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2026 NCBC WEBINAR SERIES

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

July 15, 2026

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NCBC Webinar Series 2026

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

September 16: Concrete Bridge Repair: Applying Guides to the Field

October 21: Anchoring to Concrete Part 3: Post-installed reinforcing bars and an overview of grouted joints with confinement

November 18: Silica Fume Sustainable / Low Carbon Concrete

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Industry Events 2026

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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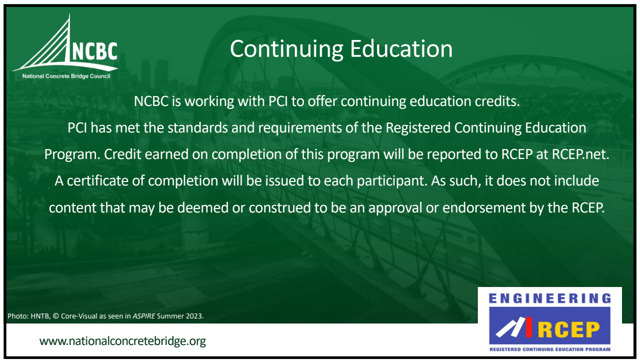
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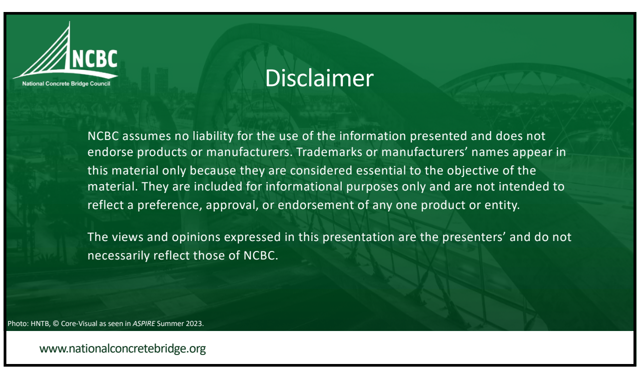
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Free ACI Anchor Resources

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)

If you did not request access during the May webinar – you can request 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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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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Presentation

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AASHTO 10th Edition Article 5.13 – Attachments with Shear Lugs

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

Image Source: https://punchlistzero.com/shear-lug

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Acknowledgements

NCBC for hosting 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

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Background
AASHTO LRFD BDS 10th Edition

- Article 5.13–ANCHORS in the 10th Ed. AASHTO LRFD Bridge Design Specifications has been revised
- The primary changes in ACI 318-19 are the addition of:
  - Screw anchors (Webinar 1)
  - Attachments with shear lugs
- Qualification documents were updated.
  - 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

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Learning Objectives

- Discuss what shear lugs are and cover key detailing requirements.
- Explain relevant failure modes and basic resistance mechanism of shear lugs.
- Go over shear lug design equations.
- Illustrate potential design issues for shear lugs through an example that also reviews key concepts from Webinar 1.

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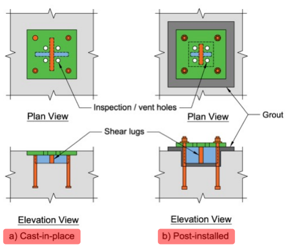
Examples of Attachments with Shear Lugs Cast-in-Place or Post-Installed



Source:
Cullen, T. (2025), "Design of Attachments to Concrete with Shear Lugs – A Primer", *PCI, Aspire* – Fall 2025, pp. 42-43.

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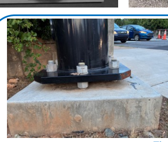
Examples of Attachments with Shear Lugs Post-Installed


Source:
Carrao, P.J. (2009), *Use of Shear Lugs for Anchorage to Concrete*, Proceedings of the ASME 2009 International Conference on Nuclear Engineering, ICONE17-7175




Field Photos by Bahram Shahrooz

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Benefits of Shear Lugs

- High shear forces can be resisted.
  - Anchor bolts can resist “small” to “moderate” shear forces.
- Without a shear lug the number of anchors becomes (a) too many and uneconomical and/or (b) must use large-diameter anchors.

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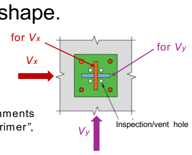
Orientation of Shear Lugs

- Shear lugs are orientated perpendicular to V_u.
- For biaxial shear loading, use a “cruciform” (a cross shape) or square shape.



Source (modified):
Cullen, T. (2025), “Design of Attachments to Concrete with Shear Lugs – A Primer”, *PCI, Aspire* – Fall 2025, pp. 42-43.

