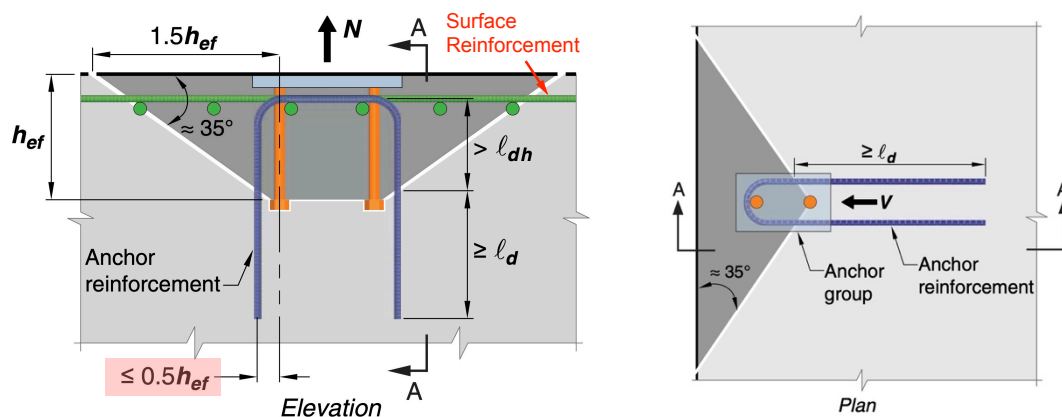


The following excellent questions were raised during the presentation. In the following, all the questions are answered even though those that were answered quickly after the presentation. If there're additional questions or you need further clarifications about the answer, Dr. Shahrooz can be contacted via email: shahroozllc@gmail.com

1. In case of post installed anchors in existing concrete, the existing reinforcement also play role in concrete breakout strength. Is there any formula in Code, which take this existing reinforcement as a supplementary reinforcement which may help in reducing the concrete breakout failure? In standard design codes like the ACI 318 Building Code, the baseline calculation for concrete breakout strength assumes plain concrete with no contribution from existing reinforcement.

In the case of screw anchors or other post-installed anchors, anchor reinforcement can't be practically added. According to ACI 318, "Strut-and-tie models may be used to design anchor reinforcement." However, the contribution of existing reinforcement may be considered as long as it meets the same requirements of anchor reinforcement for cast-in-place anchors. It's important to note that in contrast to anchor reinforcement, supplementary reinforcement does not need to be developed.

Per ACI 318, "An explicit design of supplementary reinforcement for anchor-related forces is not required; however, the arrangement of supplementary reinforcement should generally conform to that of the anchor reinforcement ...". Examples of anchor reinforcement are provided in extra slides 80-81, two of the cases are shown below. Note that for tensile loading, reinforcement needs to be within $0.5h_{ef}$ from anchor's center in order to be effective. Recent tests have shown that the contribution of "surface reinforcement" (as identified below) is much smaller than reinforcement that's in the direction of anchors.



Source: ACI 318-19 (modified)

2. Can you please share NHCRP report with us?

Yes, the report is one of the resource documents.

3. For post installed anchor in reinforced concrete, can we consider that as having supplementary reinforcement?

Yes, as long as they're "similar" to supplementary reinforcement that would be installed around cast-in anchors. Please see Q1 for further information.

4. Since concrete pryout strength is a multiple of the tension breakout strength and anchor reinforcement can be used in place of concrete breakout strength, can anchor reinforcement be used in the calculation of concrete pryout strength?

Pryout strength is the product of a factor (1 or 2) and tensile breakout strength. For tensile breakout strength, the strength reduction factor (ϕ) depends on whether supplementary reinforcement is provided or not. So, supplementary reinforcement is implicitly taken out for calculating pryout strength.

