBC-T are used.

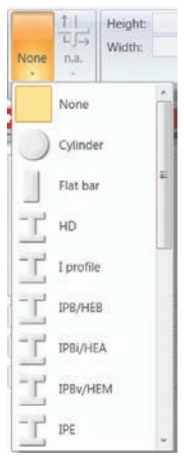
## 10.3.2.5 STEEL PROFILE

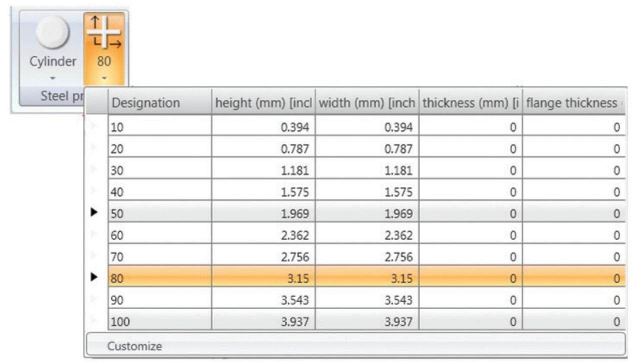



### Steel profile

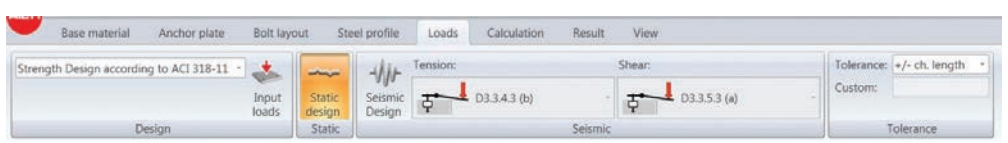

Steel profile allows adding a profile to the bracket. This is a aesthetics feature. It does not impact the design nor does it add load eccentricities.

Feature only available with a base plate.





## 10.3.2.6 LOADS

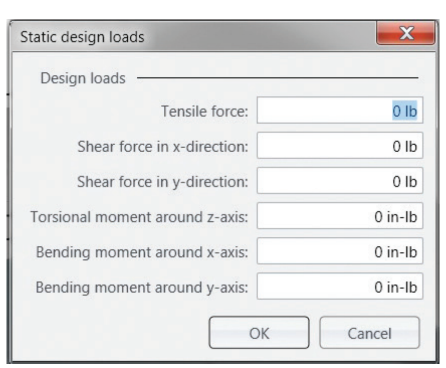


### Steel profile


Strength Design according to ACI 318-11

**Input loads**

Allows the user to input the loads in a tabular format, rather than utilizing the work-space model. Applied loads shall be Strength Level (LRFD factor – design loads)

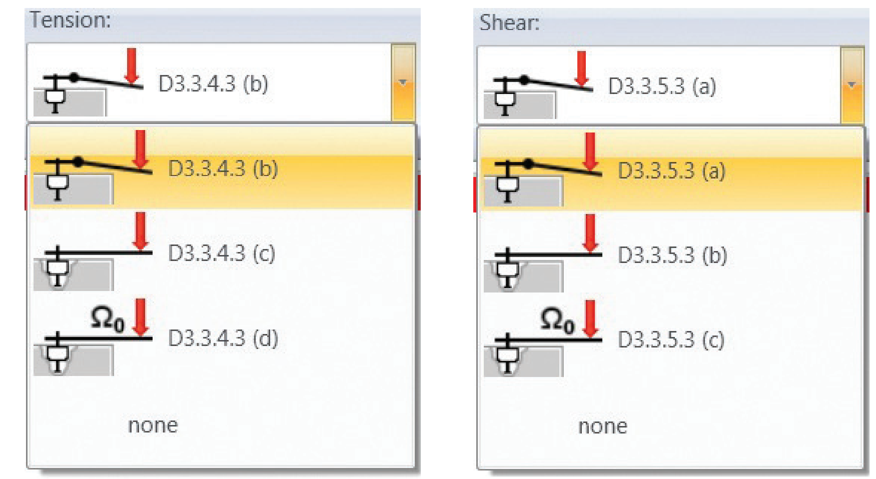



### Static

Select static design if applied loads are static loads

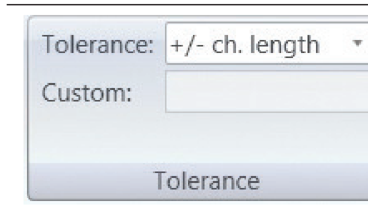
### Seismic

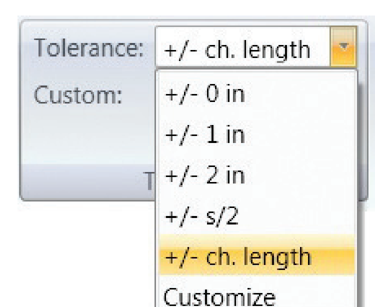
Select this option when designing per ACI 318-11 if anchor design included earthquake forces for attachment into structures assigned to Seismic Design Category C, D, E or F. Refer to the model code ACI 318-11 for specific seismic parameters.




See section 7.6 of this brochure for additional information

### Tolerance



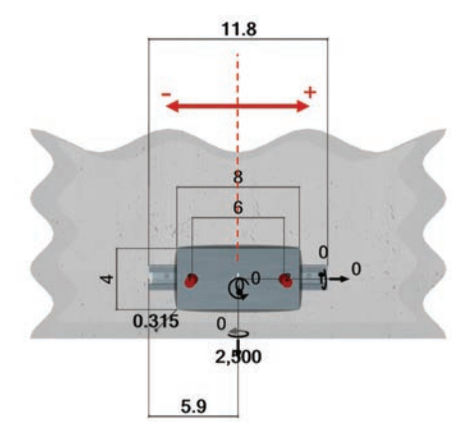

This field allows to select the left and right tolerance of the t-bolts along the anchor channel. PROFIS Anchor Channel looks for the t-bolt(s) position along the anchor channel that yields the highest utilization, unless selected otherwise.

**Tolerance: +/- 0 in**

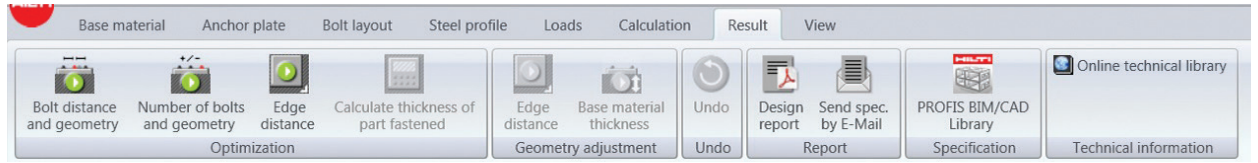
Analysis based on the nominal t-bolt location.

**Tolerance: +/- ch. Length**

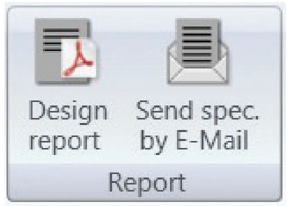
Analysis based on the t-bolt location along the channel that yields the highest utilization.



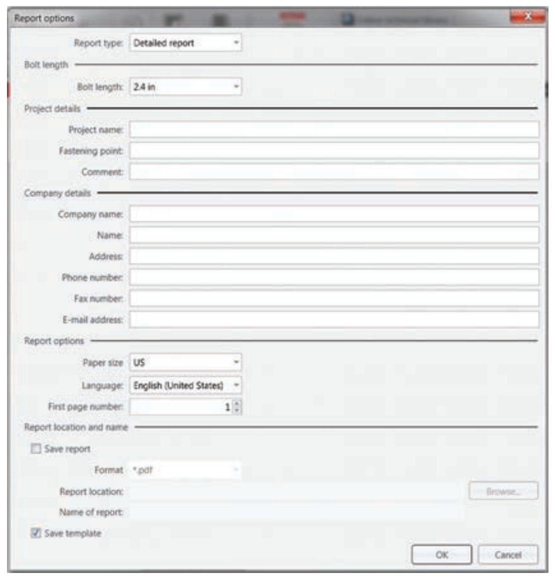
## 10.3.2.7 RESULTS



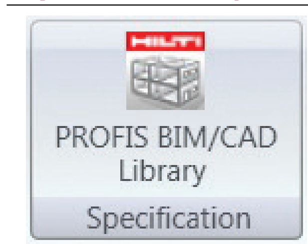

### Design report



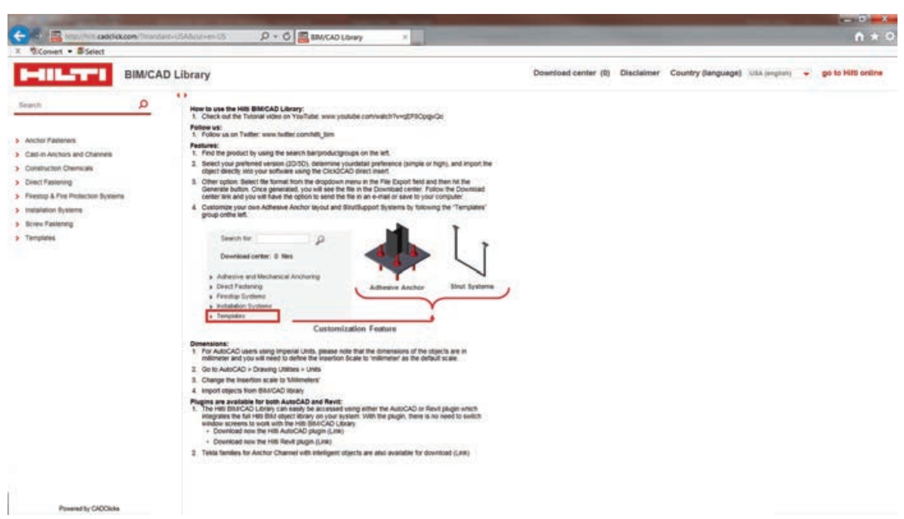

- Select report type; detailed or short report
- Select t-bolt length
- Project details and company details will be printed in the report header.
- Select report options



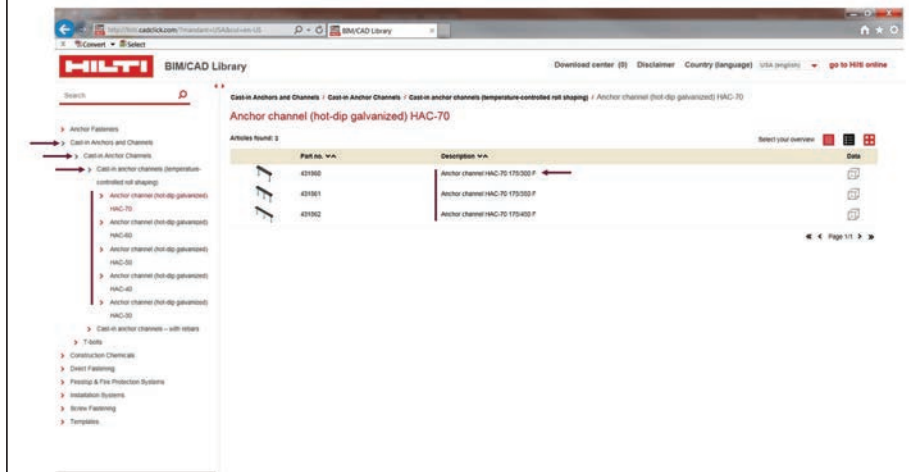

### Specification (PROFIS BIM/CAD Library)



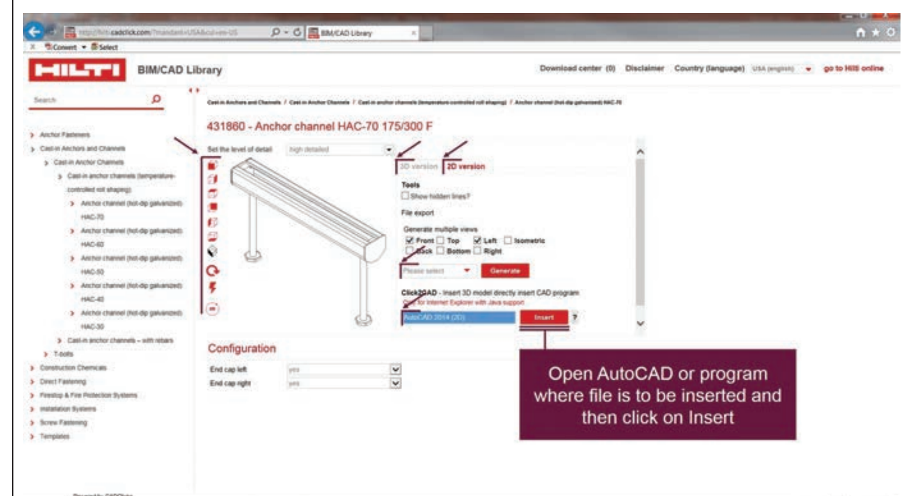

- Click on PROFIS BIM/CAD Library and it will direct you to the page shown below



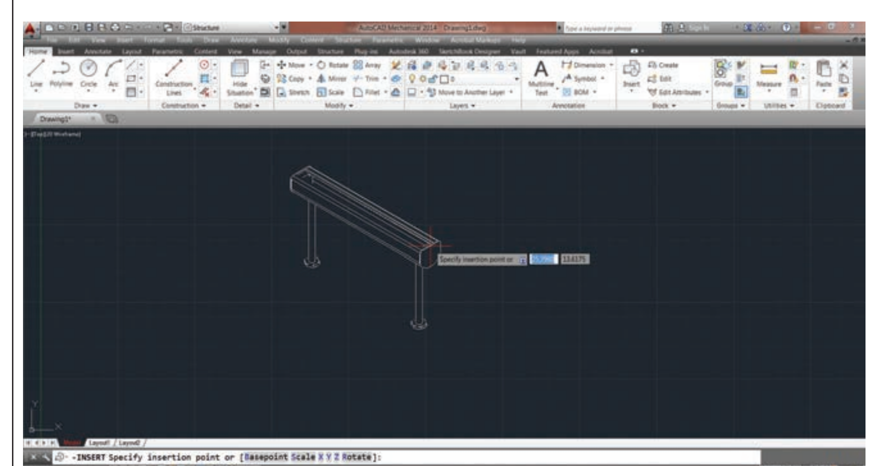
- Click on Cast-in Anchors and Channels and select the desired anchor channel



- Selected the desired view and program where file is to be inserted.
- Open program where file is to be insert.
- Click on Insert



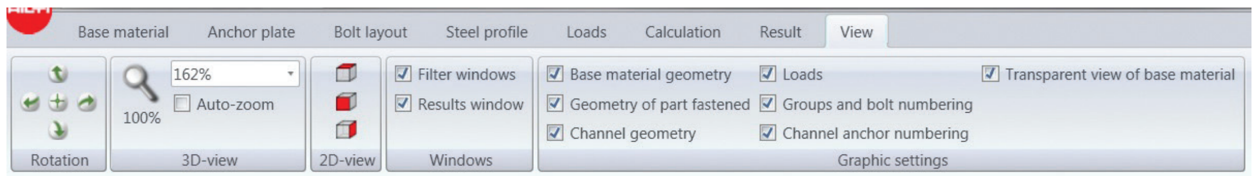

- Drag figure to the selected program (i.e. AutoCAD)



## Technical information


Takes you to the only Hilti technical library page

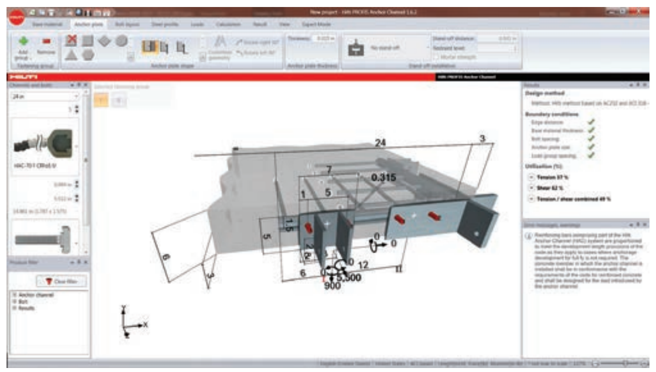
### 10.3.2.8 VIEW

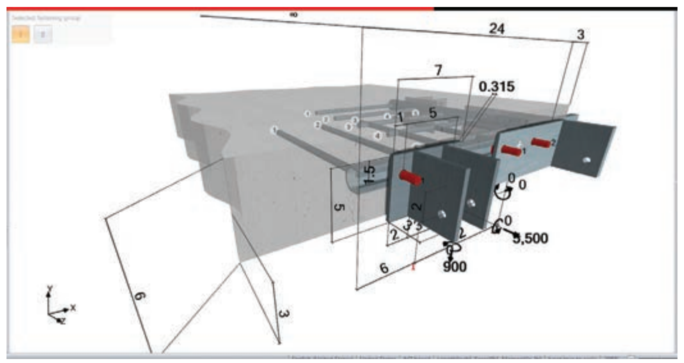



- Filter and Results windows
- Rotate, zoom, or select a 2-D view
- Show or hide Filter and Results windows
- Show or hide various items in the graphics window
- Transparent view of base material can be selected

### 10.3.3 GRAPHICS/MODEL WINDOW

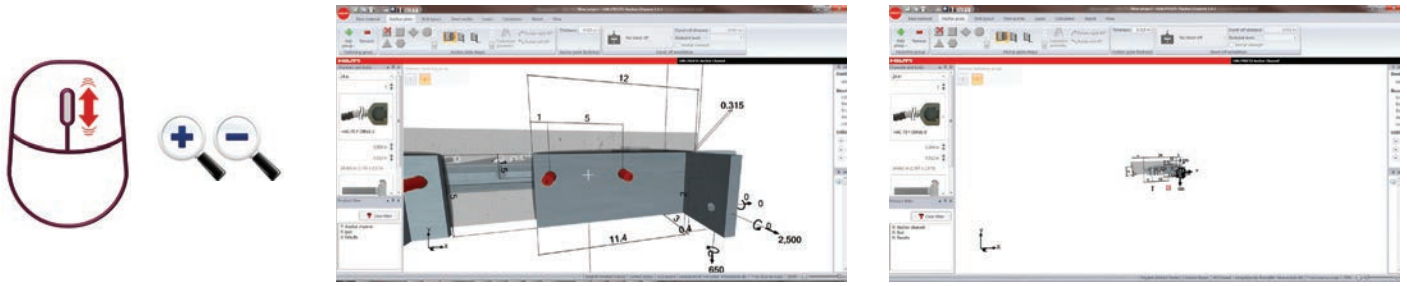
Substrate, bracket geometry and configuration can be adjusted in the workspace/model window





## Zoom in and zoom out

Zooming in and zooming out can be easily achieved by scroll up (zoom in) or down (zoom out) using the scroll wheel of the mouse.



## Rotate the view around the vertical axis

Right click (hold it) and move the mouse left (rotates clockwise) and right (rotates counter-clockwise). The model will rotate around the vertical axis


## Rotate the view around the horizontal axis

Right click (hold it) and move the mouse up or down. The model will rotate around the vertical axis

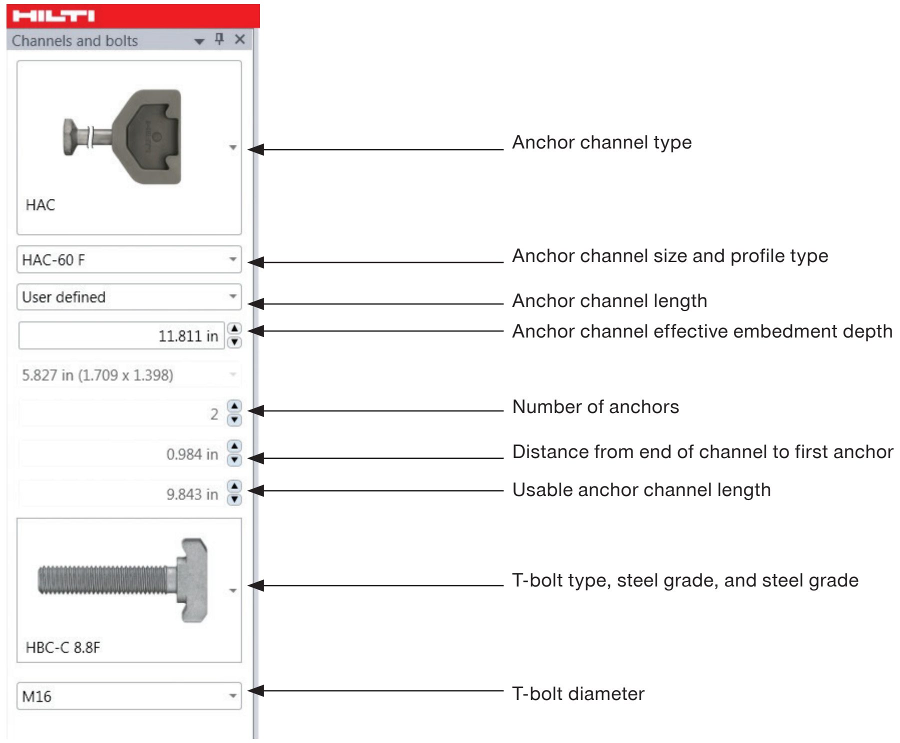

## Move the view along the horizontal axis

Left click (hold it) and move the mouse left and right. The model will move along the horizontal


## Move the screen in and out

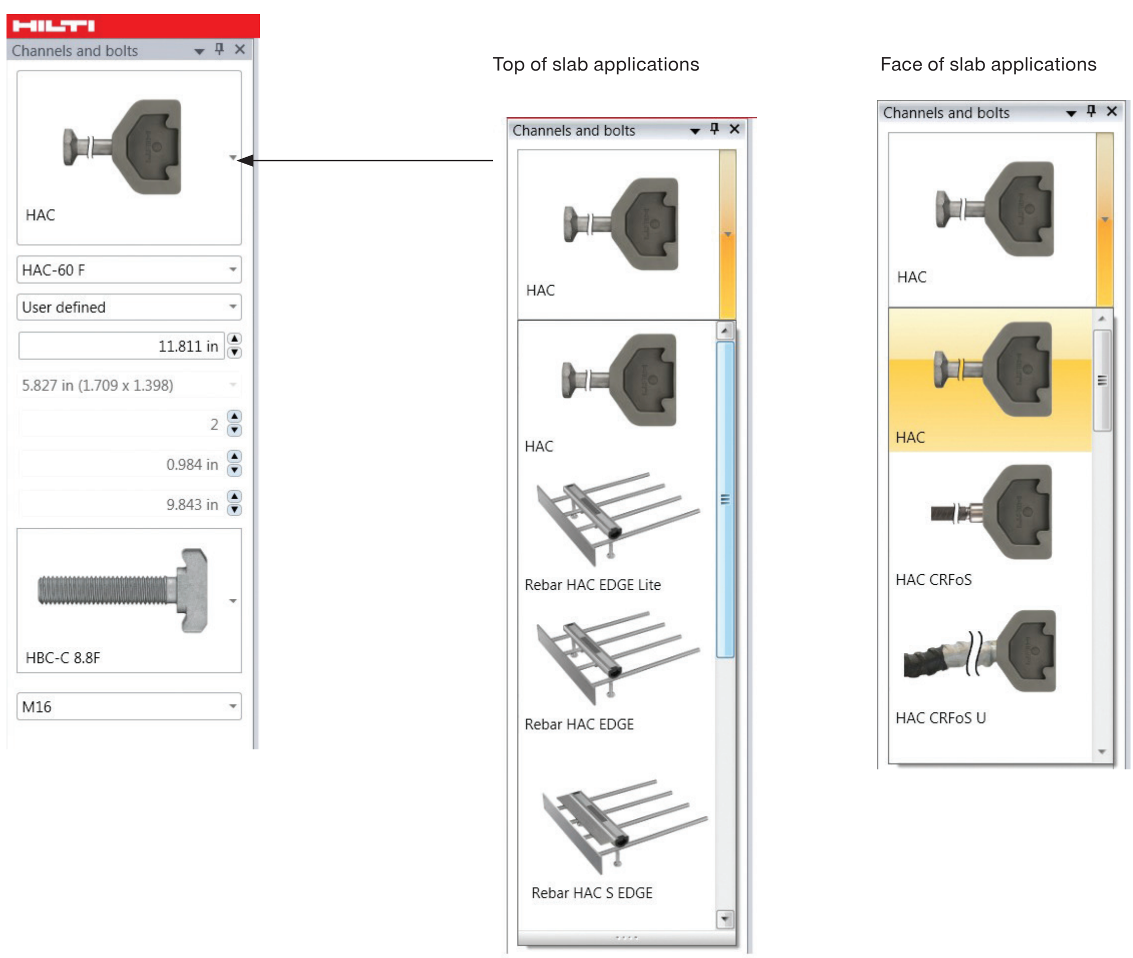
Left click (hold it) and move the mouse up and down. The model will zoom in and out

## 10.3.4 ANCHOR CHANNEL AND BOLT SELECTOR WINDOW




### Step 1: Anchor channel type

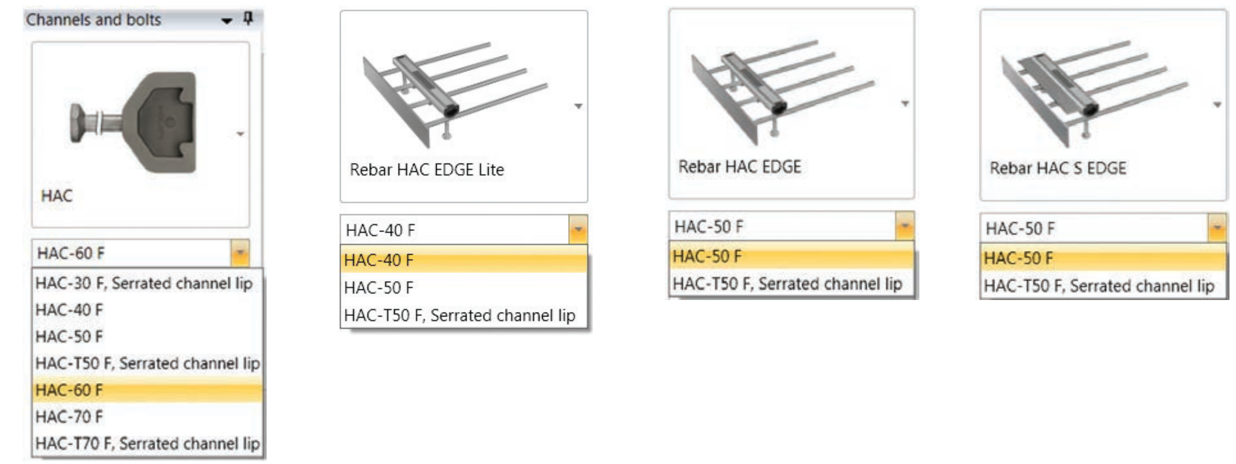
Select the desired anchor channel type




### Step 2: Anchor channel size and profile type

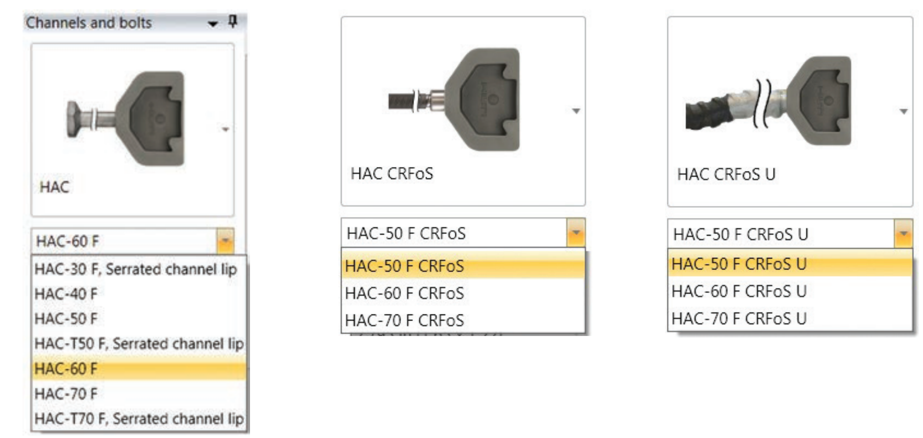
Select the desired anchor size and profile type; smooth lips (HAC) or serrated lips (HAC-T)

*Anchor channels for top of slab applications




*Anchor channels for face of slab applications

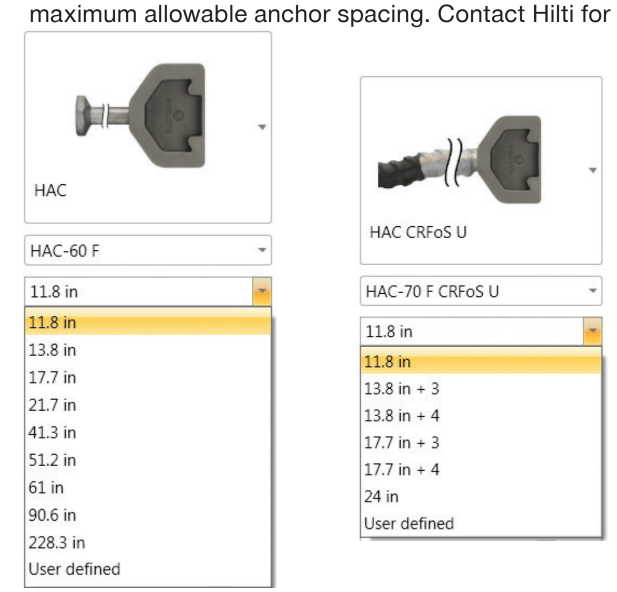
*Anchor channels for top of slab applications can be used in face of slab applications and vice-versa.




### Step 3: Anchor channel length

Select the desired anchor channel length. Standard anchor channel configurations (standard lengths with fixed number of anchors) are given in PROFIS Anchor Channel.

"User defined" allows users to input a custom channel length using the least possible number of anchors without exceeding the maximum allowable anchor spacing. Contact Hilti for custom configurations.



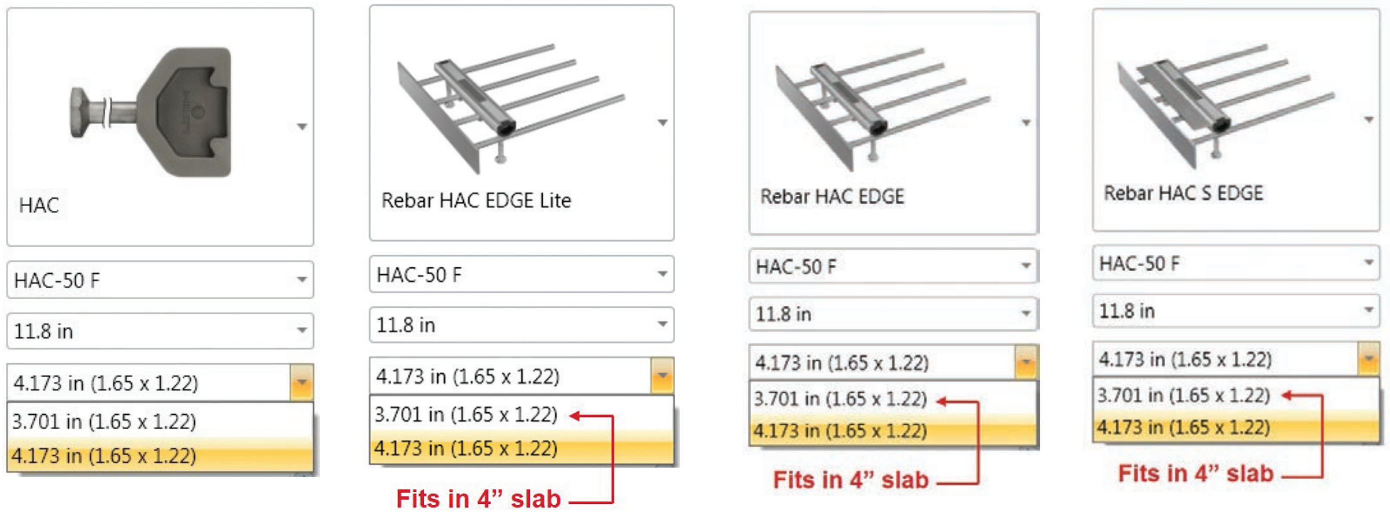

HAC-70 CRFoS U is the only anchor channel configuration that allows different number of anchors for the same anchor channel length.

The term after the length (i.e. + 3 indicates the number of rebars)

## Step 4: Anchor channel embedment depth

Select the required anchor size and profile type; smooth lips (HAC) or serrated lips (HAC-T).

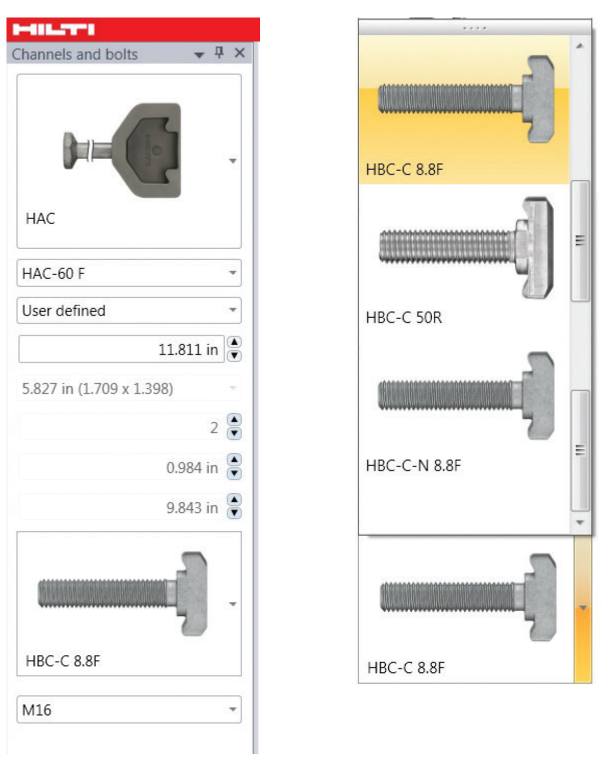
Two different effective embedment depths are offered for HAC-50 only. The 3.701 effective embedment depth allows HAC-50 to be used in a 4" slab.



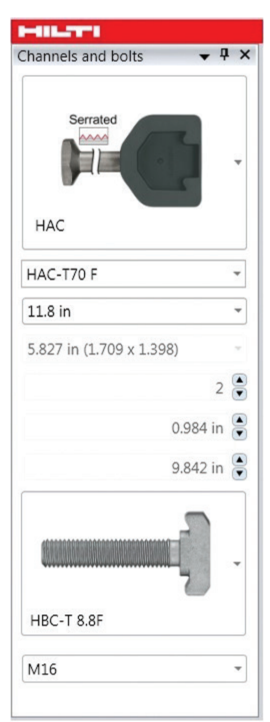

## Step 5: T-bolt type, steel grade, and steel grade

Select the required anchor size and profile type; smooth lips (HAC) or serrated lips (HAC-T).

### Smooth channel lips

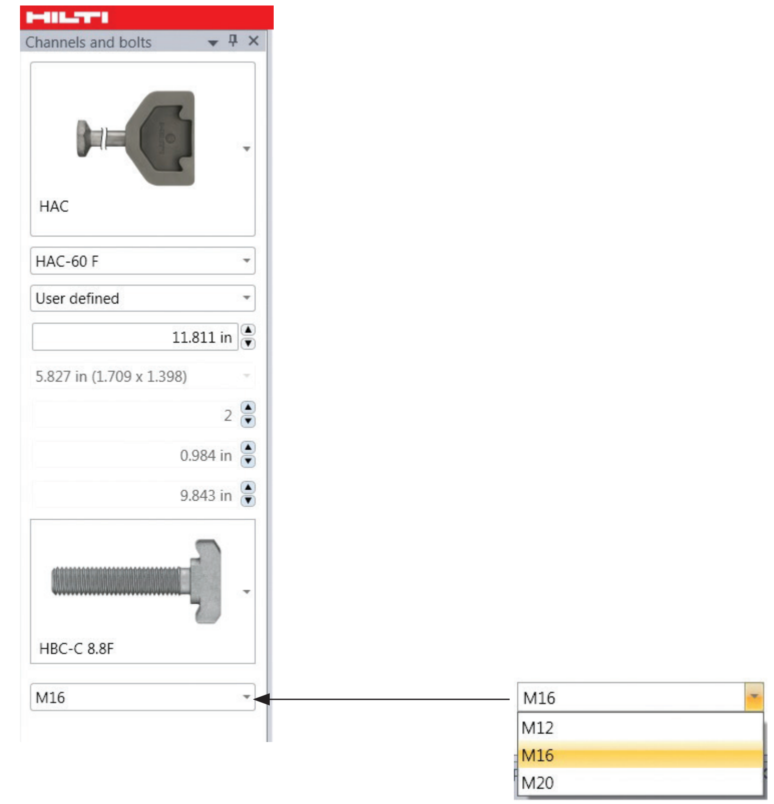



### Serrated channel lips



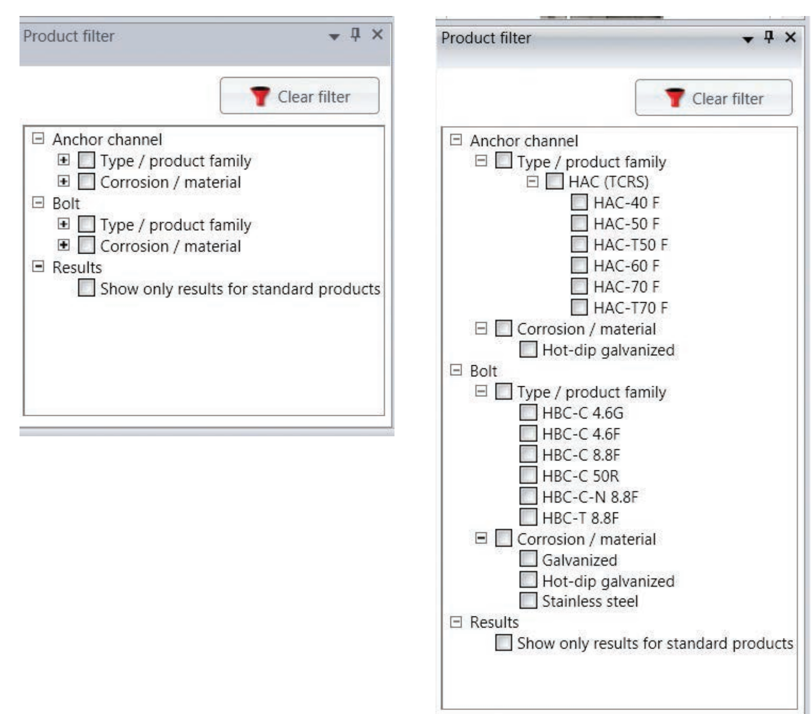

## Step 6: T-bolt diameter

Select the required t-bolt diameter



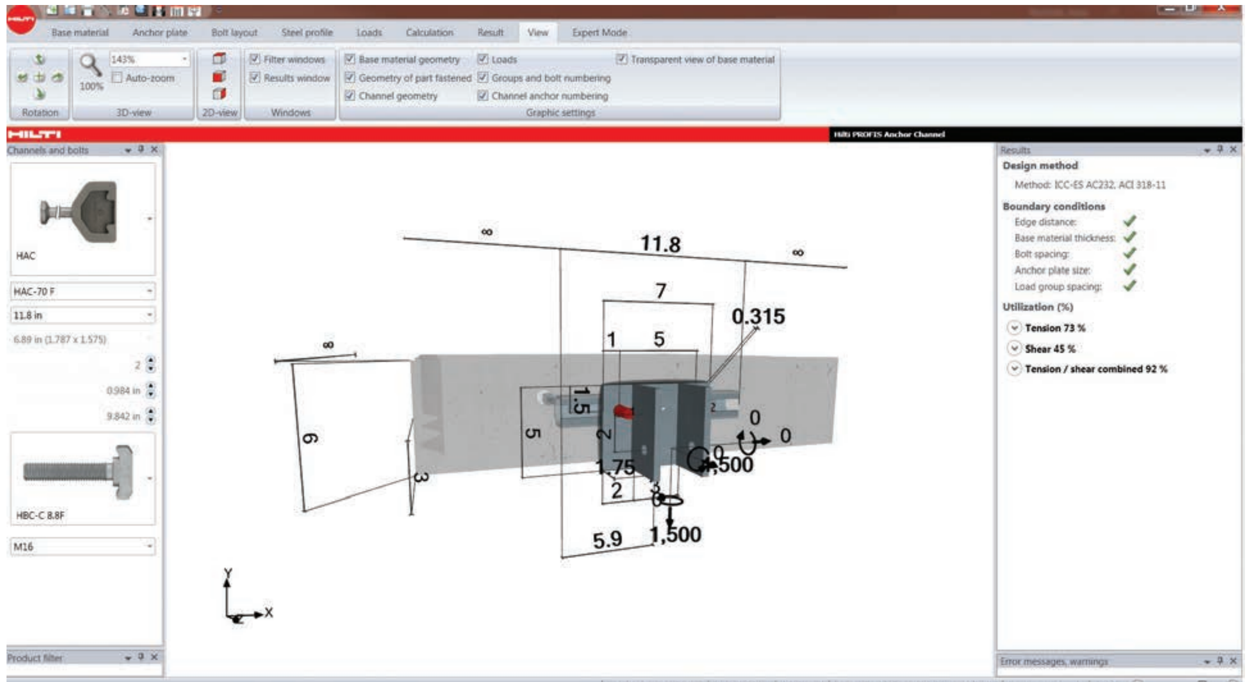

## 10.3.5 PRODUCT FILTER

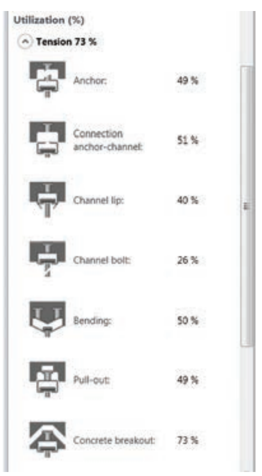
Product filter simplifies the anchor channel system portfolio