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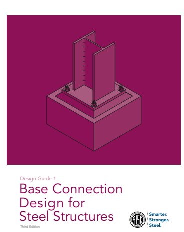
What Is Not Covered by Article 5.13

- Attachments without base plates and anchors
- Embedded members
- Design of shear lugs (shear and bending strength), base plate, and base plate-shear lug weld design
  - Steel design defers to AISC or AASHTO LRFD BDS Section 6



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Anchor Requirements

- A minimum of four anchors
- Anchors must satisfy all tension failure modes ?
- Shear failure mode exceptions ?
- For anchors welded to base plates, tension-shear interaction must be checked
  - Methodology will be discussed shortly

continue

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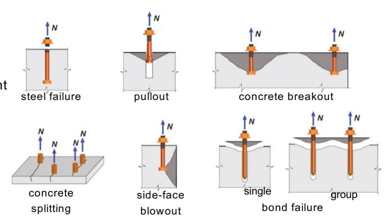
Anchor Failure Modes – Tension

Preclude splitting

- supplementary reinforcement

OR

- minimum anchor spacing/ edge distance and minimum member thickness



Source: ACI 318-19 (modified)

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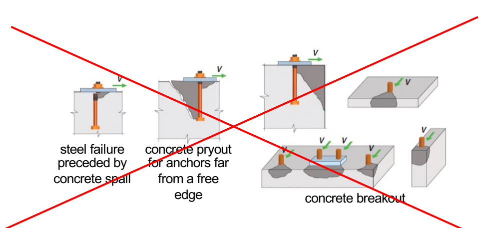
Anchor Failure Modes – Shear



Source: ACI 318-19 (modified)

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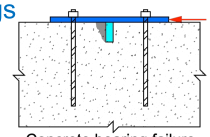
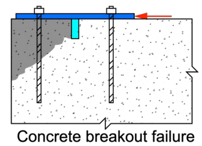
Failure Modes of Shear Lugs

- Concrete bearing failure
- Concrete breakout failure



Concrete bearing failure



Concrete breakout failure

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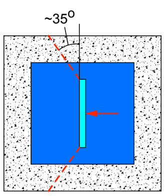
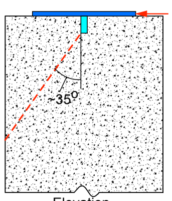
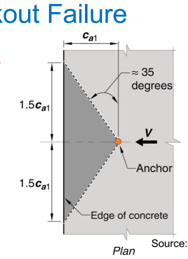
Trajectory of Concrete Breakout Failure



Plan



Elevation



Source: ACI 318-19

Concrete Capacity Design (CCD) method for anchors

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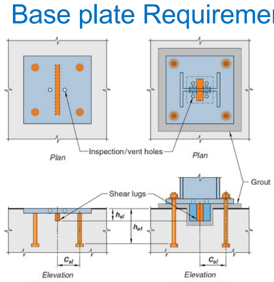
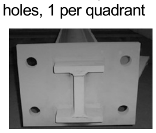
Base plate Requirements



Source: ACI 318-19 (modified)

- Base plate holes are needed to verify flow of grout/concrete consolidation.
  - Minimum 1-in. diameter inspection holes
  - Single shear lug: Min. 2 holes, 1 each side
  - Cruciform-shaped shear lug: Min. 4 holes, 1 per quadrant



Hmm, where're the inspection holes?

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Load Resistance Mechanism

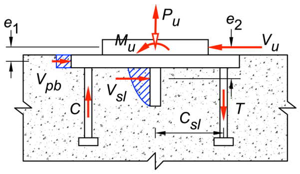
Shear force (V_u)

- Bearing against lug (V_{sl})
- Bearing against plate edge (V_{pb}) if it is below concrete surface

Note: V_{sl} > V_{pb}

Anchors (C/T) resist

- Moment (M_u) and axial force (P_u)
- Forces due to horizontal eccentricity of V_{sl} and V_{pb} (if present): e_1 and e_2



Free-body diagram of attachment with shear lug and anchors
Source: Adapted from ACI MNL-17(21)

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Load Resistance Mechanism

Small portion of V_u on anchors from (ACI R17.11.1.1.3):

Only for anchors welded to base plate/shear lug assembly

$$V_{ua,i} = V_u\left(\frac{2d_a^2}{A_{ef,sl} + n(2d_a^2)}\right)$$

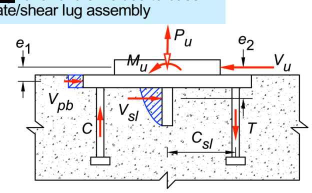
$A_{ef,sl}$ = effective bearing area of shear lug ?

d_a = outside diameter of anchors

n = number of anchors

Consider for N & V interaction of steel failure for anchors welded to the base plate

continue



Free-body diagram of attachment with shear lug and anchors
Source: Adapted from ACI MNL-17(21)

