



2026 NCBC WEBINAR SERIES

Anchoring to Concrete  
Updates for 2026-  
Part 1: Screw Anchors

May 20, 2026

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NCBC Webinar Series 2026

**June 10:** Unducted Epoxy Coated Strand in Practice: The Laurel Fork Bridge Case Study

**July 15:** Anchoring to Concrete Updates for 2026- Part 2: Attachments with Shear Lugs

**August 19:** Overview of the new M-50 Tech Note on Unducted PT with Epoxy Coated Strand

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Industry Events 2026

Jun 15-17: International Bridge Conference, National Harbor, MD  
 Jun 28- Jul 2: AASHTO COBS Annual Meeting, Charlotte, NC  
 Sep 9-12: PCI Committee Days, San Antonio, TX  
 Sep 30-Oct 2: PTI Committee Days, San Antonio TX  
 Oct 11-14: ACI Convention, Atlanta, GA  
 Oct 15-18: NRMCA Concrete Works, Nashville, TN  
 Nov 8-11: ASBI Convention, San Antonio, TX  
 Nov 15-18: CRSI Fall Meeting, Chicago, IL  
 Dec 1-2: World Bridge Engineering Conference, Miami, FL

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NCBC is working with PCI to offer continuing education credits.

PCI has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net.

A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

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5

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6

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## Free ACI Anchor Resources

ACI has assembled an extensive collection of over 1000 pages that include full documents as well as anchor-related chapters and excerpts.

A few examples:

- ACI 318-25 : Building Code for Structural Concrete (chapters 2, 17, 25, 26)
- ACI 355.4: Post-Installed Adhesive Anchors in Concrete (complete document)
- MNL-17 (21): ACI Reinforced Concrete Design Handbook (anchor design examples)

In order to provide you with complimentary access to this collection of resources that address anchorage to concrete - please click the question icon during the webinar and type "ACI Docs".

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7

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## Bahram Sharooz , PhD, PE

- Professor Emeritus of structural engineering at the University of Cincinnati
- Principal Investigator of research projects and design articles that led to the introduction of high-strength reinforcement, changes to strand debonding requirements, addition of 0.7-in. strands.
- Active in PCI Committee on Bridges and AASHTO Technical Committee for Concrete Design.



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## AASHTO 10<sup>th</sup> Edition Article 5.13 – Screw Anchors

Bahram M. Shahrooz, PhD, PE, FACI, FASCE




Image Source:  
[https://www.stroonfile.com/mechanicalanchors\\_mechanicalanchorsproducts/hd\\_anchor/diffen-hd](https://www.stroonfile.com/mechanicalanchors_mechanicalanchorsproducts/hd_anchor/diffen-hd)

05/20/26      Webinar 1      10

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### Acknowledgements

NCBC for sponsoring webinar series on anchorage to concrete

**Financial support**

- American Concrete Institute (ACI)
- Concrete Reinforcing Steel Institute (CRSI)
- Precast/Prestressed Concrete Institute (PCI)

**Review and comments**

- Neal Anderson – Simpson, Gumpertz & Heger
- Ronald Cook – Professor Emeritus, U. of Florida
- Donald Meinheit – Wiss, Janney, Elstner Associates

05/20/26      Webinar 1      11

11

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### Learning Objectives

- Review basic concepts with reference to screw anchors
- Present and explain design equations
  - Tension
  - Shear
  - Combined tension/shear
  - Demonstrate calculation of key parameters in design equations through simple examples
- Illustrate how to handle shear force not being orthogonal to edges
  - Not addressed in codes

05/20/26      Webinar 1      12

12

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## Background

- For bridge applications, attachments to concrete are designed per **Article 5.13-ANCHORS** in *AASHTO LRFD Bridge Design Specifications (BDS)*.
- Article 5.13 references Ch. 17 of ACI 318 (Building Code Requirements for Structural Concrete).
- With a few differences, the requirements of Ch. 17 are followed.
  - Those differences are not related to today's presentation.

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## Introduction: Anchor Types

### Cast-in-place anchors:

- Headed studs 
- Headed bolts 
- J or L bolts 

### Post-installed anchors:

- Expansion anchors
  - Torque controlled
  - Displacement controlled
- Undercut anchors
- Adhesive anchors

AASHTO 10<sup>th</sup> edition allows screw anchors, which were not in the 9<sup>th</sup> edition.

Sources of images:

<https://www.mcmaster.com/products/headed-weld-studs/>  
<https://www.indiamart.com/productdetail/indian-stee-steel-anchors-bolt-26387574255.html>  
<https://www.fastenersplus.com/product/4-ex-18-embed-20-4-bolts-for-concrete>  
<https://www.industrialhardware.com/formed-wire-products/hook-bolts/standard-products.html>

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## Limitations – N/A (ACI Chapter 17, § 17.1.5) No Change From Previous Editions

- Specialty inserts
- Through-bolts
- Cementitious grouted anchors 
- Power driven anchors
  - Powder or pneumatic actuated
  - Considered non-structural
- Multiple anchors connected to a single steel plate at the embedded end of the anchors

Grouted anchors are allowed in ACI 318-25 but not referenced in AASHTO 10<sup>th</sup> edition.

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### Multiple Anchors Attached to a Single Plate



Photos: Courtesy of Neal Anderson

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### New in 10<sup>th</sup> Ed. AASHTO LRFD BDS Revised Anchor Qualification Documents (CRD 6-1)

- Anchors specified in design/construction documents must meet specific qualification requirements
- “ASTM-like” testing standards/specification/evaluation requirements
  - **ACI CODE 355.2-19** (Post-Installed **Mechanical Anchors** in Concrete – Qualification Requirements and Commentary)
  - **ACI CODE 355.4-19** (Post-Installed **Adhesive Anchors** in Concrete – Qualification Requirements and Commentary)
  - Newer versions of these documents are now available: **ACI CODE-355.2-22** and **ACI CODE-355.4-24** but are not referenced in **AASHTO LRFD BDS 10<sup>th</sup>** edition.

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### Limitations – Reuse (Chapter 17, § 17.1.5)

- The removal and resetting of post-installed mechanical anchors is prohibited.
- Screw anchors
  - One-time use for permanent connections
  - Hole reuse is not uncommon for temporary works in construction (e.g., cable tie-downs, bracing)

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### Limitations – $f'_c$ (Chapter 17, § 17.1.5)

- 10,000 psi (10 ksi) for cast-in-place anchors
- 8,000 psi (8 ksi) for post-installed anchors
  - Testing is required to verify acceptable performance for applications with  $f'_c > 8,000$  psi

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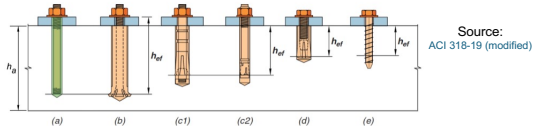
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### Key Definitions

- $d_a$  = Anchor diameter = Outside diameter
- $h_{ef}$  = Effective embedment depth of anchor from manufacturer's ACI 355.2/355.4 product evaluation report



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## Tension: Failure Modes and Design Equations

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### Failure Modes – Tension

Check multiple failure modes. The lowest strength governs.

