
Please refer to the publication in its entirety for complete details on this product including data development, product specifications, general suitability, installation, corrosion and spacing and edge distance guidelines.


To consult directly with a team member regarding our anchor fastening products, contact Hilti’s team of technical support specialists between the hours of 7:00am – 6:00pm CST.

US: 877-749-6337 or [HNATechnicalServices@hilti.com](mailto:HNATechnicalServices@hilti.com)
CA: 1-800-363-4458, ext. 6 or [CATechnicalServices@hilti.com](mailto:CATechnicalServices@hilti.com)
3.1 Anchor Principles and Design

Failure modes associated with anchors loaded to failure in shear may be characterized as follows:

- Steel failure in shear/tension
- Concrete edge breakout failure
- Pryout failure

3.1.4.1 Prestressing of Anchors

In general, properly installed anchors do not exhibit noticeable deflection at the expected service load levels due to the application of the prescribed installation torque. External tension loading results in a reduction of the clamping force in the connection with little increase in the corresponding bolt tension force. Shear loads are resisted by a combination of bearing and friction resulting from the anchor preload forces.

At load levels beyond the clamping load, anchor deflections increase and the response of the anchor varies according to the anchor force-resisting mechanism. Expansion anchors capable of follow-up expansion show increased deflections corresponding to relative movement of the cone and expansion elements. Adhesive anchors exhibit a change in stiffness corresponding to loss of adhesion between the adhesive and the base material whereby tension resistance at increasing displacement levels is provided by friction between the uneven hole wall and the adhesive plug. In all cases, increasing stress levels in the anchor bolt/element result in increased anchor displacements.

3.1.4.2 Long term behavior

Following are some factors that can influence the long-term behavior of post-installed anchoring systems.

Adhesive anchoring systems:

- Pretensioning relaxation
- Chemical resistance/durability
- Creep
- Freeze/thaw conditions
- High temperature

Mechanical anchoring systems:

- Pretensioning relaxation
- Fatigue
- Concrete cracking

Fatigue
- Concrete cracking
- Corrosion
- Creep
- Fire
- Seismic loading

All Hilti adhesive anchor systems suitable for use with the Strength Design Method have been tested for sustained loading conditions as per ACI 355.4 and ICC-ES Acceptance Criteria AC308.

3.1.5 Anchor design

The design of anchors 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, is discussed in Section 3.1.6. 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. This approach is discussed further in 3.1.7.

**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. This approach is discussed further in section 3.1.9. Allowable Stress Design is typically used today for masonry applications.

3.1.6 ACI 318 Chapter 17

**Strength Design – SD (LRFD)**

Strength Design of anchors is referenced in the provisions of ACI 355.2, ACI 355.4, ACI 318 -14 Chapter 17 and the ICC-ES Acceptance Criteria AC193 for mechanical anchors and AC308 for adhesive anchors. A summary of the relevant design provisions, especially as they pertain to post-installed anchors, is provided here.
3.1.6.1 Strength Design (SD) terminology