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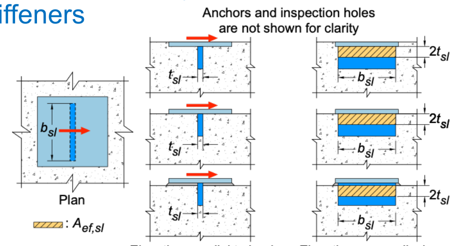
Effective Bearing Area ($A_{ef,sl}$) Without Stiffeners

$A_{ef,sl} = b_{sl}\times(2t_{sl})$

Below surface of base plate or surface of concrete

Anchors and inspection holes are not shown for clarity



Elevation parallel to load

Elevation perpendicular to load

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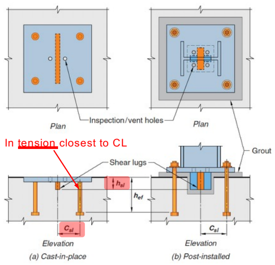
Anchor-Shear Lug Spacing Requirements



Source: ACI 318-19 (modified)

- Both of the following requirements must be met for anchors that are in tension.
  - $h_{ef}/h_{sl} \geq 2.5$
  - $h_{ef}/c_{sl} \geq 2.5$

  Could be challenging if h_{ef} cannot be increased
- These requirements are intended to conservatively preclude interaction between concrete failure surfaces of anchors and shear lug(s).
- Not applicable if anchors are in compression
  - Anchors do not carry compression except for (a) welded studs and (b) attachments with leveling nuts (bottom nuts)

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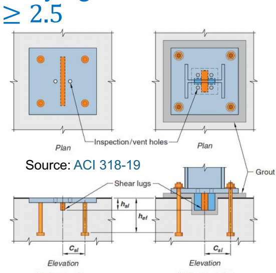
Potential Challenges of Satisfying: $h_{ef}/h_{sl} \geq 2.5$ and $h_{ef}/c_{sl} \geq 2.5$

- $h_{ef}/h_{sl} \geq 2.5$ can be satisfied by increasing h_{ef} if possible
  - Commercially available mechanical anchors have a limited range of h_{ef}
- $h_{ef}/c_{sl} \geq 2.5$ could be a challenge
  - Reduce anchor spacing
    - Could lower anchor breakout strength
    - May not satisfy minimum anchor spacing needed to prevent splitting failure



Source: ACI 318-19

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Bearing Strength in Shear

Fracture strength of concrete in front of shear lug

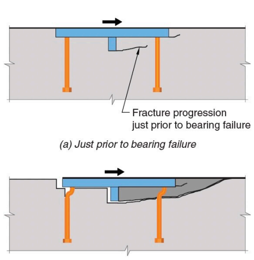
Bearing failure occurs at small displacements

After bearing failure

Strength drops significantly

Attachment undergoes large lateral displacement

Eventual anchor failure at steel shear strength (or weld fracture if the anchors are welded to the base plate)



(a) Just prior to bearing failure

(b) Just prior to anchor steel failure

Source: ACI 318-19

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Bearing Strength ($\phi V_{brg,sl}$)

$\phi V_{brg,sl} \geq V_u$ $\phi = 0.65$

$V_{brg,sl}$ = Nominal bearing strength

$V_{brg,sl} = 1.7 f_c' A_{ef,sl} \psi_{brg,sl}$

$A_{ef,sl}$ = Effective bearing area (see slide 27)

f_c' = Compressive strength in **psi**

$\psi_{brg,sl}$ = Bearing modification factor accounts for the effects of axial force on bearing strength

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Bearing Strength ($\phi V_{brg,sl}$)

- **No applied axial force**
  $\psi_{brg,sl} = 1$
- **Tensile applied axial force**
  $\psi_{brg,sl} = 1 + \frac{P_u}{nN_{sa}} \leq 1.0$
  P_u = Factored axial force is negative for tension
  n = Number of anchors in tension
  N_{sa}= Anchor nominal tensile steel strength
- **Compressive applied axial force**
  $\psi_{brg,sl} = 1 + 4\frac{P_u}{A_{bp} f_c'} \leq 2.0$
  P_u = Factored axial force is positive for compression
  A_{bp} = Area of base plate in contact with concrete or grout

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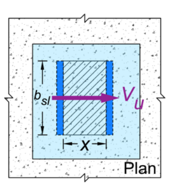
Bearing Strength ($\phi V_{brg,sl}$)

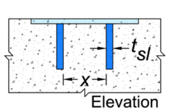
Attachments with multiple shear lugs perpendicular to the direction of applied shear

May add bearing strength of the individual shear lugs to determine the bearing strength of the attachment if $V_u/(xb_{sl}) \leq 0.2 f_c'$.