5. What is the basis of the reduction of steel strength for grout pads?

For cases without a grout pad, shear is transferred directly to anchor. When there's a grout pad, shear has to be transferred through the height of anchor before reaching the embedded anchor. Reliance on bearing against grout shouldn't be taken into account because grout can crush leaving an unsupported length between, say, a column base plate and the top surface of the element into which the anchor is attached. As a result, there'll be some bending in the anchor. The reduction factor of 0.8 approximates combined shear and flexural stresses.

6. For slide 53, do we use the minimum capacity from cases 1 and 2? (Assuming steel failure does not control.)

If the distance between anchors (s) exceeds $1.5c_{a1,1}$ (edge distance of the front anchor), the controlling value is the smaller value from cases 1 and 2. If anchors are welded to a common plate, only case 2 is checked. If $s < 1.5c_{a1,1}$, only case 3 is checked.

7. Can you elaborate on the supplementary reinforcement in terms of detailing? For example, what entitles the supplementary reinforcement? Can all the reinforcement that crosses failure surfaces be counted as supplementary reinforcement while they are also counted as main reinforcement for other design forces (shear or flexure)?

Please see response to Q1.

8. How do we handle design for torsion?

Torque can be converted into shear forces. Anchors are designed for equivalent shear forces.

9. On slide 53, what V need to be used in checking the Anchor (steel) failure?

ACI commentary R17.7.1 states "The shear applied to each anchor in an anchor group may vary depending on assumptions for the concrete breakout surface and load redistribution ...". Therefore, V used to check steel failure strength is the same as what's shown on this slide.

10. Question arises because slide 53 focuses on the concrete failure. Shear (V) load distribution on individual anchor. Total shear is from the AASHTO, but the shear demand on the individual anchors is per the figure shown?

V shown on this slide is the shear demand (V_u), which is calculated using AASHTO load factors and load combinations.

11. In page 53, if there are more the two rows of anchors, do we distribute the shear force evenly to each row (e.g., 0.33V for each row of 3 rows)?

Yes, for case 1 with 3 anchors, 0.33V is used. An excellent article published in January 2024 edition of STRUCTURE magazine covers more “challenging” cases. The paper is provided at the end of this document.

12. For clarification, manufacturer values control over calculated values?

Yes, manufacturer values would be used instead of those calculated from ACI equations. These values are from qualification tests.

13. Would it be possible to share the presentation slides afterward? I'd like to review some of the material again for my notes. Thanks in advance!

Yes, the entire presentation and all the referenced documents can be downloaded:

Link: <https://www.pci.org/AnchoringToConcreteImp>

Folder: 6 2026 Anchorage to Concrete Webinar 1 with Dr. Shahrooz May 20 2026

14. How amount of reinforcement in concrete body considered in calculating capacity of concrete breakout area (A_{vc}/A_{vco})?

The amount of reinforcement doesn't affect A_{vc}/A_{vco} . These areas are a function of anchor spacing and edge distances. The effect of reinforcement is taken into account by using $\phi = 0.70$ or 0.75 depending on whether supplementary reinforcement is not provided or provided, respectively. Please slide 45.

15. For tension anchor bolts, what would happen if the bolts are installed at a closer distance than the minimum recommended spacing? For example, 6" minimum spacing and 5" used spacing.

Splitting failure could become an issue. Anchor design software packages do not allow anchor spacing or edge distance less than ACI specified values unless test data support smaller values can be used.

16. If you have an anchor in a buried deadman used for temporary shoring, do you still need to consider breakout?

If the deadman block is not buried, anchor design would be the same as if the anchor is installed in a member. For a buried deadman block, the design would be the same because the soil around the deadman is not stiff enough to resist breakout.

17. Is there any guidance for through bolting to concrete? We have run into conditions where we through bolt into the concrete either with a plate on both sides of the concrete or on only one side.