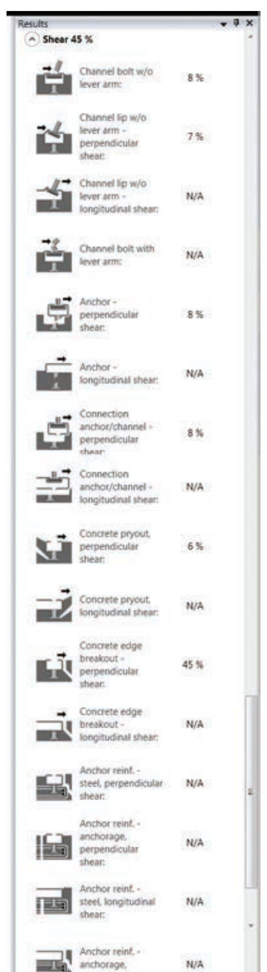


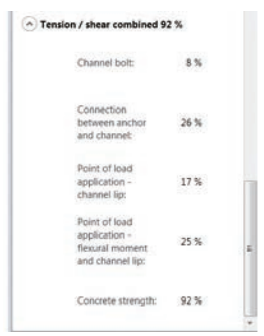
## 10.3.6 RESULTS WINDOW

Results window provides real-time utilization





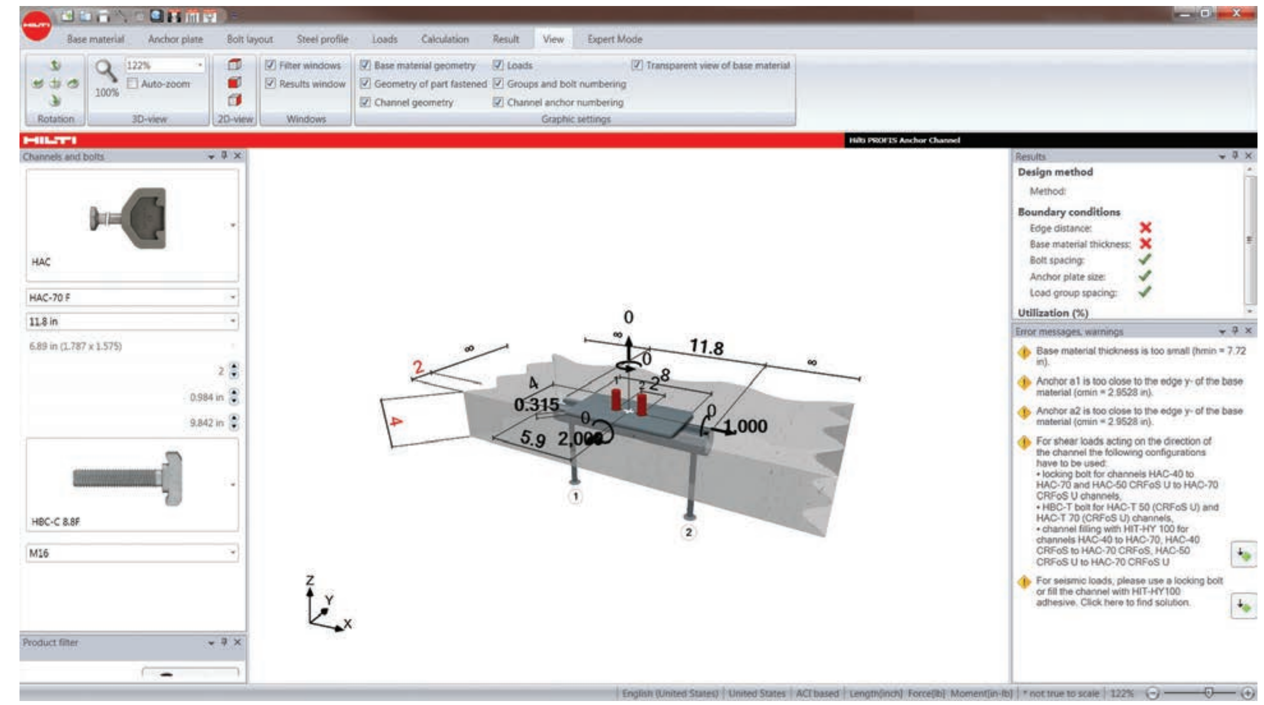


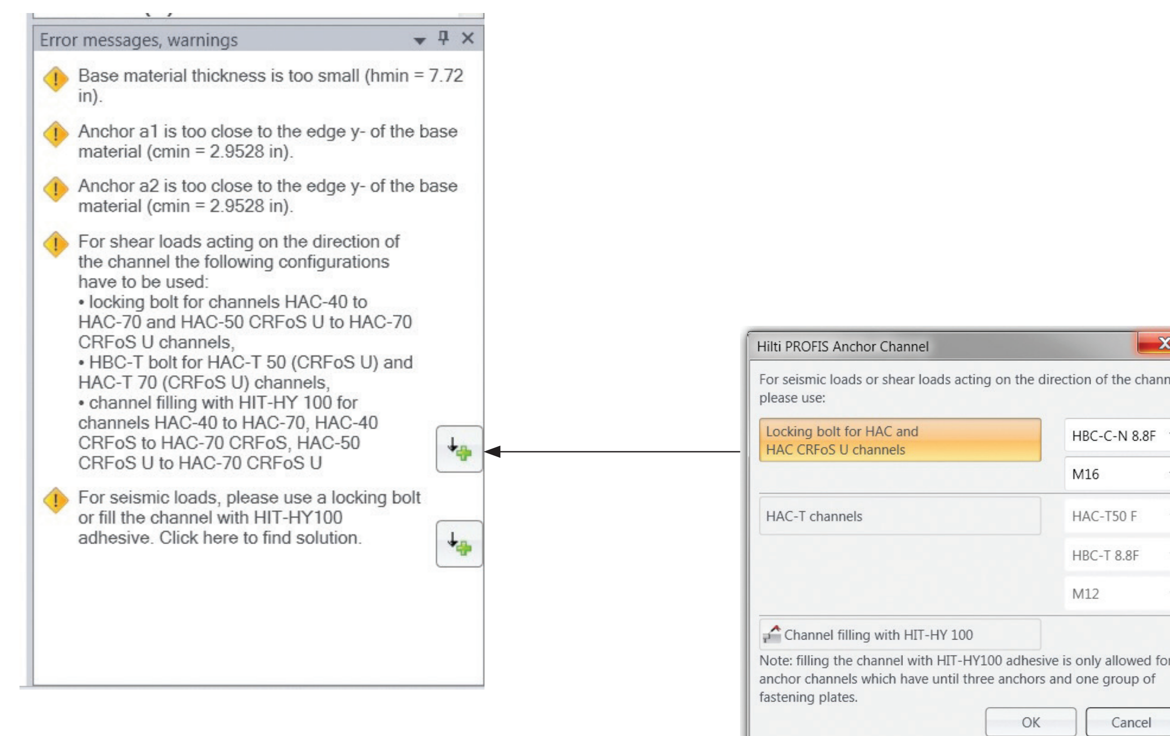


## 10.3.7 ERROR MESSAGES, WARNINGS WINDOWS

Error messages, warnings windows provide information about applications where the configuration does not meet the minimum requirements (i.e. minimum edge distance, minimum member thickness, minimum t-bolt spacing) or configurations that are not recommended (i.e. unstable configuration, longitudinal loads without HBC-C-N, serrated channels or grouting of the anchor channel).

This window also provides fixes for errors.





# 11. BEST PRACTICES

This chapters provides best practices for cast-in anchor channels. It provides some additional information for designers, reviewers, installers, and inspectors. The ultimate goal is to allow for the most model code-compliant, feasible solution, based on the project's schedule.



# 11.1 MODEL CODE COMPLIANCE

## Introduction

Building codes are series of regulations, co-created by politicians and building professionals. Building codes govern the design, construction, repair or alteration and general maintenance of buildings. The main purpose of building codes are to protect public health, safety, and general welfare as they relate to the construction and occupancy of buildings and structures. The building code becomes law of a particular jurisdiction when formally enacted by the appropriate governmental or private authority.

Depending on the project, building codes may be enforced at the international, federal, state, and/or local levels. Municipalities can adopt building model codes set forth by the model code, the International Building Code (IBC).

The concrete chapter of the International Building Code, references ACI 318 Building Code Requirements for Structural Concrete, the standard for concrete design and construction. ACI 318-11 Appendix D and ACI 318-14 Ch. 17 provide design requirements for anchors in concrete used to transmit structural loads by means of tension, shear, or a combination of tension and shear between (a) connected structural elements; or (b) safety-related attachments and structural elements.

## 11.1.1 DESIGN OF SPECIALTY INSERTS

### IBC 2012 1909

Anchorage to concrete — Strength Design

1909.1 Scope. The provisions of this section shall govern the strength design of anchors installed in concrete for purposes of transmitting structural loads from one connected element to the other. Headed bolts, headed studs, and hook (J-or-L-) bolts cast in concrete and expansion anchors and undercut bolts cast in concrete and expansion anchors and undercut anchors installed in hardened concrete shall be designed in accordance with Appendix D of ACI 318 as modified by Section 1905.1.9 and 1905.1.10, provided they are within the scope of Appendix D.

The strength design of anchors that are not within the scope of Appendix D of ACI 318, and amended in Sections 1905.1.9 and 1905.1.10, shall be in accordance with an **approved procedure**.

**Approved:** Acceptable to the building official or authority having jurisdiction.

**Building Official:** The officer or other designated authority charged with the administration and enforcement of this code, or a duly authorized representative.

**104.1 General.** The building official is hereby authorized and directed to enforce the provisions of this code. The building official shall have the authority to render interpretations of this code and to adopt policies and procedures in order to clarify the application of its provisions. Such interpretations, policies and procedures shall be compliance with the intent and purpose of this code. Such policies and procedures shall not have the effect of waiving requirements specifically provided for in this code.

**104.11 Alternative materials, design and methods of construction and equipment.** The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or methods of construction shall be approved where the building official finds that the proposed design is satisfactory and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

**104.11.1 Research reports.** Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, shall consist of valid research reports from approved sources.

**104.11.2 Tests.** Whenever there is insufficient evidence of compliance with the provisions of this code, or evidence that a material or method does not conform to the requirements of this code, or in order to substantiate claims for alternative materials or methods, the building official shall have the authority to require tests as evidence of compliance to be made at no expense to the jurisdiction. Test methods shall be as specified in this code or by other recognized test methods, the building official shall approve the testing procedures. Tests shall be performed by an approved agency. Reports of such tests shall be retained by the building official for the period required for retention of public records.

Cast-in anchor channels systems are slotted connections consisting of a steel channel, anchor element, and matching t-bolts. Therefore, anchor channel systems are considered specialty inserts.

Specialty inserts are excluded from the Anchoring to Concrete provisions of ACI 318. Acceptance Criteria 232 (AC232) was develop to show anchor channels systems for recognition under the IBC. AC232 provides testing and design guidelines for cast-in anchor channel systems. Although, specialty inserts are not within the current scope of ACI 318, AC232 Section 3.0 Design Requirements provides recommended additions to the ACI 318 anchor to concrete provisions that permit the design of anchor channel systems as if they were included in AC 318.

AC232 removes the boundaries of manufacturers technical data and limitations of testing data. Additionally, it takes into consideration additional design parameters that have not been neglected in the past such as cracked concrete, supplementary reinforcement, anchor reinforcement, 95 percent fractile, member thickness, etc.

**Anchor channel design in accordance to an ICC-ES Acceptance Criteria will help show compliance with the model code. It protects public health, safety, and general welfare. When the design is model code compliant reduces the risk of delays or job site shut downs due to noncompliant designs.**

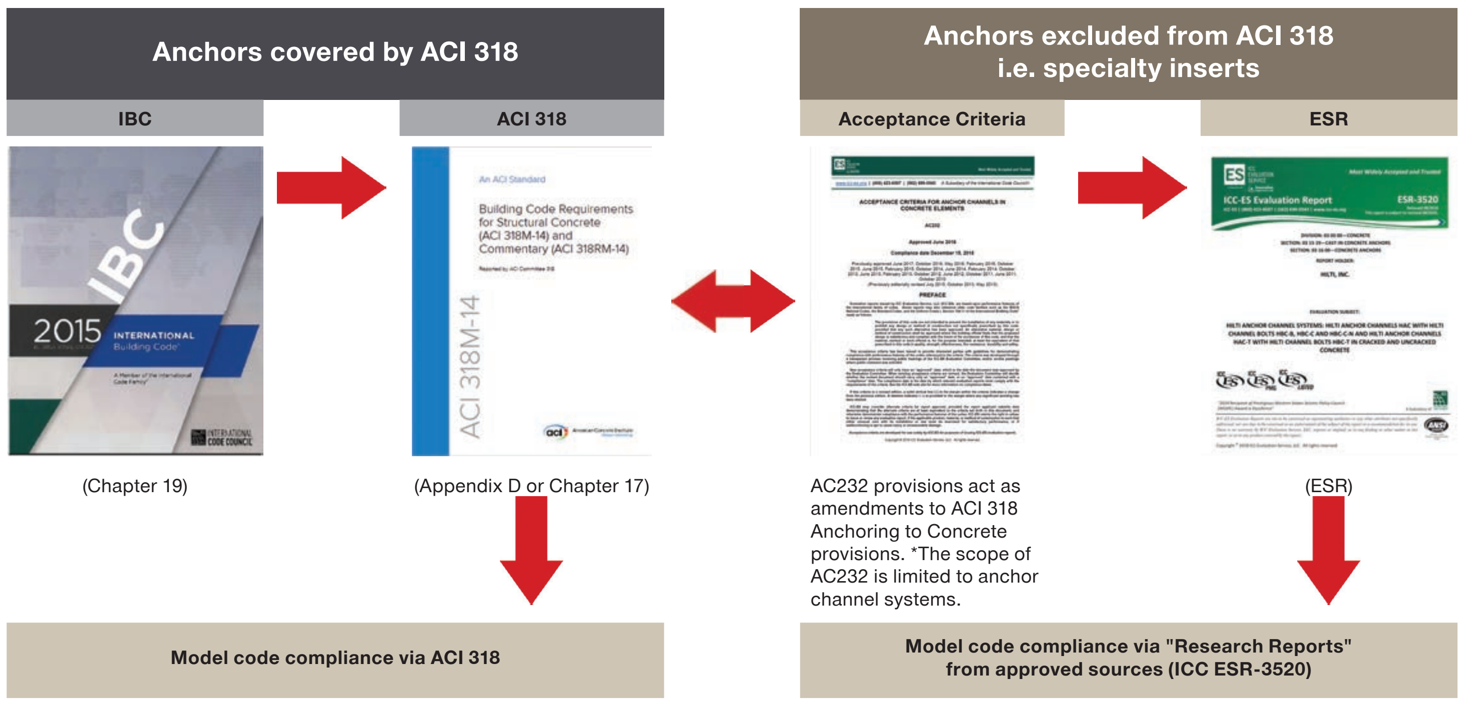



Figure 11.1.1.1 - Model code compliant anchor channel designs

## 11.1.2 ANCHOR CHANNELS OUTSIDE THE SCOPE OF AC232

Only anchor channels with rounded headed anchors or I anchors and straight deformed bars are covered by AC232. Therefore, only HAC can be shown compliant with an ESR. However, there are still applications that require the use of anchor channels not fully covered by AC232, such is the case of HAC CRFoS U and HAC EDGE.

For applications outside the scope of AC232, Hilti has developed design models based on applicable testing protocols and design provisions of AC232. For failure modes outside the scope of AC232 (i.e. pullout strength of a rebar), the principles of AC232 and ACI 318 are followed.

AC232 is a relatively new acceptance criteria. Seismic provisions were only added in 2015. The long term goal is to provide a work frame that covers all applications encountered in a project and anchor channels needed to meet the required design parameters,

# 11.2 HILTI ANCHOR CHANNEL PRICE INDEX

## 11.2.1 HAC PRICE INDEX OF STANDARD PORTFOLIO

The objective of the chart below is to guide designers the ability to select not only the most feasible anchor channel solution, but the anchor channel that makes the most sense for each specific project. The higher the channel is on the scale, the more expensive the channel is. The scale ranges from 0 to 1. Although this chart does not provide the actual cost of the product, the price difference ratio is consistent. Information may vary and therefore, is for preliminary selection purposes. Please consult your local account manager for pricing information.

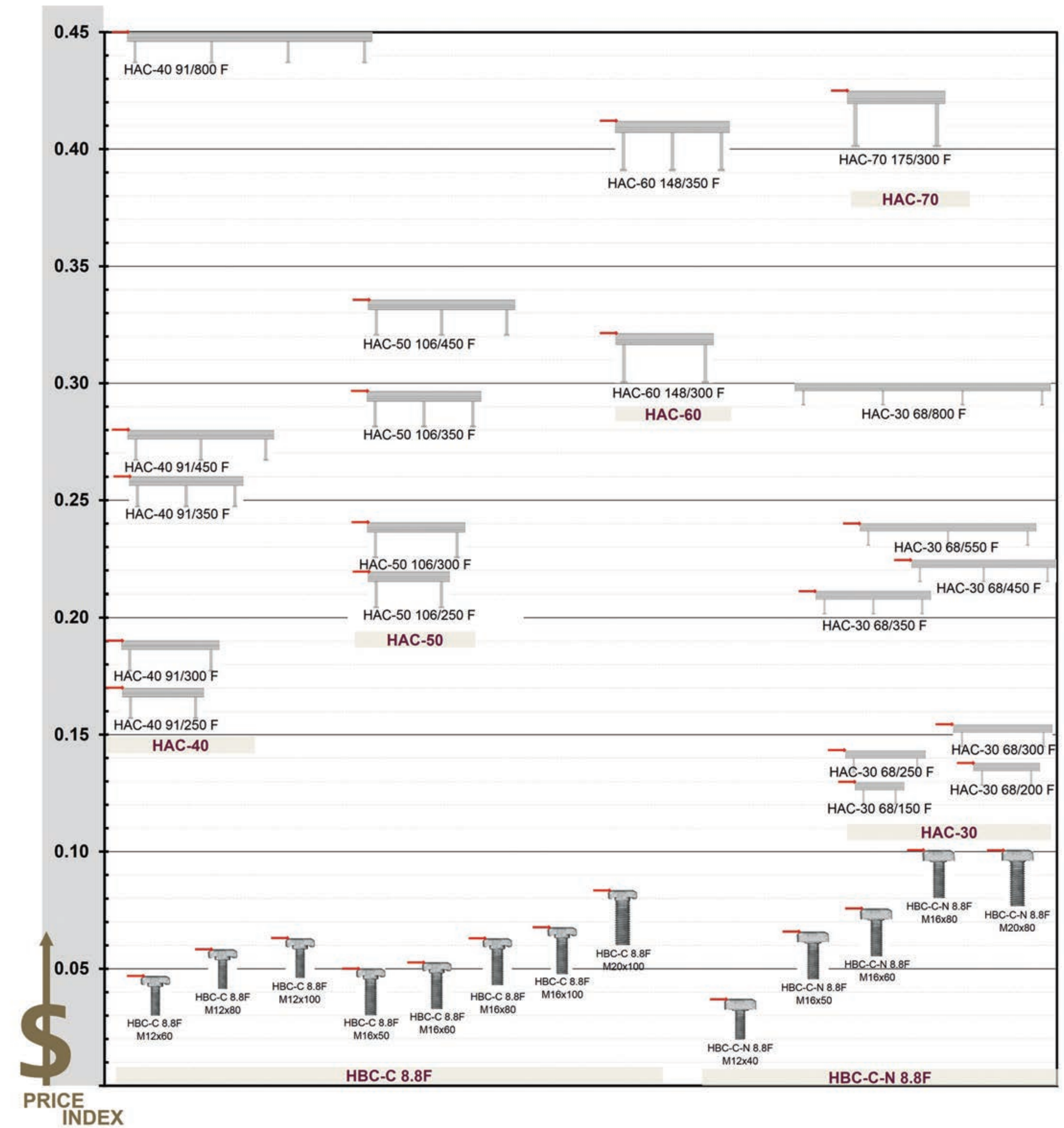



Figure 11.2.1 a — Price index of HAC and HBC

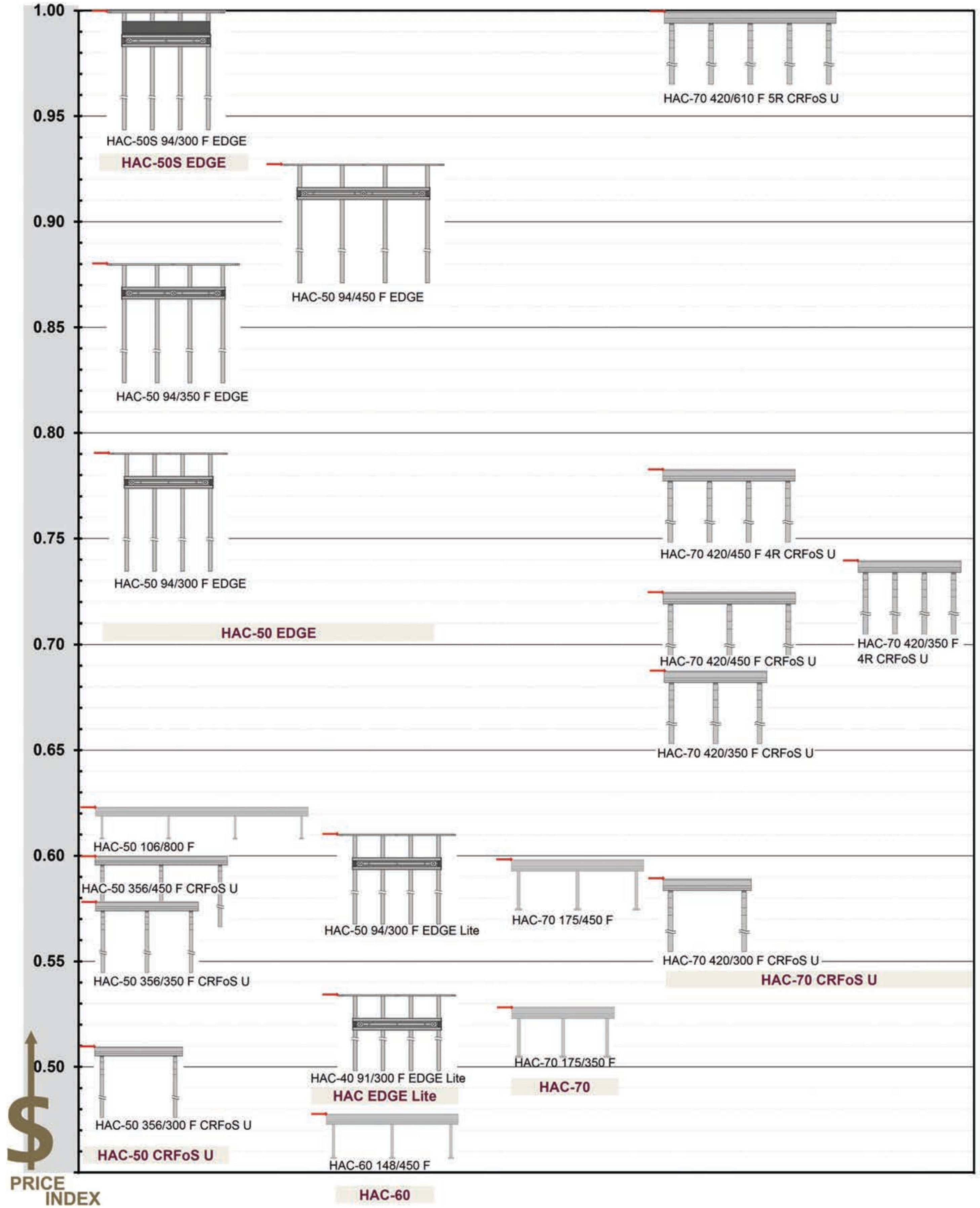



Figure 11.2.1 b — Price index of HAC and HBC

## 11.2.2 HAC VS HAC-T PRICE INDEX

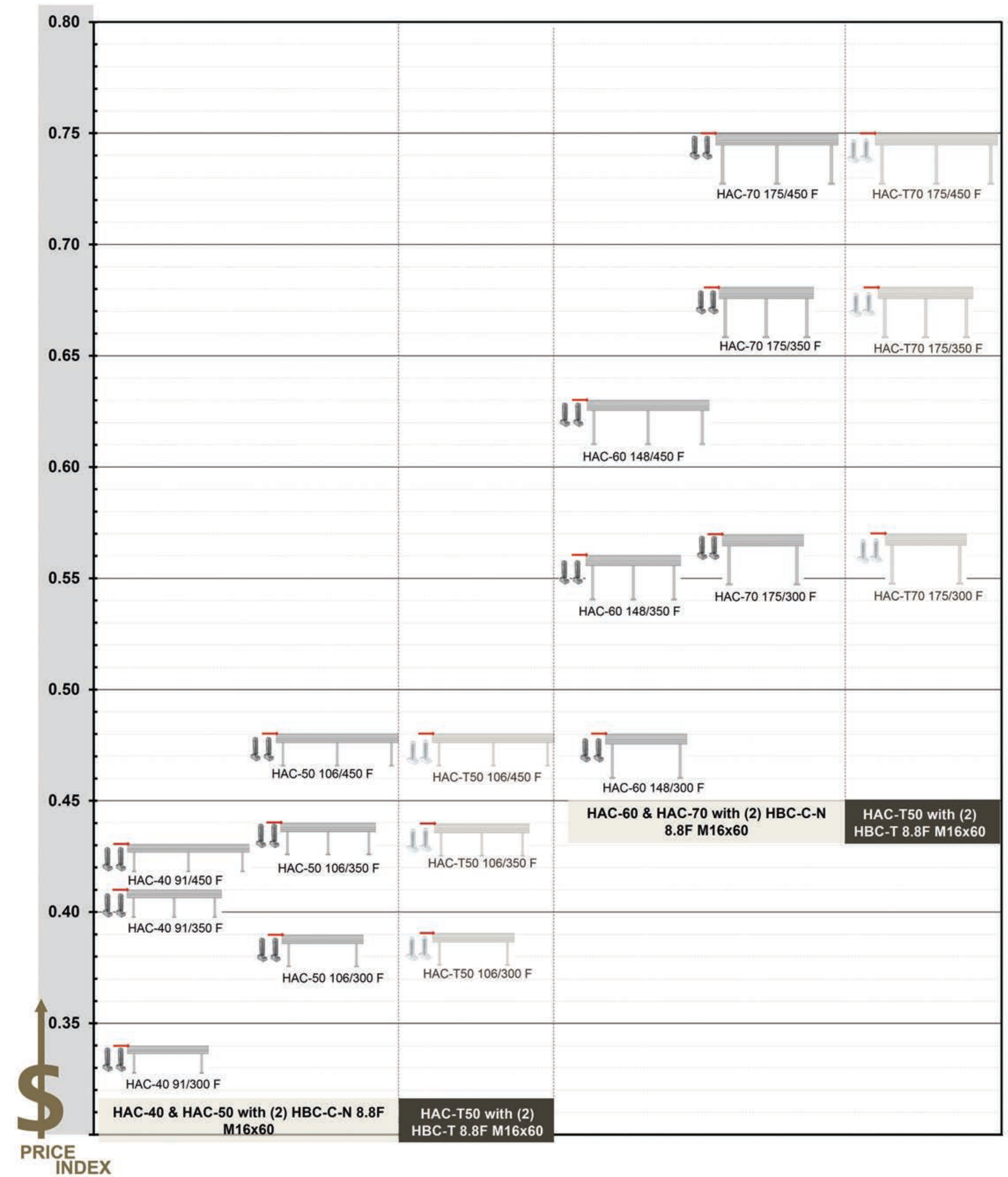



Figure 11.2.2 — Price index of HAC and HAC-T

# 11.2.3 ANCHOR CHANNEL SELECTION USING PRICE INDEX CHARTS — EXAMPLE

## Step 1 Original layout

The plan view below illustrates the original anchor channel recommendations for the typical, corner zones, and jamb conditions of a building. Curtain wall façade is present on the south side of the building.  Recommendations are as follows

- **Typical zone:** HAC-40 91/350 F with (2) HBC-C 8.8 F M12x60 @ 6” O.C.
- **Corner Zone:** HAC-50 106/300 F with (2) HBC-C 8.8 F M12x60 @ 6” O.C.
- **Jamb:** HAC-50 106/300 F with (2) HBC-C 8.8 F M12x60 @ 6” O.C.

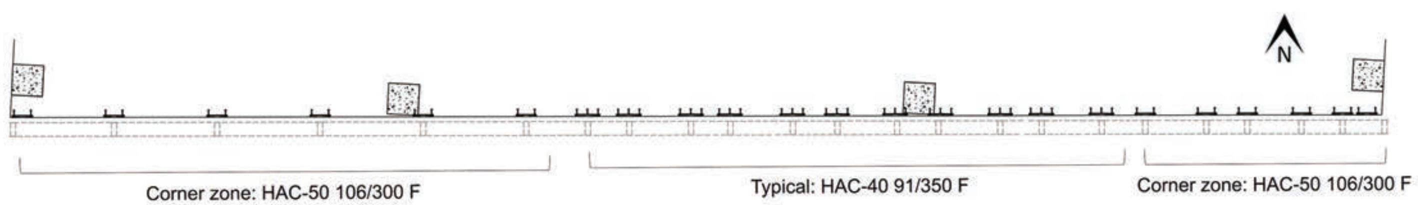



Figure 11.2.3.1 Embed layout, plan view

## Step 2 Check HAC index chart

Based on the price scale chart, HAC-50 106/300 F (unit value ≈ 0.24) is a more feasible solution than HAC-40 91/350 F (unit value ≈ 0.26).

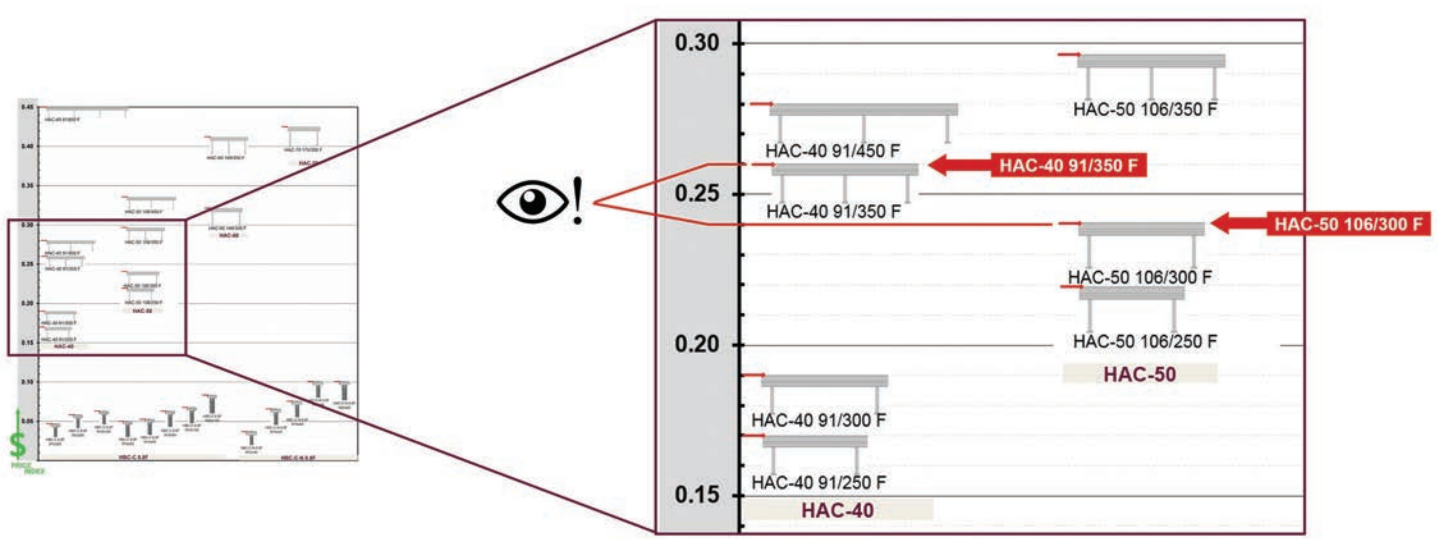



Figure 11.2.3.2 Price index

## Step 3 Check structural feasibility for the more feasible solution

- Check structural suitability of HAC-50 106/300 F at typical conditions.

**Additional feedback:**

The use of a bigger channel profile does not always mean a more expensive solution. There are other factors such as number of anchors, type of anchor, economies of scale, an others that may impact pricing.

The use of a bigger channel profile only indicates a profile with higher steel strengths. There are other failure modes that may be decisive and are influenced by the number of anchors and bolt spacing.

It is always good practice to ensure the specified product will meet the project's schedule. For typical anchor channel lead times, see section 2.4.

## Step 4 Check if the more feasible makes sense.

- HAC-50 106/300 F is structurally adequate at typical, corner zones, and jamb conditions. It is also a more feasible solution than HAC-40 91/350 F.
- Using one channel for the entire south face of the building simplifies the anchor channel installation as it reduces the probability of installation errors. Therefore, change HAC-40 91/350 F to HAC-50 106/300 F.

**Note:** Sometimes, selecting for a more feasible solution for a specific condition may not be practical. Check if the savings justify the potential embed layout complexities.

## Step 5 Original layout

Change original recommendations for the original typical conditions. Use HAC-50 106/300 F at the typical an corner zone conditions.

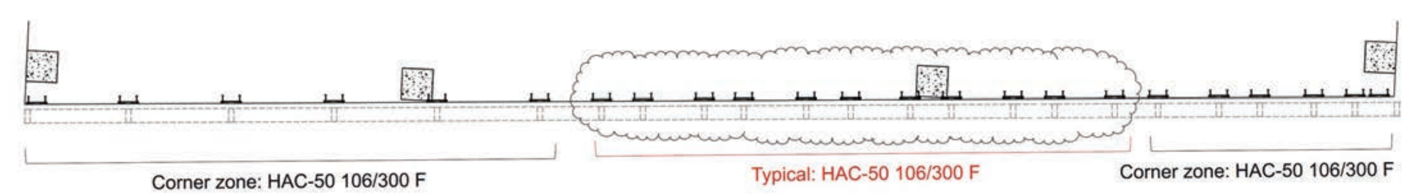



Figure 11.2.3.3 Optimized embed layout, plan view

# 11.3 HAC DESIGN OPTIMIZATION

## Introduction

For projects where thousands of conditions are covered by one anchor channel type, using a $15 vs $18 dollar solution could ultimately bring significant cost savings. This section provides work arounds to help designers optimizing the anchor channel selection without having to select a more expensive anchor channel. The guidelines or work-arounds discussed in the next section require minimum impact to the design and it is generally acceptable. Always evaluate the overall cost of each solution considering the entire requirements of the entire system.

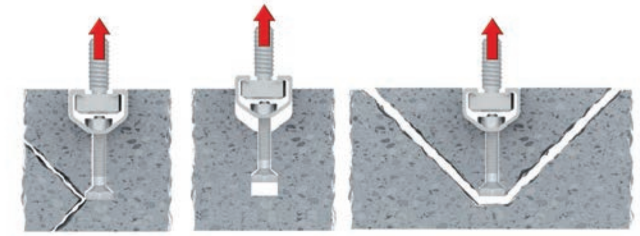
The following recommendations are intended to be used when the anchor channel is over utilized up to 10%-15%, with minimum or no impact to the fixture and without change the substrate conditions (i.e. using stirrups, supplementary reinforcement, increasing edge distance, etc.) The logical option is always using a bigger channel (except when HAC-70 is the channel under consideration) and therefore, this option is never discussed in the next guidelines

## General guidelines

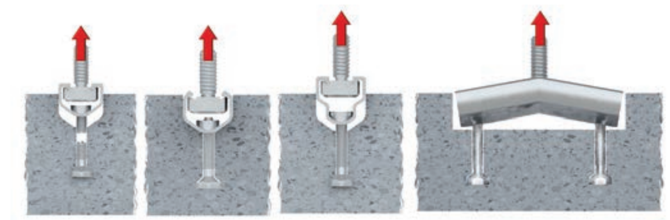
- Increasing t-bolt spacing helps to distribute the load amongst the anchors more efficiently. When the channel is slightly overutilized, consider increasing bolt spacing to reduce the acting loads at the critical anchor, reducing the overall utilization in the most utilized anchors.
- Depending on the design parameters and application type, utilizations exceeding the 100% utilization by 3% may be acceptable.
- If concrete interaction yields utilizations within 110% for static loads, try using ACI 318 interaction equations for concrete. This is only valid for concrete and for failure modes cover by ACI 318 or AC232.
- When channel lip or anchor-channel connection exceeds the utilization, consider adding a bolt with smaller channel rather than increasing channel size
- Price difference between M12 and M16 bolts is minimum. Try to avoid combining different t-bolt sizes ease installation.
- Closer edge distances do not always mean higher utilizations, if the back-span or prying leg is increased. The concrete strength may be reduced but the acting loads at the t-bolts may be reduced by a larger value.
- Consider the HAC Price index, specially at the typical conditions.
- Brackets may be wide enough to allow increasing the t-bolt spacing and use a more feasible channel.
- Brackets may provide enough room to reposition the slotted hole in order to increase the edge distance or reduce the wind load eccentricities, without the need of creating a new die.
- Check structural drawings to verify if supplementary reinforcement (i.e. straight edge reinforcement or Condition A) can be assumed.

## 11.3.1 WORK-AROUND IN TENSION

**Concrete:** Concrete breakout, $\Phi N_{cb}$
Pullout, $\Phi N_{pn}$
Blowout, $\Phi N_{sb}$




**Steel:** Anchor $\Phi N_{sa}$
Connection anchor-channel, $\Phi N_{sc}$




### WORK-AROUND: SPREAD THE LOADS AMONGST THE ANCHORS IN A MORE EFFICIENT WAY.

Increasing the bolt spacing is possible when the bracket allows (i.e. J-hook type bracket). Also, consider the cost difference between using a bigger channel size versus increasing the width of the bracket.

By increasing the t-bolt spacing, the loads are redistributed amongst the anchors in a more efficient way. Thus, reducing the acting loads at the critical anchor. Figure 11.3.1.1 illustrates this concept. Left side of Figure 11.3.1.1 has a relatively small t-bolt spacing. Therefore, t-bolt 1 and t-bolt 2 transfer most of the loads to the center anchor. Right side of figure 11.3.1.1 has the same anchor configuration but with increased t-bolt spacing. As a result, the loads at the center anchor are significantly reduced.