Bearing strength of each individual lug

Use effective area of each shear lug: $A_{ef,sl} = b_{sl}(2t_{sl})$





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Concrete Breakout Strength ($\phi V_{cb,sl}$) Shear ⊥ to Edge

$\phi V_{cb,sl} \geq V_u$ $\phi = 0.65$

Breakout strength where shear is perpendicular to the edge is similar to the method used for anchors:

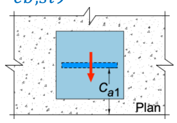
$\phi V_{cb,sl} \equiv \phi V_{cb} = \phi(A_{Vc}/A_{Vco})\,\psi_{ed,V}\,\psi_{c,V}\,\psi_{h,V} V_b$

$A_{Vco} = 4.5(c_{a1})^2$

$\psi_{ed,V}$ = edge effect factor, $\psi_{c,V}$ = cracking factor, $\psi_{h,V}$ = thickness factor

Following exceptions:

- $V_b = 9\lambda_a\sqrt{f'_c}(c_{a1})^{1.5}$
- Calculation of A_{Vc}



Note: For anchors, the smaller value from the following equations is selected:

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

$$V_b = 9\lambda_a\sqrt{f'_c}(c_{a1})^{1.5}$$

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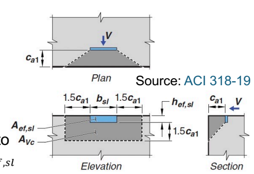
Concrete Breakout Strength of Shear Lugs A_{Vc}

A_{Vc} = Projected area of the failure surface on the side of the concrete member (similar to anchors)

- Project horizontally $1.5c_{a1}$ from the edge of shear lug
- Project vertically $1.5c_{a1}$ from the edge of the effective depth of the shear lug, $h_{ef,sl}$
  - $h_{ef,sl}$ = distance from the concrete surface to the bottom of the effective bearing area, $A_{ef,sl}$
- Do not include the effective area of the shear lug



Source: ACI 318-19

- Check if $1.5c_{a1}$ > edge distance
- Check if ($h_{ef,sl}$+$1.5c_{a1}$) > member thickness

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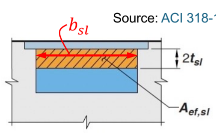
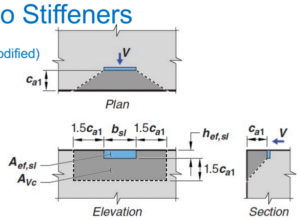
A_{Vc} For Cases With No Stiffeners

Source: ACI 318-19 (modified)



Elevation perpendicular to load



$A_{ef,sl} = h_{ef,sl} \times b_{sl} = 2t_{sl} \times b_{sl}$

$A_{Vc} = (3C_{a1} + b_{sl})(h_{ef,sl} + 1.5C_{a1}) - A_{ef,sl}$

$A_{Vc} = (3C_{a1} + b_{sl})(2t_{sl} + 1.5C_{a1}) - 2t_{sl} \times b_{sl}$

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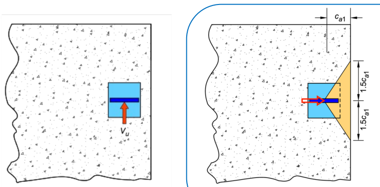
Concrete Breakout Strength ($\phi V_{cb,sl}$)
Shear || to Edge

V_u || to Edge: $\phi V_{cb,sl} \equiv 2\phi V_{cb,sl}$ for $V_u \perp$ to Edge



Actual direction of shear

Assumed direction of shear

Calculate breakout strength based on the assumed direction of shear, which is perpendicular to the edge.

Double this value to calculate breakout strength for the actual direction of shear.

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Concrete Breakout Strength ($\phi V_{cb,sl}$)
Corners

- V_u is ⊥ to Edge 1 and || to Edge 2
  - Edge 1: Calculate breakout strength directly
  - Edge 2: Calculate breakout strength for the assumed direction of V_u and double it
- Controlling value is the smaller value

Actual direction

Assumed direction

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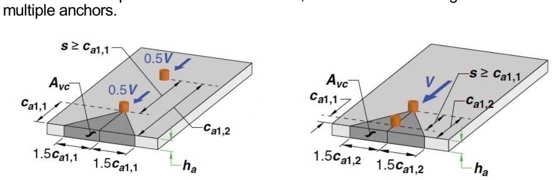
Attachments with Multiple Shear Lugs: Concrete Breakout Strength ($\phi V_{cb,sl}$)

Evaluate various potential breakout surfaces, similar to the following cases for multiple anchors.