- $A_{nc}$ = projected concrete failure area of a single anchor or group of anchors, for calculation of strength in tension, in.$^2$ (mm$^2$)
- $A_{na}$ = projected influence area of a single adhesive anchor or group of adhesive anchors, for calculation of bond strength in tension, in.$^2$ (mm$^2$)
- $A_{nao}$ = projected influence area of a single adhesive anchor, for calculation of bond strength in tension if not limited by edge distance or spacing, in.$^2$ (mm$^2$)
- $A_{nco}$ = projected concrete failure area of a single anchor, for calculation of strength in tension if not limited by edge distance or spacing, in.$^2$ (mm$^2$)
- $A_{se,N}$ = effective cross-sectional area of anchor in tension, in.$^2$ (mm$^2$)
- $A_{se,V}$ = effective cross-sectional area of anchor in shear, in.$^2$ (mm$^2$)
- $A_{se}$ = tensile stress area of threaded part, in.$^2$ (mm$^2$)
- $A_{vc}$ = projected concrete failure area of a single anchor or group of anchors, for calculation of strength in shear, in.$^2$ (mm$^2$)
- $A_{vco}$ = projected concrete failure area of a single anchor, for calculation of strength in shear, if not limited by corner influences, spacing, or member thickness, in.$^2$ (mm$^2$)
- $c$ = distance from anchor centerline to the closest free edge of concrete, in. (mm)
- $c_{ac}$ = critical edge distance required to develop the basic strength as controlled by concrete breakout or bond of a post-installed anchor in tension in uncracked concrete without supplementary reinforcement to control splitting, in. (mm)
- $c_{a,max}$ = maximum distance from the center of an anchor shaft to the edge of concrete, in. (mm)
- $c_{a,min}$ = minimum distance from the center of an anchor shaft to the edge of concrete, in. (mm)
- $c_{a1}$ = distance from the center of an anchor shaft to the edge of the concrete in one direction, in. (mm); If shear is applied to anchor, $c_{a1}$ is taken in the direction of the applied shear; If tension is applied to the anchor, $c_{a1}$ is the minimum edge distance, in. (mm)
- $c_{a2}$ = distance from center of an anchor shaft to the edge of concrete in the direction perpendicular to $c_{a1}$, in. (mm)
- $c_{ur/Na} \times C_{Na}$ = projected distance from the center of an anchor shaft on one side of the anchor required to develop the full bond strength of a single adhesive anchor, in. (mm)
- $d \times d_a$ = outside diameter of anchor or shaft diameter of headed stud, headed bolt, or hooked bolt, in. (mm)
- $d_{bit}$ = nominal drill bit diameter, in. (mm)
- $d_n$ = diameter of clearance hole in attachment (e.g. baseplate), in. (mm)
- $d_{nom}$ = nominal anchor diameter, in. (mm)
- $d_o$ = anchor outside diameter (O.D.), in. (mm)
- $e_{N}$ = distance between resultant tension load on a group of anchors loaded in tension and the centroid of the group of anchors loaded in tension, in. (mm)
- $e_{V}$ = distance between resultant shear load on a group of anchors loaded in shear in the same direction, and the centroid of the group of anchors loaded in shear in the same direction, in. (mm)
- $f'_c$ = specified concrete compressive strength, psi (MPa)
- $f_{ya}$ = specified bolt minimum yield strength, psi (MPa)
- $f_{uta}$ = specified bolt minimum ultimate strength, psi (MPa)
- $h$ or $h_a$ = thickness of member in which an anchor is located, as measured parallel to anchor axis, in. (mm)
- $h_{ef}$ = effective anchor embedment depth, in. (mm)
- $h_{min}$ = minimum member thickness, in. (mm)
- $h_0$ = depth of full diameter hole in base material, in. (mm)
- $k_{cr}$ = coefficient for basic concrete breakout strength in tension, cracked concrete
- $k_{uncr}$ = coefficient for basic concrete breakout strength in tension, uncracked concrete
- $k_{cp}$ = coefficient for pryout strength
3.1 Anchor Principles and Design

3.1.6.1 Strength Design (SD) terminology

- \( \ell_e \) = load-bearing length of anchor for shear, in. (mm)
- \( \ell_{th} \) = anchor usable thread length, in. (mm)
- \( M_s \) = characteristic value for the bending moment corresponding to rupture, in-lb (N·m)
- \( n \) = number of anchors in a group
- \( N_a \) = nominal bond strength in tension of a single adhesive anchor, lb (kN)
- \( N_{ag} \) = nominal bond strength in tension of a group of adhesive anchors, lb (kN)
- \( N_{ao} \) = characteristic tension capacity of a single adhesive anchor in tension as limited by bond/concrete failure, lb (kN)
- \( N_b \) = basic concrete breakout strength in tension of a single anchor in cracked concrete, lb (kN)
- \( N_{ba} \) = basic bond strength in tension of a single adhesive anchor, lb (kN)
- \( N_{cb} \) = nominal concrete breakout strength in tension of a single anchor, lb (kN)
- \( N_{cbg} \) = nominal concrete breakout strength in tension of a group of anchors, lb (kN)
- \( N_n \) = nominal strength in tension, lb (kN)
- \( N_p \) = pullout strength in tension of a single anchor in cracked concrete, lb (kN)
- \( N_{pp,c} \) = nominal pullout strength in tension of a single post-installed mechanical anchor, lb (kN)
- \( N_{pn} \) = nominal pullout strength in tension of a single anchor, lb (kN)
- \( N_{sa} \) = nominal strength of a single or individual anchor in a group of anchors in tension as governed by the steel strength, lb (kN)
- \( N_{sb} \) = side face blowout strength of a single anchor, lb (kN)
- \( N_{sbg} \) = side face blowout strength of a group of anchors, lb (kN)
- \( N_{sa} \) = factored tensile force applied to an anchor or an individual anchor in a group of anchors, lb (kN)
- \( s \) = anchor axial spacing, in. (mm)
- \( s_{cr,Na} \) = critical adhesive anchor spacing for tension loading at which the tension capacity of each anchor is theoretically unaffected by the presence of the adjacent loaded anchor, in. (mm)