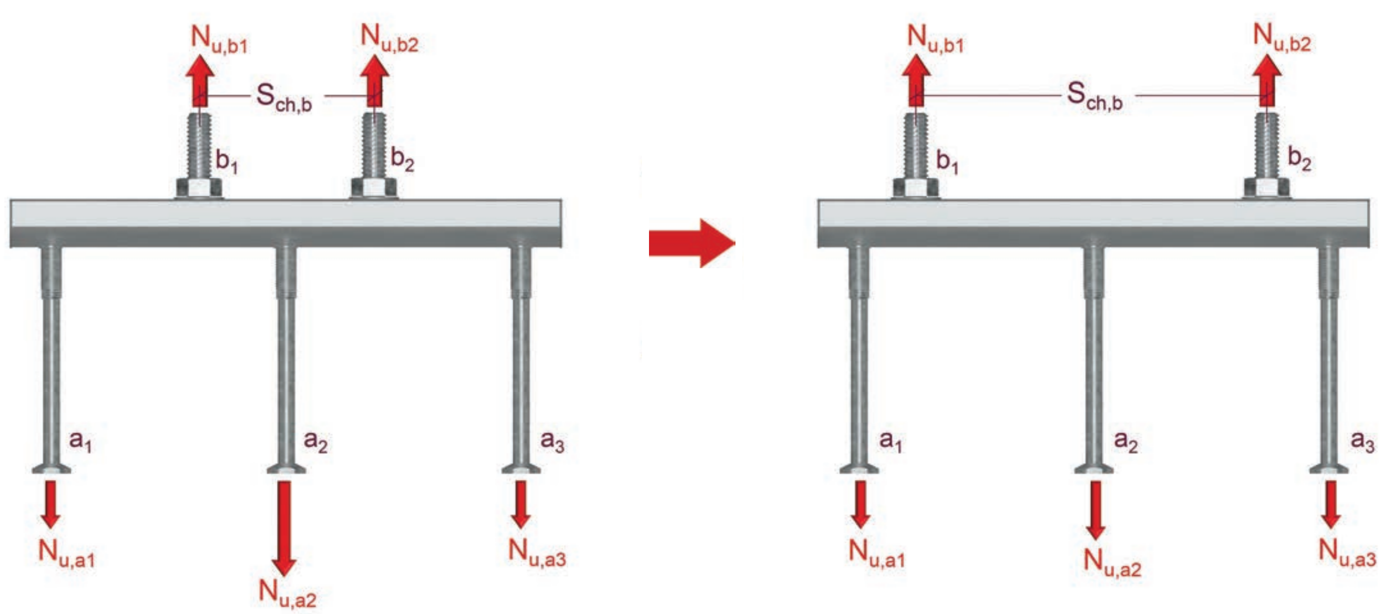
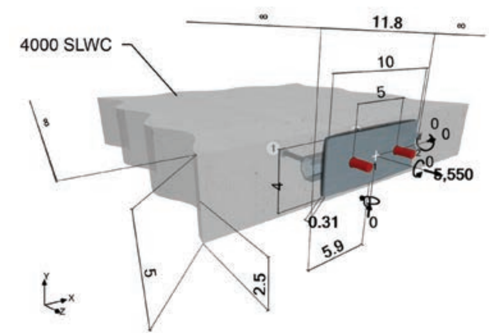



**Figure 11.3.1.1 optimization of load distribution from t-bolts to anchors**

## Example

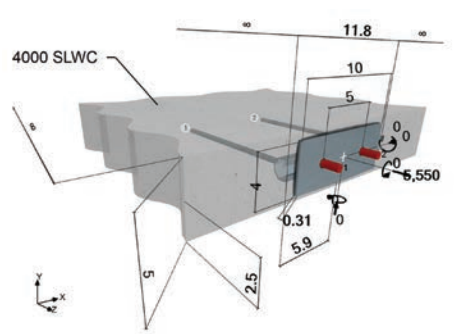
**As-is**
**Design status: Not ok**

Anchor channel: HAC-50 106/300 F
Utilization: 107%
Bolt spacing: 5.00"
Anchor channel Price Index: 0.24



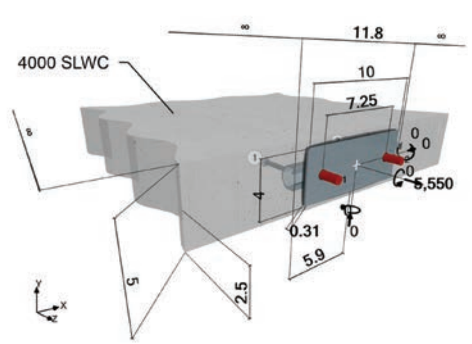

**Solution option 1: use HAC CRFoS U**
**Design status ok**

Anchor channel: HAC-50 356/300 F CRFoS U
UUtilization: 64%
Bolt spacing: 5"
Anchor channel Price index: 0.51




**Solution option 2: use longer HAC with increased bolt spacing**
**Design status: ok**

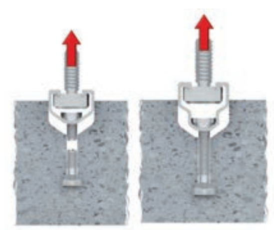
Anchor channel: HAC-50 106/450 F
Utilization: 100%
Bolt spacing: 7.125"
Anchor channel Price Index: 0.335




**Conclusion:**

Solution option 2 provides a price differential index of 0.175 (0.51-0.335). This is roughly 73% on HAC savings by just increasing the t-bolt spacing by 2.125"!

**Steel:** Anchor $\Phi N_{sa}$
Connection anchor-channel, $\Phi N_{sc}$

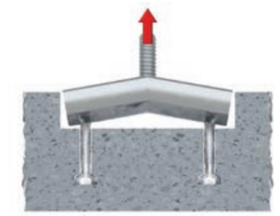


### WORK-AROUND: ADD ANCHORS

If concrete strength does not control but the anchor-channel connection and anchor strength is limiting the design, consider using an anchor channel with more anchors. Refer to price index to asses if an anchor channel with more anchors or a bigger channel is more economical.

Note: adding more anchors may negatively impact the concrete breakout strength of the anchor under consideration. For HAC CRFoS U, there is no concrete breakout in tension and therefore, adding more anchors is always a viable solution.

## Bending of channel, $\Phi M_{s,flex}$

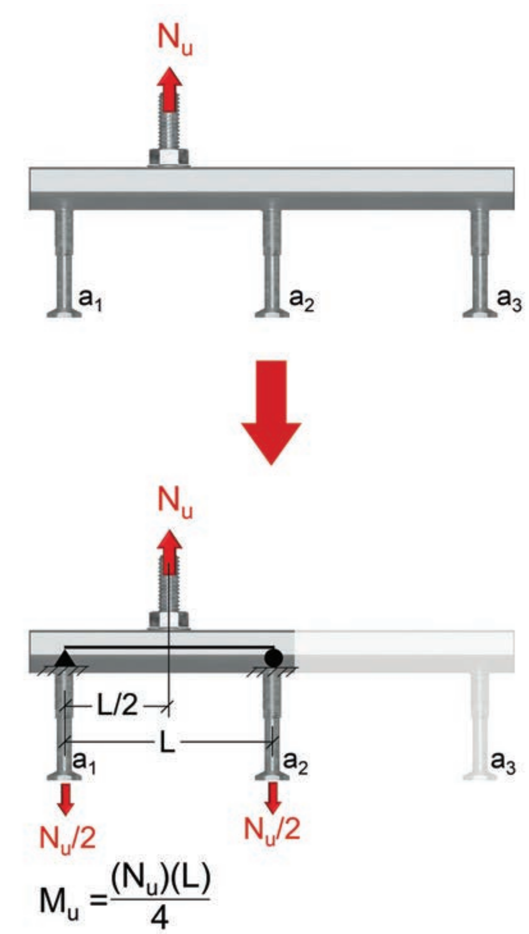


### WORK-AROUND: INCREASE T-BOLT SPACING OR REDUCE ANCHOR SPACING

Flexure of the anchor channel is another failure mode where the resistance is derived via testing and cannot be increased. However, the applied flexural forces can be reduced by increasing the t-bolt spacing or reducing the anchor spacing.

The applied bending moment at the channel is derived under the simplified model where the channel profile is treated as a simple supported beam, with a span equal to the anchor spacing.

See price index to determine if it is more feasible to use a bigger anchor channel or to add an anchor.



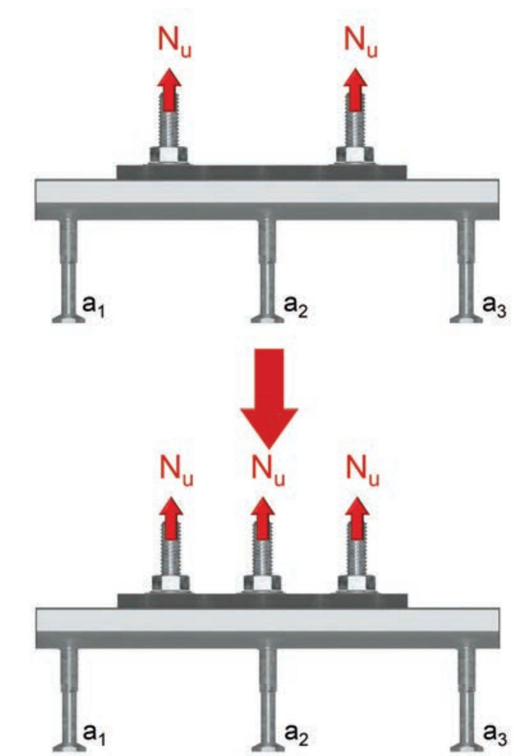

## Channel lip, $\Phi N_{sl}$

### WORK-AROUND: ADD A T-BOLT, ADD AN ANCHOR OR INCREASE T-BOLT SPACING

The channel lip strength is a value derived via testing. The design strength of the channel lip may be reduced if the t-bolt spacing spaced closely is less than 2 times the width of the channel profile, ($2b_{ch}$) and are loaded simultaneously (in tension).

One of the 5 interaction equations requires the verification of the channel lip in tension combined with the flexural strength of the channel profile. The applied bending moments can be reduced by reducing the anchor spacing.

The work around for applications where the channel lip strength is not adequate is adding a t-bolt or increasing the t-bolt spacing. This is generally acceptable at corner conditions. For typical conditions, adding a t-bolt may have the same cost as going to a bigger channel size. For other applications, the use of a bigger channel profile may be required.



## Optimize fixture

### REPOSITION SLOTTED HOLE TO INCREASE BACK-SPAN AND REDUCE WIN LOAD ECCENTRICITIES

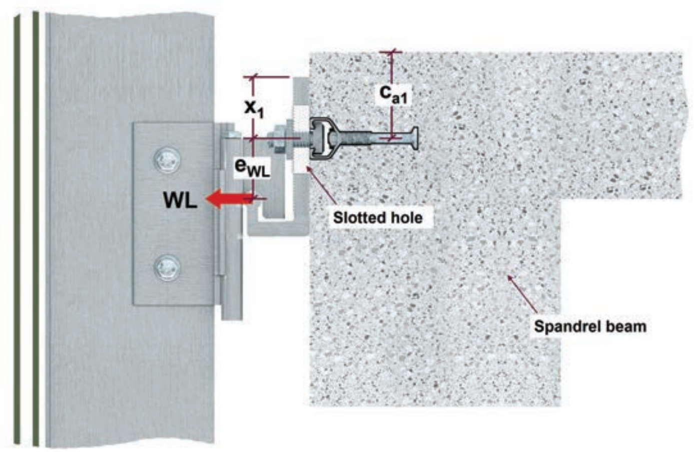
Oftentimes, a minor modification to the location of the slotted hole, without requiring a new die may help saving thousands of dollars.

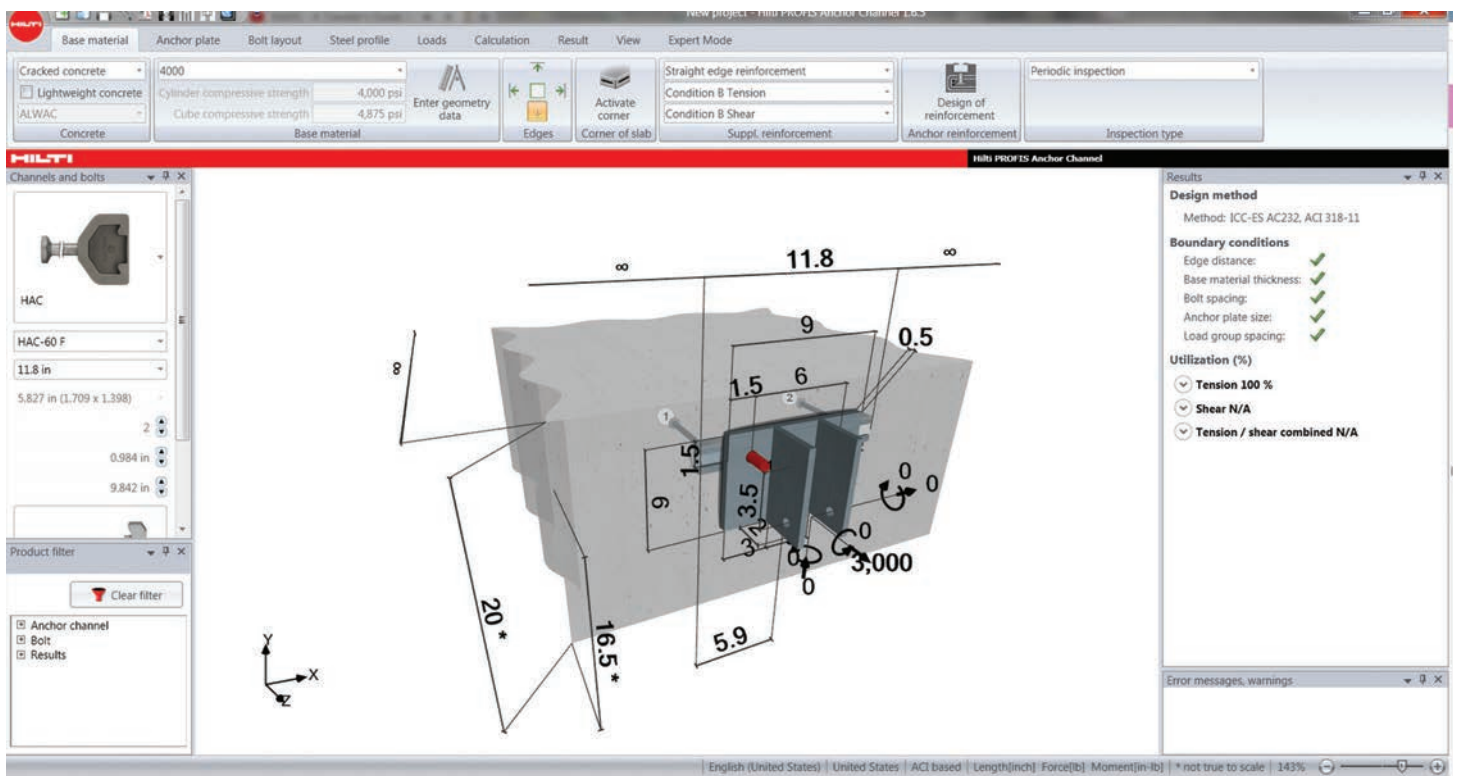
**Nominal bracket and WL information**
x1 = 2.5 in.
$e_{WL}$ = 2.5 in.
Slotted hole allows for +/- 1" up and down tolerance

**Additional information**
$c_{a1}$ = 3.5 in.
WL = 3500 lb (factored)
(only will load is applied, for illustration purposes)
Concrete compressive strength = 4,000 psi

Assume (2) t-bolt spaced at 6" O.C.

For analysis purposes, the critical bracket position is down. Therefore, for analysis purposes, the $x_1$ value is reduced by 1 in. while the $e_{WL}$ is increased by 1 in.




The above figure illustrates a screen shoot of the example in discussion, modeled in PROFIS Anchor Channel. Although the bracket in the model is not a "J" type bracket, the software assumes a rigid bracket.

Therefore, the key dimensions are the paying leg (backspan, $x_1$) and wind load eccentricity ($e_{WL,1}$). The bracket has a true hole, therefore, the bracket position is manually positioned assuming the worst position; bracket down.

In summary, the nominal dimensions need to be manually adjusted to account for the critical bracket position.

| Nominal Dimensions | Bracket Down Dimensions |
|---|---|
| $x_1$ = 2.5 in. | $x_1$ = 1.5 in. |
| $e_{WL,1}$ = 2.5 in. | $e_{WL,1}$ = 3.5 in. |

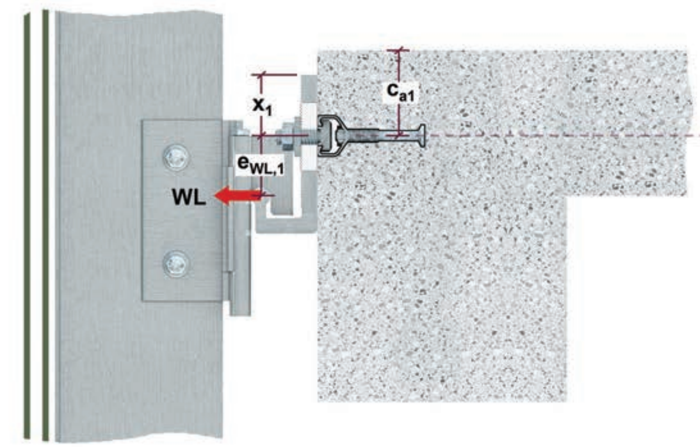
HAC-60 148/300 F with (2) HBC-C 8.8F M16x60 yields a utilization of 100%. Concrete breakout in tension is the governing failure mode.

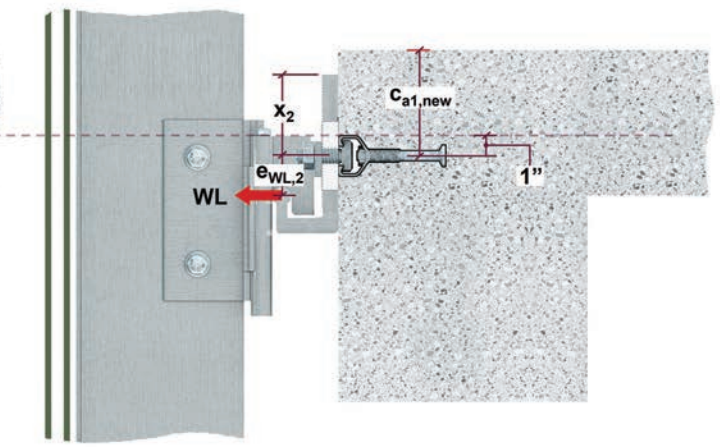


## Optimized fixture: move the anchor channel and the slotted hole 1 in. down.

The figure below (left) shows the original configuration; the anchor channel has an edge distance (ca1) equal to 3.50 in. The right figure shows the new anchor channel location; the edge distance is equal to 4.50 in.

Note that the overall bracket geometry has not been changed. Moreover, the position of the "J" bracket does not change neither.




### ORIGINAL BRACKET CONFIGURATION

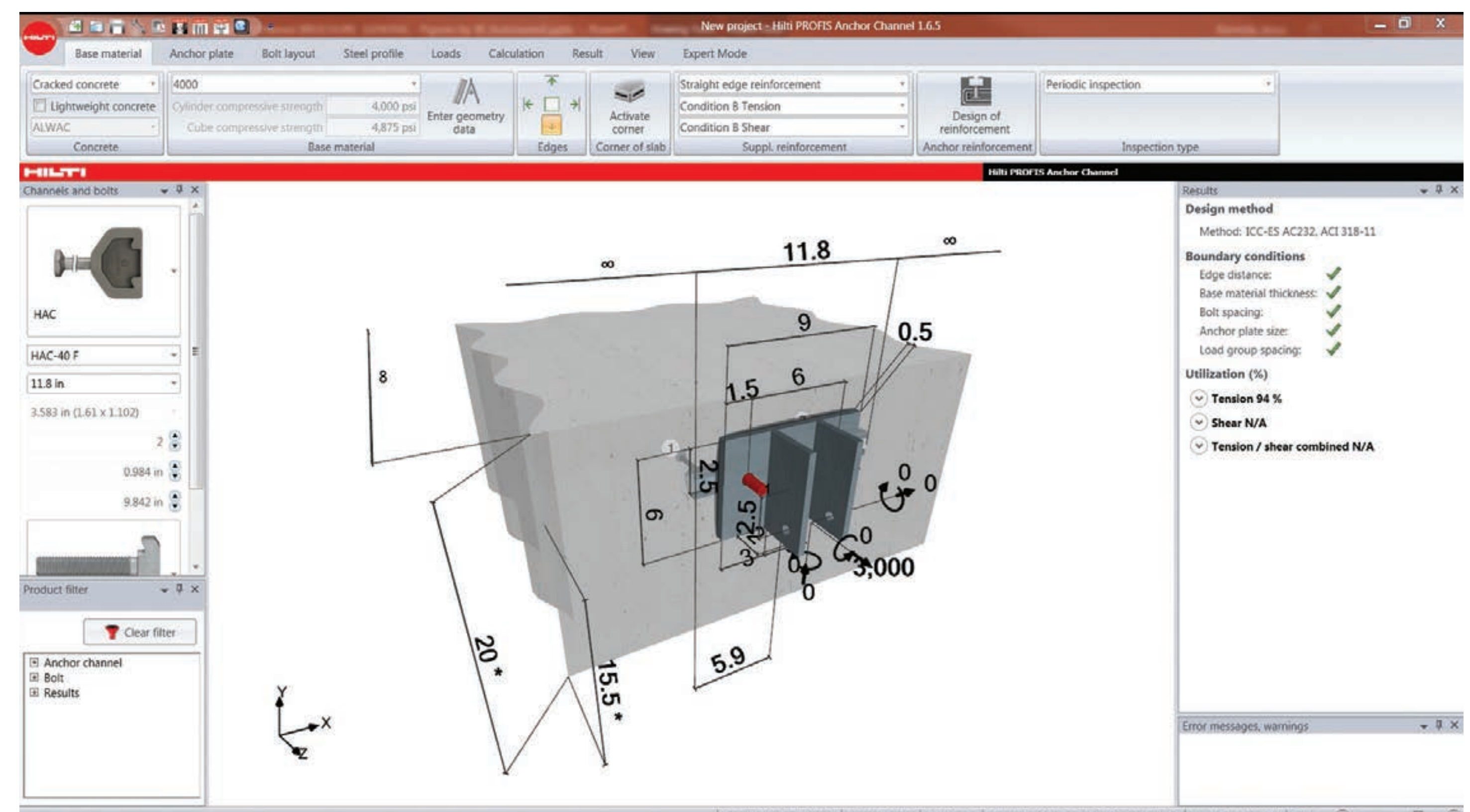
| Nominal Dimensions | Bracket Down Dimensions |
|---|---|
| $x_1$ = 2.5 in. | $x_1$ = 1.5 in |
| $e_{WL,1}$ = 2.5 in. | $e_{WL,1}$ = 3.5 in. |

Edge distance, $c_{a1}$ = 3.50 in.

### OPTIMIZED BRACKET

| Nominal Dimensions | Bracket Down Dimensions |
|---|---|
| $x_2$ = 3.5 in. | $x_2$ = 2.5 in |
| $e_{WL,2}$ = 1.5 in. | $e_{WL,2}$ = 2.5 in. |

Edge distance, $c_{a1}$ = 4.50 in.




HAC-40 91/300 F with (2) HBC-C 8.8F M16x60 yields a utilization of 94%. Connection anchor-channel is the governing failure mode.

# 11.4 CAST-IN ANCHOR CHANNEL LAYOUT

### Introduction

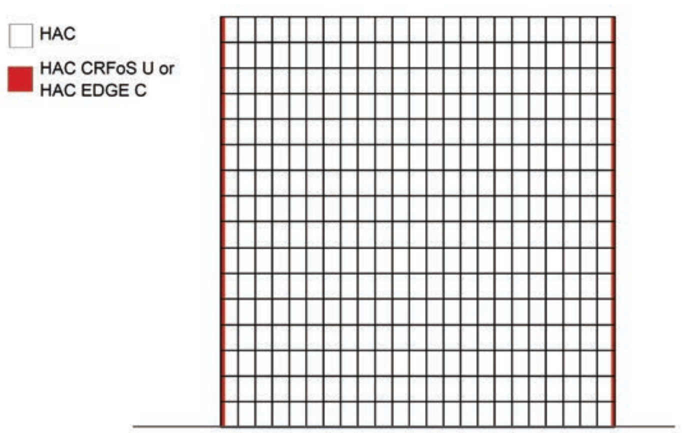
AC232  brought major benefits to the design community. One of the major benefits is that it removed the limitations bounded by relaying on test data only. AC232 provides design guidelines for anchor channels. Having model code compliant design provisions ensures the levels of reliability of the system are met. Safety factors are generally not established via manufacturers but manufacturers follow the IBC.

The publication of AC232 allows to account for design provisions that were neglected in the past. Design considerations such as 5 percent fractile, cracked concrete, seismic detailing are common examples. As the industry continues to evolve, s.

## 11.4.1 ANCHOR CHANNEL LAYOUTS

### Ideal layout:

The most cost effective practical layout is having one anchor channel type covering all typical intermediate applications and one anchor channel type covering the corner zones. A third anchor channel type is typically introduced at corner conditions. In an ideal world, this is the perfect layout.



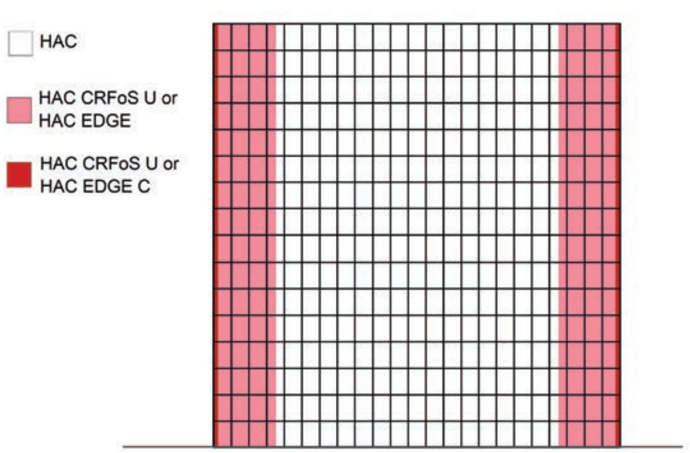




**Figure 12.4.1.1 Optimum anchor channel layout**

### Ideal layout for face of slab applications:

The added benefit of HAC CRFoS U is that it can be used at intermediate applications and corners. Therefore, the anchor channel selection can be reduced to two different anchor channels.

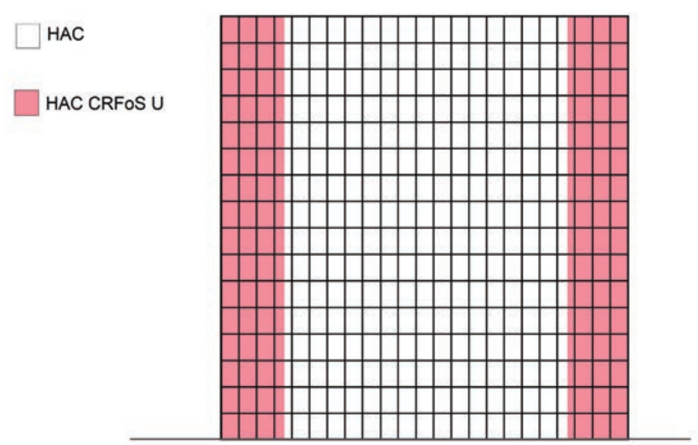



**Figure 12.4.1.2 Optimum anchor channel layout**

### Composite slabs with lightweight concrete:

For applications where the substrate is thin (thinner at pocket zones) and lightweight concrete is used, an anchor channel with rebars (HAC CRFoS U or HAC EDGE) is typically required even at the typical intermediate conditions. For these type of projects, one anchor channel type suitable for the typical intermediate and corner zones simplifies the installation of the anchor channels on the jobsite.

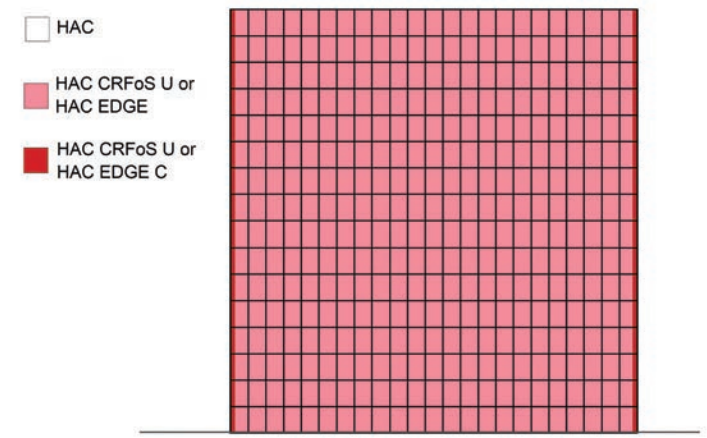



**Figure 11.4.1.3 Typical anchor channel layout for composite slabs**

### Non-traditional wind pressure distribution:

In some cases, the wind pressures acting at the façade may not allow for an optimum layout. These critically loaded conditions typically occur in less than 5% of the applications. Although introducing additional anchor channel will require additional coordination, these critically loaded areas may require customized solutions that using them throughout the entire strip will considerably increase the cost of the anchor channel.

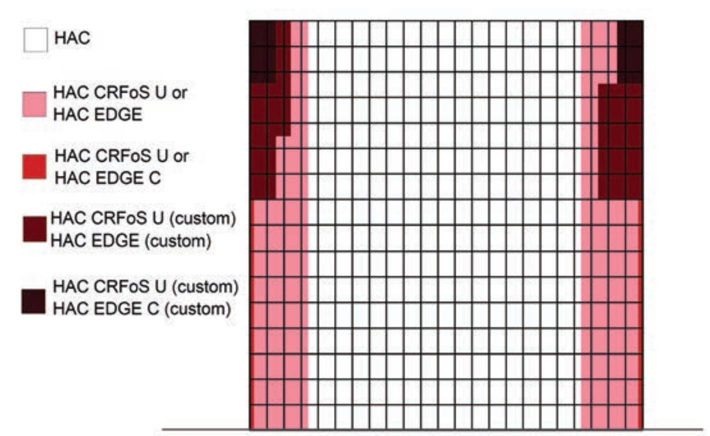



**Figure 11.4.1.4 Anchor channel layout for conditions with extreme wind pressures**

### Bring it all together:

The Hilti Anchor Channel Systems have been engineered keeping ease of installation at its root. It offers a gradual increase in performance while maintaining one t-bolt type compatible with all HAC-40 to HAC-70 channel profiles.

HAC CRFoS U which are commonly used at corner zones in face of slab applications can also be used at the corners. This is one less channel type to worry about.

HAC EDGE comes with the right edge distance simplifying even further its installation while minimizing the probability of installing the product at the right edge distance.

Some layouts cannot be idealized and there are always conditions that may require unique-custom solutions.  This section provides different layout and the fundamentals can be applied to your unique project.

# 11.5 SUBSTRATE CONSIDERATIONS

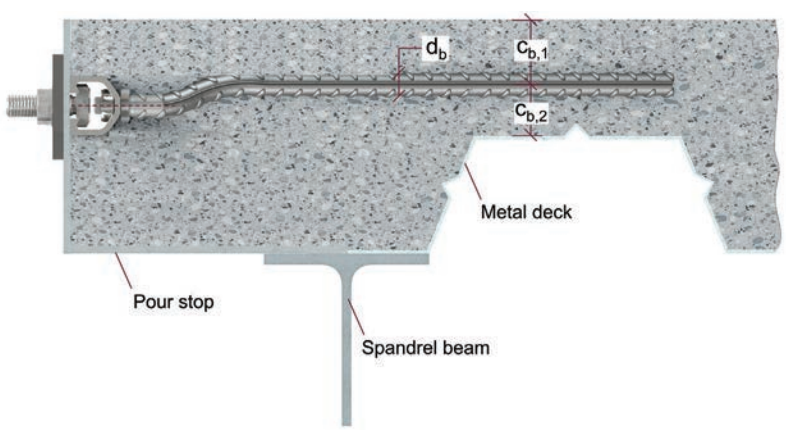
## 11.5.1 COMPOSITE SLABS

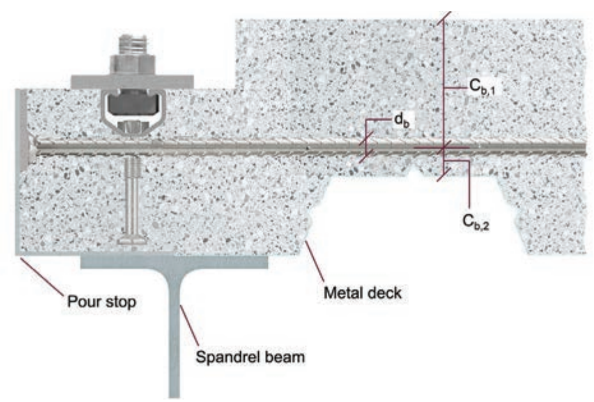
Composite slabs are one of the most common methods of steel frame floor construction; therefore, it is common substrate for anchor channels. Naturally, the use of anchor channels in composite slabs may bring additional challenges, especially for applications where anchor channel with rebar anchors or shear confinement plate is required.

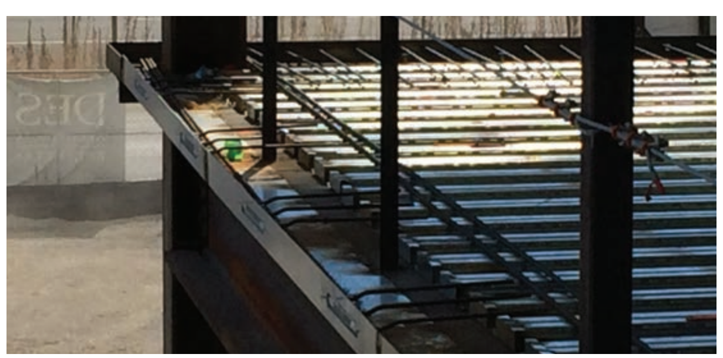
Addressing the following potential conflicts before installation of the anchor channel system takes place may avoid issues, field fixes, and speed up the installation. Moreover, each condition can be evaluated based on actual conditions.

### POTENTIAL CONFLICTS ARE AS FOLLOWS:

- Clashing of rebar with column
- Clashing of rebars with metal deck
- Corner conditions at corner columns
- If rebars extend into the deck, check adequacy of rebar cover.



**Anchor channel in composite slabs; face of slab application**

**Anchor channel in composite slabs; top of slab application**

## 11.5.2 ALL-LIGHTWEIGHT CONCRETE VS SANDLIGHTWEIGHT CONCRETE

ACI 318 and AC232 provide a modification factor for lightweight concrete (λ). Light weight concrete is sub-classified into two types; all-lightweight concrete and sand-lightweight concrete. The modification factor for all-lightweight concrete is equal to 0.75 while the modification for sand-lightweight concrete is equal to 0.85.

The use of lightweight concrete in composite slabs is quite common. Generally speaking, anchor channels are constrained by the strength of the concrete. Lightweight concrete is commonly specified for composite slabs. Hence, the concrete strength due to an anchor channel is constrained even further. It is always a good practice to verify the type of concrete specified in the project. On one hand, simply assuming sand-lightweight concrete can result in unconservative results. On the other hand, assuming all-lightweight concrete when sand-light weight concrete is present can yield to more expensive designs.

Chapter 5 (Base Material) provides additional information about all-lightweight concrete and sand-lightweight concrete. Determining what type of lightweight concrete use can present a challenge, as this information is not clearly specified all times.

| ASTM concrete type | Aggregate grading specification | Concrete unit weight pcf |
|---|---|---|
| Normal-weight | Fine: ASTM C33<br>Coarse: ASTM C33 | 145-155 |
| Sand-lightweight | Fine: ASTM C33<br>Coarse: ASTM C330 | 105-115 |
| All-lightweight | Fine: ASTM C330<br>Coarse: ASTM C330 | 85-110 |

### Determination of lightweight concrete type

1) Check General Notes of project's structural drawings.
2) Check concrete specifications of the project.
3) Reach out to the structural engineer of records for confirmation.

If there is project where there no enough evidence to support the use of sand-lightweight concrete for design purposes of the cast-in anchor channel, always assume all-lightweight concrete, as this is always the most conservative choice.

## 11.5.3 POST-TENSIONED SLABS

Clashing between embeds and post-tensioned tendons are often overlooked. Clashing between post-tensioned tendons and anchor channels tends to be a common type of field issue. It is always a good practice to coordinate the curtain wall anchorage and posttensioned cables layout, in order to avoid last minute remediations.

Current model codes provide minimal guidance to account for the influence of post-tensioned cables on anchors. The use of cast-in anchor channels in post-tensioned slabs is ideal since compared to other anchoring technologies such as post-installed anchors, it does not require drilling. However, additional measurements need to be taken to ensure the concrete is not overstressed and the concrete capacity of the anchor is not overestimated.

Generally, if the live or dead end of the tendon does not induce additional stresses in the anchorage zone, the capacity of the anchor can be predicted based on applicable anchoring-to-concrete provisions. The anchorage zone of an anchor (concrete volume due to projected area) can be predicted by idealizing the failure planes in shear and tension.

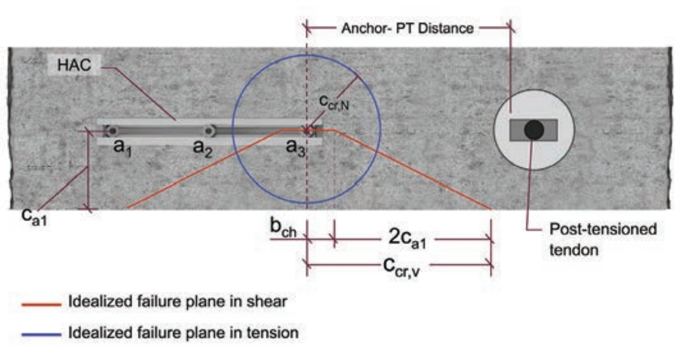



**Figure 11.5.3.1 — Face of slab configuration with live end of post-tensioned slab outside the anchorage zone.**

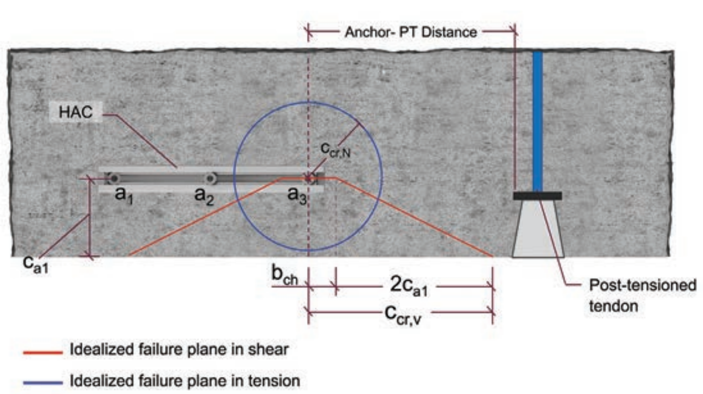



**Figure 11.5.3.2 — Top of slab configuration with live end of post-tensioned slab outside the anchorage zone.**

If the live or dead end of a post-tensioned cable is located or induces additional stresses in the anchorage zone, additional measurements should be taken. Due to model code limitations, a wide range of possible configurations, different types of anchors, and the complexities of this topic in general, these types of conditions shall be assessed on a case-by-case basis and requires additional coordination between different parties such as Engineer of Record, Specialty Engineers (Curtain Wall Designer and Post-Tensioning Engineer), and Anchor Manufacturers. For additional support, please contact Hilti at US+CA.HAC@Hilti.com.

**Figure 11.5.3.3 — Anchor channels installed near live end of post-tensioned cables. Contact Hilti for additional information.**

## 11.5.4 UNCRACKED CONCRETE

Per ACI 318-14, anchors located in a region of a concrete member where analysis indicates no cracking at service load levels, the modification factors for uncracked concrete can be applied. Figure 11.5.4.1 illustrates compression zones in different concrete structures.

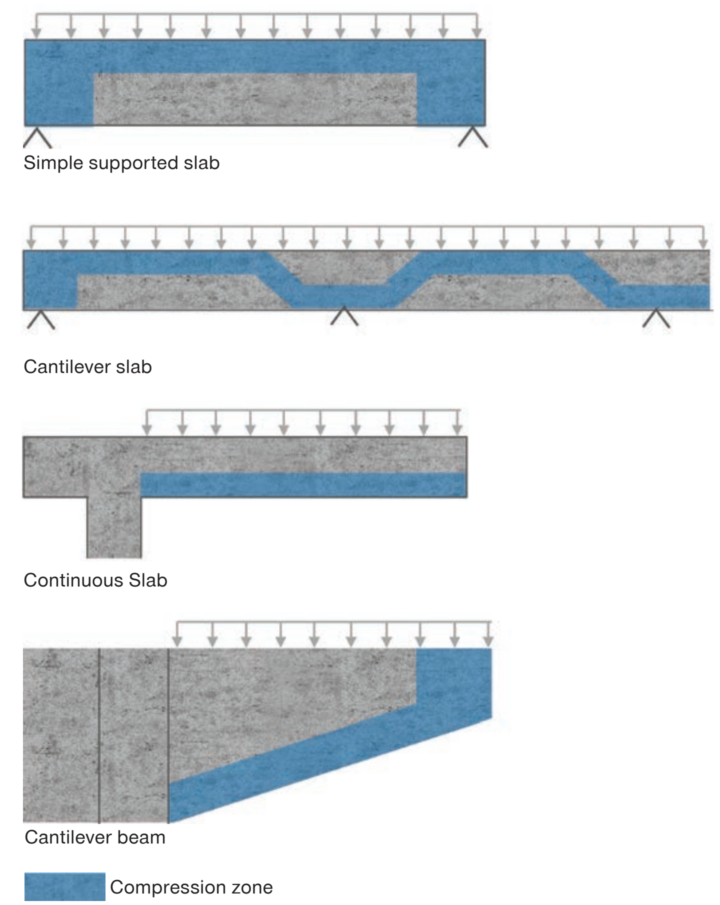



**Figure 11.5.4.1 — Compression zones in different concrete structures**

## 11.5.5 CONCRETE CURB

Although concrete curbs tend to not be the predominant condition, it is a typical condition encountered in buildings and presents additional challenges on it own such as reduced geometrical parameter and lower concrete compressive strengths. The following best practices can help to ease the design, approval process, and minimize field fixes.

1) Always verify the concrete compressive strength as it typically different from the slab or beam which is connected to.

2) Design of anchors is limited to the anchor design. Therefore, its design verifies the adequacy of the concrete at a local level; it ensures the concrete can take resist the applied loads. If a cold joint between the main structure and concrete curb is present, ensure there is proper load transfer between both structures. Additional reinforcement may be required.

3) For installation purposes of top of slab applications, it is recommended to leave exposed areas in front and behind the channel to ensure proper concrete compaction and inspection as air pockets tends to be a common field issue in this type of configurations.