Preclude splitting

- supplementary reinforcement

OR

- satisfying minimum anchor spacing, minimum edge distance, and minimum member thickness

May use anchor reinforcement design strength instead of concrete breakout strength (see extra slides)

Source: ACI 318-19 (modified)

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### Anchor Reinforcement VS. Supplementary Reinforcement

- Anchor reinforcement
  - Provides an alternate load path
  - Fully transfers loads to the concrete member
  - Needs to be fully developed
- Supplementary reinforcement
  - Does not transfer loads to the concrete member
  - Enhances connection's deformability and strength
  - Does not need to be fully developed

05/20/26 Webinar 1 23

23

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### ACI Table 17.9.2(a): Minimum Spacing

Anchor type			
Cast-in anchors		Post-installed	
Not torqued	Torqued	Adhesive, expansion, and undercut anchors	Screw anchors
$4d_a$	$6d_a$	$6d_a$	Greater of $0.6h_{ef}$ and $6d_a$

05/20/26 Webinar 1 24

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ACI Table 17.9.2(b) – Minimum Edge Distance  
In Absence of Product-Specific ACI Test Information

Post-installed anchor type	Minimum edge distance
Torque-controlled	$8d_a$
Displacement-controlled	$10d_a$
Screw	$6d_a$
Undercut	$6d_a$
Adhesive	$6d_a$

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Limits on  $h_{ef}$

Use these limits to "indirectly" check member thickness

- $h_{ef}$  is limited to
  - $2/3 \times$  member thickness ( $h_a$ )
  - $h_a - 4"$  unless justified based on ACI 355.2
- These limits do not apply to cast-in and adhesive anchors; splitting forces are smaller.

- Practical considerations
  - Select  $h_{ef}$  to prevent back-face blowout
    - During hole drilling/anchor installation
  - Embedment depth factors
    - Anchor type
    - Reinforcement presence
    - Drilling method
    - Size of drilling equipment
    - Concrete strength and condition

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Design Strength – Screw Anchors: Tension

Failure mode	Single anchor	Anchor group*	
		Individual anchor	Anchor group
Steel strength	X	X	
Concrete breakout strength	X		X
Pullout strength	X	X	

\* For tension + bending, individual anchors may have to resist different magnitudes of  $T$ . Design strengths for steel and pullout failure modes are computed for the most highly stressed anchor in the group.

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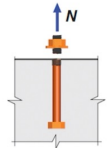
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## Steel Failure Under Tensile Loading



Source: ACI 318-19



Source:  
<https://www.hilti.com.hk/engineering/article/the-four-ways-anchors-can-fail-under-tension-load/sfr05s>

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## Tensile Strength: Steel Strength ( $N_{sa}$ )

$$\phi N_{sa} = \phi A_{se,N} f_{uta}$$

$\phi = 0.75$  for ductile anchors and  $0.65$  for brittle anchors. **Ductility is assessed by ACI 355.2/355.4.**

$A_{se,N}$  = effective cross-sectional area of an anchor in tension (in.<sup>2</sup>) provided by the manufacturer

$f_{uta}$  = specified tensile strength of anchor steel (psi) provided by the manufacturer

$f_{uta} \leq 1.9f_{ya}$  or 125,000 psi ( $f_{ya}$  = specified yield strength of anchor steel in psi)

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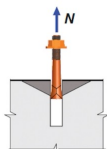
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## Pullout Failure Under Tensile Loading



Source: ACI 318-19



Source:  
<https://www.hilti.com.hk/engineering/article/the-four-ways-anchors-can-fail-under-tension-load/sfr05s>

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## Tensile Strength: Pullout Strength For a Single Anchor

$$\phi N_{pa} = \phi \psi_{c,p} N_p$$

$N_p$  = Basic pullout strength of a single anchor

**Cannot be calculated and is determined based on tests according to ACI 355.2.**

$\psi_{c,p}$  = Pullout cracking factor accounts for the influence of cracking at service load levels.

$\psi_{c,p} = 1.4$  for anchors in a region where analysis indicates no cracking at service load levels, e.g., compression face of a flexural member subjected to gravity loads

$\psi_{c,p} = 1.0$  for anchors in a region where analysis indicates cracking at service load levels, e.g., tension face of a flexural member subjected to gravity loads

Check product evaluation report as  $\psi_{c,p}$  may be different from these values.

For an individual anchor in a group:  $\phi N_{pa} \geq N_{uai}$

$N_{uai}$  = Factored tensile force applied to mostly highly stressed anchor in the group

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31

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## Strength Reduction Factors ( $\phi$ ) – Tension Concrete Failure Modes

Supplementary Reinforcement	Anchor Category	$\phi$ Tension
Present	1	0.75
	2	0.65
	3	0.55
Not Present	1	0.65
	2	0.55
	3	0.45

### Categories

1. Low sensitivity to installation and high reliability
2. Medium sensitivity to installation and medium reliability
3. High sensitivity to installation and low reliability

Installation sensitivity (category) is established using test methods in ACI 355.2/355.4 and provided in product evaluation report.

For cases controlled by breakout,  $\phi$  depends on whether supplementary reinforcement is provided or not.

The factors listed for "Not Present" apply to cases controlled by concrete pullout strength.

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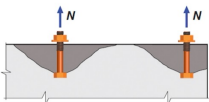
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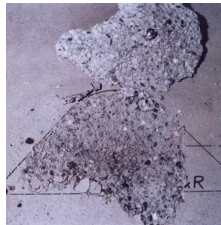
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## Breakout Failure Under Tensile Loading



Source: ACI 318-19



Source: <https://www.hill.com.hk/engineering/article/the-four-ways-anchors-can-fail-under-tension-load/sfr05s>

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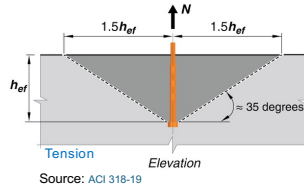
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## Breakout Cones Based on Concrete Capacity Design (CCD) Method



35° model basis

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## Tensile strength: Concrete Breakout Strength

A single anchor:  $\phi N_{cb} = \phi(A_{Nc}/A_{Nco})\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$   
 An anchor group:  $\phi N_{cbg} = \phi(A_{Nc}/A_{Nco})\psi_{ec,N}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$

- $\psi_{ed,N}$ : Breakout edge effect factor
  - $\psi_{c,N}$ : Breakout cracking factor
  - $\psi_{cp,N}$ : Breakout splitting factor
  - $\psi_{ec,N}$ : Breakout eccentricity factor
- Check product evaluation report as the values may be different from what is determined from ACI equations.