- \( s_{\min} \) = minimum spacing between adjacent loaded anchors, in. (mm)
- \( S \) = elastic section modulus of anchor bolt, in.\(^3\) (mm\(^3\))
- \( t_{fix} \) = maximum thickness of attachment (e.g. baseplate) to be fastened, in. (mm)
- \( T_{inst} \) = recommended anchor installation torque, ft-lb (N·m)
- \( T_{max} \) = maximum tightening torque, ft-lb (N·m)
- \( V_b \) = basic concrete breakout strength in shear of a single anchor in cracked concrete, lb (kN)
- \( V_{cb} \) = nominal concrete breakout strength in shear of a single anchor, lb (kN)
- \( V_{cbg} \) = nominal concrete breakout strength in shear of a group of anchors, lb (kN)
- \( V_{cp} \) = nominal concrete pryout strength of a single anchor, lb (kN)
- \( V_{cp,g} \) = nominal concrete pryout strength of a group of anchors, lb (kN)
- \( V_n \) = nominal strength in shear, lb (kN)
- \( V_{sa} \) = nominal shear strength of a single or individual anchor in a group of anchors as governed by the steel strength, lb (kN)
- \( V_{ua} \) = factored shear force applied to a single anchor or group of anchors, lb (kN)

- \( \phi \) = strength reduction factor
- \( \tau_{cr} \) = characteristic bond stress for cracked concrete conditions taken as the 5 percent fractile of results of tests performed and evaluated according to ACI 355.4 or ICC-ES AC308, psi (MPa)
- \( \tau_{uncr} \) = characteristic bond stress for uncracked concrete conditions taken as the 5 percent fractile of results of tests performed and evaluated according to ACI 355.4 or ICC-ES AC308, psi (MPa)
- \( \psi_{c,N} \) = factor used to modify tensile strength of anchors based on presence or absence of cracks in concrete
- \( \psi_{c,P} \) = factor used to modify pullout strength of anchors based on presence or absence of cracks in concrete
- \( \psi_{c,V} \) = factor used to modify shear strength of anchors based on presence or absence of cracks in concrete and presence or absence of supplementary reinforcement
### 3.1.6.2 Load distribution

As per ACI 318-14 Section 17.2, load distribution should be determined on the basis of elastic analysis unless it can be shown that the nominal anchor strength is controlled by ductile steel elements. Where plastic analysis (assumption of fully yielded anchors) is used, compatibility of deformations must be checked.

![Example of incompatibility of deformations (displacements)](image)

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 anchors. For additional information on elastic load distribution in typical column baseplate assemblies, the reader is referred to Blodgett, O., Design of Welded Structures, The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

Note: Assuming a rigid base plate condition, Hilti's PROFIS Anchor analysis and design software performs a simplified finite element analysis to establish anchor load distribution on an elastic basis.

### 3.1.6.3 General requirements for anchor strength

In accordance with general Strength Design Method principles and ACI 318-14, Section 17.3 and chapter 5, the design of anchors must satisfy the following conditions:

\[
\phi N_n \geq N_{ua} \\
\phi V_n \geq V_{ua}
\]

whereby \(\phi N_n\) and \(\phi V_n\) are the controlling design strengths from all applicable failure modes and \(N_{ua}\) and \(V_{ua}\) are the factored tension and shear loads resulting from the governing load combination. The load combinations given in ACI 318-14 Section 5.3 generally conform with ASCE 7-10 load combinations. For this assessment, the following potential failure modes are considered:

| a) Steel strength of anchor in tension |
| b) Concrete breakout strength of anchor in tension |
| c) Pullout strength cast-in, post-installed expansion or undercut anchor in tension |
| d) Concrete side-face blowout strength of headed anchor in tension |
| e) Bond strength of adhesive anchor in tension |
| f) Steel strength of anchor in shear |
| g) Concrete breakout strength of anchor in shear |
| h) Concrete pryout strength of anchor in shear |

![Example of elastic load distribution in a beam-wall connection](image)
3.1 Anchor Principles and Design

Note that as per ACI 318-14 Section 17.3.1, the strength reduction factors applicable for each failure mode must be applied prior to determining the controlling strength.