A “through bolt” on only one side apparently refers to a wedge anchor. Sometimes, wedge anchors are referred to as through bolt, which is not quite correct. Wedge anchors are a type of expansion anchor, which is covered by ACI. A through-bolt anchor passes through the entire member; these are typically threaded rods. Such anchors are not covered by ACI. Engineering principles and judgement need to be followed, e.g., one could use ACI equations with h_{ef} taken as the member thickness. The holes need to be grouted to ensure the anchors have sufficient bearing strength against the holes through which the anchors pass. Through-bolt anchors need to be “clamped” down to resist the calculated tension force. The turn of nut or a torque wrench could be used. One may need to tighten more to account for relaxation. Also, double nuts should be used to ensure the nuts won’t loosen over time. Bearing strength under the attachment needs to be checked.

18. In a majority of cases when anchoring is to a bridge element, there is reinforcement in the element. How to take advantage of that to improve the anchoring.

Please see answer to Q1.

19. Does the 35-degree angle depend on the concrete strength?

No, but we need to remember f'_c is limited to 10 ksi for cast-in-place anchors and 8 ksi for post-installed anchors. Higher values may be used if verified by test data.

20. How the concrete tensile strength is determined: Split tensile or 10 percent of the compressive strength.

Tensile strength of concrete, which is based on modulus of rupture, is not used for anchor design.

21. What are the pros and cons of screw anchors vs wedge anchors? If all other variables are equal, is one found to be stronger than the other?

Screw anchors can be installed much faster than wedge anchors. Also, screw anchors are removable, which might be needed for temporary fixtures.

22. It appears you need to put all of the shear on the front anchors if s is less than $0.5c_{a1}$. Can you assume the back anchor(s) take any shear if s is close to being greater than $0.5c_{a1}$.

**** I mean $s > c_{a1}$ (correction)**

If $s > c_{a1,1}$ ($c_{a1,1}$ is the edge distance of the front anchor), two cases need to be considered: (1) failure is initiated from the front anchor which has to resist $V/2$ (if there’re two anchors) and (2) failure is initiated from the back anchor which has to resist V . Both cases have to be checked to see which one controls. The spacing between anchors (s) is compared against the edge distance of the front anchor ($c_{a1,1}$) and not the back anchor ($c_{a1,2}$).

23. Do you use ACI Coefficients (Phi factors) for strength reduction or the AASHTO LRFD factors in calculating the resistance?

Design forces (V_u , T_u , etc.) are computed using AASHTO LRFD load combinations and load cases. Reduction factors (ϕ) are specific to anchors and are based on Chapter 17 of ACI.

24. How is fatigue capacity, under traffic load, handled in bridge application?

ACI Chapter 17 does not address high-cycle fatigue or impact loads. However, AASHTO Article 5.13 allows the use of ACI Chapter 17 for “anchors attaching pedestrian or bicycle rails or fences separated from the roadway by a traffic railing”. Design forces for such anchors would include impact loads.

Design for high-cycle fatigue requires engineering judgement. For example, breakout cracking factor for tension and shear ($\psi_{c,N}$ or $\psi_{c,V}$) should be calculated assuming cracked concrete.

25. How to calculate the anchor strength when the edge of concrete is neither parallel nor perpendicular to the applied force, like in a circular column?

Engineering judgement is necessary for such cases that are not covered by ACI. A conservative option is to draw a circle within the circular element. The square is used to determine edge distances. Moreover, the anchors should be located within this imaginary square. The strengths from this method would be conservative because the actual edge distances are larger than those from this simplified method.

26. If you install an anchor inside a beam on the top side of beam and you have a monolithic slab on the side of the beam, can I use infinite edge distance using beam depth as concrete thickness? Or do I need to use the distance to the edge of the beam as edge distance, even though we have a slab confining the side of the beam against concrete breakout?

If the two elements are designed to perform as a monolithic system, slab extension could be taken into account when determining anchor edge distance.

27. Cases 1 through 3 show $h_a < 1.5c_a$ for shear. Do you still need evaluate Cases 1 through 3 for large values of h_a ?