Source: ACI 318-19

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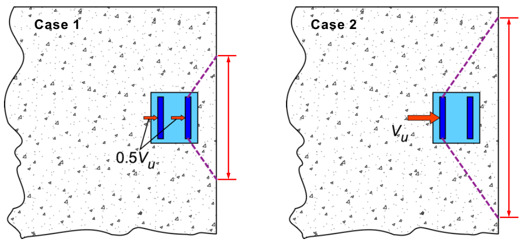
Attachments with Multiple Shear Lugs: Breakout Surfaces



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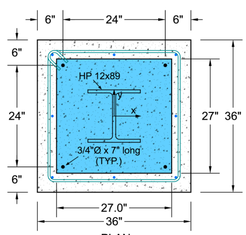
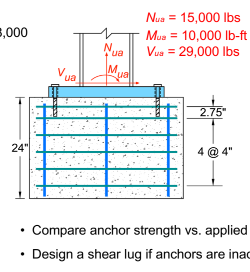
Example

f'_c = 5,000 psi NWC (post-installed anchors: 8,000 psi ✓ cast-in-place anchors: 10,000 psi ✓)





- Compare anchor strength vs. applied forces
- Design a shear lug if anchors are inadequate

ELEVATION

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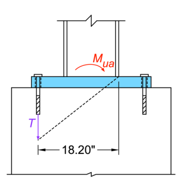
Example (cont.)

From complete solution:

- The base does not crack under service-level forces
- The base has also adequate to resist the design forces.
- Tensile force due to direction tension and overturning moment = 7,047 lbs (using a conservative method)
- Minimum edge distance, anchor spacing, and thickness are met
  - Concrete splitting is a nonissue



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Example (cont.)
Tensile Strength

- **Steel failure**

  $\frac{N_{ua}}{\phi N_{sa}} = \frac{7{,}047}{29{,}601} = \mathbf{0.24\ OK}$

- **Concrete breakout**

  $\frac{N_{ua}}{\phi N_{cb}} = \frac{7{,}047}{10{,}223} = \mathbf{0.69\ OK}$

- **Pullout**

  Product evaluation report: Pullout failure does not control for uncracked concrete and is not checked.

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Example (cont.)
Shear Strength

- **Steel failure**

  $\frac{V_{ua}}{\text{Toal } \phi V_{sa}} = \frac{29{,}000}{40{,}416} = \mathbf{0.72\ \ OK}$

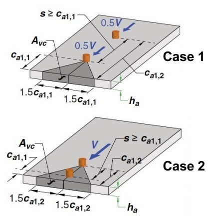
- **Pryout**

  $\frac{V_{ua}}{\phi V_{cp}} = \frac{29{,}000}{76{,}334} = \mathbf{0.38\ \ OK}$

- **Breakout**

  Case 1: $\frac{0.5V_{ua}}{\text{Total } \phi V_{cb}} = \frac{0.5 \times 29{,}000}{14{,}018} = \mathbf{1.03\ FAILS}$

  Case 1: $\frac{V_{ua}}{\phi V_{cbg}} = \frac{29{,}000}{23{,}563} = \mathbf{1.23\ FAILS}$



Source: ACI 318-19

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Example (cont.)
Shear Lug

Use a shear lug to resist 100% of V_u.

- $h_{ef}/h_{sl} \geq 2.5 \Rightarrow h_{sl} \leq 1.688$ in.

  Small embedment

- $h_{ef}/c_{sl} \geq 2.5 \Rightarrow c_{sl} \leq 1.688$ in.

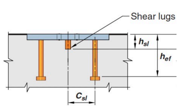
  Anchor spacing $\leq 2 \times 1.688$ in. $= 3.376$ in. $\approx 3\frac{3}{8}$ in.

  Min. spacing to avoid splitting failure

  $0.6h_{ef} = 0.6 \times 4.22$ in. $= 2.53$ in.

  $6d_a = 6 \times 3/4$ in. $= 4.5$ in. (controls)

  Required maximum anchor spacing $\approx 3\frac{3}{8}$ in. does not meet min. spacing



Source: ACI 318-19 (modified)

Note: This is a generic figure used only to illustrate various terms.

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Example (cont.)
Shear Lug

How about post-installed adhesive anchors?

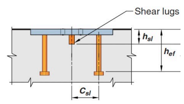
$C_{sl} = 24\text{ in.}/2 = 12\text{ in.}$

$h_{ef}/c_{sl} \geq 2.5 \rightarrow h_{ef} \geq 30\text{ in.}$

Two problems:

1. Base thickness = 24 in. This issue can be solved by making the base thicker.
2. Per ACI 318-19, length of adhesive length is limited to $20d_a$.

   $20d_a = 20 \times 3/4\text{ in.} = 15\text{ in.} < 30\text{ in.}$ **NG**



Source: ACI 318-19 (modified)

Note: This is a generic figure used only to illustrate various terms.

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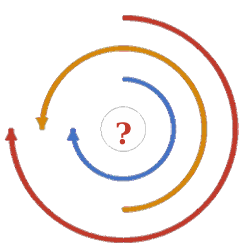

Generated by Claude

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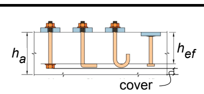
Example (cont.)
Shear Lug – Now What?