Thus, for a single anchor, the controlling strength would be determined as follows:

\[
\phi N_n = \min | \phi N_{sa}, \phi N_{pn}, \phi N_{sb}, \phi N_{cb} |
\]
\[
\phi V_n = \min | \phi V_{sa}, \phi V_{cp}, \phi V_{cb} |
\]

In analogy, the controlling strength for an anchor group would be determined as

\[
\phi N_n = \min | \phi N_{sa}, \phi N_{pn}, \phi N_{sb}, \phi N_{cb}, \phi N_{ag} |
\]
\[
\phi V_n = \min | \phi V_{sa}, \phi V_{cp}, \phi V_{cb} |
\]

In accordance with ACI 318-14 Section 17.2.6, for lightweight concrete conditions, the modification factor \( \lambda_a \) is taken as:

- 1.0 \( \lambda_a \) for cast-in and undercut anchor concrete failure
- 0.8 \( \lambda_a \) for expansion and adhesive anchor concrete failure
- 0.6 \( \lambda_a \) for adhesive bond failure

where \( \lambda \) is determined in accordance with Section 8.6.1 of the same document. It is permitted to use an alternate value of \( \lambda_a \) where tests have been performed and evaluated in accordance with ACI 355.2, ACI 355.4, or the relevant ICC-ES acceptance criteria.

3.1.6.5 Design requirements for tensile loading

In accordance with ACI 318-14 Section 17.4.1 the nominal steel strength of an anchor in tension is determined as follows:

\[
N_{sa} = A_{se,N} f_{uta} (17.4.1.2)
\]

where \( f_{uta} \leq \min [1.9 f_y, 125,000 \text{ psi (860 MPa)}] \)

Nominal minimum bolt steel yield and ultimate strengths for Hilti anchor products can be found in the product specific sections of this guide.

The nominal concrete breakout strength of a single anchor loaded in tension is determined in accordance with ACI 318-14 Section 17.4.2 as follows:

\[
N_{cb} = \Psi_{ed,N} \Psi_{ed,N} \Psi_{cp,N} N_b (17.4.2.1a)
\]

The nominal concrete breakout strength of anchor groups is likewise determined as follows:

\[
N_{cbg} = \Psi_{ed,N} \Psi_{ed,N} \Psi_{cp,N} N_b (17.4.2.1b)
\]

where:

- \( A_{Nco} \) = projected concrete failure area of a single anchor with an edge distance equal to or greater than 1.5\( h_{ef} \)
- \( 9 h_{ef}^2 \) = \( 9 h_{ef}^2 \) (17.4.2.1c)
**Anchor Principles and Design 3.1**

\[ A_{Nc} = \text{projected concrete failure area of a single anchor or group of anchors approximated as the base of the rectilinear geometrical figure that results from projecting the failure surface outward 1.5h_{ef} from the centerlines of the anchor, or in the case of a group of anchors, from a line through a row of adjacent anchors.} \ A_{Nc} \text{ shall not exceed } nA_{Nco}, \text{ where } n \text{ is the number of anchors in the group that resist tension.} \]

\[ \Psi_{ec,N} = \text{modification factor for anchor groups loaded by an eccentric tension force} \]

\[ \Psi_{ed,N} = \left( 1 + \frac{2e'_{N}}{3h_{ef}} \right) \leq 1 \]  

(17.4.2.4)

\[ \Psi_{ed,N} = \text{modification factor for edge effects for single anchors or anchor groups loaded in tension} \]

\[ = 1 \text{ if } c_{amin} \geq 1.5h_{ef} \]  

(17.4.2.5a)

\[ = 0.7 + 0.3 \frac{c_{amin}}{1.5h_{ef}} \text{ if } c_{amin} < 1.5h_{ef} \]  

(17.4.2.5b)

\[ \Psi_{c,N} = \text{Modification factor for concrete conditions (uncracked, cracked, reinforced, etc.). Ref. ACI 318-14 Section 17.4.2.6 for cast-in-place anchors. Ref. ICC-ES Evaluation Service Report for post-installed anchors} \]

\[ \Psi_{cp,N} = \text{Modification factor for splitting} \]

Ref. ACI 318-14 Section 17.4.2.7 and/or the relevant ICC-ES Evaluation Service Report for post-installed mechanical anchors

\[ N_b = \text{basic concrete breakout strength of a single anchor in tension in cracked concrete} \]

\[ = k_c a_{ef} \sqrt{f_{c}'} h_{ef}^{1.5} \]  

(17.4.2.2a)

Ref. ACI 318-14 Section 17.4.2.2 for permitted values of the effectiveness factor, \( k_{c} \).