The calculations would remain the same, except h_a is replaced by $1.5c_{a,1}$ for cases 1 and 3 and $1.5c_{a,2}$ for case 2. Please see slide 52 for why h_a changes to $1.5c_a$ ($1.5c_{a,1}$ or $1.5c_{a,2}$ for slide 53).

ANCHORING to CONCRETE

Shear Concrete Breakout Calculations for Anchorages With Multiple Rows

Extrapolating ACI 318-19(22) shear concrete breakout provisions for complex anchorages.

By Richard T. Morgan, P. E.

Anchoring-to-concrete provisions in the American Concrete Institute (ACI) standard titled *Building Code Requirements for Structural Concrete* (ACI 318) illustrate how to calculate shear concrete breakout strength for two rows of anchors having one anchor in each row. Many anchorages consist of more than two anchor rows, having multiple anchors in each row, requiring the engineer to extrapolate these provisions. This article discusses how one could extrapolate ACI 318-19(22) provisions to calculate shear concrete breakout strength for anchorages consisting of multiple anchor rows with multiple anchors in each row.

Overview of ACI 318-19(22) Anchoring-to-Concrete Provisions for Shear Concrete Breakout

Shear concrete breakout occurs at a fixed edge when shear load acts towards that edge. ACI 318-19(22) Section 17.7.2.1 provides equations for calculating nominal concrete breakout strength in shear for a single anchor (V_{cb}) and an anchor group (V_{cbg}). These equations are as follows:

$$\text{Single anchor } V_{cb} = \frac{A_{Vc}}{A_{Vc0}} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \quad (\text{Eq.17.7.2.1a})$$

$$\text{Anchor group } V_{cbg} = \frac{A_{Vc}}{A_{Vc0}} \psi_{ec,V} \psi_{ed,V} \psi_{c,V} \psi_{h,V} V_b \quad (\text{Eq.17.7.2.1b})$$

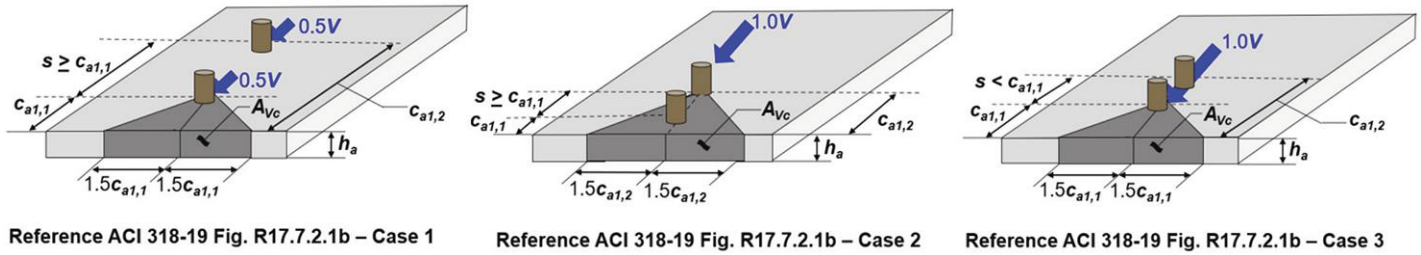
The parameters in (Eq. 17.7.2.1a) and (Eq. 17.7.2.1b) are defined in Table 1.

The parameter c_{a1} referenced in Table 1 corresponds to the distance in the direction of the applied shear load from the center of a single anchor or from a line through a row of anchors to a fixed concrete edge. When an anchorage consists of multiple anchor rows, the nominal concrete breakout strength in shear for the group of anchors, V_{cbg} , can be calculated using a c_{a1} value from a specific row. ACI 318-19(22) considers three cases for determining the value of c_{a1} . Each case considers the spacing between anchor rows in the direction of the applied shear load, which influences where potential concrete breakout failure surfaces can develop, and the magnitude of shear load assumed to act on a particular row. ACI 318-19(22) Fig. R17.7.2.1b (reproduced in Figure 1) illustrates these three cases for a simple anchor arrangement consisting of two anchor rows, with one anchor in each row.