Source: ACI 318-19 (modified)

Use cast-in-place anchors

Still need to increase the member depth to satisfy $h_{ef}/c_{sl} \geq 2.5$

$h_{ef} = 30\text{ in.}$

To allow for at least 3 in. of cover under the anchor assembly, make the base 36" thick.

Use four ¾-inch diameter ASTM F1554 Gr. 55 threaded rods each 38 in. long

Adequate to resist M_{ua} = 10,000 lb-ft and N_{ua} = 15,000 lbs (see solution)

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Example (cont.)
Shear Lug – Dimensions

Design a shear lug to resist 100% of V_u = 29,000 lbs

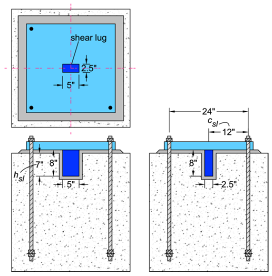
Shear lug: 2.5-in. thick × 8-in. deep x 5-in. wide with a 1-inch grout pad

h_{sl} = 8 in. −1 in. (grout pad) = 7 in.

h_{ef} = 30 in.

h_{ef}/h_{sl} = 30 in./ 7 in. = 4.29 > 2.5 ✓

h_{ef}/c_{sl} = 30 in./12 in. = 2.5 ✓



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Example (cont.)
Shear Lug – Concrete Bearing Failure

$A_{ef,sl} = (h_{ef,sl})b_{sl} = (2t_{sl})b_{sl}$ = (2×2.5)×5 = 25 in.^{2}

$V_{brg,sl} = 1.7 f'_c A_{ef,sl} \psi_{brg,sl}$

$\psi_{brg,sl} = 1 + \frac{P_u}{nN_{sa}} \leq 1.0$

P_u = −7,047 per anchor (see solution)

N_{sa} = 34,900 lbs (see solution)

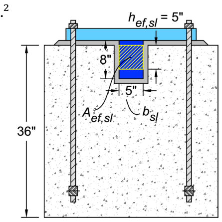
n = 1 (calculations are per anchor)

$\psi_{brg,sl}$ = 0.798

$V_{brg,sl}$ = 169,575 lbs

ϕ = 0.65

$\phi V_{brg,sl}$ = 110,224 lbs > V_{ua} (29,000 lbs) **OK**



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Example (cont.)
Shear Lug – Concrete Breakout Failure

$\phi V_{cb,sl} \equiv \phi V_{cb} = \phi(A_{Vc}/A_{Vco})\psi_{ed,V}\psi_{c,V}\psi_{h,V}V_b$

$A_{Vco} = 4.5(c_{a1})^2 = 4.5(16.75)^2$ = 1,263 in.^{2}

$A_{ef,sl}$ = 25 in.^{2} (see previous slide)

A_{Vc} = (36×30.125) − $A_{ef,sl}$ = 1060 in.^{2}

$A_{Vc} < A_{Vco}$ ✓

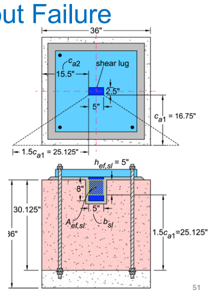
From solution:

V_b = 46,626 lbs, $\psi_{ed,V}$ = 0.885

$\psi_{c,V}$ = 1.4, $\psi_{h,V}$ = 1, ϕ = 0.65

$V_{cb,sl}$ = 45,365 lbs

$\phi V_{cb,sl}$ = 29,487 lbs ≥ V_{ua} (29,000 lbs) **OK**



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Summary

- An overview of shear lugs was presented
  - Detailing requirements
  - Load resistance mechanism
  - Design equations for bearing and breakout strength
- Example problem
  - Reviewed key concepts from Webinar 1
  - Illustrated design of shear lugs

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Summary

- Satisfying ACI requirements ($h_{ef}/h_{sl} \geq 2.5$ and $h_{ef}/c_{sl} \geq 2.5$) for shear lugs could become challenging (if not impossible) for post-installed anchors.
- Shear lugs are more common in cases with cast-in-place anchors.

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Thank you.

You now have the basic concepts and equations for design of shear lugs and, equally important, know potential issues that need to be addressed.

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Webinar Documents

https://www.pci.org/AnchoringToConcreteImp

7 2026 Anchoring Imp Series Webinar 2 with Dr Shahrooz July 15 2026

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Questions
Key Takeaways

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Thank you!