For post-installed anchors that have been tested in accordance with ACI 355.2 or ACI 355.4, specific values of the effectiveness factor (more precisely, \( k_{cr} \) for cracked concrete conditions and \( k_{uncr} \) for uncracked concrete conditions) are established in accordance with the provisions of that document or the relevant ICC-ES acceptance criteria. Values of \( k_{cr} \) and \( k_{uncr} \) for Hilti anchor products can be found in the product specific sections of this guide.

The nominal pullout strength of anchors loaded in tension is determined in accordance with ACI 318-14 Section 17.4.3 as follows:

\[ N_{pn} = \Psi_{c,P} N_p \]  

(17.4.3.1)

where:

\[ N_p = \text{for post-installed expansion and undercut anchors, pullout strength based on the 5 percent fractile of results of tests performed and evaluated according to ACI 355.2 or the relevant ICC-ES Acceptance Criteria. It is not permissible to calculate the pullout strength in tension for such anchors} \]

\[ \Psi_{c,P} = 1.4 \text{ for anchors located in a region of a concrete member where analysis indicates no cracking at service load levels} \]

\[ = 1.0 \text{ where analysis indicates cracking at service load levels} \]

Pullout values are based on direct tension testing of anchors in cracks as well as on the results of moving crack tests. Additional pullout values associated with seismic testing may also be provided.
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For headed anchors with deep embedment close to an edge \((c_{a1} < 0.4h_{ef})\), side-face blowout may control the design. In most cases, restrictions on the placement of post-installed anchors close to an edge will preclude this failure mode. For further information, see ACI 318-14 Section 17.4.4.

The nominal bond strength in tension of a single adhesive anchor loaded in tension is determined in accordance with ACI 318-14 Section 17.4.5 as follows:

\[
N_a = \frac{A_{Na}}{A_{Nao}} \psi_{ed,Na} \psi_{cp,Na} N_{ba} \tag{17.4.5.1a}
\]

The nominal bond strength of anchor groups is likewise determined as follows:

\[
N_{ag} = \frac{A_{Na}}{A_{Nao}} \psi_{ec,Na} \psi_{ed,Na} \psi_{cp,Na} N_{ba} \tag{17.4.5.1b}
\]

where:

\[
A_{Nao} = \text{projected influence area of a single adhesive anchor with an edge distance equal to or greater than } c_{Na}
\]

\[
= (2c_{Na})^2 \tag{17.4.5.1c}
\]

\[
c_{Na} = 10d_a \sqrt{\frac{\tau_{uncr}}{1100}} \tag{17.4.5.1d}
\]

\[
A_{Na} = \text{projected influence area of a single adhesive anchor or group of adhesive anchors approximated as a rectilinear area that projects outward a distance } c_{Na} \text{ from the centerline of the adhesive anchor, or in the case of a group of adhesive anchors, from a line through a row of adjacent adhesive anchors. } A_{Na} \text{ shall not exceed } nA_{Nao}, \text{ where } n \text{ is the number of adhesive anchors in the group that resist tension loads}
\]

\[
A_{Nao} = \text{modification factor for anchor groups loaded by an eccentric tension force}
\]

\[
= \frac{1}{1 + \left( \frac{e'_N}{c_{Na}} \right)} \leq 1.0 \tag{17.4.5.3}
\]

\[
\psi_{ec,Na} = \text{modification factor for edge effects for single adhesive anchors or adhesive anchor groups loaded in tension}
\]

\[
= 1.0 \text{ if } c_{a_{min}} \geq c_{Na} \tag{17.4.5.4a}
\]

\[
= 0.7 + 0.3 \frac{c_{a_{min}}}{c_{Na}} \text{ if } c_{a_{min}} < c_{Na} \tag{17.4.5.4b}
\]

\[
\psi_{cp,Na} = \text{modification factor for splitting}
\]

\[
\text{Ref. ACI 318-14 Section 17.4.5.5 and/or the relevant ICC-ES Evaluation Service Report for post-installed adhesive anchors}
\]

\[
N_{ba} = \text{basic bond strength of a single adhesive anchor in tension in cracked concrete}
\]

\[
= \lambda_a \tau_{cr} n d_a h_{ef} \tag{17.4.5.2}
\]

Where analysis indicates no cracking at service load levels, it is permitted to use \(\tau_{uncr}\) in place of \(\tau_{cr}\).