[See extra slides for the equations of these factors.](#)

05/20/26

Webinar 1

35

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## Tensile strength: Concrete Breakout Strength

A single anchor:  $\phi N_{cb} = \phi(A_{Nc}/A_{Nco})\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$   
 An anchor group:  $\phi N_{cbg} = \phi(A_{Nc}/A_{Nco})\psi_{ec,N}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$

$N_b$  = Basic concrete breakout strength in tension of a single anchor in cracked concrete (1b)

$$N_b = k_c \lambda_a \sqrt{f'_c} h_{ef}^{1.5}$$

$k_c = 17$  for post-installed anchors (may be increased based on ACI 355.2/355.4 product tests but not to exceed 24)

$\lambda_a$  = Lightweight concrete modification factor

$\lambda_a = 0.8\lambda$  for screw anchors

$\lambda$  = modification factor for lightweight concrete [Note: This factor is different in ACI (section 19.2.4) and AASHTO (Article 5.4.2.8)]

$f'_c$  = Concrete compressive strength [in psi](#)

$h_{ef}$  = Effective anchor embedment depth

05/20/26

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### Tensile strength: Concrete Breakout Strength

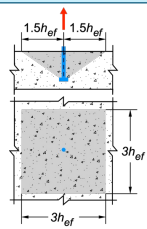
A single anchor:  $\phi N_{cb} = \phi (A_{Nc} / A_{Nco}) \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$   
 An anchor group:  $\phi N_{cbg} = \phi (A_{Nc} / A_{Nco}) \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

Failure surface is projected outward by  $1.5h_{ef}$   
 $A_{Nco}$  = Concrete failure area of a single anchor if not limited by edge distance/spacing (in.<sup>2</sup>)  
 $A_{Nc}$  = Concrete failure area of a single anchor or group of anchors (in.<sup>2</sup>)

$$A_{Nc} \leq n A_{Nco} \quad (n = \text{the number of anchors in the group})$$

Anchor is more than  $1.5h_{ef}$  from the edges

$$A_{Nc} = A_{Nco} = 9h_{ef}^2$$



05/20/26

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37

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### $A_{Nc}$ and $A_{Nco}$ : Examples

Anchor edge distance is less than  $1.5h_{ef}$  in both directions.

Anchor spacings ( $s_1$  and  $s_2$ ) are less than  $3h_{ef}$

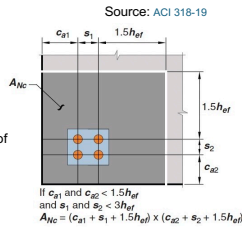
$$A_{Nco} = 9h_{ef}^2$$

$$A_{Nc} = (c_{a1} + s_1 + 1.5h_{ef})(c_{a2} + s_2 + 1.5h_{ef})$$

$c_{a1}$  and  $c_{a2}$  = distances from the center of the shaft of the exterior anchors to the edge of concrete

$c_{a1}$  = minimum edge distance

$c_{a2}$  = edge distance perpendicular to  $c_{a1}$



05/20/26

Webinar 1

38

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### $A_{Nc}$ and $A_{Nco}$ : Definitions

A single anchor:  $\phi N_{cb} = \phi (A_{Nc} / A_{Nco}) \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$   
 An anchor group:  $\phi N_{cbg} = \phi (A_{Nc} / A_{Nco}) \psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

If anchors are located less than  $1.5h_{ef}$  from three or more edges,  $h_{ef}$  used to calculate  $A_{Nc}$  is the smaller of (a)  $c_{a,max} / 1.5$  and (b)  $s / 3$  (and not the actual value of  $h_{ef}$ ).

$c_{a,max}$  = maximum distance from center of an anchor shaft to the edge of concrete (in.)

$s$  = maximum spacing between anchors with the group (in.)

An example is shown in the extra slides section.

05/20/26

Webinar 1

39

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# Shear: Failure Modes and Design Equations

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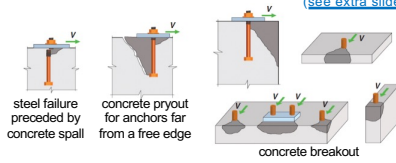
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## Failure Modes – Shear

Check multiple failure modes.  
The lesser strength governs.

May use anchor reinforcement  
design strength instead of  
concrete breakout strength  
(see extra slides)



Source: ACI 318-19 (modified)

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41

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## Design Strength – Screw Anchors: Shear

Failure mode	Single anchor	Anchor group*	
		Individual anchor	Anchor group
Steel strength	X	X	
Concrete breakout strength	X		X
Concrete pryout strength	X		X

\* For shear + torsion, individual anchors may have to resist different magnitudes of V. Design strength for ~~steel failure~~ steel failure mode is computed for the most highly stressed anchor in the group.

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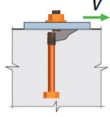
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## Steel Failure Under Shear Loading



Source: ACI 318-19



Source: <https://www.hilti.in/engineering/article/how-anchors-fail-in-shear-and-ways-to-prevent-it/eos022>

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43

43

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## Shear Strength: Steel Strength

$$\phi V_{sa} = \phi(0.6A_{se,v}f_{uta})$$

$\phi = 0.65$  for ductile anchors and  $0.60$  for brittle anchors. **Ductility is assessed by ACI 355.2/355.4.**

$A_{se,v}$  = Anchor effective cross-sectional area in shear (in.<sup>2</sup>) provided by the manufacturer

$f_{uta}$  = specified tensile strength of anchor steel (psi) provided by the manufacturer

$f_{uta} \leq 1.9f_{ya}$  or  $125,000$  psi ( $f_{ya}$  = specified yield strength of anchor steel in psi).

Note:

The above equation is for cases with sleeves that do not extend through shear plane.  
Screw anchors do not have sleeves.

See extra slides.

Use  $0.8(\phi V_{sa})$  for cases with built-up grout pads

05/20/26

Webinar 1

44

44

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## Strength Reduction Factors ( $\phi$ ) – Shear Concrete Failure Modes

Supplementary Reinforcement	$\phi$ Shear
Present	0.75
Not Present	0.70

For cases controlled by breakout,  $\phi$  depends on whether supplementary reinforcement is provided or not.

The factors listed for "Not Present" apply to cases controlled by concrete pryout strength.

05/20/26

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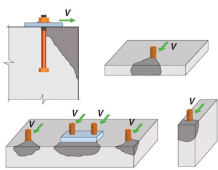
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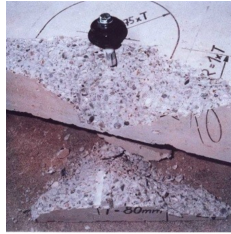
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### Breakout Failure Under Shear Loading



Source: ACI 318-19



Source: <https://www.hilti.in/engineering/article/how-anchors-fail-in-shear-and-ways-to-prevent-it/easo22>

05/20/26

Webinar 1

46

46

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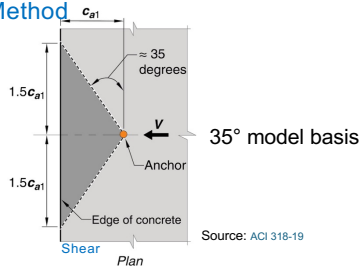
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### Breakout Cones Based on Concrete Capacity Design (CCD) Method



Source: ACI 318-19

05/20/26

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47

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### Shear Strength: Concrete Breakout Strength Shear $\perp$ to Edge

A single anchor:  $\phi V_{cb} = \phi (A_{vc} / A_{vco}) \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$   
 An anchor group:  $\phi V_{cbg} = \phi (A_{vc} / A_{vco}) \psi_{ec,v} \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

- $\psi_{ed,v}$ : Breakout edge effect factor
  - $\psi_{c,v}$ : Breakout cracking factor
  - $\psi_{h,v}$ : Breakout thickness factor
  - $\psi_{ec,v}$ : Breakout eccentricity factor
- Check product evaluation report as the values may be different from what is determined from ACI equations.