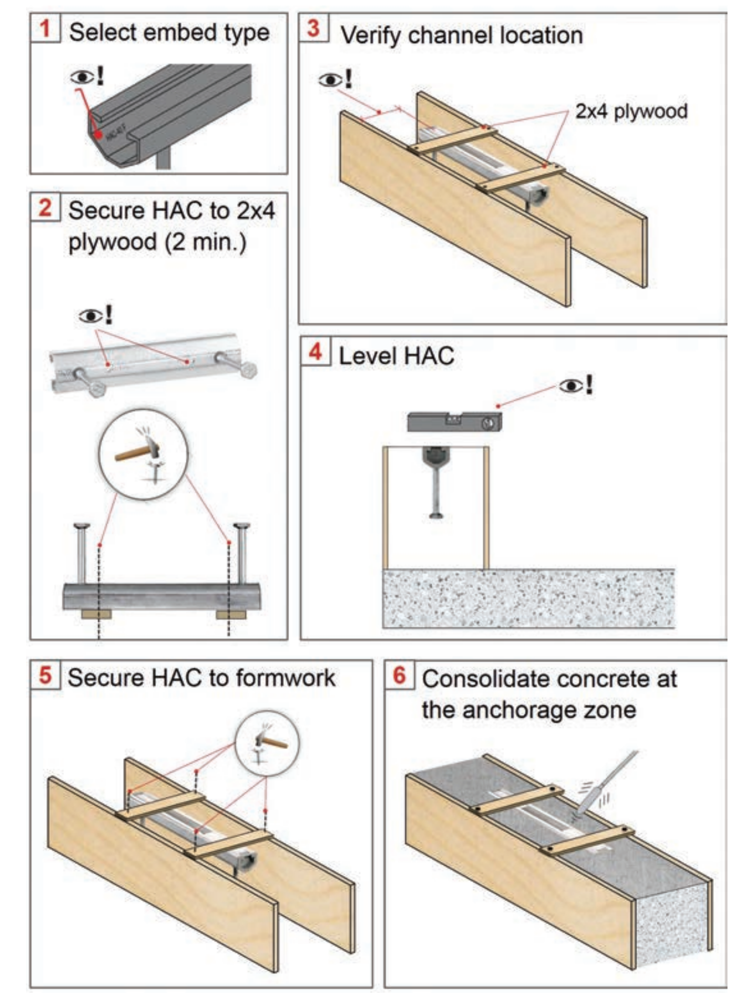



**Figure 11.5.5.1 — Installation of HAC in top of slab curbs.**

## 11.5.6 CONCRETE CONSOLIDATION

The combination of new construction practices, new technologies, and more sophisticated designs is allowing for the construction of buildings in record times. Spans get longer, columns get smaller, slabs get thinner, and lighter construction materials are used. As a result, the construction process has become more complex and best practices have evolved to solve the disputes of modern business. A common field issue encountered in building construction is the formation of air pockets (entrapped air) in the concrete at the anchorage zone.

Air pocket formation occurs due to improperly or no concrete consolidation. Repairing cured concrete with entrapped air is time-consuming, tedious, and can turn out to be quite expensive. Adopting best practices to ensure proper concrete consolidation is performed at the anchorage zone is one of the most effective ways to minimize field issues due to improper concrete consolidation. A couple of extra seconds at each connection point can pay dividends, avoid additional coordination and additional work to an already complex and fast-track work environment where the project's schedule leaves room for a minimal margin of error.

Proactivity goes a long way. Implementing best practices that ensure adequate concrete consolidation will ensure the anchorage will perform the way it was designed. **During pre-construction meetings, emphasize the importance of adequate concrete consolidation at the anchorage zone, especially if the cast-in anchor is near a confined space or congested zone. Try it out in your next project!**

**Figure 11.5.6.1 — Pictures of Conditions with Improper Concrete Consolidation at the Anchorage Zone.**

### Concrete

Concrete is the combination of four basic components:

- Water
- Cement
- Sand (small aggregate)
- Rock (large aggregate).

When mixed together, hydration, or curing, occurs, where the cement paste acts as a glue binding all of the surrounding aggregates. When concrete is poured, it contains entrapped air. If the entrapped air is not removed and the concrete is hardened in this way, it will negatively impact the expected properties of the concrete. Moreover, it will create serviceability, esthetics, and other issues such as subsidence cracking, and placement lines (1).

### Entrapped Air in Concrete

When concrete is first poured, entrapped air can occupy up to 20% of the concrete volume (1). The amount of entrapped air varies depending on the concrete's workability. As a rule of thumb, concrete compressive strength improves by about 5% for every 1% of air removed (3). Figure 11.5.6.2 illustrates the decrease in strength of the designed concrete compressive strength per percentage of entrapped air.

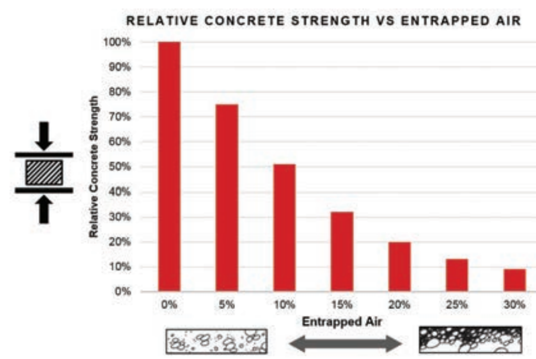



**Figure 11.5.6.2 — Loss of Concrete Compressive Strength Through Increase in Entrapped Air (2).**

### Concrete Consolidation

Concrete consolidation is defined as the process of removing entrapped air from freshly placed concrete. Several methods and techniques are available, the choice depending mainly on the workability of the mixture, placing conditions, and degree of air removal desired. Some form of vibration is usually employed (1).

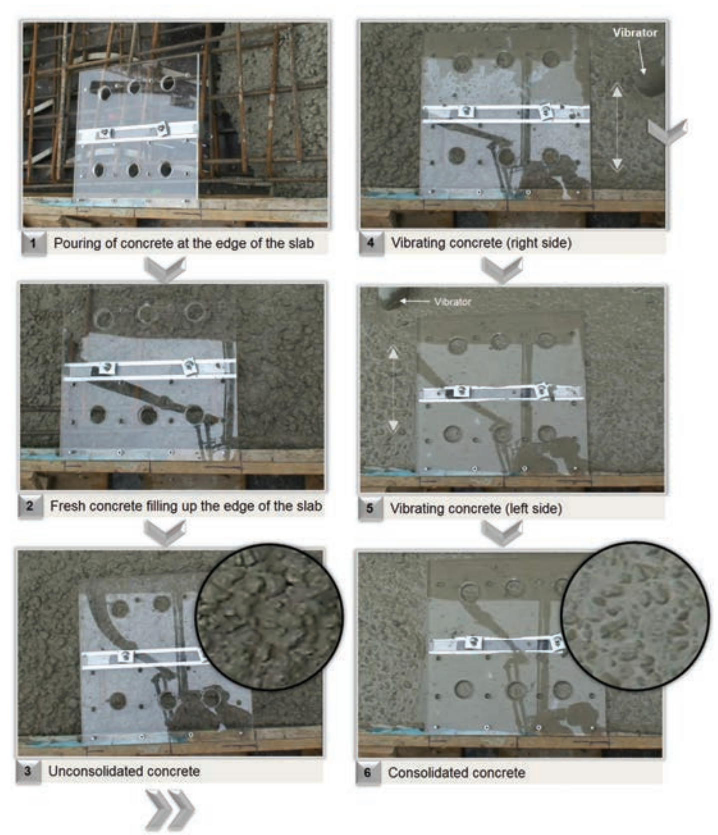



**Figure 11.5.6.3 — Pouring and Vibrating Concrete at the Edge of the Slab.**

### Purpose of Concrete Consolidation

Proper concrete consolidation helps avoid air pocket formations, honey combs, and removes the entrapped air in the concrete. Adequate concrete consolidation helps ensure the concrete will reach its designed properties as well as helping the concrete reach its designed strength. Moreover, adequate concrete consolidation helps enhance the bond of the concrete with the reinforcing bars and increases the general durability of the concrete. Finally, it helps decrease the permeability and helps minimize it's shrinkage and creep characteristics. Figure 11.5.6.4 provides pictures of jobsites with proper concrete consolidation at the anchorage zone.

**Figure 11.5.6.4 — Pictures of Conditions with Proper Concrete Consolidation at the Anchorage Zone.**

### The Process of Concrete Consolidation

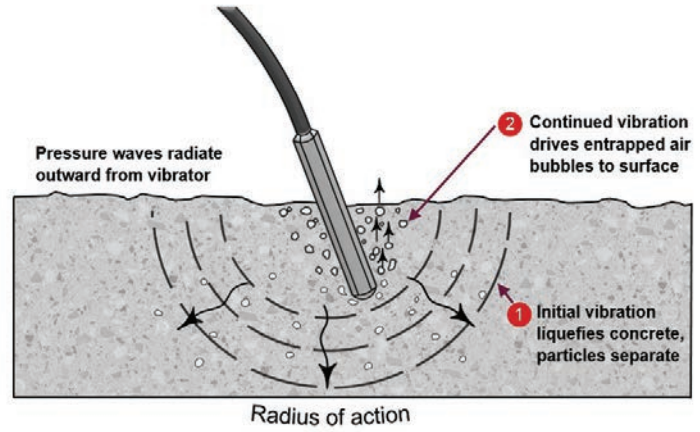
Although there are different ways to consolidate the concrete, the most effective way to remove entrapped air is vibration. Vibration consists of subjecting freshly placed concrete to rapid vibratory impulses which liquefy the mortar and significantly reduce the internal friction between aggregate particles (1). Figure 11.5.6.5 illustrates a construction member vibrating the concrete at the anchorage zone using a standard immersion vibrator.

**Figure 11.5.6.5 – Construction Member Vibrating the Concrete at the Anchorage Zone.**

Consolidation via standard immersion vibrators is best described as consisting of two stages — the first comprising subsidence or slumping of the concrete, and the second a de-aeration (removal of entrapped air bubbles). The two stages may occur simultaneously, with the second stage underway near the vibrator before the first stage has been completed at greater distances (2). Figure 11.5.6.6 illustrates the two-stage process to best consolidate concrete. **If in doubt, always err on the side of more vibration.**

Per ACI 309R-05, the procedure for internal vibration shall be as follows (1):

- Concrete should be deposited in layers compatible with the work being done.
- The maximum layer depth should be limited to 20".
- The depth of the layer should be nearly equal to the vibrator head length.
- The layer should be as level as possible so that the vibrator is not used to move the concrete laterally, as this could cause segregation.
- The vibrator should be systematically inserted vertically at a uniform spacing over the entire placement area.
- The distance between insertion should be approximately 1-1/2 times the radius of influence and should be such that the area visibly affected by the vibrator overlaps the adjacent just-vibrated area.




| Stage | 1 | 2 |
|---|---|---|
| Process | Liquefaction of the concrete which allows it to slump and fill the form | The expulsion of entrapped air |
| Time (seconds) | 3 to 5 | 7 to 15 |

**Total Time for both stages of the process: 10 to 20 seconds**

**Figure 11.5.6.6 –**

**MINIMIZING FIELD FIXES OF CAST-IN ANCHORS**

Depending on the amount of entrapped air, the field fix for the anchorage may vary from a simple patch with high strength non-shrinkable grout, installing post-installed headed rebars, or re-pouring a large amount of concrete. The field fix becomes more cumbersome and costlier for areas where anchors are highly loaded and reinforcing bars are used.

To avoid/minimize the number of conditions with entrapped air at the anchorage zone, be proactive. During pre-construction meetings, discuss the following with the concrete contractor:

a) Require concrete consolidation at each anchorage point (the GC will thank you later!). Add extra emphasis on heavily reinforced zones, congested areas, confined spaces, areas with minimum reach, and zones where the formwork prevents visibility.
b) Share the best practices and make sure the field personnel know to consolidate the concrete.

**References:**

1) Guide for Consolidation of Concrete, ACI 309 R-05
2) Cement Concrete and Aggregates Australia 2006 Compaction of concrete (Australia) 1-7
3) DesigNSWn and Construction of Concrete Floors, George Garber. Elsevier Ltd, 2006.
4) The Why and how of consolidating concrete, by Bruce A. Suprenant

# 11.6 ANCHOR CHANNEL SPECIFICATIONS

Specifier Note: This specification is intended to address the use of cast-in anchor channel for safety-related applications, such as structural connections, earthquake bracing, guard rails, mechanical and electrical equipment support, piping and ductwork support and bracing, cladding, and façade connections, or rebar doweling.

**PART 1 — GENERAL**

**1. SUMMARY**

A. Supply of anchor channels used to connect construction members

Specifier Note: Revise paragraph below to suit project requirements. Add/delete section numbers and titles per project requirements and specifier's practice.

B. Related Sections:

| | |
|---|---|
| 1. Concrete | 03000 |
| 2. Concrete Accessories | 03150 |
| 3. Precast Concrete | 03400 |
| 4. Masonry Accessories | 04090 |
| 5. Stone | 04400 |
| 6. Metal Fabrication | 05500 |
| 7. Curtain Wall and Glazed Assemblies | 08900 |
| 8. Tunnel Construction | 31740 |

C. References
1. American Concrete Institute (ACI)
2. American Institute of Steel Construction (AISC)
3. American Society of Civil Engineers (ASCE)
4. American Society for Testing and Materials (ASTM)
5. Cement Association of Canada (CAC)
6. Canadian Institute of Steel Construction (CISC)
7. Canadian Society for Civil Engineering (CSCE)
8. Canadian Standards Association (CSA)
9. International Building Code (IBC)
10. European Technical Approval (ETA)
11. International Code Council — Evaluation Service Report

**2. SUBMITTALS**

Specifier Note: Insert appropriate section for the project as referred to below for shop drawings or submittals.

A. General: Submit in accordance with Conditions of the Contract and Division 1 Submittal Procedures Section.
1. Product Data: Submit size and strength capacity information for each anchor channel profile specified in the contract drawings
2. Shop Drawings:

B. Placement Drawings: Submit drawings showing the anchor channel layout and locations required.

C. Structural calculations: Submit manufacturer-provided technical manual and calculation software based on internationally recognized design provisions as referenced in section 1.01 to support the Project Engineer in designing the anchor channels.

1. Submit an evaluation report demonstrating compliance with the 2012 or later International Building Code for cast-in channel used to resist loading in three load directions

a. Tension load

b. Shear load (perpendicular to the channel axis)
c. Longitudinal load (parallel to the channel axis)
Samples: Representative length and diameters of each type anchor channel shown on the drawings.
Quality Assurance Submittals:
ICC-ES Evaluation Report showing conformance with current applicable ICC AC232 Acceptance Criteria
Certificate of Compliance showing compliance of the anchor channel to manufacturer's published technical specifications
Manufacturer's installation instructions

**3. QUALITY AND ASSURANCE**

A. Manufacturer must have experience in anchoring technology.

B. Manufacturer shall follow a documented quality assurance program and be ISO 9001 and ISO 14001 certified.

C. Manufacturer's published anchor channel strengths to be confirmed by an independent third party testing agency.

D. Certifications: Unless otherwise authorized by the Engineer, anchor channels shall have one of the following certifications:
1. ICC-ES Evaluation Report showing conformance with current applicable ICC AC232 Acceptance Criteria
2. Certificate of Compliance showing compliance of the anchor channel to manufacturer's published technical specifications

4. DELIVERY, STORAGE AND HANDLING

A. Anchor channels and accessories must be packaged appropriately to help prevent loss or damage during transport

B. All materials received on the jobsite must be stored in a secure and dry location prior to installation

**PART 2 — PRODUCTS**

**1. MANUFACTURERS**

Cast-in Anchor Channels and accessories shall be manufactured by
1. Hilti Corp, and supplied in the US by Hilti, Inc., Plano, TX, phone (800) 879-6000;
and in Canada by Hilti (Canada) Corp, Mississauga, Ontario, (800) 363-4458
2. Jordahl DKG and supplied in the US by Decon USA Inc. (707) 996-5954
and in Canada by Continental Decon Inc., (800) 363-3266
3. Halfen Anchoring Systems, Converse, TX, phone (800) 323-6896

**2. MATERIALS**

A. Anchor channels shall consist of either cold formed V-form profile or hot rolled steel channel profiles with round steel anchors mechanically attached to the back of the channel. "L-shaped" anchors securely attached to the back of the channel with fillet welds are also acceptable. The cold formed profiles are made of carbon steel conforming to ASTM A283 Grade C with a minimum yield strength of 30,000psi. The hot rolled profiles conform to ASTM A1011 with a minimum yield strength of 33,000psi. The round anchors must conform to ASTM A108.

B. The anchor channels shall be protected by a hot dipped galvanized finish, or be stainless steel. Hot dipped galvanizing shall be in accordance to ISO 1461 with minimum thickness of 45 mm or be in accordance with ASTM A123. Stainless steel materials shall conform to stainless steel A4 grade 50.

C. T-bolts shall be used to fasten a metal or concrete member to the anchor channel. These bolts shall be designed to meet the manufacturer's published strengths. The T-bolts must show a mark on the screw indication proper engagement into the channel.

D. Finishes:
1. Hot dipped galvanizing of anchor channels shall be in accordance to ISO 1461 with minimum thickness of 45 mm or conform to ASTM A123.
2. Hot dipped galvanized T-bolts shall be in accordance to ISO 1461 with minimum thickness of 45 mm or conform to ASTM A153.
3. Zinc electroplated T-bolts shall have a coating thickness ≥ 8mm or conform to ASTM B633 or EN ISO 4042, A3K.

E. End caps and a LDPE closed-cell foam filler with integrated tear-out strip shall be placed in the channel profile to help prevent concrete from seeping into the channel.

F. Anchor channel fabrication tolerances are ± 3mm for lengths of 300mm or less and ± 6mm for lengths >300mm.

G. Anchor channels and components may be produced according to different international standards if they meet or exceed the standards shown above.

**3.01 INSTALLATION**

A. The manufacturer's instructions must be followed to install the anchor channels properly on the formwork.
B. Installer shall affix anchor channels in required locations before concrete is poured. Concrete shall be applied in a continuous pour for each anchor channel, ensuring complete coverage with no voids or gaps, and flush with the outer face of the anchor channel. The appropriate T-bolt shall be used to connect the specified metal or concrete member to the anchor channel after the concrete is cured. The specified torque shall be applied to the T-bolt as listed in the manufacturer's installation instructions

C. Only the correct type of T-bolts supplied by the anchor channel manufacturer may be used to fasten a metal or concrete member to the anchor channel. The T-bolts are designed to meet the strength limits published by the manufacturer. The setting mark must show proper T-Bolt engagement in the channel

D. No alteration, such as cutting or bending, is permitted of anchor channel legs. Channel may be cut to size only if permitted by manufacturer and performed in accordance with its published instructions

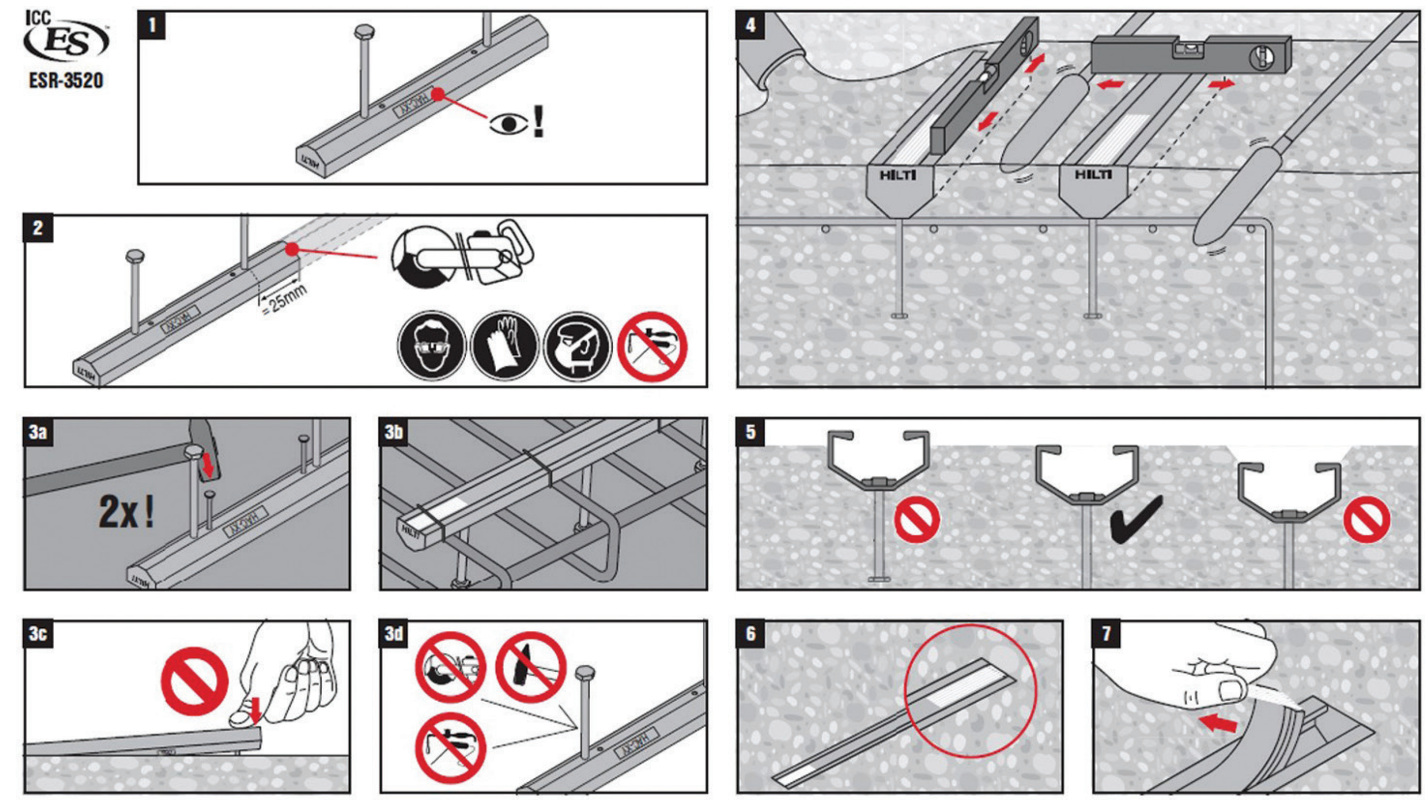
**3.02 REPAIR OF DEFECTIVE WORK**

A. Installer shall protect anchor channel and accessories from damage.

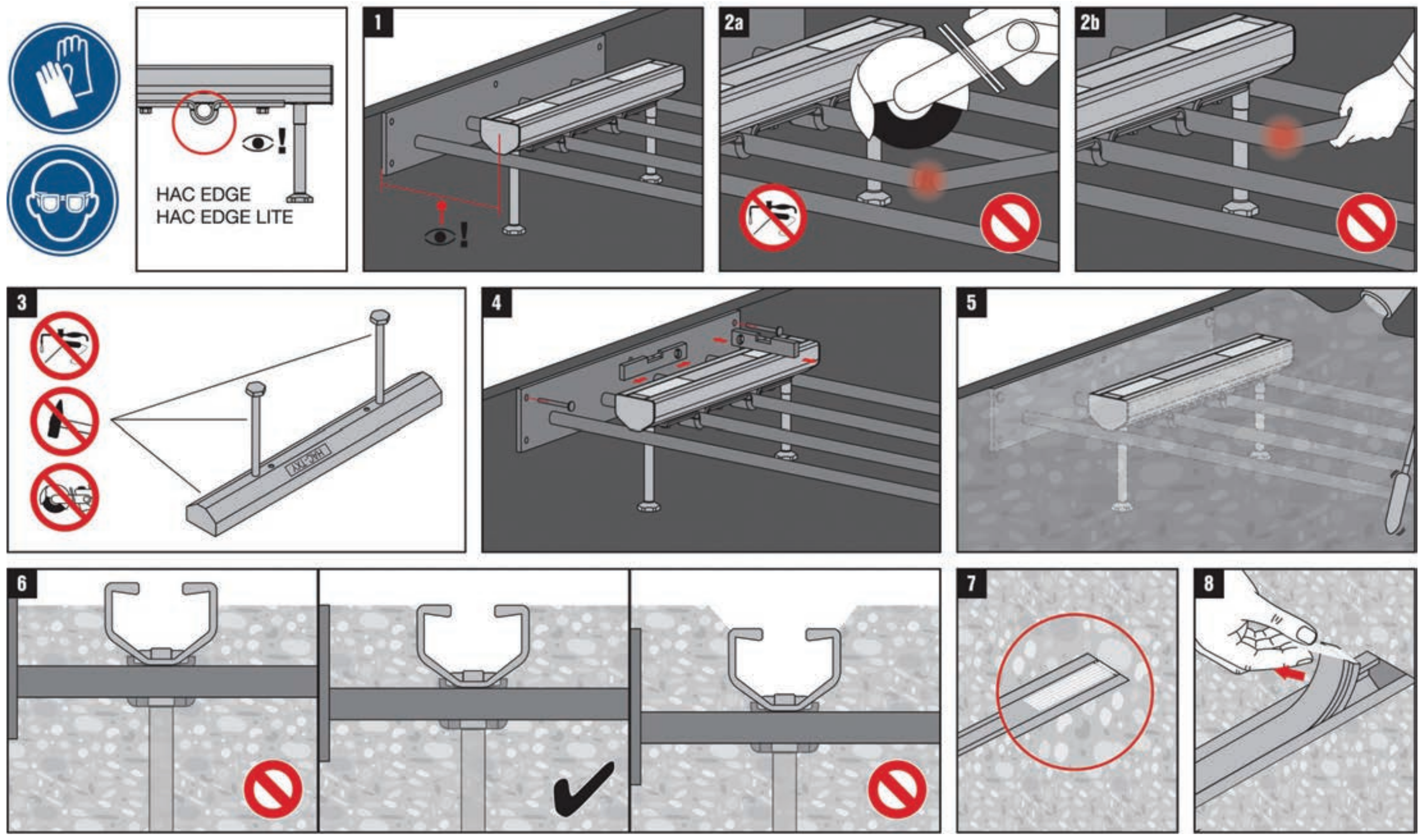
# 12. INSTRUCTIONS FOR USE

This chapter provides instructions for use for the different anchor channel systems. Instructions for may change over time. To verify if the published instructions for use are the latest, please visit our website.

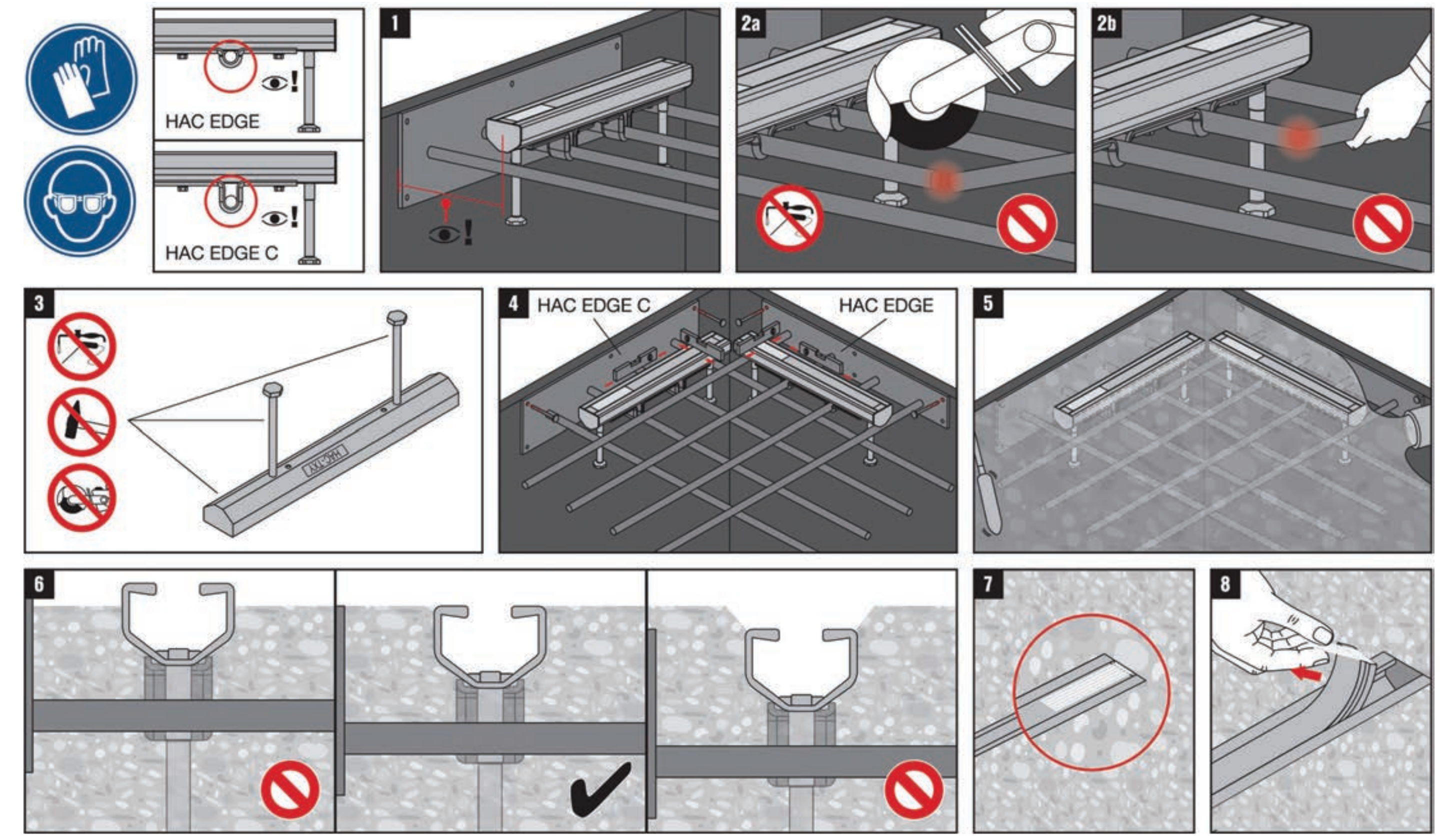
## 12.1.1 INSTALLATION INSTRUCTIONS FOR HILTI ANCHOR CHANNELS — HAC AND HAC-T



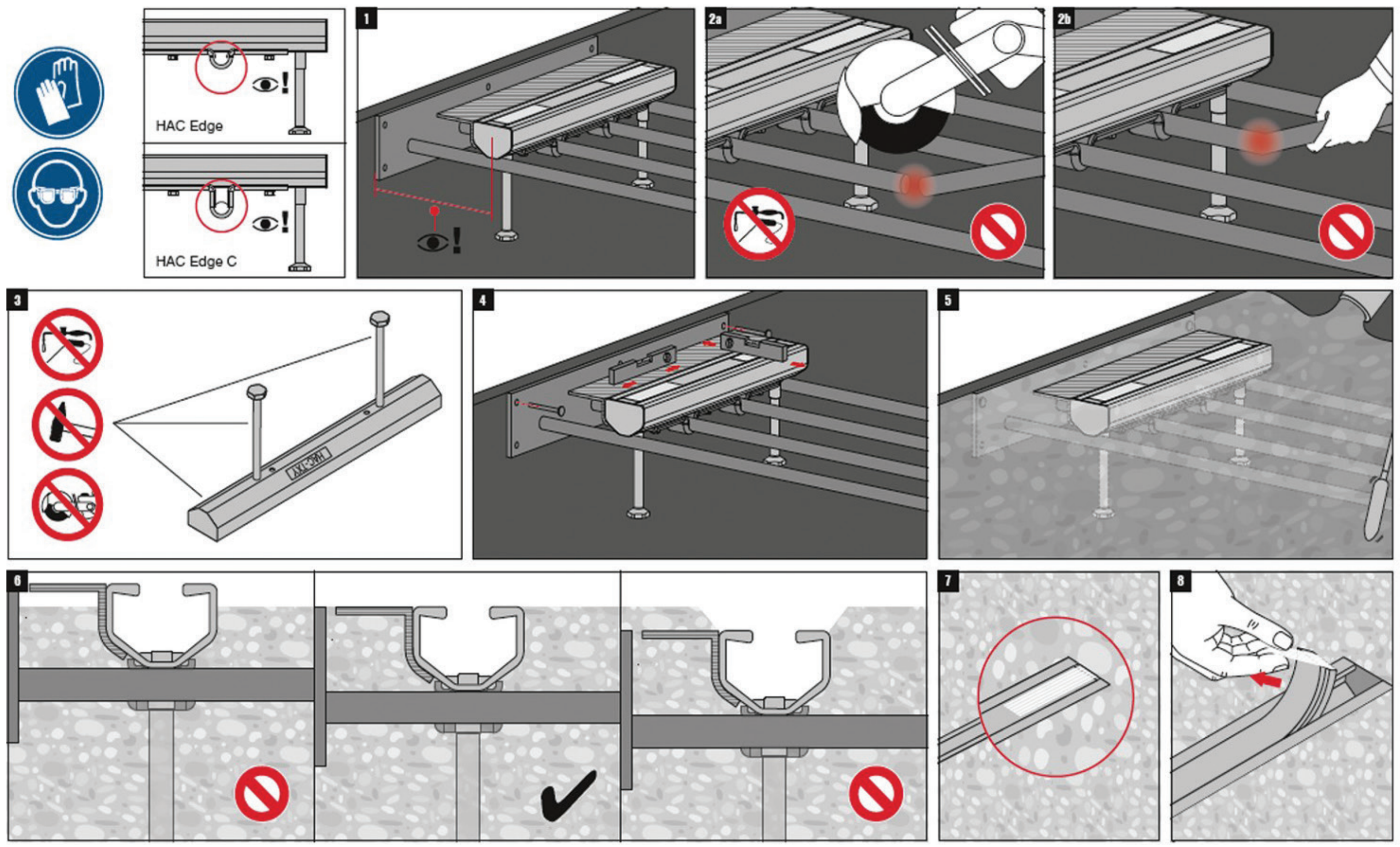
## 12.1.2 INSTALLATION INSTRUCTIONS FOR HILTI ANCHOR CHANNELS — HAC EDGE LITE, HAC EDGE, HAC-T EDGE LITE, AND HAC-T EDGE



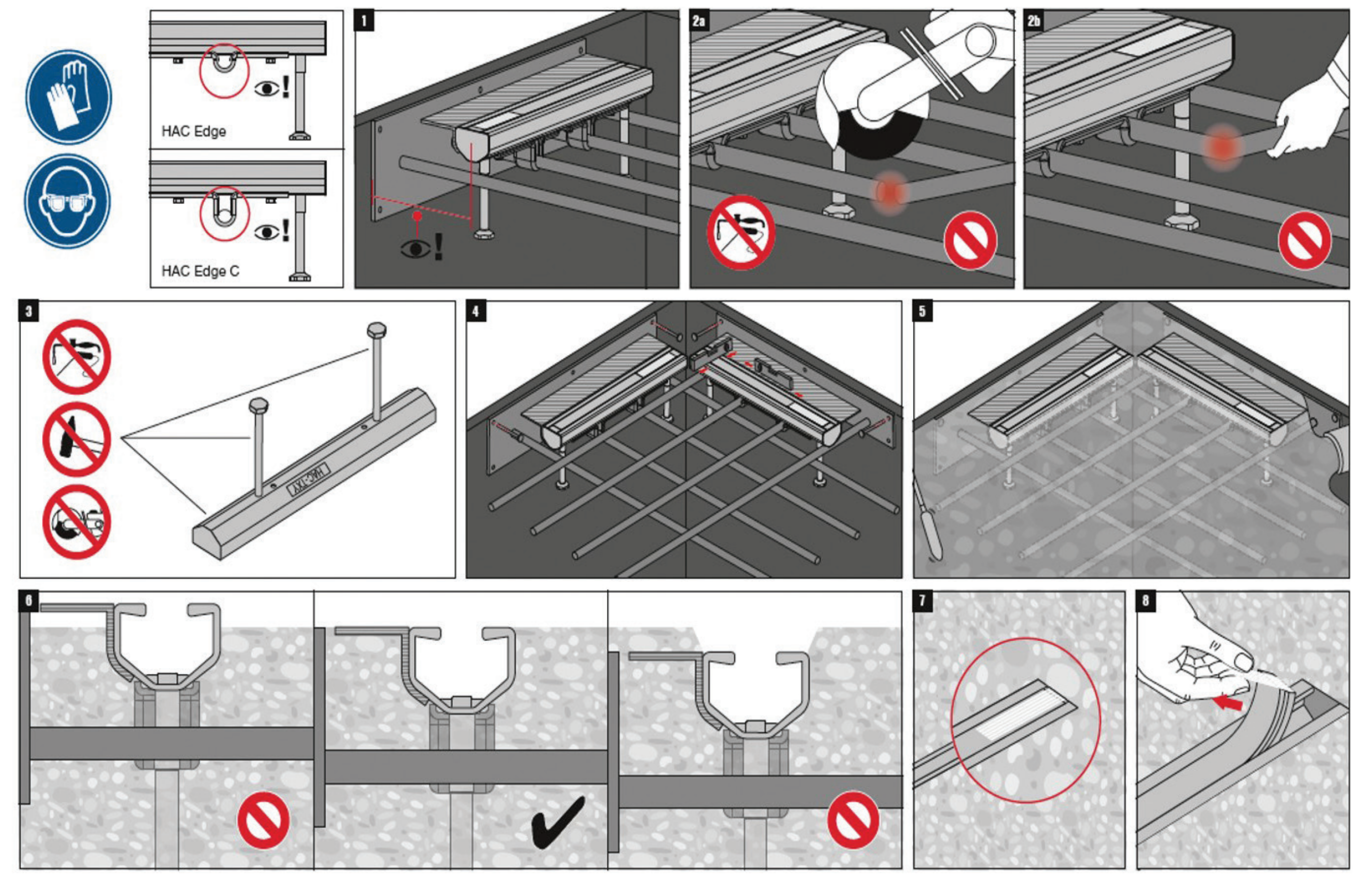

## 12.1.3 INSTALLATION INSTRUCTIONS FOR HILTI ANCHOR CHANNELS — HAC EDGE C AND HAC-T EDGE C



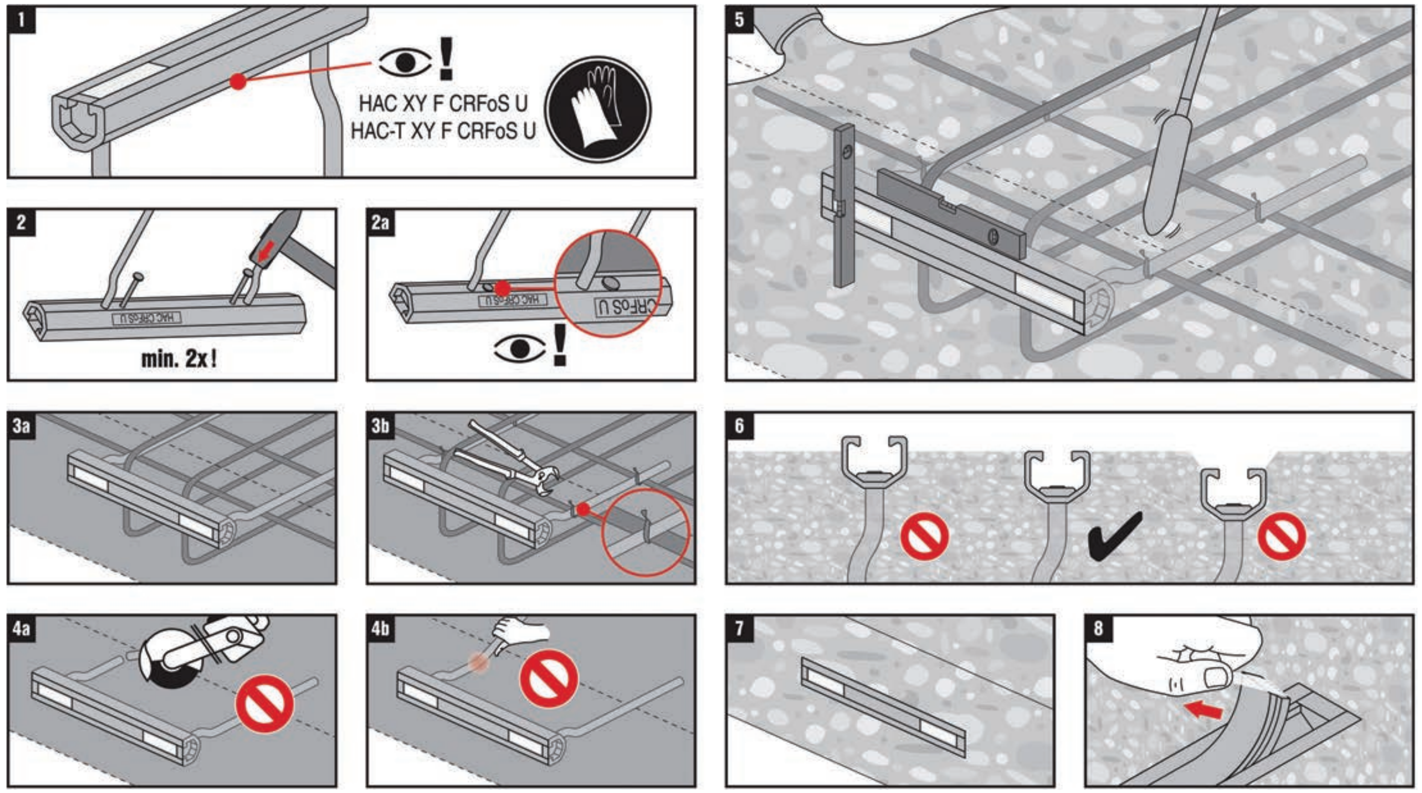
## 12.1.4 INSTALLATION INSTRUCTIONS FOR HILTI ANCHOR CHANNELS — HAC S EDGE AND HAC-T S EDGE