Please sign up for future NCBC webinars

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Extra Slides

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Effective Bearing Area ($A_{ef,sl}$)

$A_{ef,sl}$ is below the concrete surface, perpendicular to the applied shear according to the following criteria:

- Bearing area of shear lugs located within $2t_{sl}$ (thickness of shear lug) of the bottom surface of the base plate if the top or bottom surface of the base plate is flush with the surface of the concrete
- Bearing area of shear lugs located within $2t_{sl}$ of the surface of the concrete if the base plate is above the surface of the concrete
- For cases with stiffeners
  - Bearing area of shear lugs located within $2t_{sl}$ of the interface with stiffeners
  - Bearing area on the leading edge of stiffeners below the surface of the concrete

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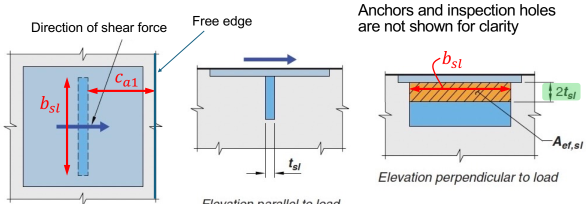
Effective Bearing Area ($A_{ef,sl}$) Without Stiffeners

Anchors and inspection holes are not shown for clarity



Plan

Elevation parallel to load

Elevation perpendicular to load

Source: ACI 318-19 (modified)

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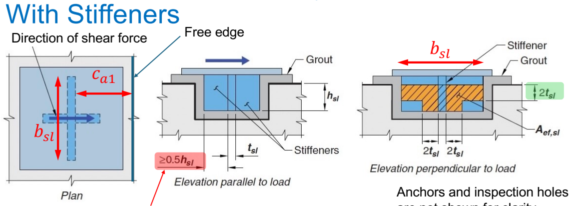
Effective Bearing Area ($A_{ef,sl}$) With Stiffeners



Note the minimum stiffener dimension $\geq 0.5h_{sl}$

Anchors and inspection holes are not shown for clarity

$A_{ef,sl} = t_{sl}(2b_{sl} + 5h_{sl} - 10t_{sl})$

Source: ACI 318-19 (modified)

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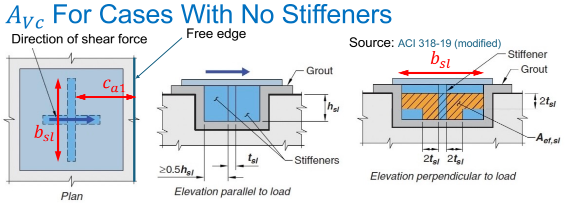
A_{Vc} For Cases With No Stiffeners

Source: ACI 318-19 (modified)



$A_{Vc} = (3C_{a1} + b_{sl})(h_{ef,sl} + 1.5C_{a1}) - A_{ef,sl} = (3C_{a1} + b_{sl})(2t_{sl} + 1.5C_{a1}) - A_{ef,sl}$

$A_{ef,sl} = t_{sl}(2b_{sl} + 5h_{sl} - 10t_{sl})$

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Example
Tensile Strength (Concrete Breakout)

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

$A_{Nco} = 9h_{ef}^2 = 9\times 4.22^2 = 160.3 \text{ in.}^2$

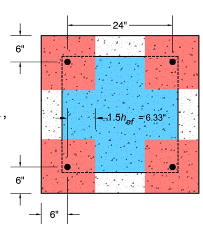
$A_{NC} = (6 + 6.33)^2 = 152 \text{ in.}^2$

$A_{NC} < nA_{Nco}$ $(n = 1)$ ✓

From solution: $N_b = 14{,}712$ lbs, $\psi_{ed,N} = 0.984$, $\psi_{c,N} = 1$, $\psi_{cp,N} = 0.933$, $\phi = 0.75$

$\phi N_{cb} = 10{,}223$ lbs

$\frac{N_{ua}}{\phi N_{cb}} = \frac{7{,}047}{10{,}223} = \mathbf{0.69\ OK}$



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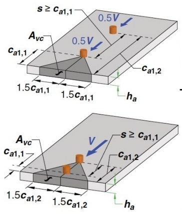
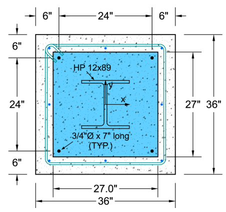
Example
Shear Strength (Concrete Breakout)



Two cases:

Front anchors resist $0.5V_{ua}$

Back anchors resist V_{ua}



Source: ACI 318-19

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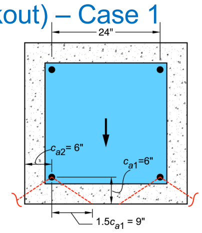
Example
Shear Strength (Concrete Breakout) – Case 1

$\phi V_{cb} = \phi(A_{Vc}/A_{Vco})\psi_{ed,V}\psi_{c,V}\psi_{h,V}V_b$



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Example
A_{Vco} and A_{Vc}

A_{Vco} = Projected concrete failure area of a single anchor for shear strength calculation, if not limited by corner influences, spacing, or member thickness