[See extra slides for the equations of these factors.](#)

05/20/26

Webinar 1

48

48

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### Shear Strength: Concrete Breakout Strength Shear $\perp$ to Edge

A single anchor:  $\phi V_{cb} = \phi(A_{Vc}/A_{Vco}) \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

An anchor group:  $\phi V_{cbg} = \phi(A_{Vc}/A_{Vco}) \psi_{ec,v} \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

$V_b$  = Basic concrete breakout strength in shear of a single anchor in cracked concrete (lb)

Smaller of  $V_b = \left[7 \left(\frac{\ell_a}{d_a}\right)^{0.2} \sqrt{d_a}\right] \lambda_a \sqrt{f'_c} (c_{a1})^{1.5}$  and  $V_b = 9 \lambda_a \sqrt{f'_c} (c_{a1})^{1.5}$

$\lambda_a$  = Lightweight concrete modification factor

$\lambda_a = 0.8\lambda$  for screw anchors ( $\lambda$  = modification factor for lightweight concrete)

$f'_c$  = Concrete compressive strength [in psi](#).

$d_a$  = Outside diameter of anchor

$c_{a1}$  = Distance from the center of an anchor shaft to the edge of concrete [in the direction of applied shear](#)

$\ell_a$  = Anchor load-bearing length for shear;  $\ell_a = h_{ef}$  for screw anchors

05/20/26

Webinar 1

49

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49

### Shear Strength: Concrete Breakout Strength Shear $\perp$ to Edge

A single anchor:  $\phi V_{cb} = \phi(A_{Vc}/A_{Vco}) \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

An anchor group:  $\phi V_{cbg} = \phi(A_{Vc}/A_{Vco}) \psi_{ec,v} \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

$A_{Vco}$  = Projected concrete failure area of a single anchor for shear strength calculation, if not limited by corner influences, spacing, or member thickness (in.<sup>2</sup>)

$A_{Vc}$  = Projected concrete failure area of a single anchor or group of anchors for shear strength calculation

$A_{Vc} \leq n A_{Vco}$  ( $n$  = number of anchors in group)

05/20/26

Webinar 1

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### $A_{Vc}$ and $A_{Vco}$ : Examples

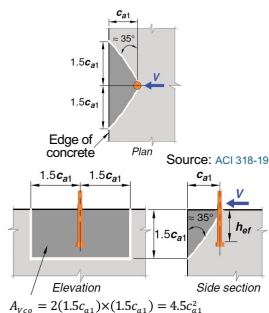
The critical edge distance is  $1.5c_{a1}$ .

This critical edge is used to calculate  $A_{Vc}$  and  $A_{Vco}$

For the case shown:  $A_{Vc} = A_{Vco} = 4.5c_{a1}^2$

$c_{a1}$  is the smallest edge distance in the direction of  $V$ .

As  $c_{a1}$  increases, the breakout strength increases. Software packages do not check for breakout strength when  $c_{a1} = \infty$ .



05/20/26

Webinar 1

51

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51

### $A_{Vc}$ and $A_{Vco}$ : Examples

**Case 1**

$h_a < 1.5c_{a1}$   
 $A_{Vc} = h_a(3c_{a1})$   
 $A_{Vco} = 4.5c_{a1}^2$

**Case 2**

$h_a > 1.5c_{a1}$  and  $c_{a2} < 1.5c_{a1}$   
 $A_{Vc} = 1.5c_{a1}(1.5c_{a1} + c_{a2})$   
 $A_{Vco} = 4.5c_{a1}^2$

Source: ACI 318-19 (modified)

**Case 3**

$h_a < 1.5c_{a1}$  and  $s_1 < 3c_{a1}$   
 $A_{Vc} = h_a(1.5c_{a1} + s_1 + 1.5c_{a1})$   
 $A_{Vco} = 4.5c_{a1}^2$

05/20/26      Webinar 1      52

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52

### $A_{Vc}$ and $A_{Vco}$ : Examples

Source: ACI 318-19 (modified)

Check case 1 AND case 2 if  $s \geq c_{a1,1}$ . Check only case 2 for anchors welded to a common plate. Case 3 is not applicable if anchors are welded to a common plate.

**1**  $\theta \geq c_{a1,1}$

**0.5V to the front anchor**

$h_a < 1.5c_{a1,1}$  and  $s \geq c_{a1,1}$   
 $A_{Vc} = h_a(1.5c_{a1,1} + 1.5c_{a1,1})$   
 $A_{Vc} = 3 h_a c_{a1,1}$   
 $A_{Vco} = 4.5c_{a1,1}^2$

Note: Breakout strength is calculated by taking  $c_{a1}$  as  $c_{a1,1}$ .

**2**  $\theta \geq c_{a1,1}$

**V to the back anchor**

$h_a < 1.5c_{a1,2}$  and  $s \geq c_{a1,1}$   
 $A_{Vc} = h_a(1.5c_{a1,2} + 1.5c_{a1,2})$   
 $A_{Vc} = 3 h_a c_{a1,2}$   
 $A_{Vco} = 4.5c_{a1,2}^2$

Note: Breakout strength is calculated by taking  $c_{a1}$  as  $c_{a1,2}$ .

**3**  $\theta < c_{a1,1}$

**V to the front anchor**

$h_a < 1.5c_{a1,1}$  and  $s < c_{a1,1}$   
 $A_{Vc} = h_a(1.5c_{a1,1} + 1.5c_{a1,1})$   
 $A_{Vc} = 3 h_a c_{a1,1}$   
 $A_{Vco} = 4.5c_{a1,1}^2$

Note: Breakout strength is calculated by taking  $c_{a1}$  as  $c_{a1,1}$ .

05/20/26      Webinar 1      53

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53

### $A_{Vc}$ and $A_{Vco}$ : Narrow Sections with Limited Thickness

For narrow members with limited thickness, do not use the actual value of  $c_{a1}$  to compute  $A_{Vc}$ .

If member thickness  $h_a < 1.5c_{a1}$  AND the edge distances perpendicular to the direction of load  $c_{a2} < 1.5c_{a1}$ ,  $c_{a1}$  is taken as the **largest** value from the following:

- $c_{a2}/1.5$  ( $c_{a2}$  is the greatest edge distance)
- $h_a/1.5$
- $s/3$  ( $s$  is the greatest spacing perpendicular to direction of shear between anchors in a group)

An example is provided in the extra slides section.

05/20/26      Webinar 1      54

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54

## Shear strength: Concrete Breakout Strength

- Shear is **perpendicular** to the edge:

A single anchor:  $\phi V_{cb} = \phi (A_{Ve}/A_{Vco}) \Psi_{ed,V} \Psi_{c,V} \Psi_{H,V} V_b$

Covered in the previous slides

An anchor group:  $\phi V_{cbg} = \phi (A_{Ve}/A_{Vco}) \Psi_{ec,V} \Psi_{ed,V} \Psi_{c,V} \Psi_{H,V} V_b$

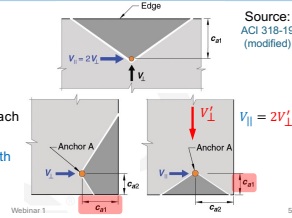
- Shear is **parallel** to the edge:

Use twice the value obtained from above equations **with**  $\Psi_{ed,V} = 1$ .

- Corner anchors:

Use the smaller value of concrete breakout strength calculated for each edge.

Note: Both  $V_{\perp}$  and  $V_{\parallel}$  incorporate strength reduction factor  $\phi$ .