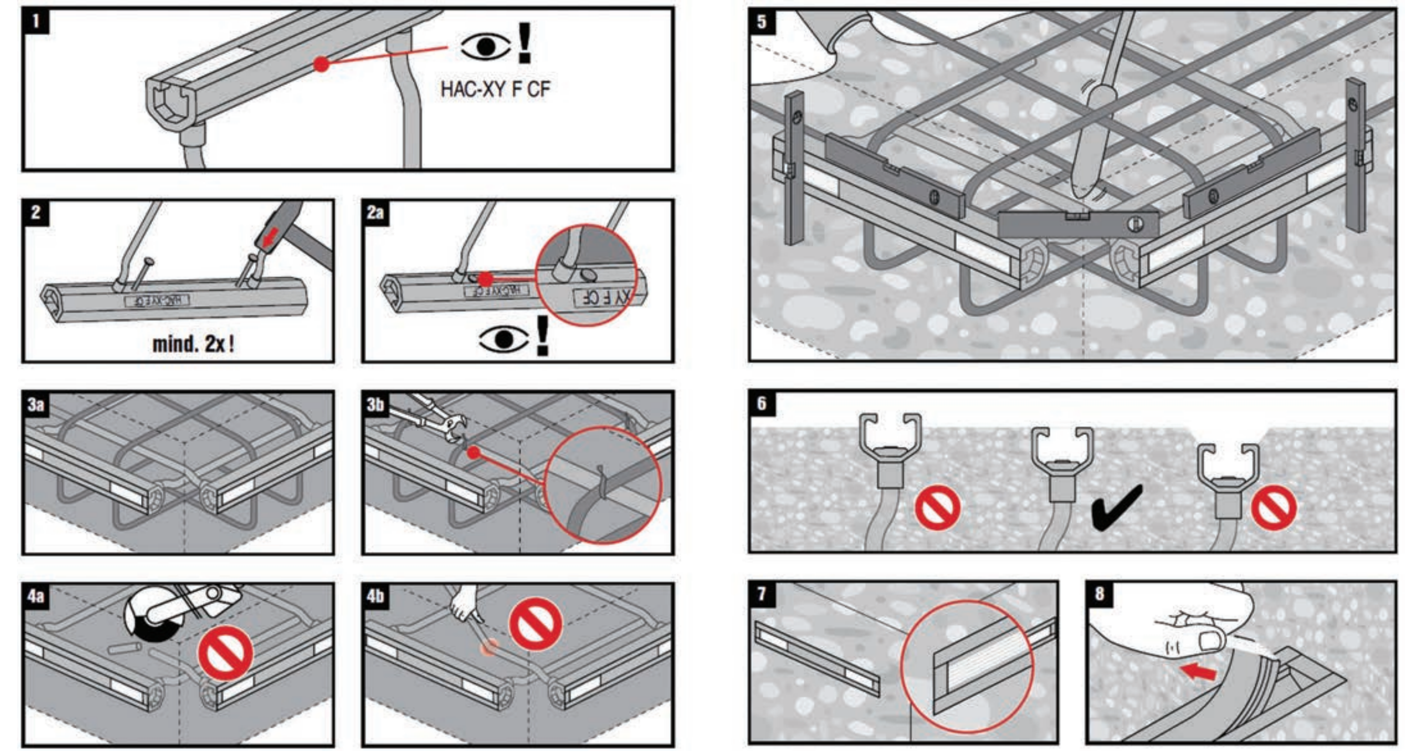

## 12.1.5 INSTALLATION INSTRUCTIONS FOR HILTI ANCHOR CHANNELS — HAC S EDGE C AND HAC-T S EDGE C



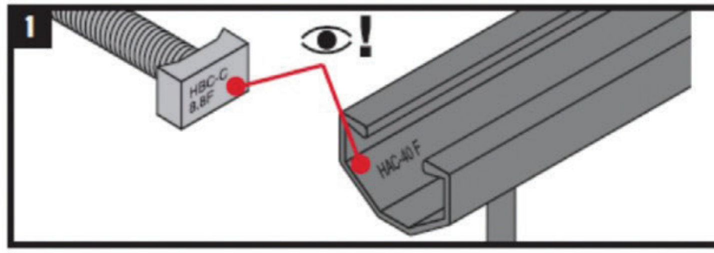
## 12.1.6 INSTALLATION INSTRUCTIONS FOR HILTI ANCHOR CHANNELS — HAC CRFOS U



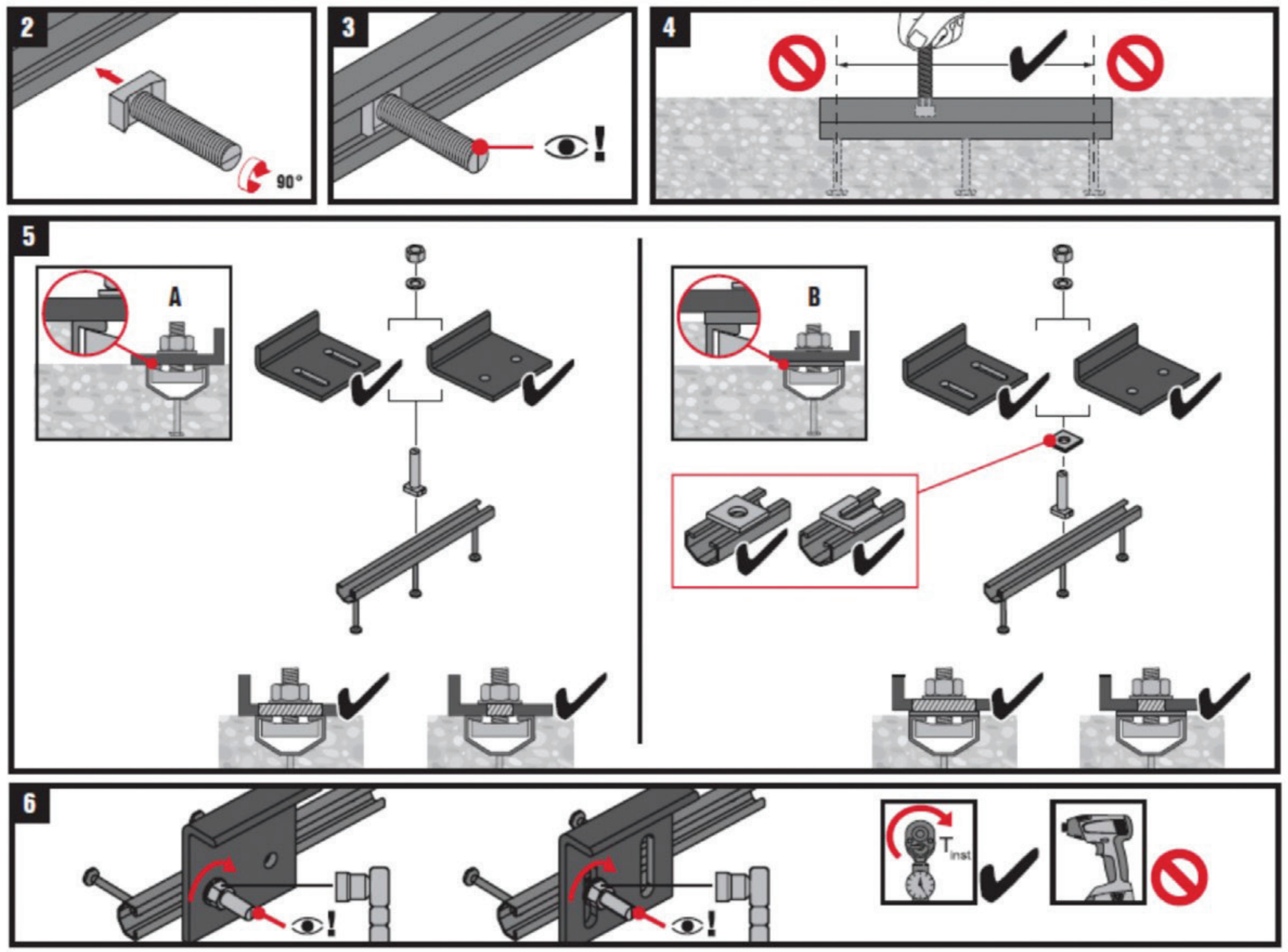

## 12.1.7 INSTALLATION INSTRUCTIONS FOR HILTI ANCHOR CHANNELS — HAC CRFOS U



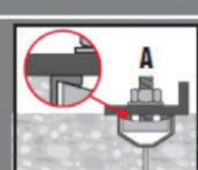
## 12.1.8 INSTALLATION INSTRUCTIONS FOR HILTI CHANNELS BOLTS — HBC-C

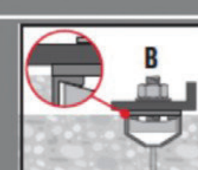



| ⊥ | ┬┬┬ |
|---|---|
| HBC-C 4.6<br>HBC-C 8.8<br>HBC-C A4-50 | HAC-40 to HAC-70 |

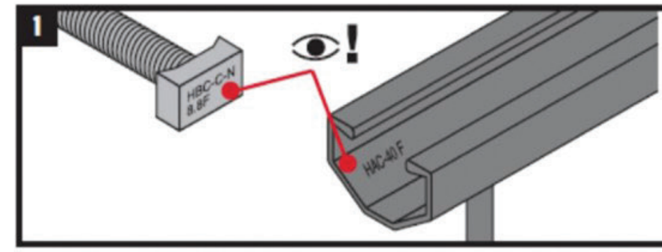



| | | Tinst | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | A | | | | B | | | |
| | | HAC-40 | HAC-50 | HAC-60 | HAC-70 | HAC-40 | HAC-50 | HAC-60 | HAC-70 |
| M12 | 8.8 | 25 Nm / 19 ft-lb | | | | 75 Nm / 55 ft-lb | | | |
| M16 | 4.6, A4-50 | 60 Nm / 44 ft-lb | | | | 60 Nm / 44 ft-lb | | | |
| | 8.8 | 60 Nm / 44 ft-lb | | | | 185 Nm / 136 ft-lb | | | |
| M20 | 8.8 | 70 Nm / 52 ft-lb | 105 Nm / 78 ft-lb | 120 Nm / 89 ft-lb | | 320 Nm / 236 ft-lb | | | |

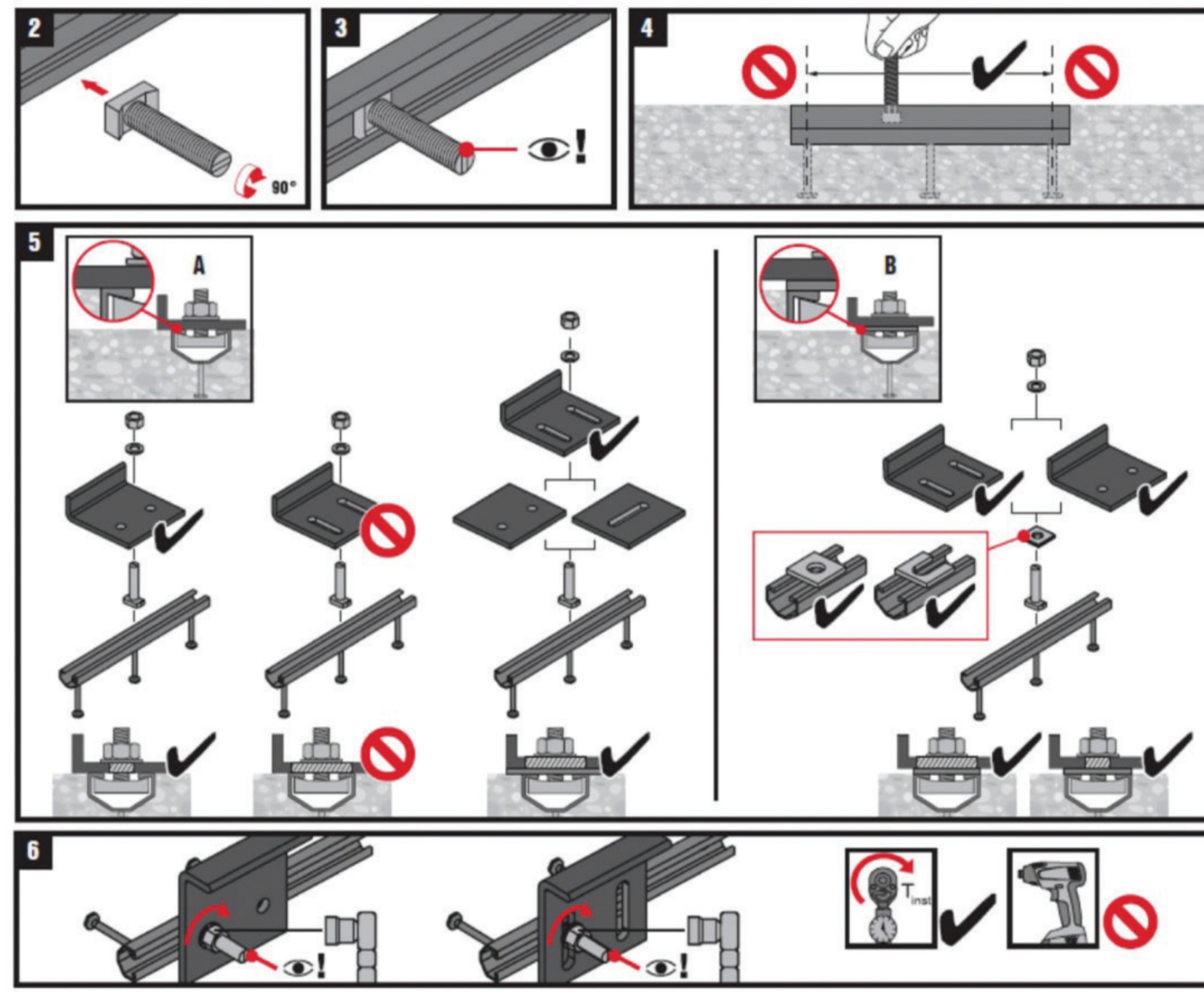


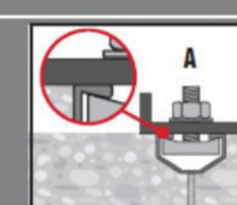

## 12.1.9 INSTALLATION INSTRUCTIONS FOR HILTI CHANNELS BOLTS — HBC-C-N

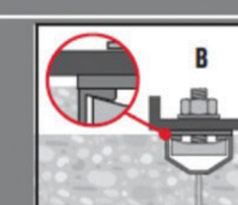



| ⊥ | ┬┬┬ |
|---|---|
| HBC-C-N 8.8 | HAC-40 to HAC-70 |

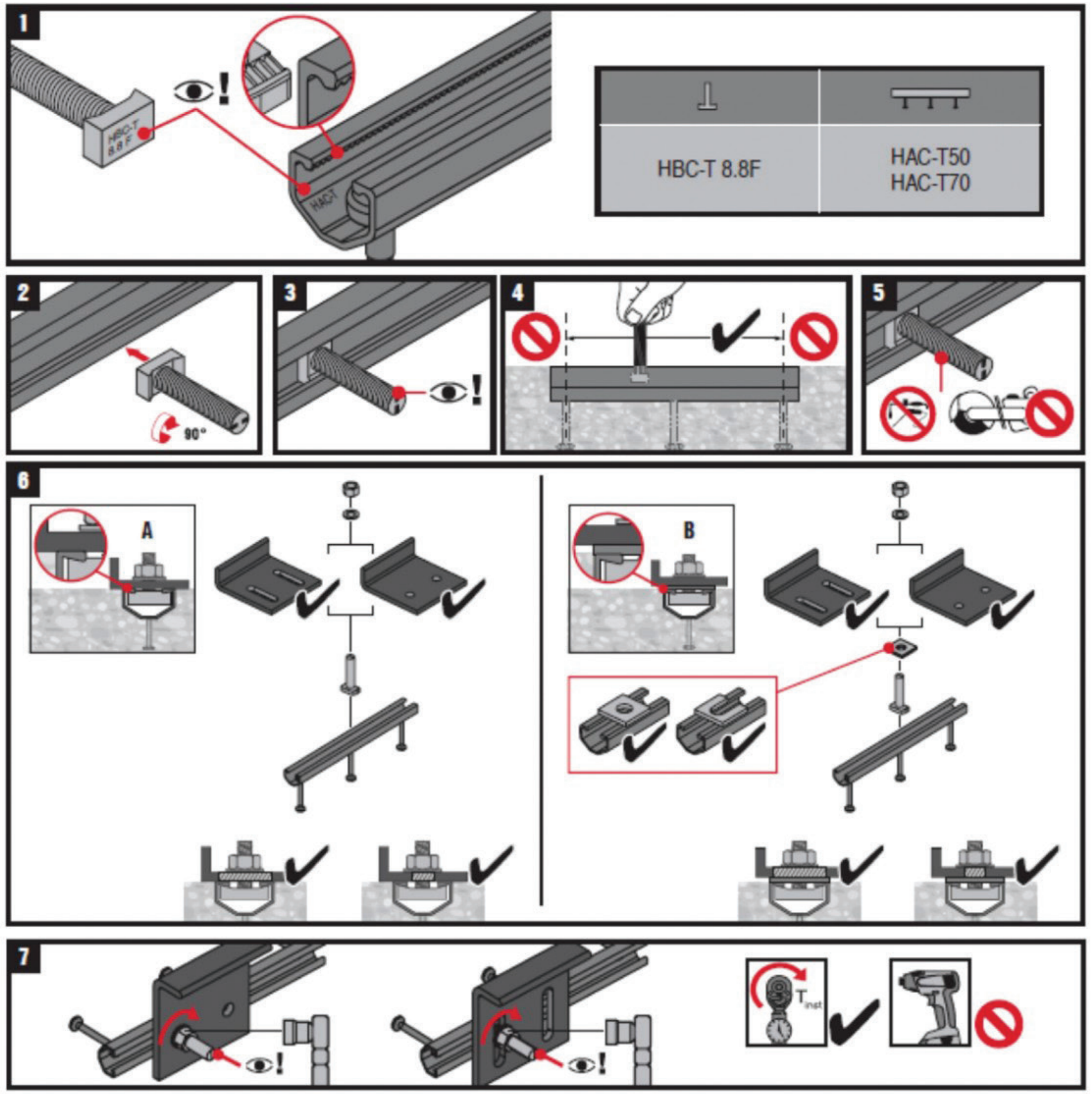



| | | Tinst | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | A | | | | B | | | |
| | | HAC-40 | HAC-50 | HAC-60 | HAC-70 | HAC-40 | HAC-50 | HAC-60 | HAC-70 |
| M12 | 8.8 | 75 Nm / 55 ft-lb | | | | 75 Nm / 55 ft-lb | | | |
| M16 | 8.8 | 185 Nm / 136 ft-lb | | | | 185 Nm / 136 ft-lb | | | |
| M20 | 8.8 | – | 320 Nm / 236 ft-lb | | | – | 320 Nm / 236 ft-lb | | |



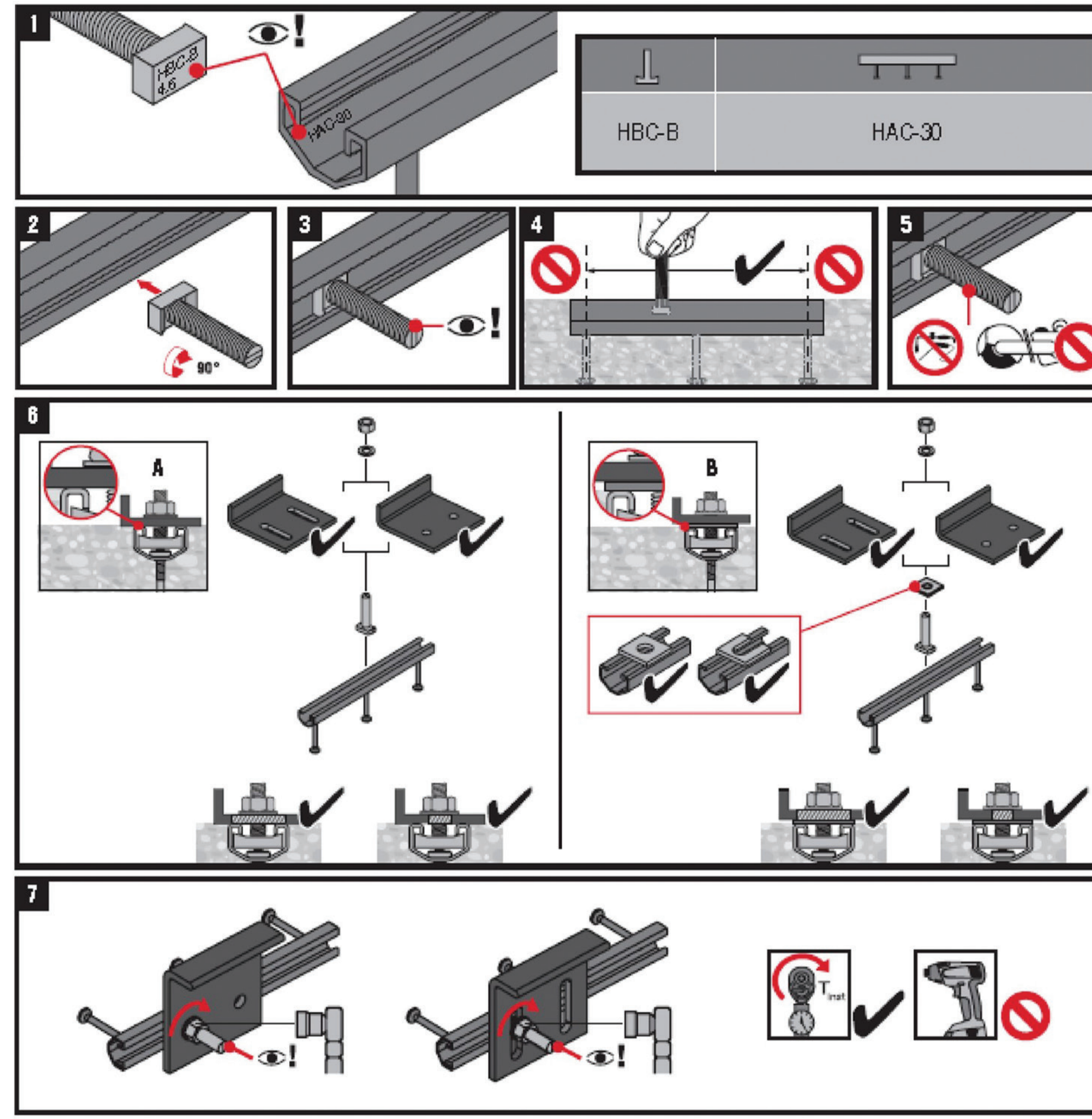



## 12.1.10 INSTALLATION INSTRUCTIONS FOR HILTI SERRATED CHANNELS BOLTS — HBC-T



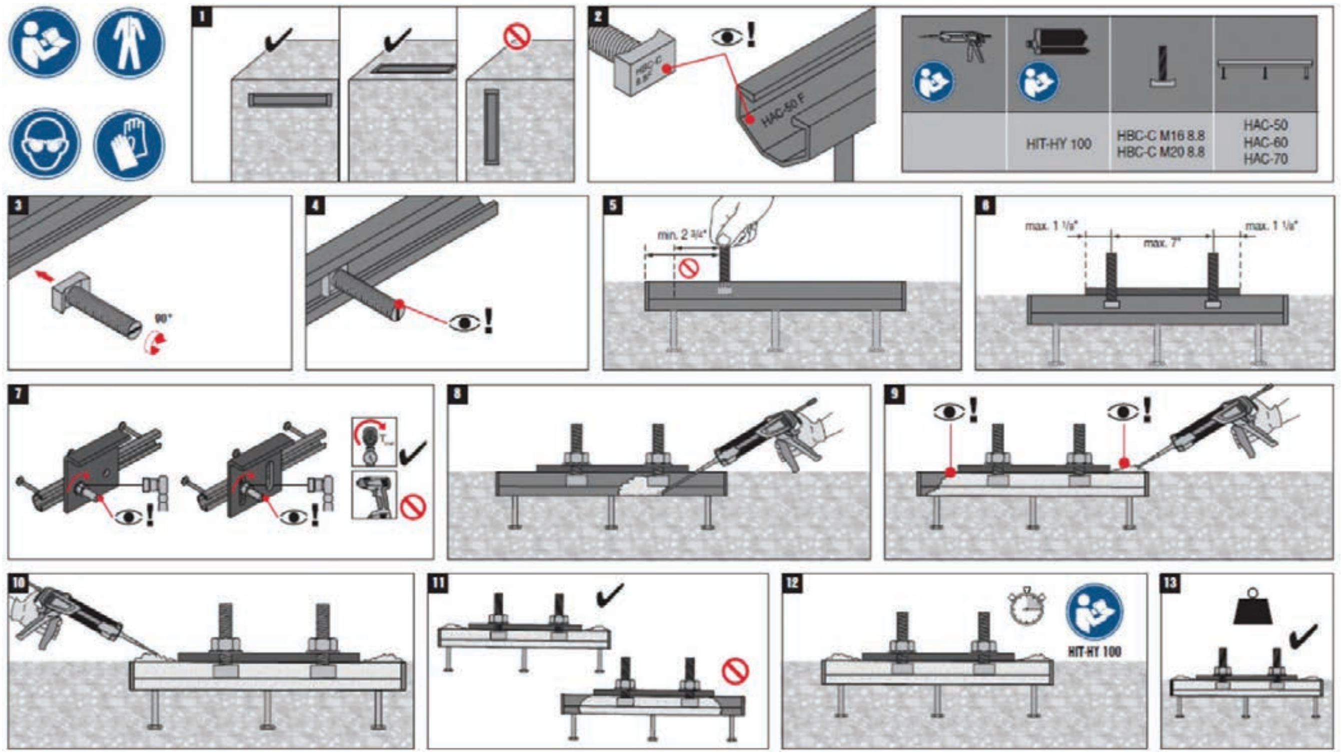

| $T_{inst}$ [Nm] | | | | | |
|---|---|---|---|---|---|
| | | A | | B | |
| | | HAC-T50 | HAC-T70 | HAC-T50 | HAC-T70 |
| M12 | 8.8 | 75 Nm / 55 ft-lb | | 75 Nm / 55 ft-lb | |
| M16 | 8.8 | 100 Nm / 74 ft-lb | | 185 Nm / 136 ft-lb | |
| M20 | 8.8 | 120 Nm / 89 ft-lb | | 320 Nm / 236 ft-lb | |

## 12.1.11 INSTALLATION INSTRUCTIONS FOR HILTI SERRATED CHANNELS BOLTS — HBC-B




| Tinst | | | |
|---|---|---|---|
| | | A | B |
| | | HAC-30 | HAC-30 |
| M10 | 4.6, A4-50 | 15 Nm / 11 ft-lb | 15 Nm / 11 ft-lb |
| M12 | 4.6, A4-50 | 25 Nm / 19 ft-lb | 25 Nm / 19 ft-lb |

## 12.1.12 INSTALLATION INSTRUCTIONS FOR HILTI CHANNELS BOLTS (HBC-C) USED IN CONJUNCTION WITH HILTY HIT HY-100 ADHESIVE




# 13. FIELD FIXES

This chapters provides best practices for cast-in anchor channels. This chapter provides some additional information for designers, reviewers, installers, and inspectors. The ultimate goal is to allow for the most code-compliant, feasible solution, based on the project's schedule.

**Coming soon**

# 14. DESIGN EXAMPLES

This chapter provides a step by step detail explanation of every single failure mode of an anchor channel with rounded head anchors.



## 14.1 DESIGN EXAMPLES

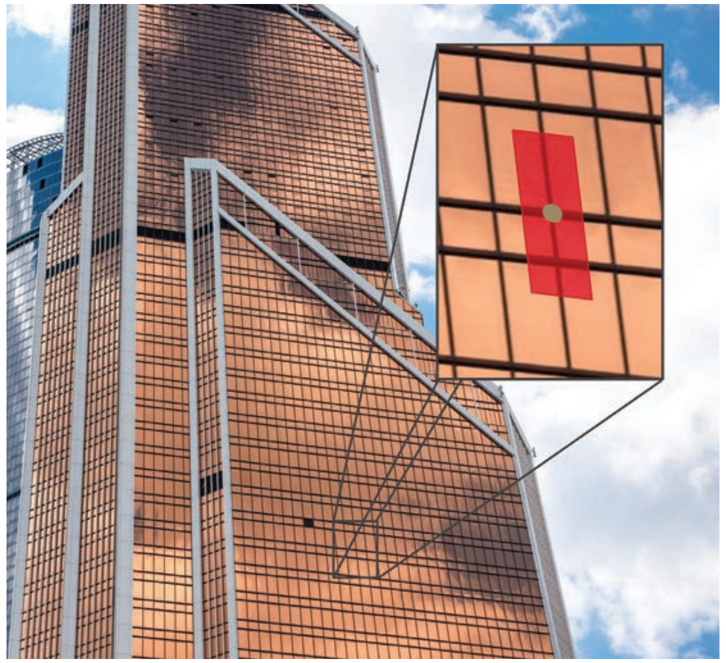


Figure 14.1.1 — Design example - Facade Connection

**Given:**

Floor - Floor height = 10.5’

Mullion Spacing = 5’

DL = 14 psf

Wind Pressure (ASD) = 40psf

Code = ASCE 7-10

### Snap shot from structural notes

CONCRETE SHALL BE NORMAL WEIGHT AND SHALL OBTAIN 28 DAY COMPRESSIVE STRENGTHS AS FOLLOWS:

| | | |
|---|---|---|
| A. | SLAB-ON-GRADE | 3,500 PSI |
| B. | WALLS | 6,000 PSI |
| C. | STRUCTURAL SLABS AND BEAMS | 6,000 PSI |
| D. | CONCRETE NOT OTHERWISE NOTED | 3,000 PSI |
| E. | PILE CAPS | 4,000 PSI |
| F. | COLUMNS | SEE SHEET S-601 |
| D. | SEISMIC DESIGN DATA: | |
| | RISK CATEGORY | II |
| | SEISMIC IMPORTANCE FACTOR | 1.0 |
| | SS | 0.094g |
| | S1 | 0.048g |
| | SITE | CLASS D |
| | SDS | 0.100g |
| | SD1 | 0.077g |
| | SEISMIC DESIGN CATEGORY | B |
| | DESIGN BASE SHEAR | 1276 KIPS |
| | SEISMIC RESPONSE COEFFICIENT | 0.021 |
| | RESPONSE MODIFICATION FACTOR | 4.0 |
| | ANALYSIS PROCEDURE EQUIVALENT LATERAL FORCE | |
| | BASIC SEISMIC-FORCE-RESISTING SYSTEM IS ORDINARY REINFORCED CONCRETE SHEAR WALLS | |

Figure 14.1.2 — Design example – Structural notes

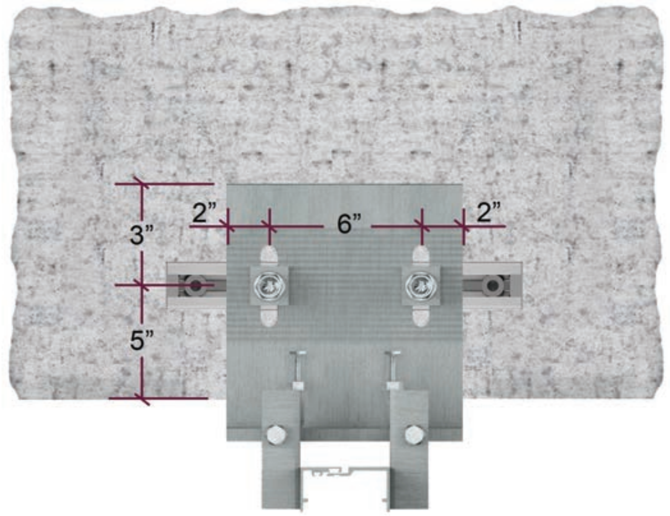



Figure 14.1.3 — Design example – Bracket Plan View

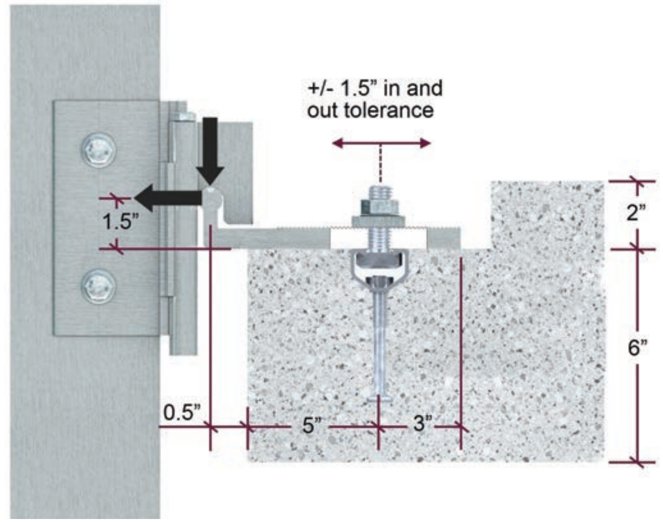



Figure 14.1.4 — Design example – Bracket Section View

Seismic provision will not apply since the project is located in SDC B.

Concrete ----

$f_c$= 6000psi

$c_{a1}$=5.00”

λ=1.0 (normal weight concrete)

HAC-50 106/350 F is used with (2) HBC-C 8.8F, M16x60

$h_{ef}$ = 4.173 in.

Length: 13.8 in., anchor spacing: 5.906 in., projection: 0.984 in., width: $b_{ch}$ = 1.650 in., height: $h_{ch}$ = 1.220 in.

Please refer to chapter 02 for properties of the channel.

| Code | Discussion | Calculations |
|---|---|---|
| **Step 1: Load Combination and Bracket dimension** | | |
| **ASCE 7-10 2.3.2** | There load combination that is evaluated: | **Wind Load:** |
| | 1.2DL + WL/0.6 | WL(ASD)=40psfx10.5'x5'=2100lbs |
| | Slab depth: 8" | WL(Strength level)=2100lbs/0.6=3500lbs |
| | Pocket height: 2" | DL(ASD)=14psfx10.5'x5'=735lbs |
| | Front edge distance : 5" | DL(Strength level)=1.2x735lbs=882lbs |
| | Side edge distance : 6" | Slab depth deducting pocket: 8"-2"=6" |
| | T-bolt spacing: 6" | Available tolerance along the channel length: (13.8"-(2x0.984")-6")/2=2.916" |
| | Bracket tolerance: 1.5" in/out | Bracket dimension in y-direction: 8.75" |
| | Worst position: Bracket out | Bracket dimension in x-direction: 1.5" |

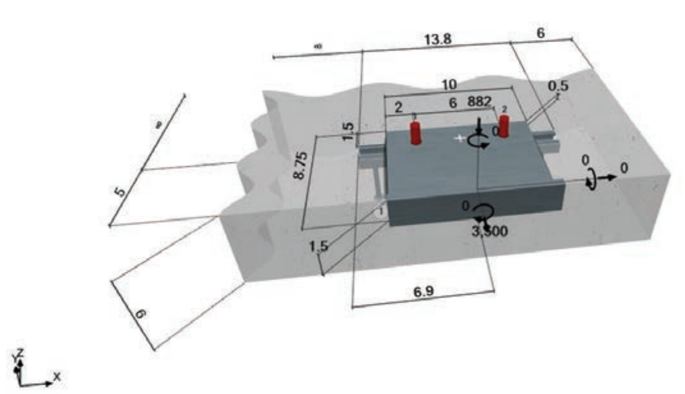


**Figure 14.1.5— Design example – Profis anchor channel - 3D front View**

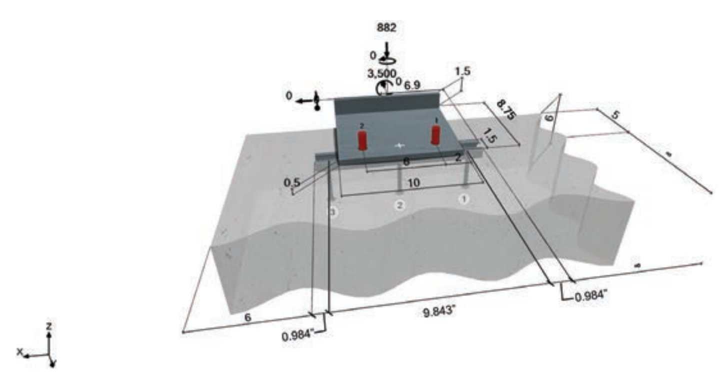
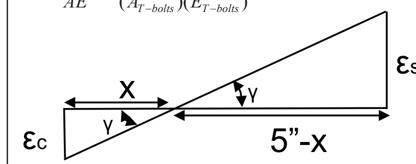


**Figure 14.1.6— Design example – Profis anchor channel - 3D Back View**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 2: Determination of T-bolt Tension and shear forces** | | |
| | Determine the tension loads on the T-bolts. Assume the fixture is rigid. PROFIS Anchor Channel assumes Ec = 30,000 Mpa<br>(2) HBC-C 8.8F M16x60 are used. | $A_{T\text{-bolts}}$ = (2)(tensile stress area of T-bolt) = (2)(157 mm²)[1in² / (25.4 mm)²] = 0.487in²<br>$E_{T\text{-bolts}}$ = (modulus of elasticity for T-bolt) = 29,000,000 lb/in²<br>$E_{concrete}$ = (modulus of elasticity for concrete) = 30,000 MPa = 4,351,200 lb/in² |

| Discussion | Calculations |
|---|---|
| The application is statically indeterminate. Use compatibility equations and statics equations to solve for the location of the neutral axis (x). Once x is known, the tension force on each T-bolt can be calculated. Using the compatibility equations, define the tension force acting on both T-bolts (FT-bolts) in terms of the concrete compressive stress under the fixture (σc). | $F_{T-bolts} = \frac{(0.487\ in^2).(29000000\ lb/in^2).(\sigma_c).(5-x)}{(4351200\ lb/in^2).(x)}$ |
| $\frac{PL}{AE} \rightarrow \frac{(F_{T-bolts})(L)}{(A_{T-bolts})(E_{T-bolts})}$ | $F_{T-bolts} = \frac{(3.246\ in^2).(\sigma_c).(5-x)}{x}$ |
|  | *Sum the tension forces and moments* |
| $\gamma\ is\ so\ small\ that\ \tan(\gamma) = \frac{\varepsilon_c}{x} = \frac{\varepsilon_s}{(5-x)}$ | $\sum F + \uparrow = 0$ |
| $\frac{\varepsilon_c}{x} = \frac{\varepsilon_s}{(5-x)}$ | $F_{T-bolts} + 882\ lb - \frac{(1).(\sigma_c).(x).(b)}{2} = 0$ |
| $\varepsilon_s = \frac{F_{T-bolts}.L}{E_{T-bolts}.A_{T-bolts}}$ | $\frac{(3.246\ in^2).(\sigma_c).(5-x)}{x} + 882 - \frac{(1).(\sigma_c).(x).(b)}{2} = 0$ |
| $\varepsilon_c = \frac{\sigma_c.L}{E_c}$ | $\sigma_c.\left[\left[\frac{(1).(x).(10)}{2}\right]\right] - \sigma_c.\left[\frac{(3.246\ in^2).(5-x)}{x}\right] = 882$ |
| $\frac{\sigma_c}{E_c.x} = \frac{F_{T-bolts}}{E_{T-bolts}.A_{T-bolts}.(5-x)}$ | $\sigma_c.\left[\frac{(5).(x^2)+3.246x-16.23}{x}\right] = 882$ |
| *Compatility equations : assume L = "unity"* | $\sigma_c = \left[\frac{882x}{(5).(x^2)+3.246x-16.23}\right] \rightarrow\rightarrow\rightarrow Eqn\ 1$ |
| $F_{T-bolts} = \frac{(A_{T-bolts}).(E_{T-bolts}).(\sigma_c).(5-x)}{(E_c).(x)}$ | $F_{T-bolts} = \frac{(3.246\ in^2).(\sigma_c).(5-x)}{x}$ |
| | $F_{T-bolts} = \frac{(3.246).\left[\frac{882x}{(5).(x^2)+3.246x-16.23}\right].(5-x)}{x}$ |
| | $F_{T-bolts} = \left[\frac{14314.86-2862.972x}{(5).(x^2)+3.246x-16.23}\right] \rightarrow\rightarrow\rightarrow Eqn\ 2$ |
| Using statics equations, define the concrete stress under the fixture (σc) in terms of the lcompressive ocation of the neutral axis (x). | $\sum M = 0$ |
| | $(882).\left[2+\frac{x}{3}\right] + (3500).[1.5] - (F_{T-bolts}).\left[5-\frac{x}{3}\right] = 0$ |
| Solve for x via trial and error. Once x is known, the values for σc and FT-bolts can be calculated. Once FT-bolts is known, the tension force on each T-bolt can be determined. The applied shear force is distributed equally on each T-bolt. | $(882).\left[2+\frac{x}{3}\right] + (3500).[1.5] - \left[\frac{14314.86-2862.972x}{(5).(x^2)+3.246x-16.23}\right].\left[5-\frac{x}{3}\right] = 0 \rightarrow\rightarrow\rightarrow Eqn\ 3$ |
| | After trial and error x=1.779993152175" the solution to Eqn3 leads to 0.0000000221, which is approximately equal to zero. |
| | Substituting the value for x into equation 2 will lead to FT-bolts= 1700lbs. |
| | Tension force on each t-bolt = 1700lbs/2=850lbs. |
| | Shear Force per each t-bolt = Vy=3500lbs/2=1750lbs per t-bolt |