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

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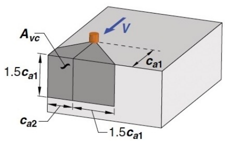
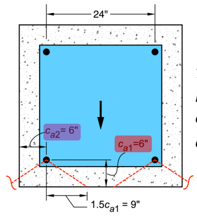
Example
A_{Vco} and A_{Vc}



Source: ACI 318-19



$1.5c_{a1} = 1.5{\times}6 \text{ in.} = 9 \text{ in.}$
$h_a = 24 \text{ in.} > 1.5c_{a1}$
$c_{a2} = 6 \text{ in.}$
$c_{a2} < 1.5c_{a1}$

$A_{Vco} = 4.5c_{a1}^2 = 4.5{\times}6^2 = 162 \text{ in.}^2$
$A_{Vc} = 1.5c_{a1}(1.5c_{a1} + c_{a2})$
$A_{Vc} = (1.5{\times}6)(1.5{\times}6 + 6) = 135 \text{ in.}^2$

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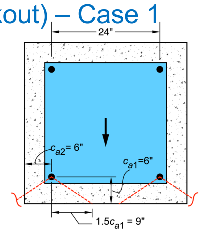
Example
Shear Strength (Concrete Breakout) – Case 1

$\phi V_{cb} = \phi(A_{Vc}/A_{Vco})\psi_{ed,V}\psi_{c,V}\psi_{h,V}V_b$
$A_{Vco} = 162 \text{ in.}^2$
$A_{Vc} = 135 \text{ in.}^2$
$A_{Vc} < nA_{Vco}$ $(n = 1)$ ✓ (failure planes do not overlap)
From solution: $V_b = 8{,}900$ lbs, $\psi_{ed,V} = 0.9$, $\psi_{c,V} = 1.4$, $\psi_{h,V} = 1$, $\phi = 0.75$
Total $\phi V_{cb} = 2{\times}7{,}009 \text{ lbs} = 14{,}018 \text{ lbs}$ (failure planes do not overlap)
$0.5\,V_{ua}/\text{Total } \phi V_{cb} = (0.5{\times}29{,}000)/14{,}018 = \mathbf{1.03}$ **FAILS**



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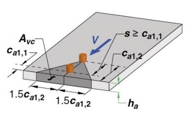
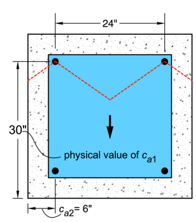
Example
Shear Strength (Concrete Breakout) – Case 2

$\phi V_{cbg} = \phi(A_{Vc}/A_{Vco})\psi_{ec,V}\psi_{ed,V}\psi_{c,V}\psi_{h,V}V_b$





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Example
Shear Strength (Concrete Breakout) – Case 2

$\phi V_{cbg} = \phi(A_{Vc}/A_{Vco})\psi_{ec,V}\psi_{ed,V}\psi_{c,V}\psi_{h,V}V_b$

Physical value of c_{a1} = 30 in.

h_a(= 24 in.) < $1.5c_{a1}$ **AND** c_{a2} (= 6 in.) < $1.5c_{a1}$

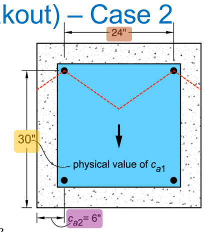
c_{a1} is limited to the greater value of

- $c_{a2}/1.5 = 6/1.5 = 4$ in.
- $s/3 = 24/3 = 8$ in.
- $h_a/1.5 = 24/1.5 = 16$ in. ← use this as c_{a1}

$A_{Vco} = 4.5c_{a1}^2 = 4.5 \times 16^2 = 1{,}152$ in.^{2}

$A_{Vc} = (1.5c_{a1}) \times (6 + 24 + 6) = (1.5 \times 16)36 = 864$ in.^{2}

$A_{Vc} < nA_{Vco} = 2 \times 1{,}152 = 2{,}304$ in.^{2} ✓



$1.5c_{a1} = h_a$, so the entire value of $1.5c_{a1}$ can be used.

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Example
Shear Strength (Concrete Breakout) – Case 2

$\phi V_{cbg} = \phi(A_{Vc}/A_{Vco})\psi_{ec,V}\psi_{ed,V}\psi_{c,V}\psi_{h,V}V_b$

From solution: $V_b = 38{,}756$ lbs, $\psi_{ec,V} = 1$, $\psi_{ed,V} = 0.775$, $\psi_{c,V} = 1.4$, $\psi_{h,V} = 1$, $\phi = 0.75$

$\phi V_{cbg} = 23{,}563$ lbs

$V_{ua}/\phi V_{cbg} = 29{,}000/23{,}563 = \mathbf{1.23}$ **FAILS**

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