05/20/26

Webinar 1

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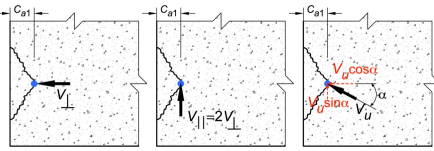
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## Shear strength: Concrete Breakout Strength

ACI does not specifically address if the shear force is at angle other than  $0^\circ$  and  $90^\circ$  relative to the edge.

The shear force could be resolved into two orthogonal components and then apply the following equation (Eligehausen et al., 2006):

$$\frac{V_u \cos \alpha}{V_{\perp}} + \frac{V_u \sin \alpha}{V_{\parallel}} \leq 1.0$$



Source: Adapted from Eligehausen, R., Mallé, R., and Silva, J., 2006, Anchorage in Concrete Construction, Ernst & Sohn (J. T. Wiley), Berlin, Germany, May, 380 pp.

05/20/26

Webinar 1

56

56

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## Shear strength: Concrete Breakout Strength

Eligehausen et al. (2006):

Check the strength for each free edge.

Case 1:

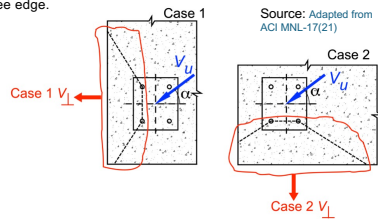
$$\frac{V_u \cos \alpha}{\text{Case 1 } V_{\perp}} + \frac{V_u \sin \alpha}{\text{Case 1 } V_{\parallel}} \leq 1.0$$

Case 1  $V_{\parallel} = 2 \times (\text{Case 1 } V_{\perp})$

Case 2:

$$\frac{V_u \sin \alpha}{\text{Case 2 } V_{\perp}} + \frac{V_u \cos \alpha}{\text{Case 2 } V_{\parallel}} \leq 1.0$$

Case 2  $V_{\parallel} = 2 \times (\text{Case 2 } V_{\perp})$



Source: Adapted from ACI MNL-17(Z1)

05/20/26

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57

57

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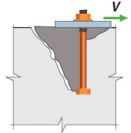
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## Pryout Failure Under Shear Loading



Source: ACI 318-19



Source: <https://www.hilti.in/engineering/article/how-anchors-fail-in-shear-and-ways-to-prevent-it/ens02>

05/20/26

Webinar 1

58

58

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## Shear Strength: Concrete Pryout Strength

The pryout shear strength is approximately one to two times the anchor tensile breakout strength.

A single anchor:  $\phi V_{cp} = \phi(k_{cp} N_{cp})$

An anchor group:  $\phi V_{cpg} = \phi(k_{cpg} N_{cpg})$

$N_{cp}$  = Basic concrete pryout strength of a single anchor

$N_{cp} = N_{cb}$  (breakout strength for a single anchor) =  $(A_{Nc}/A_{Nco})\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$

$N_{cpg}$  = Basic concrete pryout strength of a group of anchors

$N_{cpg} = N_{cbg}$  (breakout strength of an anchor group) =  $(A_{Nc}/A_{Nco})\psi_{ec,N}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$

$k_{cp} = 1.0$  for  $h_{ef} < 2.5$  in.

$k_{cp} = 2.0$  for  $h_{ef} \geq 2.5$  in.

05/20/26

Webinar 1

59

59

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## Tension + Shear

05/20/26

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60

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## Tension and Shear Interaction

The interaction between tension and shear can be neglected if either of the following two cases is satisfied.

$$N_{ua}/(\phi N_n) \leq 0.2 \quad \text{OR} \quad V_{ua}/(\phi V_n) \leq 0.2$$

$N_{ua}$  = Factored tensile force applied to anchor or an individual anchor in a group of anchors

$\phi N_n$  = Anchor tensile strength (the controlling value from steel, concrete breakout, and pullout strength)

$V_{ua}$  = Factored shear force applied to anchor or an individual anchor in a group of anchors

$\phi V_n$  = Anchor shear strength (the controlling value from steel, concrete breakout, and pryout strength)

05/20/26

Webinar 1

61

61

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## Tension and Shear Interaction

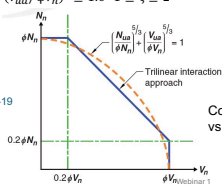
If  $N_{ua}/(\phi N_n) > 0.2$  AND  $V_{ua}/(\phi V_n) > 0.2$ , satisfy:

$$\frac{N_{ua}}{\phi N_n} + \frac{V_{ua}}{\phi V_n} \leq 1.2$$

Note: This equation is a trilinear representation of power tensile-shear interaction:

$$(N_{ua}/\phi N_n)^\zeta + (V_{ua}/\phi V_n)^\zeta \leq 1.0 \quad 1 \leq \zeta \leq 2$$

Source: ACI 318-19



Comparison of trilinear representation vs power interaction with  $\zeta=5/3$ .

05/20/26

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62

62

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## Design Loads and Strength Reduction Factors

05/20/26

Webinar 1

63

63

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## AASHTO and ACI

- For hand calculations and/or design software packages:
  - Use AASHTO load factors and combinations to determine design loads
  - Follow ACI equations with the applicable ACI reduction factors and modification factors
  - This mix of codes was validated in NCHRP Report 22470 (*Long-Term Performance of Epoxy Adhesive Anchor Systems*)
- Pay attention to the units
  - AASHTO: inch-kip units
  - ACI: inch-pound units

05/20/26

Webinar 1

64

64

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## Summary

05/20/26

Webinar 1

65

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## Summary

- We went over screw anchors, which are now allowed in AASHTO.
  - Basic behavior of screw anchors is similar to other types of mechanical anchors.
- Several design equations must be checked for
  - Tension: steel failure, pullout failure, concrete breakout, concrete splitting May be precluded by providing supplementary reinforcement or meeting min. spacing/edge distance and member thickness
  - Shear: steel failure, concrete pryout, concrete breakout

05/20/26

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66

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## Summary

- ACI 318-19 provides values for parameters in design equations.
  - Values from manufacturer's product evaluation reports "override" ACI values.
- Anchor design could become onerous
  - Software packages such as *PROFIS* by Hilti or *Anchor Designer* by Simpson Strong-Tie are available.
  - These programs are focused on the specific anchors from the company.
  - Pay attention to the units and go over the design reports to verify the calculations, e.g.,
    - Are all appropriate failure modes have been considered?
    - All the modification factors/strength reductions are consistent with ACI 318-19?

05/20/26

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67

67

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## Summary

- Several resources are available to delve into anchor behavior and design as well as installation procedures.
  - PCI 2020 five-part webinars and 4 articles in ASPIRE magazine
  - Anchorage Design webinars from ACI University
  - Design examples in ACI Publication MNL-17(21)
  - Anchor manufactures have very good documents on their website and offer free webinars

05/20/26

Webinar 1

68

68

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## Thank you.

You now have the core principles for designing post-installed screw anchors.