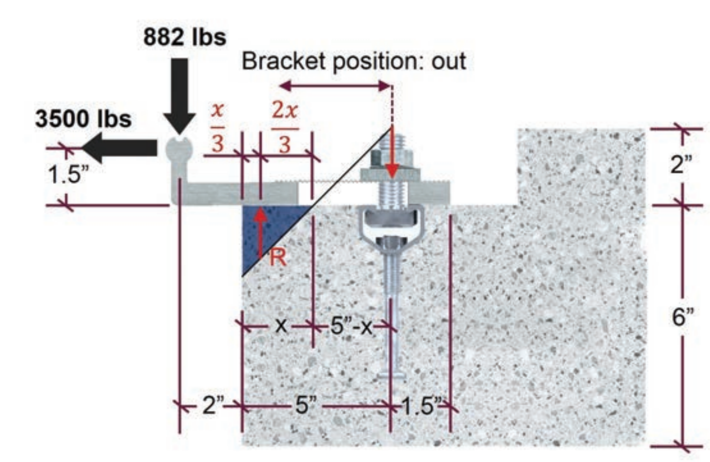



**Figure 14.1.7 — Design example – Section View - Force Resultant**

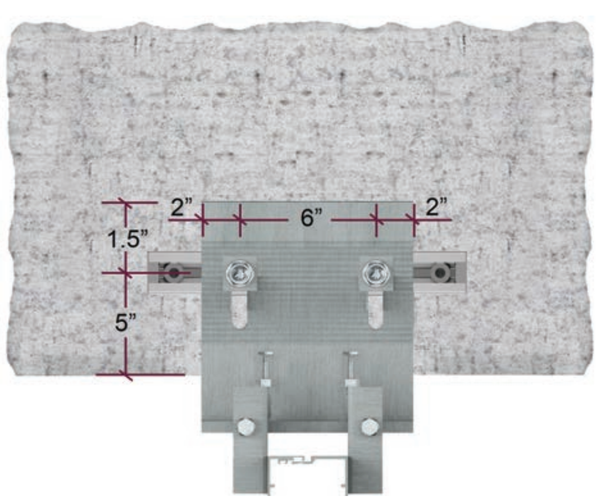



**Figure 14.1.8 — Design example – Plan View**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3: Determination of worst tolerance** | | |
| | Please note that the t-bolt forces are applied all along the channel length and the forces at anchors are determined. Then the worst case utilization report will be printed out in profis anchor channel software.<br>Therefore the bracket can be located any where along the available channel length. The anchor element forces are evaluated in this example at the worst location along the channel length. | The worst utilization is obtained at 2.896”. The tolerance interval is -11.812” and 11.812” (13.8”-(2x0.984”). |

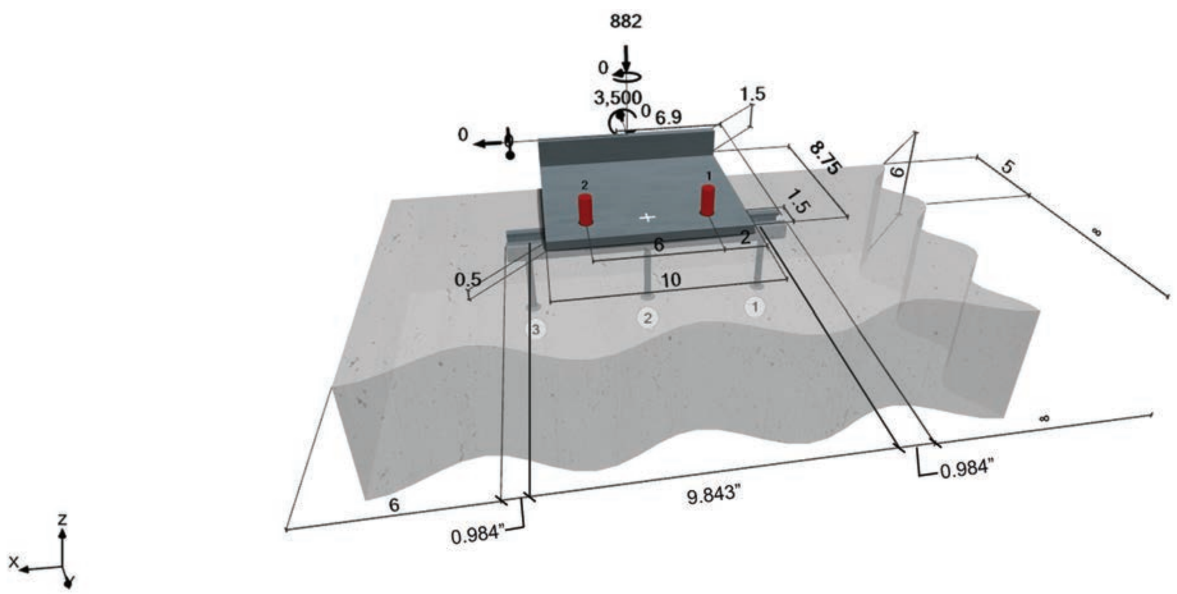



**Figure 14.1.9 — Design example – Profis anchor channel - 3D Back View**

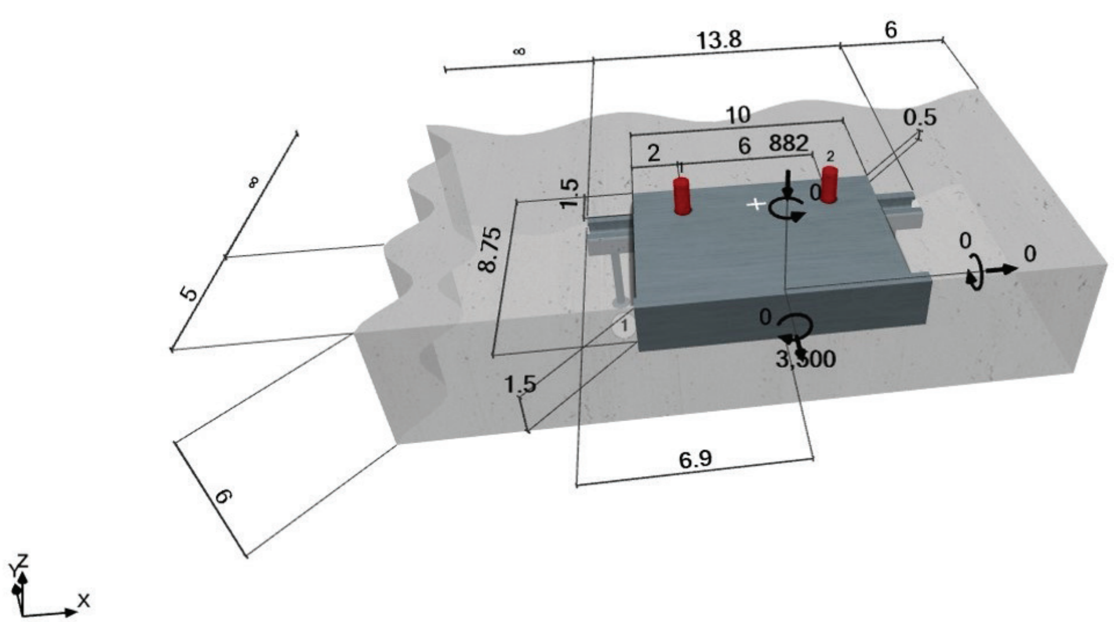



**Figure 14.1.10 — Design example – Profis anchor channel - 3D Front View**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3: Determination of worst tolerance** | | |
| **ESR-3520 Section 4.1.2.2** | The T-bolt #1 tension force (850 lb) will have an influence on each anchor element as shown below. The tension forces on anchor elements #1, #2 and #3 resulting from this influence will be defined as $N_{ua1,1}$, $N_{ua1,2}$ and $N_{ua1,3}$ respectively. The influence factor $A_{1,\#x}$ corresponds to the influence on anchor element #x from T-bolt #1. The parameter “s” corresponds to the spacing between each anchor element. The parameter $\ell_{in}$ corresponds to the influence length for T-bolt #1.<br>The T-bolt #2 tension force (850 lb) will have an influence on each anchor element as shown below. The tension forces on anchor elements #1, #2 and #3 resulting from this influence will be defined as $N_{ua2,1}$, $N_{ua2,2}$ and $N_{ua2,3}$ respectively. The influence factor $A_{\#x,2}$ corresponds to the influence on anchor element #x from T-bolt #2. The parameter “s” corresponds to the spacing between each anchor element. The parameter $\ell$ in corresponds to the influence length for T-bolt #2.<br>$\ell_{in} = 4.93\,(I_y)^{0.05}\sqrt{s}$ | $h_{ef}$ = 4.173 in.<br>Channel specification Length: 13.8 in., anchor spacing s: 5.906 in., projection: 0.984 in., width: $b_{ch}$ = 1.650 in., height: $h_{ch}$ = 1.220 in.<br>$I_y$ = 0.0796 in.$^4$<br>s = 5.906 in.<br>$\ell_{in}$ = 4.93x(0.0796 in.$^4$)$^{0.05}$ (5.906 in)$^{0.5}$<br>$\ell_{in}$ =10.56 in<br> |



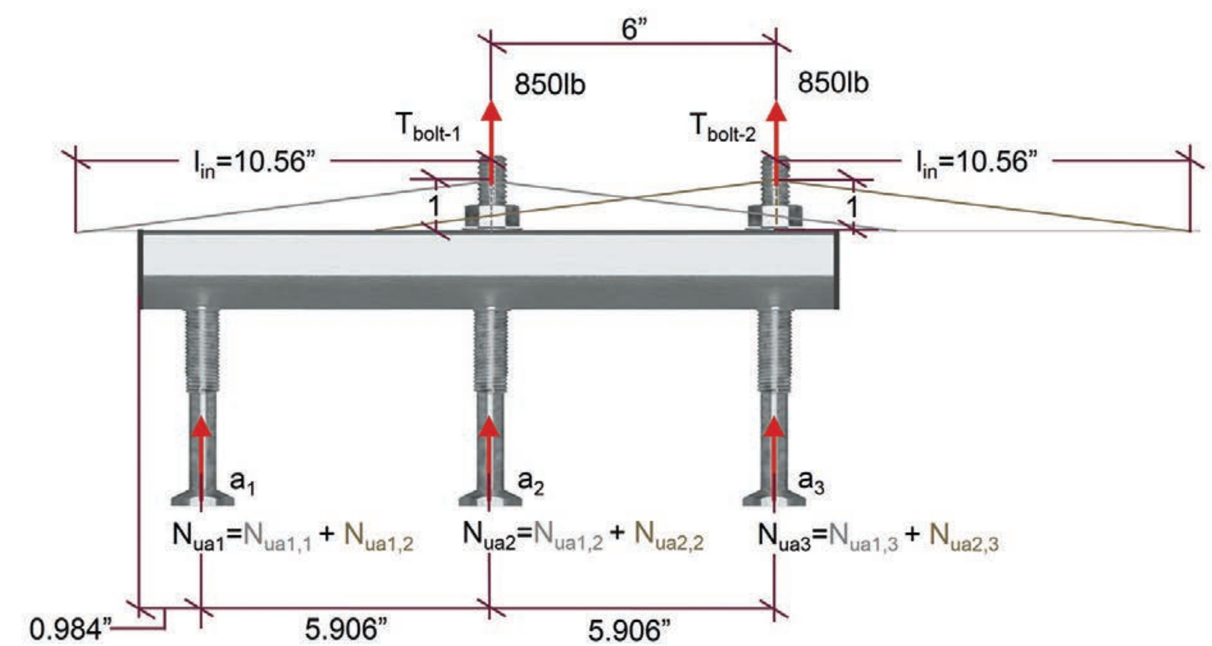



**Figure 14.1.11 — Design example – Anchor Tension Forces**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3: Determination of worst tolerance** | | |
| **ESR-3520**<br>**4.1.2.2**<br>**Eq (2)**<br>**Eq (1)** | The highest loaded anchor element in tension does not always control the anchor channel design in tension. The highest utilization, defined by the parameter ($N_{ua,total}$ / $\varphi N_n$) controls the design. Therefore, the tension design strengths must be calculated for each anchor element and checked against the total factored tension load acting on that element. The most unfavorably loaded anchor element (highest utilization) controls the design in tension.<br><br>The tension forces acting on each anchor element can be determined assuming a triangular force distribution.<br><br>The triangular force distribution assumes the tension force acting on each T-bolt (850 lb) has an influence on each of the anchor elements within a given distance ($\ell$ in) from the T-bolt.<br><br>The resulting tension force on each anchor element ($N_{1, uax}$) from the tension force acting on T-bolt #1 will be proportionate by the factor<br><br>($A_{1, \#x}$) to the distance of the anchor element with respect to the distance $\ell$ in. Note that the influence length ($\ell$ in) does not necessarily coincide with the channel length.<br><br>Even when a T-bolt is located directly over one anchor element, the T-bolt load is still distributed to all other anchor elements within the distance $\ell_{in}$ from the T-bolt. | $\frac{A_{1,1}}{(10.56\ in - 5.906\ in + 0.1\ in)} = \frac{1}{10.56\ in}$<br>$A_{1,1} = 0.45$<br>$\frac{A_{1,2}}{(10.56\ in - 0.1\ in)} = \frac{1}{10.56\ in}$<br>$A_{1,2} = 0.9905$<br>$\frac{A_{1,3}}{(10.56\ in - 0.1\ in - 5.906\ in)} = \frac{1}{10.56\ in}$<br>$A_{1,3} = 0.431$<br>$k_1 = \frac{1}{A_{1,1} + A_{1,2} + A_{1,3}} \rightarrow k_1 = 0.5342$<br>$N_{ua1,1} = (k_1)(A_{1,1})(850\ lb)$<br>$N_{ua1,1} = 204.4\ lbs$<br>$N_{ua1,2} = (k_1)(A_{1,2})(850\ lb)$<br>$N_{ua1,2} = 449.8\ lbs$<br>$N_{ua1,3} = (k_1)(A_{1,3})(850\ lb)$<br>$N_{ua1,3} = 195.8\ lbs$<br>Check:<br>$N_{ua1,1} + N_{ua1,2} + N_{ua1,3} = 850 lbs$<br>OK |

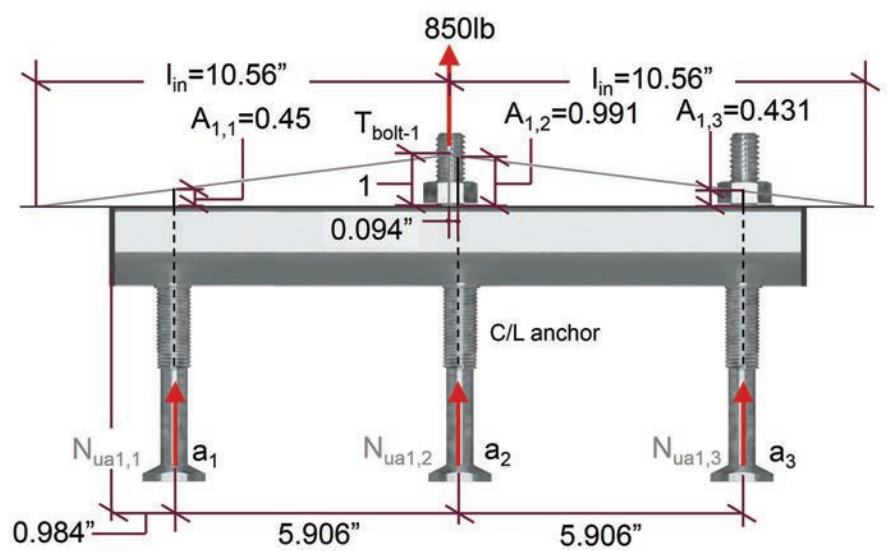



**Figure 14.1.12 — Design example – effect of t-bolt 1 on anchors**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3: Determination of worst tolerance** | | |
| **ESR-3520**<br>**4.1.2.2**<br>**Eq (2)**<br>**Eq (1)** | The highest loaded anchor element in tension does not always control the anchor channel design in tension. The highest utilization, defined by the parameter ($N_{ua,total}$ / $\varphi_{Nn}$) controls the design. Therefore, the tension design strengths must be calculated for each anchor element and checked against the total factored tension load acting on that element. The most unfavorably loaded anchor element (highest utilization) controls the design in tension.<br><br>The tension forces acting on each anchor element can be determined assuming a triangular force distribution.<br><br>The triangular force distribution assumes the tension force acting on each T-bolt (850 lb) has an influence on each of the anchor elements within a given distance ($\ell$ in) from the T-bolt.<br><br>The resulting tension force on each anchor element ($N_{2, uax}$) from the tension force acting on T-bolt #1 will be proportionate by the factor<br><br>($A_{2, \#x}$) to the distance of the anchor element with respect to the distance l in. Note that the influence length ($\ell$ in) does not necessarily coincide with the channel length.<br><br>Even when a T-bolt is located directly over one anchor element, the T-bolt load is still distributed to all other anchor elements within the distance $\ell_{in}$ from the T-bolt. | $\frac{A_{2,1}}{0\ in} = \frac{1}{10.56\ in}$<br>$A_{2,1} = 0$<br>$\frac{A_{2,2}}{(10.56\ in - 5.906\ in)} = \frac{1}{10.56\ in}$<br>$A_{2,2} = 0.441$<br>$\frac{A_{2,3}}{(10.56\ in)} = \frac{1}{10.56\ in}$<br>$A_{2,3} = 1$<br>$k_1 = \frac{1}{A_{2,1} + A_{2,2} + A_{2,3}} \rightarrow k_1 = 0.6941$<br>$N_{ua2,1} = (k_1)(A_{2,1})(850\ lb)$<br>$N_{ua2,1} = 0\ lbs$<br>$N_{ua2,2} = (k_1)(A_{2,2})(850\ lb)$<br>$N_{ua2,2} = 260\ lbs$<br>$N_{ua2,3} = (k_1)(A_{2,3})(850\ lb)$<br>$N_{ua2,3} = 590\ lbs$<br>Check:<br>$N_{ua2,1} + N_{ua2,2} + N_{ua2,3} = 850 lbs$<br>OK |

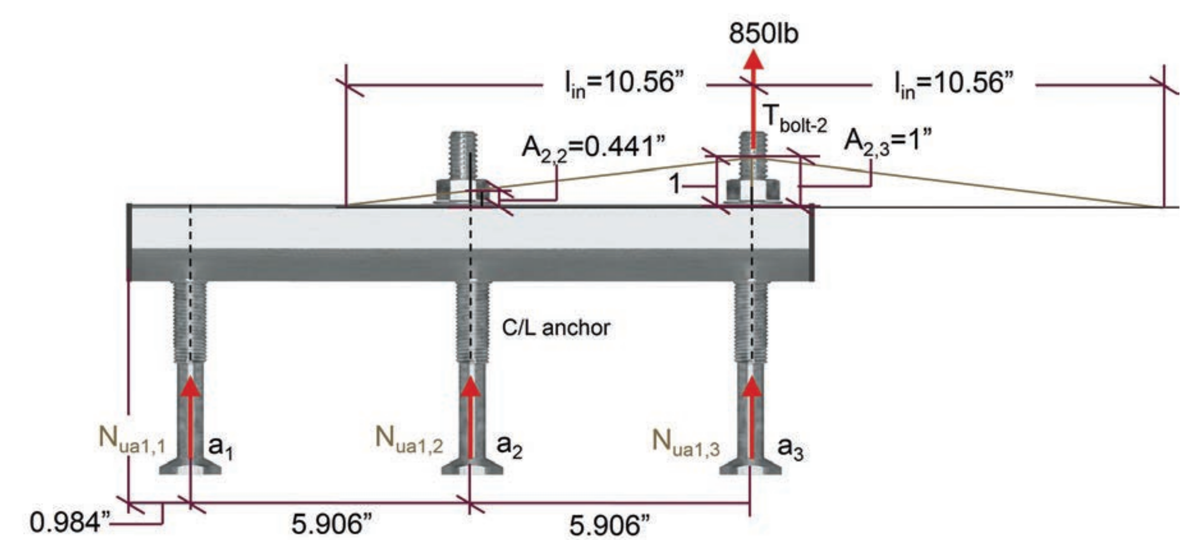



**Figure 14.1.13 — Design example – effect of t-bolt 2 on anchors**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3: Determination of worst tolerance** | | |
| **ESR-3520<br>4.1.2.2<br>Eq (2)<br>Eq (1)** | The total tension force acting on each anchor element ($N_{uax,total}$) will be the sum of the T-bolt forces ($N_{1,uax}$ + $N_{2,uax}$) acting on that element.<br>As a check, the sum of the total tension forces acting on all of the anchor elements should equal the sum of the tension forces acting on all of the T-bolts. | $N_{ua1,1}$ = 204.4 *lbs* $N_{ua2,1}$ = 0 *lbs*<br>$N_{ua1,2}$ = 449.8 *lbs* $N_{ua2,2}$ = 260 *lbs*<br>$N_{ua1,3}$ = 195.8 *lbs* $N_{ua2,3}$ = 590 *lbs*<br>$N_{ua1,total} = N_{ua,1,1} + N_{ua2,1}$ = 204 *lbs*<br>$N_{ua2,total} = N_{ua,1,2} + N_{ua2,2}$ = 710 *lbs*<br>$N_{ua3,total} = N_{ua,1,3} + N_{ua2,3}$ = 786 *lbs* |

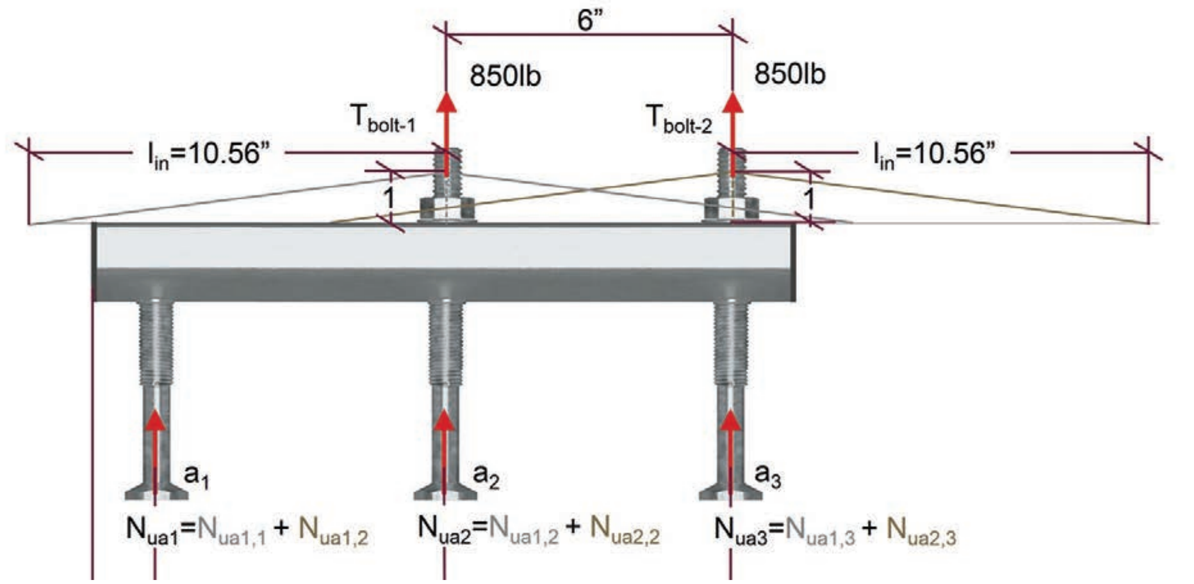
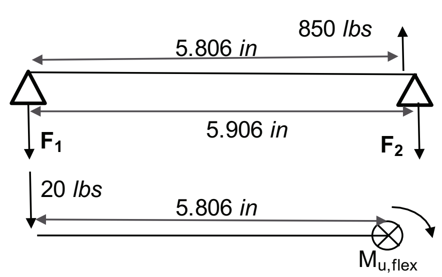
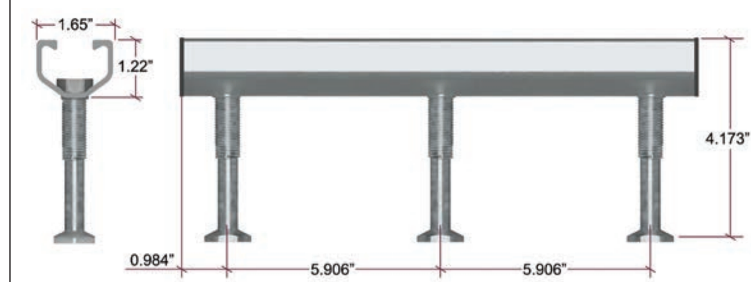



**Figure 14.1.14 — Design example – Anchor Tension forces**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 4: Determine the flexural moment ($M_{u,flex}$) acting on the anchor channel.** | | |
| **ESR-3520<br>4.1.2.2<br>Eq (2)<br>Eq (1)** | $M_{u,flex}$ is a bending moment.<br>Assume $M_{u,flex}$ occurs at the "point of load application" → $M_{u,flex}$ occurs at the location of the T-bolt.<br>Assume the channel is a simply supported beam.<br><br> | ΣF : 850 lbs – $F_1$ –$F_2$ = 0<br>ΣM:<br>(850 lbs )(5.806 in ) – ($F_2$)(5.906 in) = 0<br>$F_2$ = 835.61 lbs → $F_1$ = 14.39 lbs<br>ΣM: (14.39 lbs)(5.806 in ) – $M_{u,flex}$ = 0<br>$M_{u,flex}$ = 83.6 in-lb |

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3: Determine the shear forces acting on each anchor element.** | | |
| **ESR-3520<br>4.1.2.2<br>Eq (2)<br>Eq (1)** | The T-bolt #1 shear force (1750 lb) will have an influence on each anchor element as shown below. The shear forces on anchor elements #1, #2 and #3 resulting from this influence will be defined as $V_{ua1,1}$, $V_{ua1,2}$ and $V_{ua1,3}$ respectively. The influence factor $A_{1,\#x}$ corresponds to the influence on anchor element #x from T-bolt #1. The parameter "s" corresponds to the spacing between each anchor element. The parameter ℓ in corresponds to the influence length for T-bolt #1.<br>The T-bolt #2 shear force (1750 lb) will have an influence on each anchor element as shown below. The shear forces on anchor elements #1, #2 and #3 resulting from this influence will be defined as $V_{ua2,1}$, $V_{ua2,2}$ and $V_{ua2,3}$ respectively. The influence factor $A_{\#x,2}$ corresponds to the influence on anchor element #x from T-bolt #2. The parameter "s" corresponds to the spacing between each anchor element. The parameter ℓ in corresponds to the influence length for T-bolt #2<br>$\ell_{in} = 4.93\,(I_y)^{0.05}\sqrt{s}$ | $h_{ef}$ = 4.173 in.<br>Channel specification Length: 13.8 in., anchor spacing s: 5.906 in., projection: 0.984 in., width: $b_{ch}$ = 1.650 in., height: $h_{ch}$ = 1.220 in.<br>$\ell_y$ = 0.0796 $in.^4$<br>s = 5.906 in.<br>$\ell_{in}$ = 4.93x(0.0796 $in.^4)^{0.05}$ (5.906 $in)^{0.5}$<br>$\ell_{in}$ =10.56 in<br><br> |

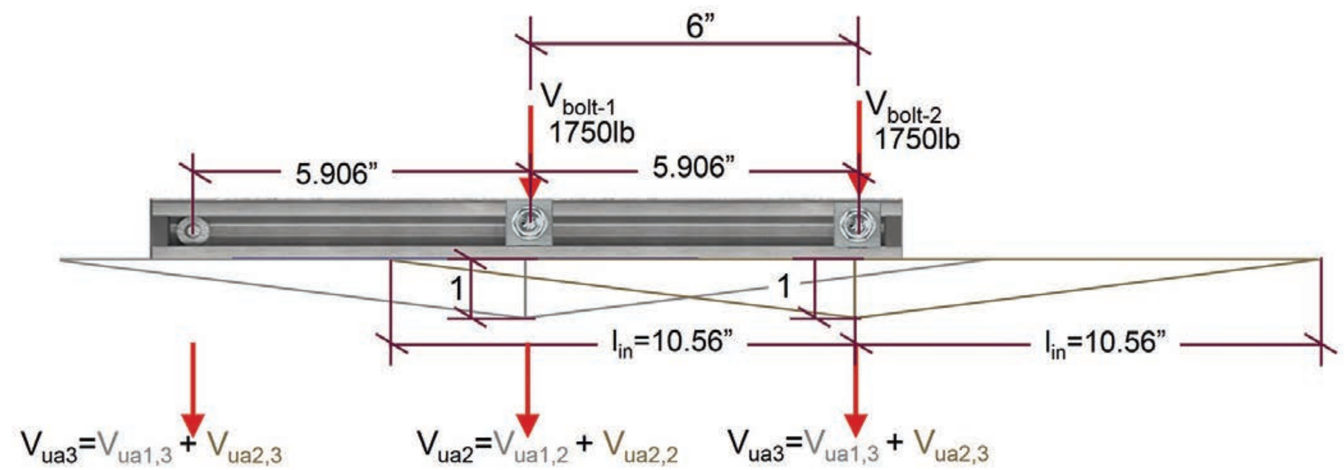



**Figure 14.1.15 — Design example – Anchor Shear forces**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3: Determination of Tension forces on to anchor element.** | | |
| **ESR-3520 4.1.2.2 Eq (2) Eq (1)** | The highest loaded anchor element in shear does not always control the anchor channel design in shear. The highest utilization, defined by the parameter ($V_{ua,total}$ / $\varphi_{Vn}$) controls the design. Therefore, the shear design strengths must be calculated for each anchor element and checked against the total factored shear load acting on that element. The most unfavorably loaded anchor element (highest utilization) controls the design in shear.<br><br>The shear forces acting on each anchor element can be determined assuming a triangular force distribution.<br><br>The triangular force distribution assumes the shear force acting on each T-bolt (1750 lb) has an influence on each of the anchor elements within a given distance ($\ell$ in) from the T-bolt.<br><br>The resulting shear force on each anchor element ($V_{1, uax}$) from the shear force acting on T-bolt #1 will be proportionate by the factor<br><br>($A_{1, \#x}$) to the distance of the anchor element with respect to the distance $\ell$ in. Note that the influence length ($\ell$ in) does not necessarily coincide with the channel length.<br><br>Even when a T-bolt is located directly over one anchor element, the T-bolt load is still distributed to all other anchor elements within the distance $\ell_{in}$ from the T-bolt. | $\frac{A_{1,1}}{(10.56\,in - 5.906\,in + 0.1\,in)} = \frac{1}{10.56\,in}$<br>$A_{1,1} = 0.45$<br>$\frac{A_{1,2}}{(10.56\,in - 0.1\,in)} = \frac{1}{10.56\,in}$<br>$A_{1,2} = 0.9905$<br>$\frac{A_{1,3}}{(10.56\,in - 0.1\,in - 5.906\,in)} = \frac{1}{10.56\,in}$<br>$A_{1,3} = 0.431$<br>$k_1 = \frac{1}{A_{1,1} + A_{1,2} + A_{1,3}} \longrightarrow k_1 = 0.5342$<br>$V_{ua1,1} = (k_1)(A_{1,1})(1750\,lb)$<br>$V_{ua1,1} = 420.86\,lbs$<br>$V_{ua1,2} = (k_1)(A_{1,2})(1750\,lb)$<br>$V_{ua1,2} = 925.99\,lbs$<br>$V_{ua1,3} = (k_1)(A_{1,3})(1750\,lb)$<br>$V_{ua1,3} = 403.15\,lbs$<br>Check:<br>$V_{ua1,1} + V_{ua1,2} + V_{ua1,3} = 850 lbs$<br>OK |

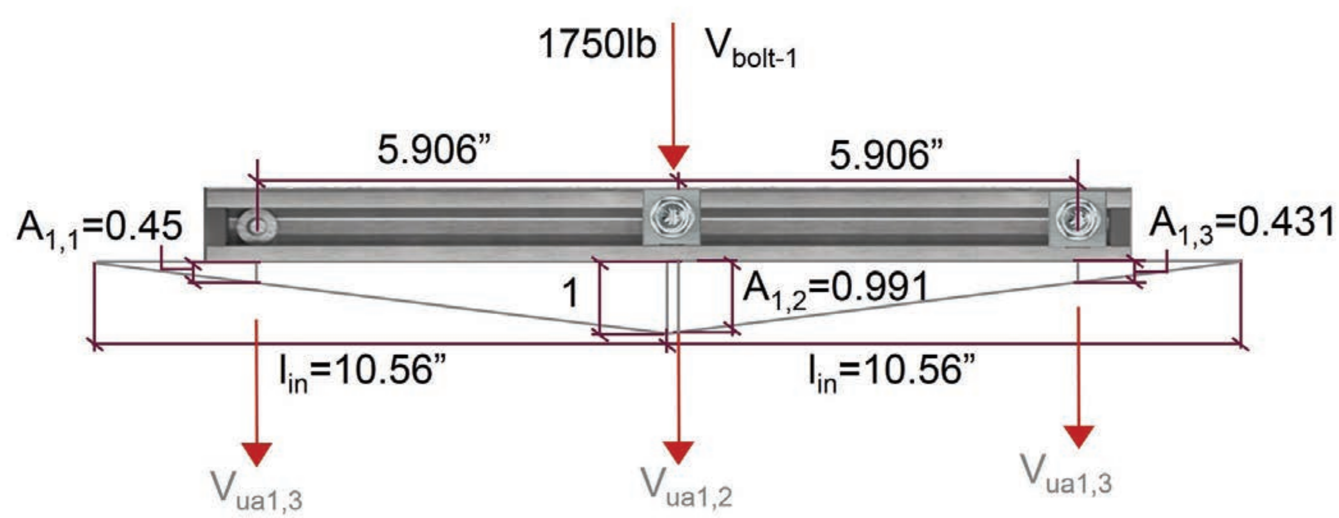



**Figure 14.1.16 — Design example – effect of t-bolt 1 on anchors**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3: Determination of Tension forces on to anchor element.** | | |
| **ESR-3520 4.1.2.2 Eq (2) Eq (1)** | The highest loaded anchor element in shear does not always control the anchor channel design in shear. The highest utilization, defined by the parameter ($V_{ua,total}$ / $\varphi_{Vn}$) controls the design. Therefore, the shear design strengths must be calculated for each anchor element and checked against the total factored shear load acting on that element. The most unfavorably loaded anchor element (highest utilization) controls the design in shear.<br><br>The shear forces acting on each anchor element can be determined assuming a triangular force distribution.<br><br>The triangular force distribution assumes the shear force acting on each T-bolt (1750 lb) has an influence on each of the anchor elements within a given distance ($\ell$ in) from the T-bolt.<br><br>The resulting shear force on each anchor element ($V_{2, uax}$) from the shear force acting on T-bolt #1 will be proportionate by the factor<br><br>($A_{2, \#x}$) to the distance of the anchor element with respect to the distance $\ell$ in. Note that the influence length ($\ell$ in) does not necessarily coincide with the channel length.<br><br>Even when a T-bolt is located directly over one anchor element, the T-bolt load is still distributed to all other anchor elements within the distance lin from the T-bolt. | $\frac{A_{2,1}}{0\,in} = \frac{1}{10.56\,in}$<br>$A_{2,1} = 0$<br>$\frac{A_{2,2}}{(10.56\,in - 5.906\,in)} = \frac{1}{10.56\,in}$<br>$A_{2,2} = 0.441$<br>$\frac{A_{2,3}}{(10.56\,in)} = \frac{1}{10.56\,in}$<br>$A_{2,3} = 1$<br>$k_1 = \frac{1}{A_{2,1} + A_{2,2} + A_{2,3}} \longrightarrow k_1 = 0.6941$<br>$V_{ua2,1} = (k_1)(A_{2,1})(1750\,lb)$<br>$V_{ua2,1} = 0\,lbs$<br>$V_{ua2,2} = (k_1)(A_{2,2})(1750\,lb)$<br>$V_{ua2,2} = 535.33\,lbs$<br>$V_{ua2,3} = (k_1)(A_{2,3})(1750\,lb)$<br>$V_{ua2,3} = 1214.67\,lbs$<br>Check:<br>$V_{ua2,1} + V_{ua2,2} + V_{ua2,3} = 1750 lbs$<br>OK |

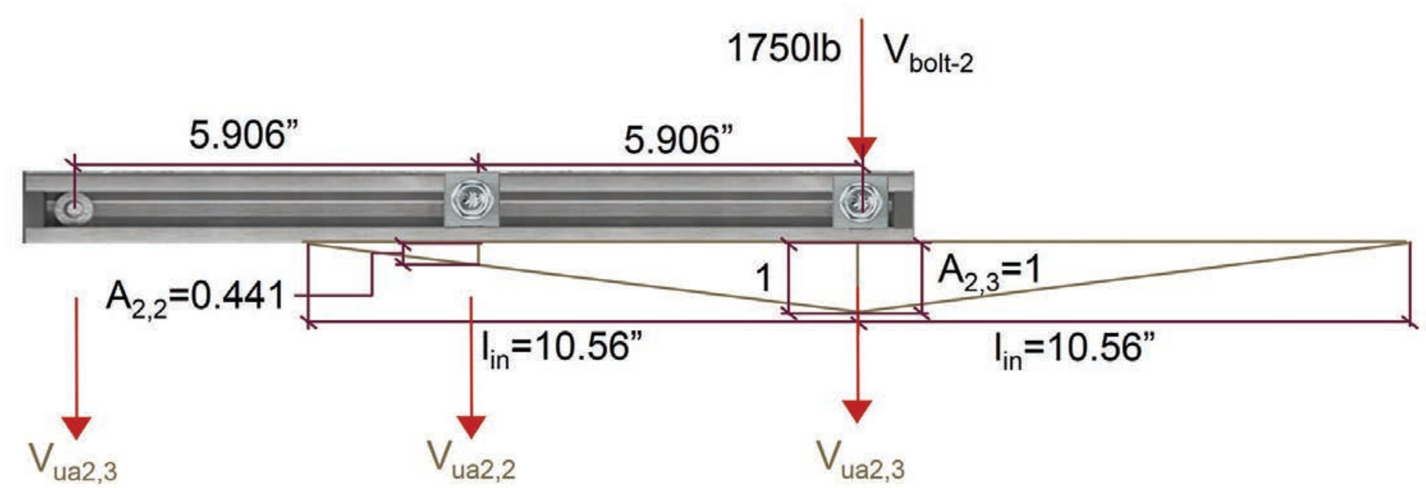



**Figure 14.1.17 — Design example – effect of t-bolt 2 on anchors**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 3:Determination of Tension forces on to anchor element.** | | |
| **ESR-3520 4.1.2.2 Eq (2) Eq (1)** | The total shear force acting on each anchor element (Vuax,total) will be the sum of the T-bolt forces (V1,uax + V2,uax) acting on that element.<br>As a check, the sum of the total shear forces acting on all of the anchor elements should equal the sum of the shear forces acting on all of the T-bolts. | $V_{ua1,1}$ = 420.86 *lbs* $V_{ua2,1}$ = 0 *lbs*<br>$V_{ua1,2}$ = 925.99 *lbs* $V_{ua2,2}$ = 535.33 *lbs*<br>$V_{ua1,3}$ = 403.15 *lbs* $V_{ua2,3}$ = 1214.67 *lbs*<br>$V_{ua1,total} = V_{ua,1,1} + V_{ua2,1}$ = 421 *lbs*<br>$V_{ua2,total} = V_{ua,1,2} + V_{ua2,2}$ = 1461 *lbs*<br>$V_{ua3,total} = V_{ua,1,3} + V_{ua2,3}$ = 1618 *lbs* |