Figure 2 illustrates how the three ACI 318-19(22) cases for shear concrete breakout could be extrapolated for an anchorage consisting of three rows with three anchors in each row. Case 1 (Figure 2a) assumes the shear load (V_{ua}) is equally distributed between Rows 1, 2, and 3 if the row spacings, $s_{y,12}$ and $s_{y,23}$, are greater than or equal to $c_{a1, \text{row } 1}$. For Rows 1, 2, and 3, if the anchor spacings $s_{x,1}$ and $s_{x,2}$ perpendicular to the direction of V_{ua} are less than or equal to $3c_{a1, \text{row } 1}$, the anchors in each of these rows are considered to act as a group per ACI 318-19(22) 17.5.1.3.1. Since $s_{y,12}$ and $s_{y,23}$ are greater

Table 1

Parameter	Description	ACI 318-19 Equation
A_{Vc}	projected concrete failure area	reference Fig. R17.7.2.1b
A_{Vc0}	idealized concrete failure area for a single anchor	$A_{Vc0} = 4.5(c_{a1}^2)$ Eq. (17.7.2.1.3)
$\psi_{ec,V}$	modification factor for eccentric load	$\psi_{ec,V} = \frac{1}{(1 + \frac{e_V}{1.5c_{a1}})}$ Eq. (17.7.2.3.1)
$\psi_{ed,V}$	modification factor for edge distance (c_{a2}) when $c_{a2} < 1.5c_{a1}$	$\psi_{ed,V} = 0.7 + 0.3 \frac{c_{a2}}{1.5c_{a1}}$ Eq. (17.7.2.4.1b)
$\psi_{c,V}$	modification factor for uncracked concrete, or cracked concrete with supplementary reinforcement	reference Section 17.7.2.5
$\psi_{h,V}$	modification factor for concrete thickness (h_a) when $h_a < 1.5c_{a1}$	$\psi_{h,V} = \sqrt{\frac{1.5c_{a1}}{h_a}}$ Eq. (17.7.2.6.1)
V_b	basic concrete breakout strength (anchors not rigidly attached to fixture)	$V_b = (7(\frac{l_e}{d_a})^{0.2} \sqrt{d_a}) \lambda_a \sqrt{f'_c} (c_{a1})^{1.5}$ Eq. (17.7.2.2.1a)
	basic concrete breakout strength (anchors rigidly attached to fixture)	$V_b = (8(\frac{l_e}{d_a})^{0.2} \sqrt{d_a}) \lambda_a \sqrt{f'_c} (c_{a1})^{1.5}$ Eq. (17.7.2.2.2)
	basic concrete breakout strength (limiting equation)	$V_b = 9\lambda_a \sqrt{f'_c} (c_{a1})^{1.5}$ Eq. (17.7.2.2.1b)



Reference ACI 318-19 Fig. R17.7.2.1b – Case 1 Reference ACI 318-19 Fig. R17.7.2.1b – Case 2 Reference ACI 318-19 Fig. R17.7.2.1b – Case 3

Figure 1 ACI 318-19(22) Shear Concrete Breakout Assumptions.

than or equal to $c_{a1, row 1}$, the c_{a1} value used to calculate V_{cbg} can be taken as equal to $c_{a1, row 1}$, and V_{ua} can be assumed to be equally distributed on each anchor row. For the example illustrated in Figure 2a, Case 1 is satisfied if the design concrete breakout strength (ϕV_{cbg}) calculated with $c_{a1, row 1}$ is greater than or equal to ($V_{ua}/3$).