05/20/26

Webinar 1

69

69

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## Webinar Documents

<https://www.pci.org/AnchoringToConcreteImp>  
 6 2026 Anchorage to Concrete Webinar 1 with Dr. Shahrooz May 20 2026

05/20/26      Webinar 1      70

70

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## Free ACI Anchor Resources

ACI has assembled an extensive collection of over 1000 pages that include full documents as well as anchor –related chapters and excerpts.  
 A few examples:  
 ACI 318-25 : Building Code for Structural Concrete (chapters 2, 17, 25, 26)  
 ACI 355.4: Post-Installed Adhesive Anchors in Concrete (complete document)  
 MNL-17 (21): ACI Reinforced Concrete Design Handbook (anchor design examples)

In order to provide you with complimentary access to this collection of resources that address anchorage to concrete - please click the question icon during the webinar and type "ACI Docs"

[www.nationalconcretebridge.org](http://www.nationalconcretebridge.org)

71

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## Questions Key Takeaways



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 **NCBC**  
National Concrete Bridge Council

Thank you!

Please sign up for future NCBC webinars

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73

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Extra Slides

05/20/26 Webinar 1 74

74

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Torque and Displacement-Controlled Anchors Examples



Torque-controlled Displacement-controlled

Source  
Elsevier: Structures 34 (2021) 2276–2287

05/20/26 Webinar 1 75

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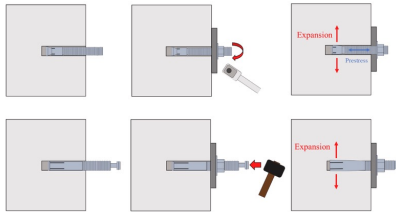
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## Torque-Controlled vs. Displacement-Controlled Expansion Anchors



Source:  
Zhao, C. (2021). A review of current research progress on tensile behavior of expansion anchors in concrete. Elsevier, Structures, Vol. 34, pp. 2276-2287.

05/20/26

76

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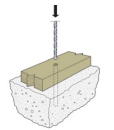
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## Screw Anchors – General Installation Steps



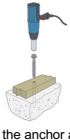
Source:  
[https://www.stonotie.com/mechanicalanchors\\_mechanicalanchorsin\\_products/hd\\_anchor/c10ten-hd](https://www.stonotie.com/mechanicalanchors_mechanicalanchorsin_products/hd_anchor/c10ten-hd)



Follow Manufacturer's Printed Installation Instructions (MPII) for correct drill size and hole-depth.



Clean the drilled hole



Insert the anchor and use an impact hammer to drive the anchor into the hole. Ensure there is no gap between the head and attachment.



Sources:  
[https://www.stonotie.com/resources/product\\_installers-guide/tenhd-installation](https://www.stonotie.com/resources/product_installers-guide/tenhd-installation)  
<https://dmsupply.dk/media/orkdn/32/technical-datasheet-hus4-technical-information-asset-doc-16702928.pdf>

Webinar 1

77

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## Anchor Reinforcement Instead of Concrete Breakout Strength

- Anchor reinforcement provides an alternate load path
- Anchor reinforcement effectiveness:
  - Tension
    - Developed on both sides of concrete breakout surface
  - Shear
    - Encloses and contacts the anchor
    - Develop beyond the concrete breakout surface
- Instead of using Chapter 17, development length rules of Chapter 25 have to be followed.

05/20/26

Webinar 1

78

78

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## Anchor Reinforcement Instead of Concrete Breakout Strength

- Beneficial
  - If tensile or shear exceeds concrete breakout strength
  - If the concrete breakout strength is not checked.
- Limitations
  - Anchor reinforcement is only used for cast-in-anchors, e.g., in precast sections.
  - Placement of anchor reinforcement is important.

05/20/26

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79

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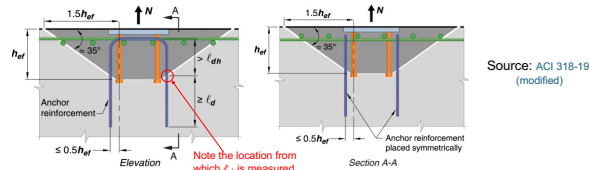
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## Anchor Reinforcement – Tension



Source: ACI 318-19 (modified)

- Stirrups, ties, or hairpins are preferred tension anchor reinforcement.
- If possible, anchor reinforcement should enclose the surface reinforcement.
- Anchor reinforcement within  $0.5h_{ef}$  from anchor is considered to be effective.
- The provisions are based on tests with anchor reinforcement with maximum diameter equivalent to a No. 5 bar.

05/20/26

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80

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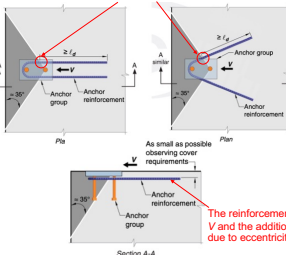
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## Anchor Reinforcement – Shear

Note the location from which  $f_u$  is measured.



Source: ACI 318-19 (modified)

05/20/26

Webinar 1

81

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### Anchor Reinforcement – Shear

- The anchor reinforcement for shear could also consist of stirrups, ties, hoops, or hairpins that enclose the edge reinforcement embedded in the breakout volume and placed as close as possible to the anchors.
- Reinforcement spacing is the smaller of  $0.5C_{at}$  and  $0.3C_{az}$  from the anchor center line.
- Anchor reinforcement must be developed on both sides of the breakout surface.
- The provisions are based on tests with anchor reinforcement with maximum diameter equivalent to a No. 6 bar.

Source: ACI 318-19

82

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### Anchor Reinforcement vs. Supplementary Reinforcement

LOAD PATH

- Anchor reinforcement**
  - Designed specifically for load transfer anchors into the member
  - Must be developed
    - On **both sides** of the critical section
    - Location where the failure surface intersects the reinforcement
  - Hairpins are preferred type of reinforcement
- Supplementary reinforcement**
  - Similar configuration and placement as anchor reinforcement
  - Not designed and detailed specifically to transfer loads
  - Stirrups (shear reinforcement) are an example

83

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### Oversized Anchor Use

- It may be desirable to use a larger-diameter anchor than the minimum spacing and edge distance that are permitted by ACI Table 17.9.2. Such cases can be handled as follows:
- Strength calculations
  - Based on a smaller assumed anchor diameter  $d'_a$  that meets the requirements of ACI Table 17.9.2.
- ACI permits exception
  - For anchors not torqued, and
  - Installation does not induce a splitting force

84

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# Modification Factors

Tensile Loading

05/20/26

Webinar 1

85

85

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## Breakout Edge Effect Factor: $\psi_{ed,N}$

A single anchor:  $\phi N_{cb} = \phi(A_{Nc}/A_{Nco})\psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

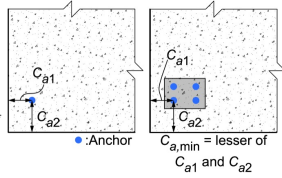
An anchor group:  $\phi N_{cbg} = \phi(A_{Nc}/A_{Nco})\psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

If  $c_{a,min} < 1.5h_{ef}$ , complete breakout volume cannot be developed

Reduce strength **further** beyond  $A_{Nc}/A_{Nco}$  by  $\psi_{ed,N}$ .

If  $c_{a,min} \geq 1.5h_{ef}$   $\psi_{ed,N} = 1$

If  $c_{a,min} < 1.5h_{ef}$   $\psi_{ed,N} = 0.7 + 0.3 c_{a,min}/1.5h_{ef}$



05/20/26

Webinar 1

86

86

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## Breakout Cracking Factor: $\psi_{c,N}$

A single anchor:  $\phi N_{cb} = \phi(A_{Nc}/A_{Nco})\psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

An anchor group:  $\phi N_{cbg} = \phi(A_{Nc}/A_{Nco})\psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

Breakout cracking factor accounts for the influence of cracking in anchor region at service load.