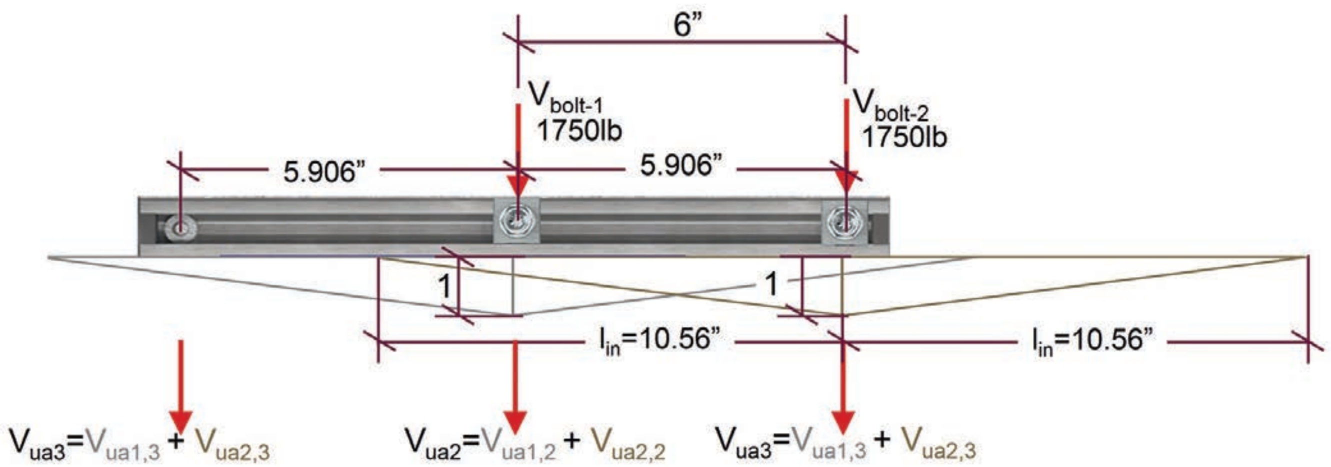



**Figure 14.1.18 — Design example – Anchor Shear forces**

**$M_{u,flex}$ = 83.6 in-lb**
**T-bolt forces**

| Bolt | $N^b_{ua}$ (lbs) | $V^b_{ua}$ (lbs) | $V^b_{uax}$ (lbs) | $V^b_{uay}$ (lbs) |
|---|---|---|---|---|
| 1 | 850 | 1750 | 0 | -1750 |
| 2 | 850 | 1750 | 0 | -1750 |

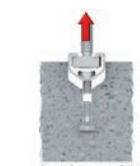
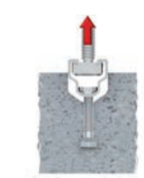
**T-bolt forces**

| Anchor element | $N^b_{ua}$ (lbs) | $V^b_{ua}$ (lbs) | $V^b_{uax}$ (lbs) | $V^b_{uay}$ (lbs) |
|---|---|---|---|---|
| $a_1$ | 204 | 421 | 0 | 421 |
| $a_2$ | 710 | 1461 | 0 | 1461 |
| $a_3$ | 786 | 1618 | 0 | 1618 |

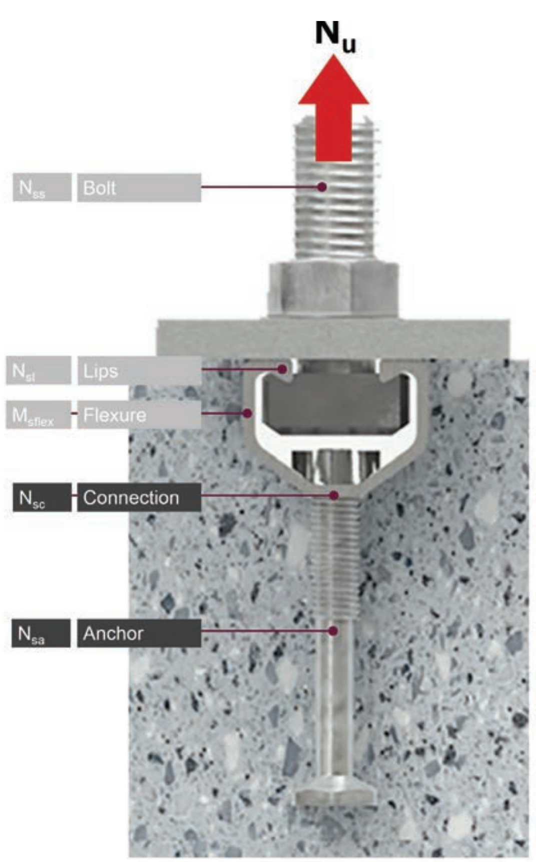
AC232 strength design provisions require calculation of nominal strengths corresponding to possible failure modes. Each nominal shear strength is multiplied by a strength reduction factor (Φ-factor) to obtain a design shear strength. The parameter "% utilization" corresponds to the ratio:

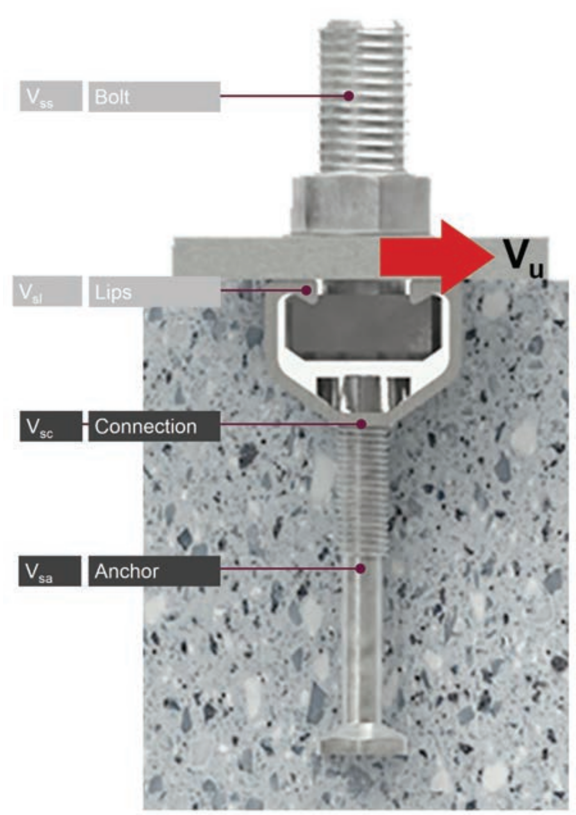
$$\frac{\text{factored load } (N_{ua} \text{ or } V_{ua})}{\text{design strength } (\varphi N_n \text{ or } \varphi V_n)}$$

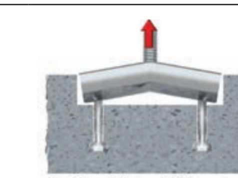
where "factored load" corresponds to the total factored load ($N_{axx,total}$ or $N_{T\text{-}bolt}$) and ($V_{axx,total}$ or $V_{T\text{-}bolt}$) acting on an anchor element in tension or shear respectively, and "design strength" corresponds to the calculated design strength for the failure mode being considered in tension or shear respectively, Utilizations less than 100% indicate the factored load is less than the design strength, while utilizations greater than 100% indicate the factored load exceeds the design strength. Therefore, the anchor channel design is considered acceptable if all of the utilizations are less than 100%, and the combined interaction checks using these utilizations are satisfied. When both tension and shear loads act on the anchor channel system, combined interaction checks must be made for both steel failure and concrete failure.

| Code | Discussion | Calculations |
|---|---|---|
| **Step 4: Steel strength Anchor and connection between anchor and channel profile.** | | |
| **ESR-3520 section 4.1.3.2.2** | Anchor strength Tension (Anchor a3, Channel a)<br>$\Phi N_{sa} \geq N^a_{ua}$<br>Nominal strength corresponding to the anchor element → $N_{sa}$<br>Reference ESR-3520 Table 8-3.<br>$N_{sa}$ for the anchor element of an HAC-50F channel = 11240 lb Φ=0.75 | $N^a_{ua3} = 786\ lbs$<br>$\phi N_{sa} = 8430\ lbs$<br>$\beta_{N,sa} : \frac{N^a_{ua3}}{\phi N_{sa}} x100 = 10\%$<br><br>Anchor: $\phi N_{sa}$ |
| **ESR-3520 section 4.1.3.3.2, 4.1.3.4.2** | Anchor strength perpendicular shear (Anchor a3 )<br>$\Phi V_{say} \geq V^a_{uay}$<br>Nominal strength corresponding to the anchor element → $V_{say}$<br>Reference ESR-3520 Table 8-5.<br>$V_{say}$ for the anchor element of an HAC-50F channel = 7865 lb Φ=0.75 | $V^a_{ua3} = 1618\ lbs$<br>$\phi V_{sa,y} = 5899\ lbs$<br>$\beta_{N,sa} : \frac{V^a_{ua3}}{\phi V_{sa,y}} x100 = 28\%$<br><br>Anchor and channel connection: $\phi V_{sc,y}$ |
| **ESR-3520 section 4.1.3.2.2** | Tension Strength of connection between anchor and channel (Anchor a3)<br>$\Phi N_{sc} \geq N^a_{ua}$<br>Nominal strength corresponding to the anchor element → $N_{sc}$<br>Reference ESR-3520 Table 8-3.<br>$N_{sc}$ for the anchor element of an HAC-50F channel = 7865 lb Φ=0.75 | $N^a_{ua3} = 786\ lbs$<br>$\phi N_{sc} = 5899\ lbs$<br>$\beta_{N,sa} : \frac{N^a_{ua3}}{\phi N_{sc}} x100 = 14\%$<br><br>Anchor and channel connection: $\phi N_{sc}$ |
| ESR-3520 section 4.1.3.3.2, 4.1.3.4.2 | Strength of connection between anchor and channel — perpendicular shear (Anchor a3)<br>$\Phi V_{scy} \geq V^a uay$<br>Nominal strength corresponding to the anchor element → $V_{scy}$<br>Reference ESR-3520 Table 8-5.<br>$V_{scy}$ for the anchor element of an HAC-50F channel = 7865 lb Φ=0.75 | $V^a_{ua3} = 1618\ lbs$<br>$\phi V_{sc,y} = 5899\ lbs$<br>$\beta_{N,sa} : \frac{V^a_{ua3}}{\phi V_{sc,y}} x100 = 28\%$<br><br>Anchor and channel connection: $\phi V_{sc,y}$ |

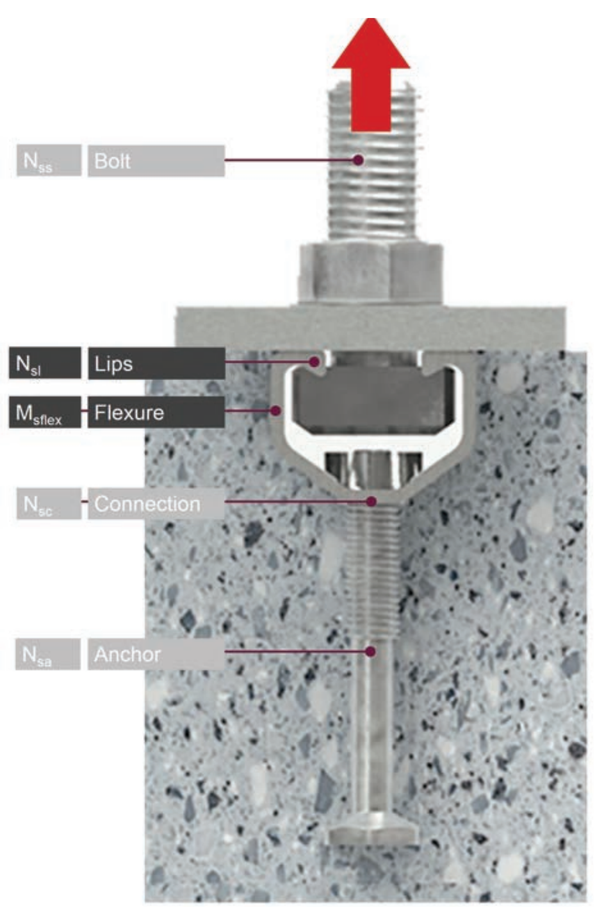
| Code | Discussion | Calculations |
|---|---|---|
| **Step 4: Steel strength Anchor and connection between anchor and channel profile.** | | |
| ESR-3520 section 4.1.3.6 | Combined tension and shear loads (Interaction)<br><br>Anchor and connection between anchor and channel (Anchor a3) The interaction check for steel failure of the channel requires the ratio (factored load acting on the anchor element/anchor element or anchor-channel connection design strength) to be checked using Equation (44) in ESR-3520. $V^{a}_{ua,x}$ =0lbs<br><br>$\max\left(\frac{N^a_{ua}}{\phi N_{sa}},\frac{N^a_{ua}}{\phi N_{sc}}\right)^{\alpha}+\max\left(\frac{V^a_{ua,y}}{\phi V_{sa,y}},\frac{V^a_{ua,y}}{\phi V_{sc,y}}\right)^{\alpha}+\max\left(\frac{V^a_{ua,x}}{\phi V_{sa,x}},\frac{V^a_{ua,x}}{\phi V_{sc,x}}\right)^{2}\leq 1.0$<br><br>Governing failure mode in tension is Connection anchor-channel.<br>$\beta_{N,sc}=\frac{N^a_{ua}}{\Phi N_{sc}}$<br><br>Governing failure mode in shear is Anchor/connection - perpendicular shear.<br>$\beta_{V,sa,y}=\frac{V^a_{ua,y}}{\Phi V_{sa,y}}$ | $\max\left(\frac{N^a_{ua}}{\phi\ N_{sa}},\frac{N^a_{ua}}{\phi\ N_{sc}}\right)^{2.0}$<br><br>$\beta^2_{N,ac}$ =0.01770<br><br>$\max\left(\frac{V^a_{ua,y}}{\phi\ V_{sa,y}},\frac{V^a_{ua,y}}{\phi\ V_{sc,y}}\right)^{2.0}$<br><br>$\beta^2_{V,sa,y}$ = 0.07528<br><br>= 1.00000<br><br>0.01770 + 0.07528 ≤ 1.00000<br><br>Utilization : 10%. |

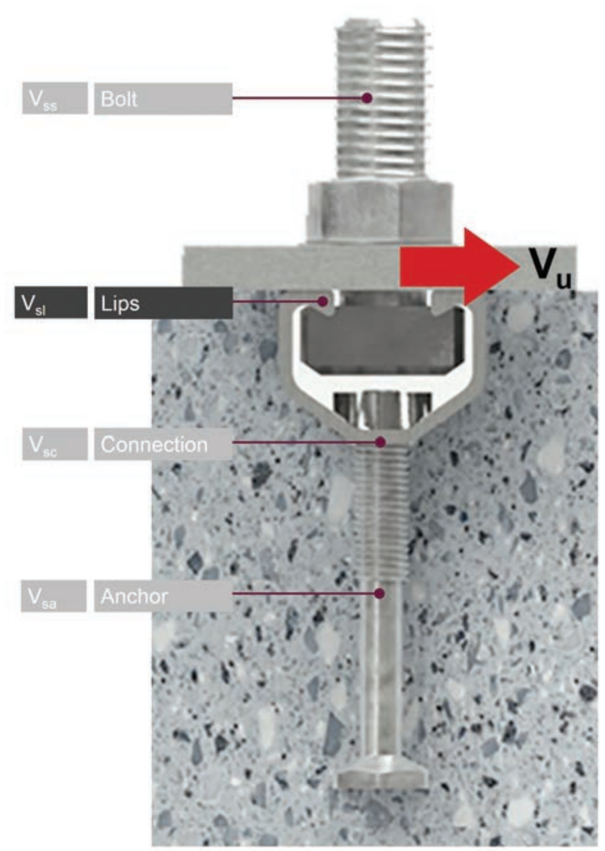


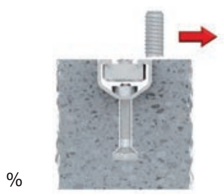



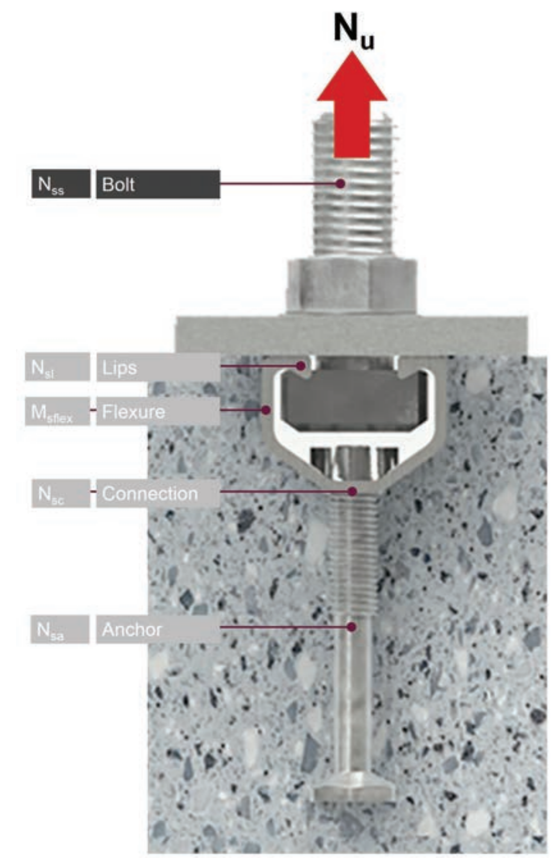

| Code | Discussion | Calculations |
|---|---|---|
| **Step 5: Steel strength local flexure channel lip and flexure of channel** | | |
| **ESR-3520 section 4.1.3.2.2** | Channel lip strength in tension: ESR-3520 Section 4.1.3.2.2 requires a check to made to determine if the clear distance between two T-bolts ($s_{chb}$) is > the parameter 2($b_{ch}$), where bch corresponds to the channel width. Values for bch are given in Table 8-1 of ESR- 3520.<br><br>If schb is < 2($b_{ch}$), the value for $N_{sl}$ given in ESR-3520 Table 8-3 must be reduced by the parameter calculated using Equation (5) in ESR- 3520. Calculate nominal tension strengths ($N_n$) nominal strength corresponding to local failure of channel lips Φ $N_{sl}$,<br><br>Reference ESR-3520 Table 8-1 and Table 8-3.<br><br>Check:<br><br>$s_{chb}$ > 2$b_{ch}$ Reference ESR-3520 Section 4.1.3.2.2.<br><br>$s_{chb}$ = clear distance between T-bolts Reference ESR-3520 Figure 8-5.<br><br>$b_{ch}$ = channel width Reference ESR-3520 Table 8-1.<br><br>If $s_{chb}$ is < 2$b_{ch}$, calculate the reduction factor<br><br>$(0.5)\left(1+\frac{s_{chb}}{2(b_{ch})}\right)$ and multiply $N_{sl}$, by this factor.<br><br>$N_{sl}$, for an HAC-50F channel = 7865 lb Φ=0.75<br><br>Reference ESR-3520 Table 8-3. Φ $N_{sl}$ ≥ $N^{s}_{ua}$ | T-bolts are spaced at 6 in o.c.<br><br>Each bolt has a diameter = 16 mm.<br><br>$s_{chb}$ = 6 in – (16 mm)(1 in/25.4 mm) = 5.37 in<br><br>HAC-50F channel width ($b_{ch}$) = 1.65 in → 2($b_{ch}$) = 3.3 in<br><br>5.37 in > 3.3 in → no reduction required.<br><br>$N^b_{ua}=850\ lbs$<br>$\phi N_{sl}=5899\ lbs$<br>$\beta_{N,sa}\ :\frac{N^b_{ua}}{\phi N_{sl}}x100\ =15\%$<br><br><br>Channel lip: $\phi N_{sl}$ |
| **ESR-3520 section 4.1.3.3.2, 4.1.3.4.2** | Strength for local flexure of channel lip — perpendicular shear load w/o lever arm Φ $V_{sly}$ ≥ $V^{a}_{uay}$<br><br>Nominal strength corresponding of channel lip → $V_{sly}$<br><br>Reference ESR-3520 Table 8-5.<br><br>α = 2 for anchor channels with $V_{sl,y}$ ≤ $N_{s,l}$<br><br>α = 1 for anchor channels with $V_{sl,y}$ > $N_{s,l}$<br><br>It shall be permitted to assume reduced values for Vsl,y corresponding to the use of an exponent α = 2. In this case the reduced value for Vsl,y shall also be used in Section 4.1.3.3.1a).<br><br>$V_{sly}$ for the anchor element of an HAC-50F channel<br><br>$V_{sl,y}$ = 7868 lb for α = 2 $V_{sl,y}$ = 10,675 lb for α = 1<br><br>Φ = 0.75 | $V^b_{ua,y}=1750\ lbs$<br>$When\ \alpha=2$<br>$\phi V_{sl,y}=5899\ lbs$<br>$\beta_{V,sl,y}\ :\frac{V^b_{ua,y}}{\phi V_{sl}}x100\ =30\%$<br>$When\ \alpha=1$<br>$\phi V_{sl,y}=8006\ lbs$<br>$\beta_{V,sl,y}\ :\frac{V^b_{ua,y}}{\phi V_{sl}}x100\ =22\%$<br><br><br>Channel lip: $\phi V_{sl,y}$ |
| ESR-3520 section 4.1.3.2.2 | Flexure of channel in tension:<br>Φ $M_{s,flex}$ ≥ $M_{u,flex}$<br>nominal strength corresponding to channel bending: Φ$M_{s,flex}$<br>Reference ESR-3520 Table 8-3.<br>$M_{s,flex}$ for an HAC-50F channel with an HBC-C T-bolt = 14,125 in-lb Φ=0.85<br>Note that the value for $M_{s,flex}$ corresponds to the type of T-bolt being used.<br>HBC-C bolts are being used for this example. | $M_{u,flex}=83.6\ in-lbs$<br>$\phi M_{s,flex}=12006\ lbs$<br>$\beta_{N,sa}\ :\frac{M_{u,flex}}{\phi M_{s,flex}}x100\ =1\%$<br><br><br>Bending of channel: $\phi M_{s,flex}$ |

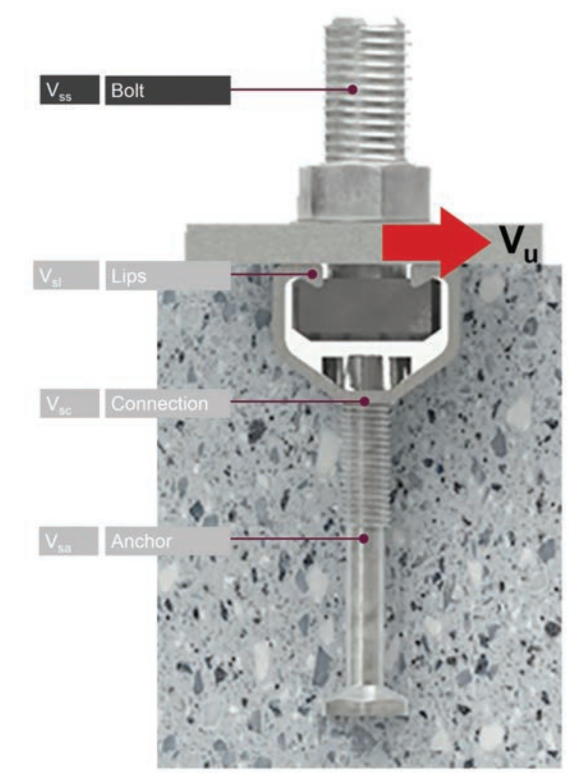
| Code | Discussion | Calculations |
|---|---|---|
| **Step 5: Steel strength local flexure channel lip and flexure of channel** | | |
| ESR-3520 section 4.1.3.6 | Combined tension and shear loads — flexure moment and channel lip (Interaction )<br><br>Channel lip in tension and shear and Flexure of channel in tension. The interaction check for steel failure of the channel requires the ratio (factored load acting on the channel lip or Flexure of channel design strength) to be checked using Equation (45) and Equation (46) in ESR-3520. $V^b_{ua,x}$ =0lbs<br>Point of load application - channel lip<br><br>$\left(\frac{N^b_{ua}}{\phi N_{sl}}\right)^{\alpha} + \left(\frac{V^b_{ua,y}}{\phi V_{sl,y}}\right)^{\alpha} + \left(\frac{V^b_{ua,x}}{\phi V_{sl,x}}\right)^{2} \leq 1.0$<br><br>Point of load application — flexural moment and channel lip<br><br>$\left(\frac{M_{u,flex}}{\phi M_{s,flex}}\right)^{\alpha} + \left(\frac{V^b_{ua,y}}{\phi V_{sl,y}}\right)^{\alpha} + \left(\frac{V^b_{ua,x}}{\phi V_{sl,x}}\right)^{2} \leq 1.0$<br><br>$\alpha$ = 2 for anchor channels with $V_{sl,y} \leq N_{s,l}$<br>$\alpha$ = 1 for anchor channels with $V_{sl,y} > N_{s,l}$<br>It shall be permitted to assume reduced values for $V_{sl,y}$ corresponding to the use of an exponent $\alpha$ = 2. In this case the reduced value for $V_{sl,y}$ shall also be used in Section 4.1.3.3.1a). | Point of load application — channel lip<br><br>$\beta^2_{N,sl}$= 0.02070<br>$\beta^2_{V,sl,y}$= 0.08801<br>$\beta^2_{N,sl} + \beta^2_{V,sl,y}$ =0.11<br><br>Utilization: 11%<br><br>Point of load application — flexural moment and channel lip<br><br>$\beta_{N,s,flex}$ = 0.00654<br>$\beta'_{V,sl,y}$ = 0.21858<br>$\beta_{N,s,flex} + \beta'_{V,sl,y}$ = 0.23<br><br>Utilization: 23% |




| Code | Discussion | Calculations |
|---|---|---|
| **Step 6: Channel bolt strength** | | |
| **ESR-3520 section 4.1.3.2.2** | Channel bolt strength in tension:<br>$\Phi N_{ss} \geq N^b_{ua}$<br>nominal strength corresponding to the T-bolt → $N_{ss}$<br>Nominal tension steel strengths for T-bolts are given in ESR-3520 Table 8-7.<br>$N_{ss}$ for an M16 diameter HBC-C 8.8 F T-bolt = 28,235 lb Φ=0.65 | $N^b_{ua}$= 850 lbs<br>$\Phi N_{ss}$ 18353 lbs<br>$\beta_{N,ss}$ : $\frac{N^b_{ua}}{\Phi N_{ss}}$ x 100 = 5 %<br><br>Channel bolt: $\phi N_{ss}$ |
| **ESR-3520 section 4.1.3.3.2, 4.1.3.4.2** | Channel bolt strength – without lever arm, longitudinal shear included in shear:<br>$\Phi V_{ss} \geq V^b_{ua}$<br>$V^b_{ua} = \sqrt{V^{b\ 2}_{ua,x} + V^{b\ 2}_{ua,y}}$<br>nominal strength corresponding to the T-bolt → Vss<br>Nominal tension steel strengths for T-bolts are given in ESR-3520 Table 8-7.<br>Vss for an M16 diameter HBC-C 8.8 F T-bolt = 16940 lb<br>Φ=0.60 | $V^b_{ua,x}$ = 1750 lbs<br>$V^b_{ua,y}$ = 0 lbs<br>$V^b_{ua}$ = 1750 lbs<br>$\Phi V_{ss}$= 10164 lbs<br>$\beta_{v,ss}$ : $\frac{V^b_{ua}}{\Phi V_{ss}}$ x 100 = 18 %<br><br>Channel bolt: $\phi V_{ss} / \phi V_{ss,M}$ |
| ESR-3520 section 4.1.3.6 | Combined tension and shear loads — Channel bolt (Interaction )<br>$\left(\frac{N^s_{ua}}{\phi\ N_{ss}}\right)^2 + \left(\frac{\sqrt{V^{s\ 2}_{ua,y} + V^{s\ 2}_{ua,x}}}{\phi\ V_{ss}}\right)^2 \leq 1.000$ | $\beta^2_{N,ss}$ = 0.00214<br>$\beta^2_{v,ss}$ = 0.02964<br>$\beta^2_{N,ss} + \beta^2_{v,ss}$ = 0.03178<br><br>Utilization : 4% |



| Code | Discussion | Calculations |
|---|---|---|
| **Step 7: Concrete strength** | | |

**Code:** ESR-3520 section 4.1.3.2.4
ACI 318-14 Chapter 17

**Discussion:**

Pull-out strength Tension
PROFIS Anchor Channel has determined that anchor element #3 controls for pullout in tension.
Per ESR-3520 Section 4.1.3.2.4, nominal pullout strength (Npn) is calculated using ACI 318 anchoring-to-concrete provisions. This example is based on ACI 318-14 provisions; therefore, pullout calculations will be per ACI 318-14 Chapter 17.

$\Phi N_{pn} \geq N^a_{ua}$

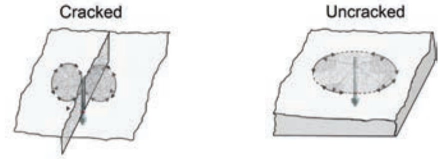
$N_{pn} = \Psi_{c,P} \cdot \lambda \cdot N_p$ ACI 318-14 Eq.(17.4.3.1)

$N_p = 8\, A_{brg}\, f'_c$ ACI 318-14 Eq. (17.4.3.4)

$A_{brg}$ for an HAC-50F anchor channel = 0.40 in2 ESR-3520 Table 8-1
λ =1 normal weight concrete Reference 1st of example
$f'_c$ = 6000 psi Reference 1st of example

ACI 318-14 17.4.3.6

| Concrete | $\Psi_{c,P}$ |
|---|---|
| Cracked | 1 |
| Uncracked | 1.25 |

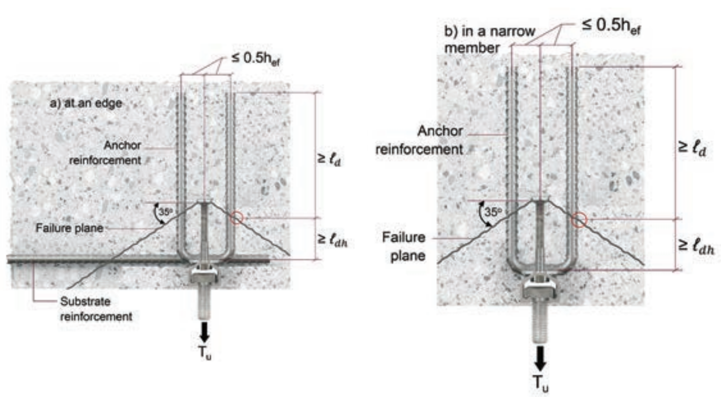



Considering cracked concrete $\Psi_{c,P}$ =1.0

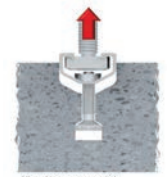
Φ factor:
Condition A (Φ =0.75) is considered when
- Supplementary reinforcement is present
- Reinforcement does not need to be explicitly designed for the anchor channel
- Arrangement should generally conform to anchor reinforcement
- Development is not required

Condition B (Φ =0.70) is considered when
- No Supplementary reinforcement is present

Assume Condition B
Φ =0.70




**Calculations:**


Pullout: $\phi N_{pn}$

$N^a_{ua3}$= 786 lbs

$N_p$ = (8) (0.40 in2) (6000 lb/in2) = 19,195 lb

$N_{pn}$ = (1.0) (1.0) (19,195 lb) = 19195 lb

$\Phi\, N_{pn}$ = 13437 lbs

$\beta_{N,pn}$ : $\frac{N_{aua3}}{\Phi\, N_{pn}}$ x100 = 6 %

| Code | Discussion | Calculations |
|---|---|---|
| **Step 7: Concrete strength** | | |

**Code:** ESR-3520 section 4.1.3.2.3
ACI 318-14 Chapter 17

**Discussion:**

Concrete breakout strength in Tension.
PROFIS Anchor Channel has determined that anchor element #3 controls for concrete breakout in tension.
Per ESR-3520 Section 4.1.3.2.3, nominal concrete breakout strength ($N_{cb,3}$) is calculated using ESR 3520 Equation (6). The value calculated for concrete breakout strength in tension ($N_{cb}$) is based on the location of the anchor element being considered. The basic concrete breakout strength in tension ($N_b$) is not dependent on the anchor element being considered or the concrete geometry. Therefore, the calculated value for $N_b$ will be the same for each anchor element.

$\Phi\, N_{cb} \geq N^a_{ua}$

$N_{cb} = N_b \cdot \psi_{s,N} \cdot \psi_{ed,N} \cdot \psi_{co,N} \cdot \psi_{cp,N} \cdot \psi_{c,N}$ ESR-3520 Equation(6)

$N_b$ = basic concrete breakout strength in tension
$\psi_{s,N}$ = modification factor for anchor spacing
$\psi_{ed,N}$ = modification factor for edge effects
$\psi_{co,N}$ = modification factor for corner effects
$\psi_{c,N}$ = modification factor cracked/uncracked concrete
$\psi_{cp,N}$ = modification factor for splitting

Nominal concrete breakout strength in tension for Anchor Element #3

$$N_{b,3} = 24 \cdot \lambda \cdot \alpha_{ch,N} \cdot \sqrt{f'_c} \cdot h_{ef}^{1.5}$$

Calculate the basic concrete breakout strength in tension ($N_{b,3}$). ESR-3520 Equation (7)
λ = 1 normal weight concrete Reference 1st of example
$f'_c$ = 6000 psi Reference 1st of example
HAC-50F channel: $h_{ef}$ = 4.173 in ESR-3520 Table 8-1

$$\alpha_{ch,N} = \left(\frac{h_{ef}}{7.1}\right)^{0.15} \leq 1.0$$ ESR-3520 Equation (8)

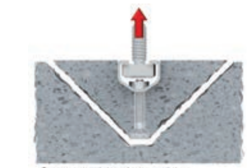
The parameter $\alpha_{ch,N}$ is a factor that is used to account for the influence of the channel size on the concrete breakout capacity in tension. The value 7.1 is a constant. ESR-3520 Table 8-1 provides minimum effective embedment depth values ($h_{ef,min}$) for each anchor channel size. The $h_{ef,min}$ value given for an HAC-50F channel will be used for $h_{ef}$ in this example.

Calculate the modification factor for anchor influence ($\psi_{s,N,3}$).

$$\psi_{s,N,3} = \frac{1}{1 + \sum_{i=2}^{n+1}\left[\left(1 - \frac{s_i}{s_{cr,N}}\right)^{1.5} \cdot \frac{N^a_{ua,i}}{N^a_{ua,3}}\right]}$$ ESR-3520 Equation (10)

The value calculated for concrete breakout strength in tension ($N_{cb}$) is based on the location of the anchor element being considered. Therefore, for this example, $\psi_{s,N}$ is calculated to account for the influence of anchor element #1 and anchor element #3 on anchor element #2.

**Calculations:**

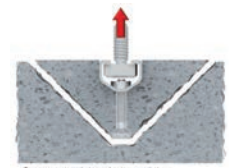

Concrete breakout: $\phi N_{cb}$

Concrete breakout: $\Phi N_{cb}$

$N_{aua3}$= 786 lbs

$\alpha_{ch,N} = \left(\frac{4.173}{7.1}\right)^{0.15}$ = 0.923. < 1

$N_{b,3} = 24 \cdot 1 \cdot 0.923 \cdot \sqrt{60000} \cdot (4.173)^{1.5}$ = 14634 lbs

| Code | Discussion | Calculations |
|---|---|---|
| **Step 7: Concrete strength** | | |
| ESR-3520 section 4.1.3.2.3<br>ACI 318-14 Chapter 17 | Concrete breakout strength in Tension continued.<br>This influence takes into consideration the loading on each anchor element as well as the distance (spacing) of these elements from anchor element #2. Reference ESR-3520 Equations (10) and (11) for more information on how to calculate $\psi_{s,N}$.<br><br>The parameter $s_{cr,N}$ corresponds to the maximum distance that is assumed with respect to the influence of an anchor element on the anchor element being considered. Any anchor elements that are within $s_{cr,N}$ from the anchor element being considered are assumed to have an influence on that anchor element.<br><br>The calculated value for $s_{cr,N}$ will be the same for each anchor element; however, the number of anchor elements within the distance $s_{cr,N}$ from the anchor element being considered may not always be the same. Reference ESR-3520 Equation (11) for more information on how to calculate $s_{cr,N}$.<br><br>$s_i$ = spacing between each anchor element = 5.91 in<br>$s_{xx,1}$ = distance of each influencing anchor element from anchor element #3<br>$s_{1,3}$ = distance from anchor element #1 to anchor element #3 = 11.812 in<br>$s_{2,3}$ = distance from anchor element #2 to anchor element #3 = 5.906 in<br>$s_{cr,N}$ = critical anchor spacing for tension loading ($h_{ef}$ =4.173 in)<br><br>$s_{cr,N} = 2\left(2.8 - \frac{1.3h_{ef}}{7.1}\right)h_{ef} \geq 3h_{ef}$ ESR-3520 Equation (11)<br><br>The parameter ψs,N is a modification factor that is used to account for the influence of adjacent anchor elements on the anchor element being considered.<br>$N^a_{ua,1}$ = tension load on anchor element #1 = 204 lb<br>$N^a_{ua,2}$ = tension load on anchor element #2 = 710 lb<br>$N^a_{ua,3}$ = tension load on anchor element #3 = 786 lb | <br><br>Concrete breakout: $\Phi N_{cb}$<br><br>$s_{cr,N} = 2\left(2.8 - \frac{1.3(4.173in)}{7.1}\right)4.173in$<br>$= 16.980in$<br>$3h_{ef} = 3(4.173in) = 12.519in$<br>$s_{cr,N} = 16.980in \geq 12.519in$<br><br>influence of anchor element #1 on anchor element #3:<br>$\left(1 - \frac{11.812in}{16.980in}\right)^{1.5} \frac{204lbs}{786lbs}$<br>$= 0.0436$<br><br>influence of anchor element #2 on anchor element #3:<br>$\left(1 - \frac{5.906in}{16.980in}\right)^{1.5} \frac{710lbs}{786lbs}$<br>$= 0.4758$<br><br>$\psi_{s,N,3} = \frac{1}{1 + (0.0436 + 0.4758)}$<br>$\psi_{s,N,3} = 0.658$ |

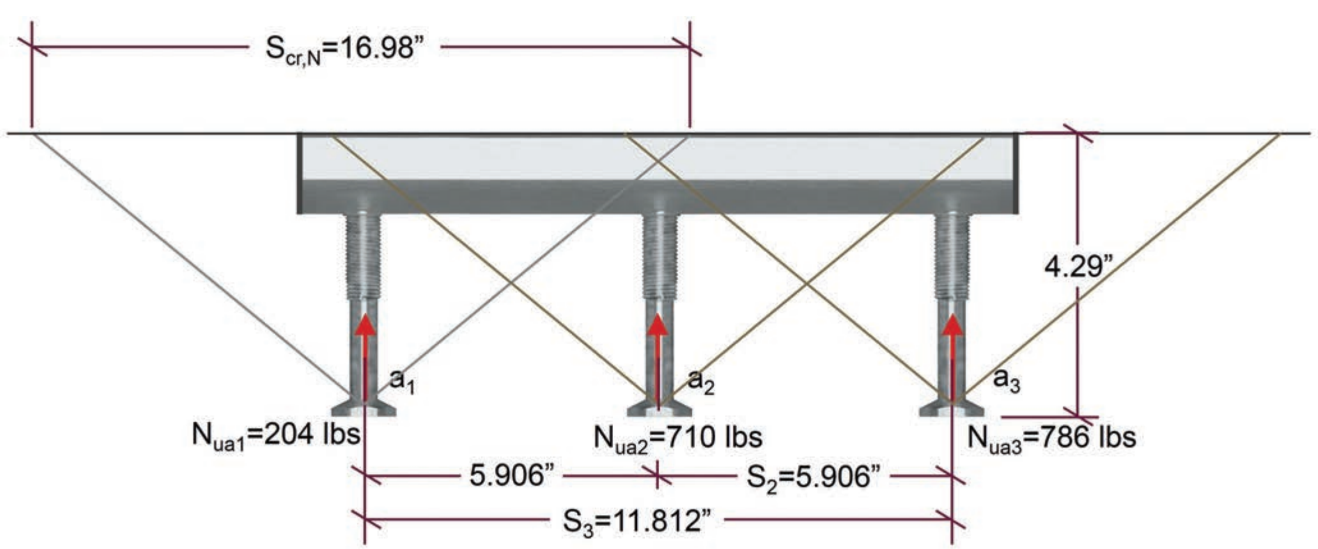
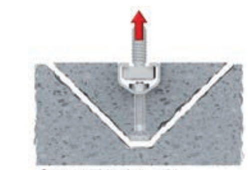



**Figure 14.1.19 — Design example – spacing reduction factor - $S_{cr,N}$**



$$\psi_{s,N3} = \frac{1}{1 + \sum\left[\left(1 - \frac{5.906in}{16.980in}\right)^{1.5} \cdot \frac{710lbs}{786lbs}\right] + \left[\left(1 - \frac{11.812in}{16.980in}\right)^{1.5} \cdot \frac{204lbs}{786lbs}\right]}$$

$$\therefore \psi_{s,N3} = 0.658$$

| Code | Discussion | Calculations |
|---|---|---|
| **Step 7: Concrete strength** | | |
| ESR-3520 section 4.1.3.2.3<br>ACI 318-14 Chapter 17 | Concrete breakout strength in Tension continued...<br><br>Calculate the modification factor for edge influence ($\psi_{ed,N,3}$).<br><br>The parameters $c_{a1}$ and $c_{a2}$ correspond to the distance from the center of the anchor element being considered to a fixed edge. $c_{a1}$ is measured perpendicular to the anchor channel longitudinal axis, and is considered when calculating the modification factor for edge influence ($\psi_{ed,N}$).<br><br>$c_{a1}$ ... edge distance of the anchor channel<br>$c_{cr,N}$ ... critical edge distance for tension loading<br><br>$\psi_{ed,N} = \left(\frac{c_{a1}}{c_{cr,N}}\right)^{0.5} \leq 1.0$ ESR-3520 Equation (13)<br><br>$c_{cr,N} = 0.5s_{cr,N} \geq 1.5h_{ef}$ ESR-3520 Equation (14)<br><br>$s_{cr,N} = 2\left(2.8 - \frac{1.3h_{ef}}{7.1}\right)h_{ef} \geq 3h_{ef}$ | <br><br>Concrete breakout: $\Phi N_{cb}$<br><br>$s_{cr,N} = 16.98in$<br>$c_{cr,N} = 0.5s_{cr,N} = (0.50)16.98in$<br>$c_{cr,N} = 8.49in$<br><br>$\psi_{ed,N} = \left(\frac{5.0in}{8.49in}\right)^{0.5} < 1.0$<br>$\therefore \psi_{ed,N} = 0.767$ |

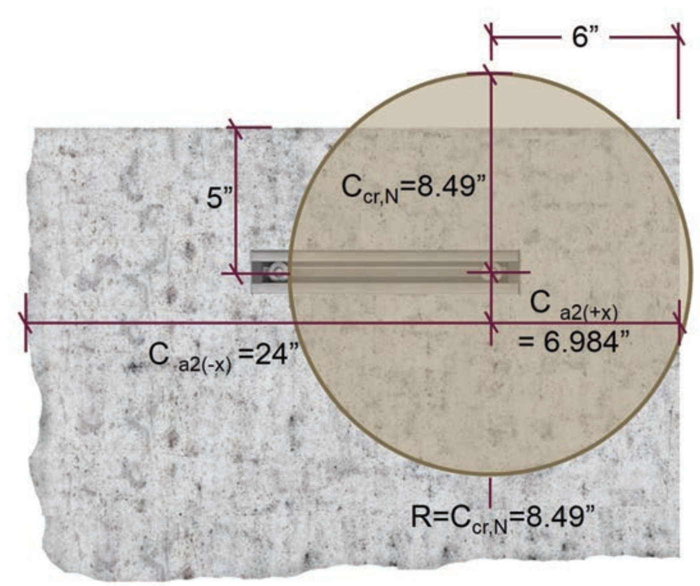



**Figure 14.1.20-a — Design example – $C_{cr,N}$**

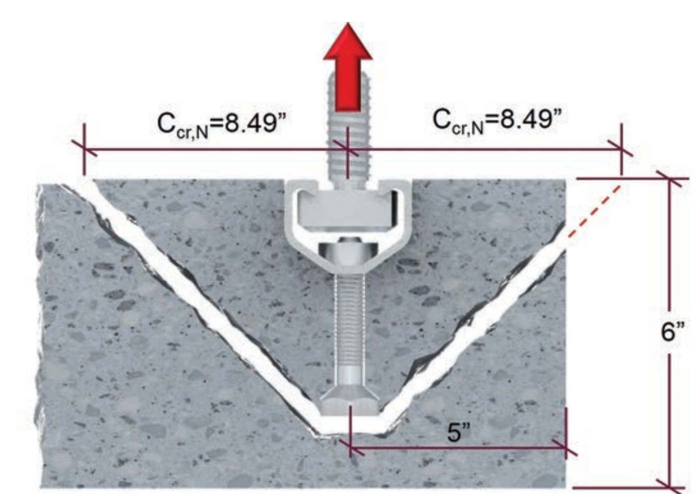



**Figure 14.1.20-b — Design example – $C_{cr,N}$**

| Code | Discussion | Calculations |
|---|---|---|

**Step 7: Concrete strength**

**Code:** ESR-3520 section 4.1.3.2.3
ACI 318-14 Chapter 17

**Discussion:**

Concrete breakout strength in Tension continued...