### 3.1.6.6 Design requirements for shear loading

In accordance with ACI 318-14 Section 17.5.1, the nominal steel strength for headed stud anchors in shear is determined as follows:

\[
V_{sa} = A_{se,v} f_{uta} \tag{17.5.1.2a}
\]

For cast-in headed bolt and hooked bolt anchors and for post-installed anchors where sleeves do not extend through the shear plane:

\[
V_{sa} = 0.6A_{se,v} f_{uta} \tag{17.5.1.2b}
\]

Where \(f_{uta} \leq \min \{1.9 f_y, 125,000 \text{ psi} \ (860 \text{ MPa})\}\)

For other post-installed anchors where sleeves extend through the shear plane, \(V_{sa}\) is based on the results of tests performed and evaluated according to ACI 355.2 or the relevant ICC-ES Acceptance Criteria. Alternatively, Eq. (17.5.1.2b) is permitted to be used.

In accordance with ACI 318-14 Section 17.5.1.3, the nominal shear strength of anchors used with built-up grout pads must be multiplied by a 0.80 factor.

The nominal concrete breakout strength of a single anchor loaded in shear is determined in accordance with ACI 318-14 Section 17.5.2 as follows:

\[
V_{cb} = A_{Vc,Vo} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \tag{17.5.2.1a}
\]

The concrete breakout strength of anchor groups is likewise determined as follows:

\[
V_{cbg} = A_{Vc,Vo} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \tag{17.5.2.1b}
\]

where:

\[
A_{Vc,Vo} = \text{projected area for a single anchor in a deep member with a distance from edges equal to or greater than } 1.5c_{a1} \text{ in the direction perpendicular to the shear force. It is permitted to evaluate } A_{Vc,Vo} \text{ as the base of a half pyramid with a side length parallel to the edge of } 3c_{a1} \text{ and a depth of } 1.5c_{a1}
\]

\[
= 4.5(c_{a1})^2 \tag{17.5.2.1c}
\]
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The nominal pryout strength of a single anchor is determined in accordance with ACI 318-14 Section 17.5.3 as follows:

\[ V_{cp} = k_{cp} N_{cp} \quad (17.5.3.1a) \]

For cast-in, expansion, and undercut anchors, \( N_{cp} \) must be taken as \( N_{cb} \) (17.4.2.1a). For adhesive anchors, \( N_{cp} \) must be the lesser of \( N_{a} \) (17.4.5.1a) and \( N_{cb} \) (17.4.2.1a).

Likewise, for anchor groups, the pryout strength is determined as follows:

\[ V_{cpg} = k_{cp} N_{cpg} \quad (17.5.3.1b) \]

For cast-in, expansion, and undercut anchors, \( N_{cpg} \) must be taken as \( N_{cbg} \) (17.4.2.1b). For adhesive anchors, \( N_{cpg} \) must be the lesser of \( N_{ag} \) (17.4.5.1b) and \( N_{cbg} \) (17.4.2.1b).

In Eq. (17.5.3.1a) and (17.5.3.1b):

- \( k_{cp} = 1.0 \) for \( h_{ae} < 2.5 \) in.
- \( k_{cp} = 2.0 \) for \( h_{ae} \geq 2.5 \) in.