Post-installed anchors not meeting the requirements of ACI 355.2/355.4 for use in cracked concrete should be installed only for regions that remain uncracked.

*The effects of restrained shrinkage should also be included.*

ACI 355.2/355.4 qualification tests require anchors in cracked zone perform well in a 0.012-in. wide crack.

Provide crack control reinforcement if the crack width is expected to exceed 0.012 in.

05/20/26

Webinar 1

87

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### Breakout Cracking Factor: $\psi_{c,N}$

A single anchor:  $\phi N_{cb} = \phi(A_{Nc}/A_{Nco})\psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

An anchor group:  $\phi N_{cbg} = \phi(A_{Nc}/A_{Nco})\psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

(a) Anchor in a region with no cracking expected at service load:

$\psi_{c,N} = 1.4$  for post-installed anchors if  $k_c = 17$  in  $N_b = k_c \lambda_a \sqrt{f'_c} h_{ef}^{1.5}$

If  $k_c$  is from product evaluation report (from ACI 355.2/355.4 tests):

Use  $\psi_{c,N}$  from product evaluation report for anchors qualified (according to ACI 355.2/355.4) for both cracked and uncracked concrete

$\psi_{c,N} = 1$  for anchors qualified (according to ACI 355.2/355.4) for uncracked concrete

(b) Anchor in a region where cracking is expected at service load:

$\psi_{c,N} = 1$

05/20/26

Webinar 1

88

88

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### Breakout Splitting Factor: $\psi_{cp,N}$

A single anchor:  $\phi N_{cb} = \phi(A_{Nc}/A_{Nco})\psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

An anchor group:  $\phi N_{cbg} = \phi(A_{Nc}/A_{Nco})\psi_{ec,N} \psi_{ed,N} \psi_{c,N} \psi_{cp,N} N_b$

Breakout splitting factor ( $\psi_{cp,N}$ ) accounts for potential splitting mode of failure.

Tensile strength of post-installed anchors is based on achieving  $N_b$  if  $c_{a,min} = 1.5h_{ef}$ .

For post-installed anchors designed for uncracked concrete (see discussion for  $\psi_{c,N}$ ) without supplementary reinforcement to control splitting:

If  $c_{a,min} \geq c_{ac}$   $\psi_{cp,N} = 1$

If  $c_{a,min} < c_{ac}$   $\psi_{cp,N} = c_{a,min}/c_{ac} \geq 1.5h_{ef}/c_{ac}$

$\psi_{cp,N} = 1$  for all other cases

05/20/26

Webinar 1

89

89

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### Critical Edge Distance ( $c_{ac}$ )

Unless determined from tension tests in accordance with ACI 355.2/355.4, the critical edge distance from Table 17.9.5 must be satisfied.

ACI Table 17.9.5 – Critical Edge Distance

Post-installed anchor type	Critical edge distance $c_{ac}$
Torque-controlled	$4h_{ef}$
Displacement-controlled	$4h_{ef}$
Screw	$4h_{ef}$
Undercut	$2.5h_{ef}$
Adhesive	$2h_{ef}$

05/20/26

Webinar 1

90

90

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### Breakout Eccentricity Factor: $\psi_{ec,N}$

A single anchor:  $\phi N_{cb} = \phi(A_{Nc}/A_{Nco})\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$

An anchor group:  $\phi N_{cbg} = \phi(A_{Nc}/A_{Nco})\psi_{ec,N}\psi_{ed,N}\psi_{c,N}\psi_{cp,N}N_b$

This factor applies to anchor groups loaded eccentrically in tension.

$$\psi_{ec,N} = \frac{1}{\left(1 + \frac{e'_N}{1.5h_{ef}}\right)} \leq 1$$

$e'_N$  = Distance between resultant tension load on a group of anchors and the centroid of group of anchors (in.). ( $e'_N > 0$  always)

Only anchors in tension are used to calculate  $e'_N$ .

Note: For loading in two orthogonal axes,  $\psi_{ec,N}$  is calculated in both directions, and the product of these two factors is used as  $\psi_{ec,N}$ .

05/20/26

Webinar 1

91

91

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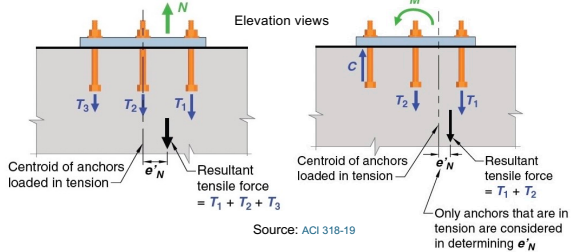
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### Eccentricity ( $e'_N$ )



05/20/26

Webinar 1

92

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### Additional Examples

$A_{Nc}$  and  $A_{Nco}$

Tensile Loading

05/20/26

Webinar 1

93

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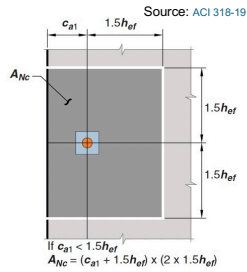
### $A_{NC}$ and $A_{NCO}$ : Examples

Anchor is more than  $1.5h_{ef}$  from the edge in one direction but is less than  $1.5h_{ef}$  from the edge in another direction.

$$A_{NCO} = 9h_{ef}^2$$

$$A_{NC} = (c_{a1} + 1.5 h_{ef})(2 \times 1.5 h_{ef})$$

$c_{a1}$  = distance from the center of the anchor shaft to the edge of concrete



05/20/26

Webinar 1

94

94

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### $A_{NC}$ and $A_{NCO}$ : Examples

Anchor is more than  $1.5h_{ef}$  from the edge in one direction but is less than  $1.5h_{ef}$  from the edge in another direction.

Anchor spacing ( $s_1$ ) is less than  $3h_{ef}$

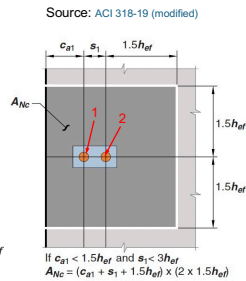
$$A_{NCO} = 9h_{ef}^2$$

$$A_{NC} = (c_{a1} + s_1 + 1.5 h_{ef})(2 \times 1.5 h_{ef})$$

If  $s_1 > 3h_{ef}$

For anchor 1:  $A_{NC} = (c_{a1} + 1.5 h_{ef})(2 \times 1.5 h_{ef})$

For anchor 2:  $A_{NC} = (2 \times 1.5 h_{ef})(2 \times 1.5 h_{ef}) = 9h_{ef}^2$



05/20/26

Webinar 1

95

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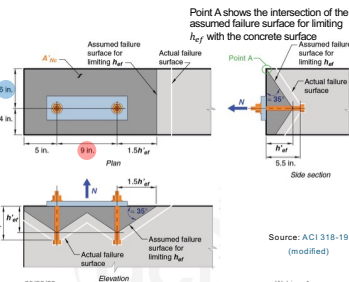
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### Example: Truncation of $A_{NC}$ and $A_{NCO}$



The actual  $h_{ef} = 5.5$  in. but three edges are  $\leq 1.5h_{ef}$ ; therefore, the limiting value of  $h_{ef}$  (shown as  $h'_{ef}$  in the figure) is the larger of  $c_{a,max}/1.5$  and  $1/3$  of the maximum spacing for an anchor group:

$$h'_{ef} = \max(6, 1.5, 9/3) = 4 \text{ in.}$$

Therefore, use  $h'_{ef} = 4$  in. in the equations.

$$A_{NC} \text{ (shown as } A'_{NC} \text{ in the figure)} = (6 + 4)[5 + 9 + (1.5 \times 4)] = 200 \text{ in.}^2$$

05/20/26

Webinar 1

96

96

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# Shear Strength of Anchors with Sleeves

05/20/26

Webinar 1

97

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97

## Shear Strength: Steel Strength (Sleeves Do Not Extend Through Shear Plane)

$$\phi V_{sa} = \phi(0.6A_{se,v}f_{uta})$$

$\phi$  = 0.65 for ductile anchors and 0.60 for brittle anchors. Ductility is assessed by ACI 355.2/355.4.