Calculate the modification factor for corner influence ($\psi_{co,N,3}$).

$c_{a2}$ is measured parallel to the anchor channel longitudinal axis, and is considered when calculating the modification factor for corner influence ($\psi_{co,N}$).

Since the calculated value for concrete breakout in tension ($N_{cb}$) is dependent on the concrete geometry, it is important to note that values for ca1 and ca2 must be taken with respect to the relevant edge distances from the anchor element being considered.

$$\psi_{co,N,3} = \left(\frac{c_{a2(+x)}}{c_{cr,N}}\right)^{0.5} \leq 1.0 - and - \psi_{co,N,3} = \left(\frac{c_{a2(-x)}}{c_{cr,N}}\right)^{0.5} \leq 1.0$$ ESR-3520 Equation (16)

The parameter $c_{cr,N}$ corresponds to the maximum edge distance that is assumed with respect to values for $c_{a1}$ and $c_{a2}$. Any $c_{a1}$ or $c_{a2}$ value less than $c_{cr,N}$ must be considered when calculating $\psi_{ed,N}$ and $\psi_{co,N}$. If more than one $c_{a1}$ value is less than $c_{cr,N}$, the smallest $c_{a1}$ value will be used to calculate $\psi_{ed,N}$. If more than one $c_{a2}$ value is less than $c_{cr,N}$, $\psi_{co,N}$ will be calculated for each $c_{a2}$ value and the product of these $\psi_{co,N}$ values will be used to calculate the nominal concrete breakout strength in tension ($N_{cb}$).
Calculate the modification factor for cracked/uncracked concrete ($\psi_{c,N,3}$)

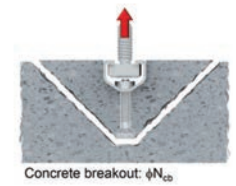
Concrete is typically assumed to be cracked under normal service load conditions. If uncracked concrete conditions are assumed, an increase in $N_{cb}$ is permitted via the modification factor $\psi_{c,N}$.

if uncracked concrete conditions are assumed,$\psi_{c,N,3}$ =1.25.

Calculate the modification factor for splitting ($\psi_{cp,N}$

$c_{ac}$ = critical edge distance for splitting
$c_{cr,N}$ = critical anchor edge distance
$c_{a,min}$ = minimum edge distance

**Calculations:**




Concrete breakout: $\Phi N_{cb}$

$c_{a2(+x)}$ = 6.00 in + 0.984 in
$c_{a2(+x)}$ = 6.984 in

$$c_{a2(-x)} = \infty \rightarrow \left(\frac{c_{a2(-x)}}{c_{cr,N}}\right)^{0.5} = 1$$

$$c_{cr,N} = 8.49in$$

$$\psi_{co,N,3} = \left(\frac{6.984in}{8.49in}\right)^{0.5} < 1.0$$

$$\therefore \psi_{co,N,3} = 0.907$$

Cracked concrete conditions

→ $\psi_{c,N,3}$ = 1.0

Cracked concrete conditions

→ $\psi_{cp,N,3}$ = 1.0

| Uncracked concrete with no supplementary reinforcement | $\psi_{cp,N}$ |
|---|---|
| if $c_{a,min} \geq c_{ac}$ | 1 |
| if $c_{amin} < c_{ac}$ | $\psi_{cp,N} = \text{MAX}\left\{\left(\frac{c_{a,min}}{c_{ac}}\right);\left(\frac{c_{cr,N}}{c_{ac}}\right)\right\}$ |
| Uncracked concrete with supplementary reinforcement | 1 |
| Cracked concrete | 1 |



| Code | Discussion | Calculations |
|---|---|---|

**Step 7: Concrete strength**

**Code:** ESR-3520 section 4.1.3.2.3
ACI 318-14 Chapter 17

**Discussion:**

Concrete breakout strength in Tension continued....

Nominal concrete breakout strength in tension for anchor element #3

$\Phi N_{cb} \geq N^a_{ua}$

$N_{cb} = N_b \cdot \psi_{s,N} \cdot \psi_{ed,N} \cdot \psi_{co,N} \cdot \psi_{cp,N} \cdot \psi_{c,N}$ ESR-3520 Equation (6)

The calculated value for $N_{cb,3}$ will be multiplied by a strength reduction factor (φ-factor) to give a design strength ($\varphi_{Ncb,3}$). Design strengths for this example are summarized in the table on this page titled Summary for Concrete Breakout in Tension.

The calculated $\varphi_{Ncb,3}$ value for anchor element #3 will be checked against the factored load acting on anchor element #3 ($N_{aua,3}$) to obtain the % utilization ($N_{aua,3}$ / $\varphi_{Ncb3}$).

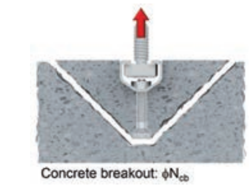
The anchor element with the highest % utilization will control the design with respect to concrete breakout failure in tension.

φ-factors for concrete breakout in tension are given in ESR-3520 Table 8-4.
Φ factor:
Condition A (Φ =0.75) is considered when
- Supplementary reinforcement is present
- Reinforcement does not need to be explicitly designed for the anchor channel
- Arrangement should generally conform to anchor reinforcement
- Development is not required

Condition B (Φ =0.70) is considered when
- No Supplementary reinforcement is present

Assume Condition B
Φ =0.70
The concrete breakout calculations ($\varphi_{Ncb}$) were influenced by the anchor location and the concrete geometry via the modification factors $\psi_{s,N}$, $\psi_{ed,N}$ and $\psi_{co,N}$

**Calculations:**




Concrete breakout: $\Phi N_{cb}$

$$N_{cb} = N_b \cdot \psi_{s,N} \cdot \psi_{ed,N} \cdot \psi_{co,N} \cdot \psi_{cp,N} \cdot \psi_{c,N}$$
$$\psi_{s,N} = 0.658$$
$$\psi_{ed,N} = 0.767$$
$$\psi_{co,N} = 0.907$$
$$\psi_{cp,N} = 1.0$$
$$\psi_{c,N} = 1.0$$
$$N_{b3} = 14634\ lbs$$
$$N_{cb,3} = 14634x0.658x0.767x0.907x1.0x1.0$$
$$N_{cb,3} = 6699lbs$$
$$Condition\ B$$
$$\varphi = 0.7$$
$$\varphi N_{cb,3} = 4689\text{lbs}$$
$$N^a_{ua,3} = 786lbs$$
$$\beta_{cb,N,3} = \left(\frac{786}{4690}\right)x100\% = 17\%$$

| Code | Discussion | Calculations |
|---|---|---|

**Step 7: Concrete strength**

**Code:** ESR-3520 Section 4.1.3.3.4.
ACI 318-14 Chapter 17

**Discussion:**

Concrete pryout strength - perpendicular shear (Anchor a3)

The ICC-ES Acceptance Criteria AC232 includes amendments to the ACI 318 anchoring to concrete provisions. These amendments are given in Section 3.1 Strength Design – Amendments to ACI 318. Part D.6.3.2 (ACI 318-11) and Section 17.5.3.2 (ACI 318-14) of these amendments requires the factor $\psi_{s,N}$ to be modified when calculating concrete pryout strength in shear. All of the parameters used to calculate $\psi_{s,N}$ in tension are used except the parameter ($N_{aua,i}$ / $N_{aua,3}$). The shear loads acting on the anchor elements are substituted for the tension loads such that ($V_{aua,i}$ / $V_{aua,3}$) is used instead of ($N_{aua,i}$ / $N_{aua,3}$).

These provisions for calculating concrete pryout strength are also given in ESR-3520 Section 4.1.3.3.4.

$V_{cp,y,3} = k_{cp} N_{cb,3}$ — ESR-3520 Equation (41)

$K_{cp3} = 2.0$ — ESR-3520 Table 8-6

$N_{cb3} = N_{b3} \cdot \psi_{s,N3} \cdot \psi_{ed,N3} \cdot \psi_{co,N3} \cdot \psi_{c,N3} \cdot \psi_{cp,N3}$ — ESR-3520 Equation (6)

$s_i$ = spacing between each anchor element = 5.91 in
$s_{xx,1}$ = distance of each influencing anchor element from anchor element #3
$s_{1,}3$ = distance from anchor element #1 to anchor element #3 = 11.812 in
$s_{2,3}$ = distance from anchor element #2 to anchor element #3 = 5.906 in
$s_{cr,N}$ = critical anchor spacing for tension loading ($h_{ef}$ =4.173 in)

$$s_{cr,N} = 2\left(2.8 - \frac{1.3h_{ef}}{7.1}\right)h_{ef} \geq 3h_{ef}$$ ESR-3520 Equation (10)

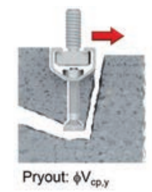
The parameter $\psi_{s,N}$ is a modification factor that is used to account for the influence of adjacent anchor elements on the anchor element being considered.
$V^a_{ua,1}$ = tension load on anchor element #1=421 lb
$V^a_{ua,2}$ = tension load on anchor element #2 1461 lb
$V^a_{ua,3}$ = tension load on anchor element #3=1618 lb

The calculated value for $V_{cp,y,3}$ will be multiplied by a strength reduction factor (φ-factor) to give a design strength ($\varphi V_{cp,y,3}$).

The calculated $\varphi V_{cp,y,3}$ value for anchor element #3 will be checked against the factored load acting on anchor element #3 ($V_{ua3}$) to obtain the % utilization ($V_{ua3}$ / $\varphi V_{cp,y,3}$).

The anchor element with the highest % utilization will control the design with respect to concrete pryout failure in shear.

**Calculations:**




Pryout: $\Phi N_{cp,yb}$

$s_{cr,N}$ = 16.98 in

refer to concrete breakout tension influence of anchor element #1 on anchor element #3:

$$\left(1 - \frac{11.812in}{16.980in}\right)^{1.5} \frac{421lbs}{1618lbs}$$
$$= 0.0437$$

influence of anchor element #2 on anchor element #3:

$$\left(1 - \frac{5.906in}{16.980in}\right)^{1.5} \frac{1461lbs}{1618lbs}$$
$$= 0.4756$$

$$\psi_{s,N,3} = \frac{1}{1 + (0.0437 + 0.4756)} = 0.658$$

$$c_{cr,N} = 0.5 s_{cr,N} = (0.50)16.98in$$
$$c_{cr,N} = 8.49in$$

$$\psi_{ed,N} = \left(\frac{5.0in}{8.49in}\right)^{0.5} < 1.0$$
$$\therefore \psi_{ed,N} = 0.767$$

$$c_{a2(+x)} = 6.00\ in + 0.984\ in$$
$$c_{a2(+x)} = 6.984\ in$$
$$c_{a2(-x)} = \infty \rightarrow \left(\frac{c_{a2(-x)}}{c_{cr,N}}\right)^{0.5} = 1$$
$$c_{cr,N} = 8.49in$$

$$\psi_{co,N,3} = \left(\frac{6.984in}{8.49in}\right)^{0.5} < 1.0$$
$$\therefore \psi_{co,N,3} = 0.907$$

$$\psi_{s,N} = 0.658$$
$$\psi_{ed,N} = 0.767$$
$$\psi_{co,N} = 0.907$$
$$\psi_{cp,N} = 1.0$$
$$\psi_{c,N} = 1.0$$
$$N_{b3} = 14634\ lbs$$
$$N_{cb,3} = 6699lbs$$
$$k_{cp} = 2$$
$$V_{cp,y,3} = k_{cp} x N_{cb,3}$$
$$V_{cp,y,3} = 2x6699lbs = 13397lbs$$
$$Condition\ B$$
$$\varphi = 0.7$$
$$\varphi V_{cp,y,3} = 9378lbs$$
$$V^a_{ua,3} = 1618lbs$$
$$\beta_{cp,v,3} = \left(\frac{1618}{9378}\right) x100\% = 18\%$$



| Code | Discussion | Calculations |
|---|---|---|

**Step 7: Concrete strength**

**Code:** ESR-3520 section 4.1.3.3.3
ACI 318-14 Chapter 17

**Discussion:**

Concrete breakout strength in perpendicular shear for anchor element #3

$\Phi V_{cb} \geq V^a_{ua}$

$V_{cb,3} = V_{b,3} \cdot \psi_{s,V,3} \cdot \psi_{co1,V,3} \cdot \psi_{co2,V,3} \cdot \psi_{h,V,3} \cdot \psi_{c,V,3}$ — ESR-3520 Equation (30)

$V_b$ = Basic concrete breakout strength in shear
$\psi_{s,V}$ = Modification factor for anchor spacing
$\psi_{co,V}$ = Modification factor for corner effects
$\psi_{c,V}$ = Modification factor cracked/uncracked concrete
$\psi_{h,V}$ = Modification factor for concrete thickness

Calculate the basic concrete breakout strength in shear ($V_{b,3}$).

$$V_b = \lambda \cdot \alpha_{ch,V} \cdot \sqrt{f'_c} \cdot (c_{a1})^{4/3}$$ ESR-3520 Equation (31)

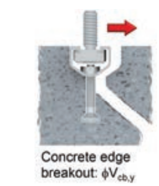
λ... Modification for lightweight concrete
Lightweight concrete = 0.75
Sand-Lightweight concrete = 0.85

$\alpha_{ch,V}$ ... Influence factor for channel size (10.50, max.)

$f'_c$ ... Concrete compressive strength (psi) (8,500 psi, max)

$c_{a1}$ ... Perpendicular edge distance (in.) (edge to center line of channel)

**Calculations:**




Concrete edge breakout: $\Phi V_{cb,y}$

$$V_b = (1.0)(10.50)\sqrt{6{,}000psi} \cdot (5.0in)^{4/3}$$
$$\therefore V_b = 6{,}954lbs$$

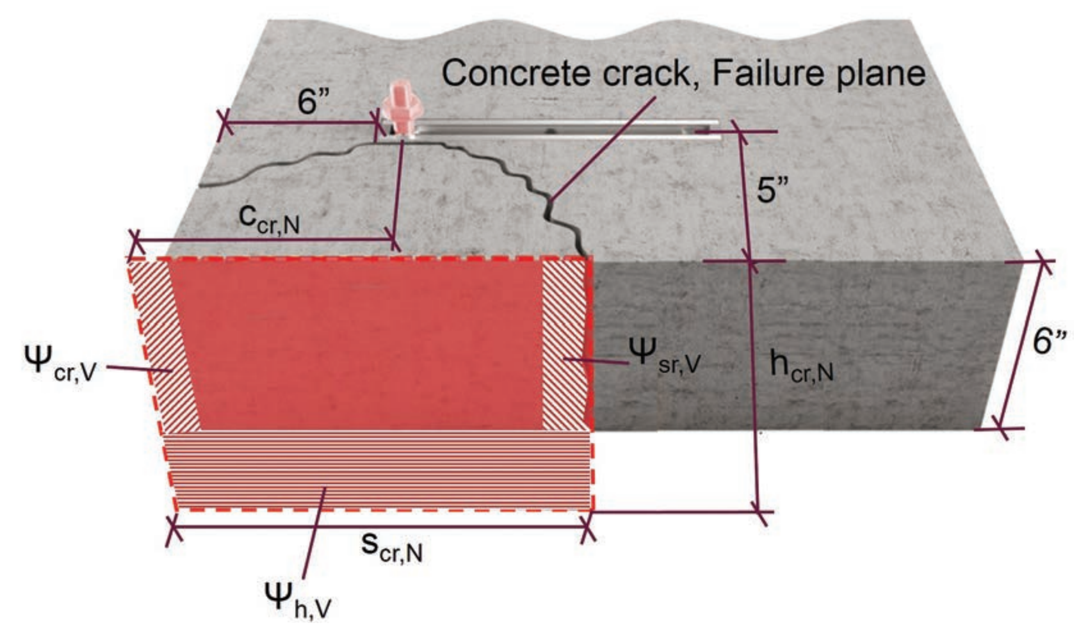
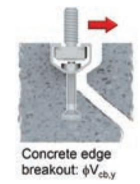



**Figure 14.1.21 — Design example – reduction factors of $V_{cb}$**

| Code | Discussion | Calculations |
|---|---|---|
| **Step 7: Concrete strength** | | |
| ESR-3520 Section 4.1.3.3.4.<br>ACI 318-14 Chapter 17 | Concrete breakout strength in perpendicular shear for anchor element #3 continued...<br><br>The value calculated for concrete breakout strength in shear ($V_{cb}$) is based on the location of the anchor element being considered. The basic concrete breakout strength in shear ($V_b$) is not dependent on the anchor element being considered, but it is dependent on the concrete geometry via the parameter $c_{a1}$. However, the calculated value for $V_b$ will be the same for each anchor element if the $c_{a1}$ value is the same for each element.<br><br>The parameter $\psi_{s,V}$ will be dependent on the anchor element being considered and the concrete geometry. Reference ESR-3520 Equation (32) for more information on how to calculate $\psi_{s,V}$.<br><br>The parameter $s_{cr,V}$ corresponds to the maximum distance that is assumed with respect to the influence of an anchor element on the anchor element being considered. Any anchor elements that are within $s_{cr,V}$ from the anchor element being considered are assumed to have an influence on that anchor element. The calculated value for $s_{cr,V}$ will be the same for each anchor element if the $c_{a1}$ value is the same for each element; however, the number of anchor elements within the distance $s_{cr,V}$ from the anchor element being considered may not always be the same. Reference ESR-3520 Equation (33) for more information on how to calculate $s_{cr,V}$.<br><br>Calculate the modification factor for anchor influence ($\psi_{s,V,3}$).<br>ESR-3520 Equation (32)<br><br>$\psi_{s,V,3} = \dfrac{1}{1+\sum_{i=2}^{n+1}\left[\left(1-\frac{s_i}{s_{cr,V}}\right)^{1.5}\cdot\frac{V^a_{ua,i}}{V^a_{ua,3}}\right]}$<br><br>$s_i$ = spacing between each anchor element = 5.91 in<br>$s_{xx,1}$ = distance of each influencing anchor element from anchor element #3<br>$s_{1,3}$ = distance from anchor element #1 to anchor element #3 = 11.82 in<br>$s_{2,3}$ = distance from anchor element #2 to anchor element #3 = 5.91 in<br>$s_{cr,V}$ = critical anchor spacing for shear loading<br>$c_{a1}$ = 4.50 in<br>$b_{ch}$ = 1.65 in (reference ESR-3520 Table 8-1)<br><br>$s_{cr,V} = 4_{ca1} + 2b_{ch}$ ESR-3520 Equation (33)<br><br>$V_{a\,ua,1}$ = shear load on anchor element #1 = 422 lb<br>$V_{a\,ua,2}$ = shear load on anchor element #2 = 1464 lb<br>$V_{a\,ua,3}$ = shear load on anchor element #3 = 1615 lb | <br><br>Concrete edge breakout: $\Phi V_{cb,y}$<br><br>$s_{cr,N}$ = 4 x 5 in + 2 x 1.65 in<br><br>$s_{cr,N}$ = 23.3 in<br><br>influence of anchor element #1 on anchor element #3:<br>$\left(1-\frac{11.812in}{23.30in}\right)^{1.5}\frac{421lbs}{1618lbs}$<br>$=0.0901$<br><br>influence of anchor element #2 on anchor element #3:<br>$\left(1-\frac{5.906in}{23.3in}\right)^{1.5}\frac{1461lbs}{1618lbs}$<br>$=0.582$<br><br>$\psi_{s,V,3} = \frac{1}{1+(0.0901+0.582)}$<br>$\psi_{s,V,3} = 0.598$ |

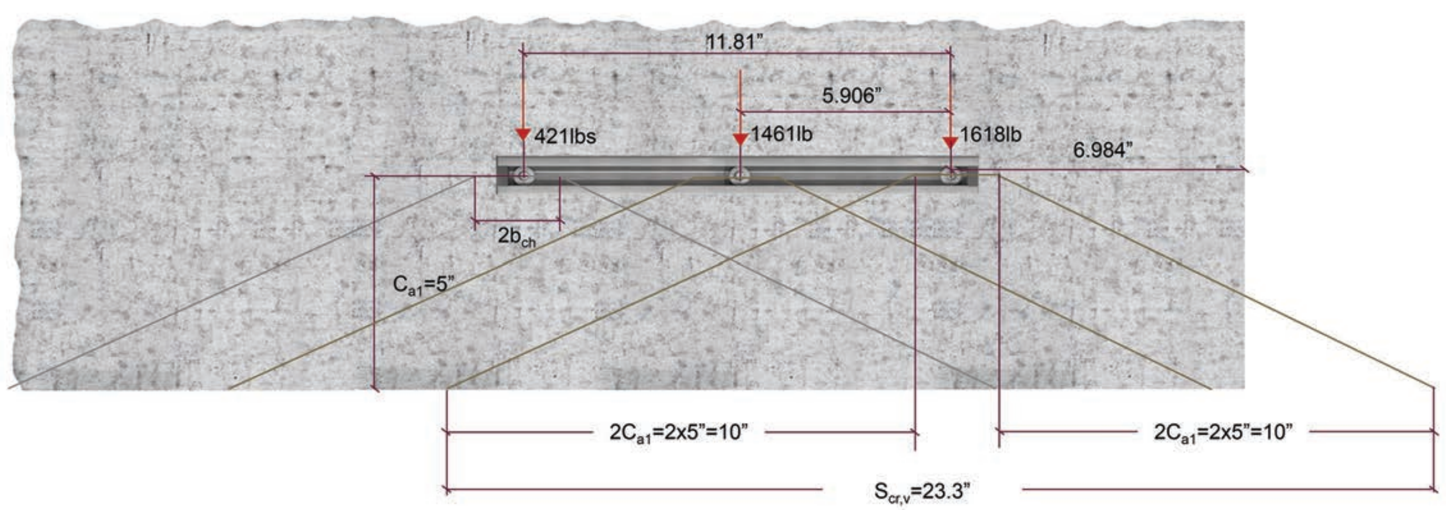
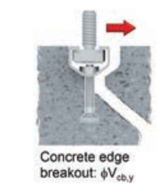



Figure 14.1.22 — Design example – spacing reduction factor of $\psi_{s,v}$

$$\psi_{s,v,3} = \frac{1}{1+\sum\left[\left(1-\frac{11.812\text{in}}{23.30\text{in}}\right)^{1.5}\cdot\frac{421\text{lbs}}{1618\text{lbs}}\right]+\left[\left(1-\frac{5.906\text{in}}{23.30\text{in}}\right)^{1.5}\cdot\frac{1461\text{lbs}}{1618\text{lbs}}\right]}$$

$$\therefore \psi_{s,v,3} = 0.598$$

| Code | Discussion | Calculations |
|---|---|---|
| **Step 7: Concrete strength** | | |
| ESR-3520 section 4.1.3.3.3<br>ACI 318-14 Chapter 17 | Concrete breakout strength in perpendicular shear for anchor element #3 continued...<br><br>Calculate the modification factor for corner influence ($\psi_{co,V,3}$).<br><br>$\psi_{co,V} = \left(\frac{c_{a2}}{c_{cr,V}}\right)^{0.5} \le 1.0$ ESR-3520 Equation (35)<br><br>$c_{cr,V} = 0.5\cdot s_{cr,V} = 2c_{a1} + b_{ch}$ ESR-3520 Equation (36)<br><br>$c_{a2}$ ... corner distance of the anchor under consideration<br>$c_{cr,V}$ ...critical edge distance for anchor channel for shear loading<br><br>The parameters $c_{a1}$ and $c_{a2}$ correspond to the distance from the center of the anchor element being considered to a fixed edge. $c_{a2}$ is measured parallel to the anchor channel longitudinal axis, and is considered when calculating the modification factor for corner influence ($\psi_{co,V}$). When concrete breakout in shear ($V_{cb,y,3}$) is being calculated for anchor element #3. It is important to note that values for $c_{a1}$ and $c_{a2}$ must be considered with respect to the relevant edge distances from anchor element #3.<br><br>The parameter $c_{cr,V}$ corresponds to the maximum distance that is assumed with respect to the value for $c_{a2}$. Any $c_{a2}$ value less than $c_{cr,V}$ must be considered when calculating $\psi_{co,V}$. If more than one $c_{a2}$ value is less than $c_{cr,V}$, $\psi_{co,V}$ will be calculated for each $c_{a2}$ value, and the product of these $\psi_{co,V}$ values will be used to calculate the nominal concrete breakout strength in shear ($V_{cb,y}$). | <br><br>Concrete edge breakout: $\Phi V_{cb,y}$<br><br>$c_{cr,V}$ = 2 (5 in) + 1.65 in<br><br>$c_{cr,V}$ = 11.65 in<br><br>$\psi_{co1,V} = \left(\frac{6.984\text{in}}{11.65\text{in}}\right)^{0.5} = 0.774$<br>$\therefore \psi_{co1,V} = 0.774$<br><br>$\psi_{co2,V} = \left(\frac{\infty\ \text{in}}{9.61\text{in}}\right)^{0.5} > 1.0$<br>$\therefore \psi_{co2,V} = 1.00$ |

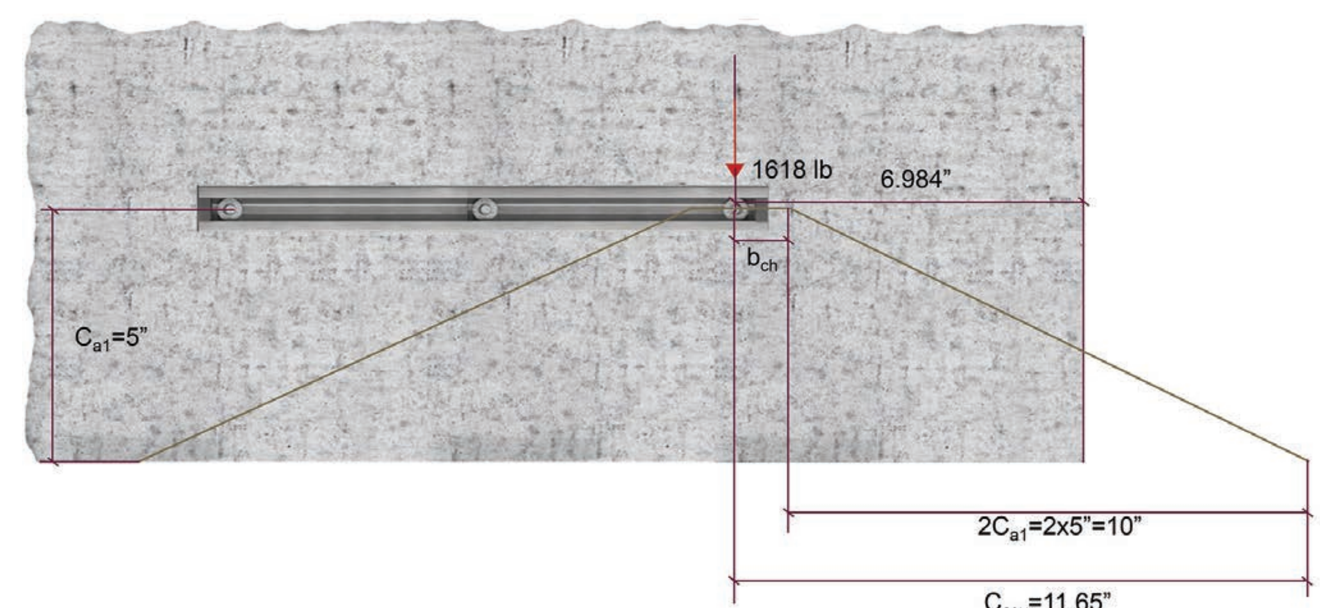
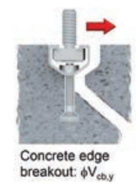



Figure 14.1.23 — Design example – corner reduction factor of $\psi_{cr,v}$

| Code | Discussion | Calculations |
|---|---|---|
| **Step 7: Concrete strength** | | |
| ESR-3520 Section 4.1.3.3.4.<br>ACI 318-14 Chapter 17 | Concrete breakout strength in perpendicular shear for anchor element #3 continued...<br><br>Calculate the modification factor for member thickness ($\psi_{h,V,3}$).<br><br>$c_{a1}$ is measured perpendicular to the anchor channel longitudinal axis, and is considered when calculating the basic concrete breakout strength in shear ($V_b$) and the modification factor for member thickness ($\psi_{h,V}$).<br><br>$h_{cr,V} = 2c_{a1} + 2h_{ch}$ ESR-3520 Equation (38)<br><br>$h_{ch}$ ... height of anchor channel<br>$b_1$ ... Given in ICC-ESR alternatively a default value of 0.50 shall be used<br>$h_{ch}$ ... critical member thickness,<br><br>$\psi_{h,V} = \left(\frac{h}{h_{cr,V}}\right)^{\beta_1} \leq 1.0$ if $h < h_{cr,V}$ ESR-3520 Equation (37) | <br>Concrete edge breakout: $\Phi V_{cb,y}$<br><br>$h_{cr,V}$ = 2 (5.00 in) + 2 (1.22 in)<br><br>$h_{cr,V}$ = 12.44<br><br>$\psi_{h,V} = \left(\frac{6in}{12.44in}\right)^{0.5}$<br>$\psi_{h,V} = 0.694 \leq 1.0$<br>$\therefore \psi_{h,V} = 0.694$ |

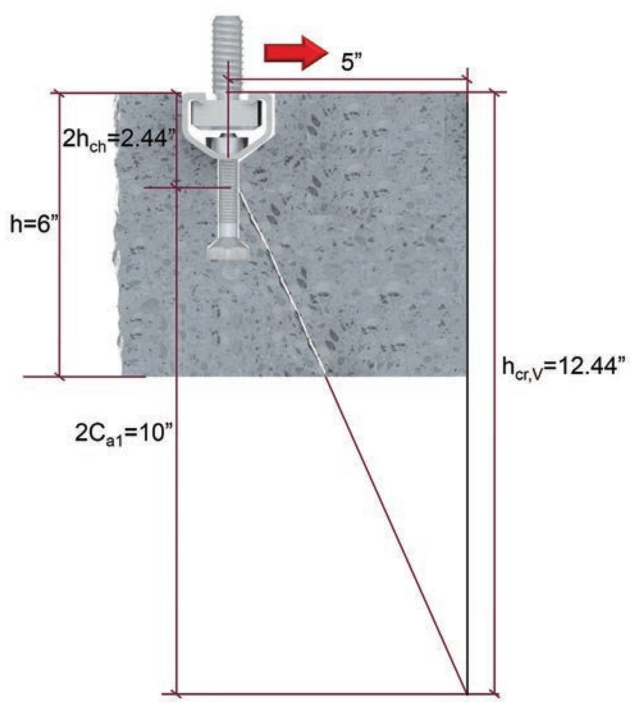
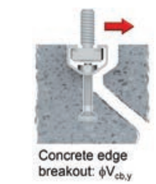



Figure 14.1.24 — Design example – height reduction factor $h_{cr,v}$

| Code | Discussion | Calculations |
|---|---|---|
| **Step 7: Concrete strength** | | |
| ESR-3520 section 4.1.3.3.3<br>ACI 318-14 Chapter 17 | Concrete breakout strength in perpendicular shear for anchor element #3 continued...<br><br>Calculate the modification factor for cracked/uncracked concrete ($\psi_{c,V,3}$).<br>Cracked concrete conditions with no supplementary reinforcement → $\psi_{c,V,3}$ = 1.0<br><br>Note: if cracked concrete conditions are assumed, and supplementary edge reinforcement as defined in ESR-3520 Section 4.1.3.3.3 is used, $\psi_{c,V,3}$ can be increased to either $\psi_{c,V,3}$ = 1.2 or $\psi_{c,V,3}$ = 1.4.<br><br>**Cracked concrete**<br>No supplementary reinforcement<br>$\psi_{c,V}$ = 1.0<br><br>With supplementary reinforcement<br>• Cracked concrete with edge reinforcement (#4 min.)<br> $\psi_{c,V}$ = 1.2<br><br>• Cracked concrete with edge reinforcement (#4 min.) and stirrups (#4 min.) spaced at 4" O.C.<br> $\psi_{c,V}$ = 1.4<br><br>**Uncracked Concrete**<br>Anchor channels located in a region of a concrete member where analysis indicates no cracking at service load levels.<br>$\psi_{c,V}$ = 1.4<br><br>Note: in order to activate the reinforcement, concrete has to crack. Therefore, if uncracked concrete is assumed, supplementary reinforcement does not impact this factor.<br><br>Concrete is typically assumed to be cracked under normal service load conditions. If cracked concrete conditions are assumed, an increase in $V_{cb,y}$ is permitted via the modification factor $\psi_{c,V}$ if supplementary edge reinforcement is used. If uncracked concrete conditions are assumed, an increase in $V_{cb,y}$ is likewise permitted via the modification factor $\psi_{c,V}$ . Reference ESR-3520 Section 4.1.3.3.3 for more information. | <br>Concrete edge breakout: $\Phi V_{cb,y}$<br><br>If uncracked concrete conditions are assumed, $\psi_{c,V,3}$ = 1.4. |

| Code | Discussion | Calculations |
|---|---|---|

**Step 7: Concrete strength**

**Code:** ESR-3520 section 4.1.3.3.3
ACI 318-14 Chapter 17

**Discussion:**

Concrete breakout strength in perpendicular shear for anchor element #3 continued...

Nominal concrete breakout strength in tension for anchor element #3

ESR-3520 Equation (6)
The calculated value for $V_{cb,3}$ will be multiplied by a strength reduction factor (φ-factor) to give a design strength ($φV_{cb,3}$). Design strengths for this example are summarized in the table on this page titled Summary for Concrete Breakout in Tension.

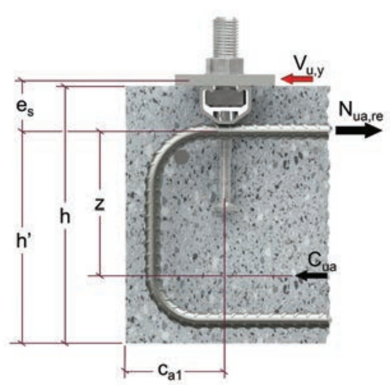
The calculated $φV_{cb,3}$ value for anchor element #3 will be checked against the factored load acting on anchor element #3 ($V_{aua,3}$) to obtain the % utilization ($V_{aua,3}$ / $φV_{cb3}$).

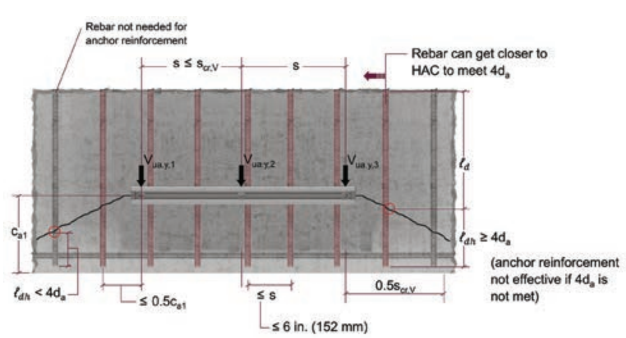
The anchor element with the highest % utilization will control the design with respect to concrete breakout failure in tension.

φ-factors for concrete breakout in tension are given in ESR-3520 Table 8-4.
▯ factor:
ACI 318-14:
17.3.3 Strength reduction factor ϕ for anchors in concrete shall be as follows when the load combinations of 5.3 are used:
(c) Anchor governed by concrete breakout, side-face, blowout, pullout, or pryout strength

**Condition A**

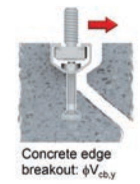
- Supplementary reinforcement is present
- Reinforcement does not need to be explicitly designed for the anchor channel
- Should generally conform to reinforcement shown in Fig. R17.4.2.9 and R17.5.2.9b
- Full development is not required




**Condition B**
No supplementary reinforcement

**Calculations:**




Concrete edge breakout: $ΦV_{cb,y}$

$$V_{cb,3} = V_{b,3} \cdot \psi_{s,V,3} \cdot \psi_{co1,V,3} \cdot \psi_{co2,V,3} \cdot \psi_{h,V,3} \cdot \psi_{c,V,3}$$

$$V_{b,3} = 6954 lbs$$

$$\psi_{s,v} = 0.598$$

$$\psi_{co1,v} = 0.774$$

$$\psi_{co2,v} = 1.0$$

$$\psi_{c,v} = 1.2$$

$$\psi_{h,v} = 0.694$$

$$V_{cb,y,3} = 2681\ lbs$$

$$Condition\ B$$

$$\varphi = 0.7$$

$$\varphi V_{cb,y,3} = 1876 \text{lbs}$$

$$V^a{}_{ua,3} = 1618 lbs$$

$$\beta_{cb,3} = \left(\frac{1618}{1876}\right) x100$$

$$\beta_{cb,v,3} = 87\%$$

| Code | Discussion | Calculations |
|---|---|---|

**Step 7: Concrete strength**

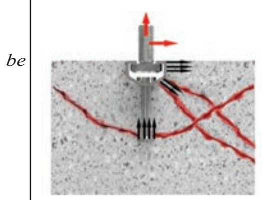
**Code:** ESR-3520 section 4.1.3.2.2

**Discussion:**

Concrete failure modes of anchor channels under combined loads:

$$ESR\ 3520\ section\ 4.1.3.6.3\ \text{b) If } N^a_{ua} < 0.2\phi N_{nc}\ then\ the\ full\ strength\ in\ shear\ shall\ be\ permitted: \left(\frac{V^a_{ua,y}}{\varphi V_{nc,y}}\right) + \left(\frac{V^a_{ua,x}}{\varphi V_{nc,x}}\right) \leq 1.0$$

**Calculations:**



$$\beta_{cb,N,3} = 0.17 < 0.2$$

$$\beta_{cb,V,3} = 0.87 < 1.0$$

$$\therefore\ Concrete\ utilization = 87\%$$

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