### 3.1.6.7 Interaction – Strength Design

Where anchors are loaded simultaneously in tension and shear, interaction must be considered. In accordance with ACI 318-14 Section 17.6, interaction may be checked as follows:

- If \( V_{ua} \leq 0.2 \Phi N_{n} \quad \Phi N_{n} \geq N_{ua} \)
- If \( N_{ua} \leq 0.2 \Phi N_{n} \quad \Phi V_{n} \geq V_{ua} \)

\[
\begin{align*}
N_{ua} &> 0.2 \Phi N_{n} \\
\text{and} \quad \left[ \frac{N_{ua}}{\Phi N_{n}} + \frac{V_{ua}}{\Phi V_{n}} \right] &\leq 1.2 \\
V_{ua} &> 0.2 \Phi V_{n}
\end{align*}
\quad (17.6.3)
\]

Alternatively, ACI 318-14 Section 17.6 permits the use of an interaction expression of the form:

\[
\left[ \frac{N_{ua}}{\Phi N_{n}} \right]^{\alpha} + \left[ \frac{V_{ua}}{\Phi V_{n}} \right]^{\alpha} \leq 1.0
\]

Where \( \alpha \) varies from 1 to 2. The current trilinear recommendation is a simplification of the expression where \( \alpha = 5/3 \).
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3.1.6.8 Required edge distances, anchor spacing and member thickness - Strength Design

Refer to ACI 318 -14 Section 17.7, ACI 355.2, ACI 355.4, or the relevant ICC-ES acceptance criteria for the geometry requirements for cast-in-place and post-installed anchors.

3.1.6.9 Bolt bending - Strength Design

An additional check for shear load resulting from stand-off conditions can be performed when calculating nominal shear strengths.

\[ V_s^M = \frac{\alpha_M \cdot M_s}{\ell} \]

whereby:

- \( \alpha_M \) = adjustment of bending moment associated with rotational restraint, where \( 1 \leq \alpha_M \leq 2 \)
- \( M_s \) = resultant flexural resistance of single anchor
  \[ M_s = M_s^0 \left( \frac{1 - N_{sa}}{\Phi N_{sa}} \right) \]
- \( M_s^0 \) = characteristic flexural resistance of single anchor
  \[ M_s^0 = 1.2 \cdot S \cdot f_{u/min} \]
- \( f_{u/min} \) = minimum nominal ultimate tensile strength of anchor element
- \( S \) = elastic section modulus of anchor bolt at concrete surface (a uniform cross section is assumed)
  \[ S = \left( \frac{n \cdot d^3}{32} \right) \]
- \( \ell \) = internal lever arm adjusted for spalling of the concrete surface as follows:
  \[ \ell = z + (n \cdot d_o) \]
- \( z \) = distance from center of base plate to surface of concrete (standoff distance)
- \( d_o \) = anchor outside diameter at concrete surface
- \( n \) = 0, for loading with clamping at the concrete surface as provided by a nut and washer assembly (required for mechanical anchors)
  = 0.5, for loading without clamping at the concrete surface, e.g., adhesive anchor without nut and washer at concrete surface

Note that stand-off installations of post-installed mechanical anchors require a nut and bearing washer at the concrete surface as shown below for proper anchor function and to properly resist compression loads.

Determination of bolt bending - Strength Design

3.1.7 CSA A23.3 Annex D Limit State Design

Limit State Design of anchors is referenced in the provisions of CSA A23.3-14 Annex D, which cover headed studs and bolts, hooked bolts and post-installed anchors that meet the assessment of ACI 355.2 and ACI 355.4. Furthermore, the suitability of post-installed anchors for use in concrete must be demonstrated by the ACI 355.2 and ACI 355.4 prequalification tests. A summary of the relevant design provisions, especially as they pertain to post-installed anchors, is provided here.

3.1.7.1 Load Distribution

The provisions of CSA A23.3-14 Annex D and ACI 318-14 Chapter 17 are based on identical assumptions. Refer to Section 3.1.6.2 for more details.

3.1.7.2 General Requirements for Anchor Strength

In accordance with CSA A23.3-14 Annex D, the design of anchors must satisfy the following conditions:

\[ N_r \geq N_r \]
\[ V_r \geq V_r \]

whereby \( N_r \) and \( V_r \) are the lowest design resistances determined from all applicable failure modes in tension and shear, respectively, and \( N_l \) and \( V_l \) are the factored tension and shear loads resulting from the governing load combination. For this assessment, identical failure modes as described in Section 3.1.6.3 must be considered.

Thus, for a single anchor, the controlling resistance would be determined as follows:

\[ N_r = \min \left| N_{sar}, N_{cbr}, N_{apr}, N_{pr}, N_{ar} \right| \]
\[ V_r = \min \left| V_{sar}, V_{cbr}, V_{apr}, V_{pr} \right| \]