$A_{se,v}$  = Anchor effective cross-sectional area in shear (in.<sup>2</sup>) provided by the manufacturer

$f_{uta}$  = specified tensile strength of anchor steel (psi)

$f_{uta} \leq 1.9f_{ya}$  or 125,000 psi ( $f_{ya}$  = specified yield strength of anchor steel in psi)

05/20/26

Webinar 1

98

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98

## Sleeve Position

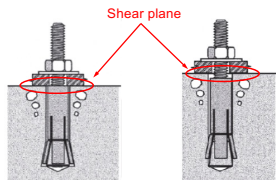
Not applicable to screw anchors.



Source:

[https://www.stromotie.com/mechanicalanchors\\_mechanicalanchoringproducts/sleeve\\_anchor/sleeve-all](https://www.stromotie.com/mechanicalanchors_mechanicalanchoringproducts/sleeve_anchor/sleeve-all)

05/20/26



Sleeve is in shear plane

Sleeve is not in shear plane

Source: 355.2\_22 (modified)

Webinar 1

99

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99

## Shear Strength: Steel Strength (With Sleeves Extend Through the Shear Plane)

$\phi V_{sa}$   $V_{sa}$  is 5% fractile of results from tests per ACI 355.2

- ACI also allows the use of  $V_{sa} = 0.6A_{se}V_{futa}$

05/20/26

Webinar 1

100

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## Modification Factors

Shear Loading

05/20/26

Webinar 1

101

101

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## Breakout Edge Effect Factor: $\psi_{ed,v}$

A single anchor:  $\phi V_{cb} = \phi(A_{vc}/A_{vco}) \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

An anchor group:  $\phi V_{cbg} = \phi(A_{vc}/A_{vco}) \psi_{ec,v} \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

If  $c_{a2} \geq 1.5c_{a1}$   $\psi_{ed,v} = 1$

If  $c_{a2} < 1.5c_{a1}$   $\psi_{ed,v} = 0.7 + 0.3 c_{a2}/1.5c_{a1}$

Use the lesser value of  $c_{a2}$

05/20/26

Webinar 1

102

102

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### Breakout Cracking Factor: $\psi_{c,v}$

A single anchor:  $\phi V_{cb} = \phi (A_{vc}/A_{vco}) \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

An anchor group:  $\phi V_{cbg} = \phi (A_{vc}/A_{vco}) \psi_{ec,v} \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

Analysis indicates no cracking at service level loads where anchors are located:  $\psi_{c,v} = 1.4$

Analysis indicates cracking at service level loads where anchors are located:  $\psi_{c,v}$  from the following table:

Condition	$\psi_{c,v}$
Anchors without supplementary reinforcement of with edge reinforcement smaller than a No. 4 bar	1.0
Anchors with reinforcement of at least No. 4 bar or greater between the anchor and the edge	1.2
Anchors with reinforcement of at least No. 4 bar or greater between the anchor and the edge, and with the reinforcement enclosed with stirrups at not more than 4 in.	1.4

05/20/26

Webinar 1

103

103

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### Breakout Thickness Factor: $\psi_{h,v}$

A single anchor:  $\phi V_{cb} = \phi (A_{vc}/A_{vco}) \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

An anchor group:  $\phi V_{cbg} = \phi (A_{vc}/A_{vco}) \psi_{ec,v} \psi_{ed,v} \psi_{c,v} \psi_{h,v} V_b$

For anchors with  $h_a < 1.5c_{a1}$

$$\psi_{h,v} = \sqrt{\frac{1.5c_{a1}}{h_a}} \geq 1.0$$

05/20/26

Webinar 1

104

104

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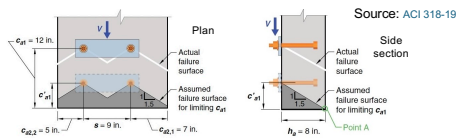
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### Breakout Thickness Factor: $\psi_{h,v}$

$$\psi_{h,v} = \sqrt{\frac{1.5c_{a1}}{h_a}} \geq 1.0$$

The limiting value of  $c_{a1} = 5.33$  in. (see next slide)

$\psi_{h,v} = 1$  because  $c_{a1} = h_a/1.5$



05/20/26

Webinar 1

105

105

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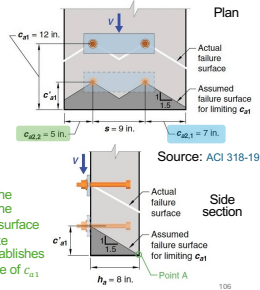
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### $A_{Vc}$ and $A_{Vco}$ : Narrow Sections with Limited Thickness (Example)

$c_{a1} = 12$  in.  
 $c_{a2, min} = 5$  in.  $< 1.5 c_{a1}$ .  $h = 8$  in.  $< 1.5 c_{a1}$   
 Limiting  $c_{a1}$  (shown as  $c'_{a1}$  in the figure): Larger of  
 •  $c_{a2, max}/1.5 = 7/1.5 = 4.67$  in.  
 •  $h/1.5 = 8/1.5 = 5.33$  in. **Controls**  
 •  $s/3 = 9/3 = 3$  in.  
 $A_{Vc} = (5 + 9 + 7)(1.5 \times 5.33) = 168$  in.<sup>2</sup>  
 $A_{Vco} = 4.5(5.33^2) = 128$  in.<sup>2</sup>



Point A shows the intersection of the assumed failure surface with the concrete surface that establishes the limiting value of  $c_{a1}$

05/20/26

Webinar 1

106

106

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### Breakout Eccentricity Factor: $\psi_{ec,V}$

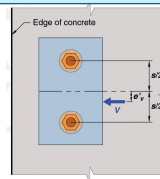
A single anchor:  $\phi V_{cb} = \phi(A_{Vc}/A_{Vco}) \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b$   
 An anchor group:  $\phi V_{cbg} = \phi(A_{Vc}/A_{Vco}) \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b$

$$\psi_{ec,V} = \frac{1}{\left(1 + \frac{e'_V}{1.5c_{a1}}\right)} \leq 1.0$$

Compute  $e'_V$  only for the anchors with shear in the same direction.

If  $V$  is above the plane of concrete surface, resolve it to a shear in the plane of concrete surface.

Do not forget about potential net tension from moment



Source: ACI 318-19

05/20/26

Webinar 1

107

107

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