Case 2 (Figure 2b) is an alternative design assumption to Case 1 and assumes a full failure surface could develop from the anchor row farthest from the fixed edge (Row 3) if the spacing between rows in the direction of V_{ua} is greater than or equal to c_{a1} for the row nearest the fixed edge ($c_{a1, row 1}$). The total shear load is assumed to act on Row 3. If the anchor spacings $s_{x,1}$ and $s_{x,2}$ perpendicular to the direction of V_{ua} are less than or equal to $3c_{a1, row 1}$, the anchors in each of these rows are considered to act as a group per ACI 318-19(22) 17.5.1.3.1. Case 2 is satisfied if ϕV_{cbg} calculated for the anchors in Row 3 using $c_{a1, row 3}$ is greater than or equal to the total shear load V_{ua} .

Case 3 (Figure 2c) assumes a full failure surface can only develop from the anchor row nearest to the fixed edge (Row 1) because the spacing between rows in the direction of V_{ua} is less than c_{a1} for the row nearest the fixed edge ($c_{a1, row 1}$). The total shear load is assumed to act on Row 1. If the anchor spacings $s_{x,1}$ and $s_{x,2}$ perpendicular to the direction of V_{ua} are less than or equal to $3c_{a1, row 1}$, the anchors in each of these rows are considered to act as a group per ACI 318-19(22) 17.5.1.3.1. Since $s_{y,12}$ and $s_{y,23}$ are less than $c_{a1, row 1}$, Case 3 assumes a full concrete breakout surface cannot develop from either Row 2 or Row 3, so the c_{a1} -value used to calculate V_{cbg} is taken equal to $c_{a1, row 1}$. Case 3 is satisfied if ϕV_{cbg} calculated for the anchors in Row 1 using $c_{a1, row 1}$ is greater than or equal to the total shear load V_{ua} .

If anchors are not rigidly attached (e.g., not welded) to a fixture, shear load cannot necessarily be re-distributed between rows, potentially

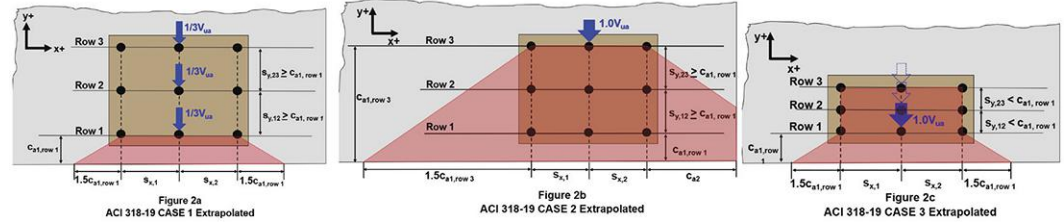


Figure 2 Extrapolated ACI 318-19(22) Shear Concrete Breakout Assumptions.

precluding the assumptions utilized in Case 2. Examples of anchors not rigidly attached to a fixture include post-installed anchors and ASTM (American Society for Testing and Materials) F1554 headed bolts. However, if anchors are rigidly attached (e.g., welded) to a fixture, Case 2 is the default assumption when calculating ϕV_{cbg} because the shear load can be redistributed to the back row of anchors, thereby permitting the assumptions utilized in Case 2. Examples of anchors rigidly attached to a fixture include AWS (American Welding Society) D1.1 headed studs.

How To Determine C_{a1} ? – Things To Consider

As noted on page 1, the parameter c_{a1} corresponds to the distance in the direction of the applied shear load from the center of a single anchor or from a line through the center of anchors in a row to the edge where shear concrete breakout is assumed to occur. Shear concrete breakout occurs when the applied shear load causes the attached fixture to bear on the anchors such that a failure surface develops from the anchors to a fixed concrete edge.

If anchors are not rigidly attached to a fixture, an annular space exists between each anchor and the fixture. The origin of a potential failure surface depends on which anchors are assumed to be in bearing with the fixture and the spacing between anchors in the direction of the shear load. For example, if all anchors are centered in the fixture holes, bearing could occur simultaneously on each anchor as the shear load is applied, and a failure surface could develop from one or more anchor rows. However, if any anchors are not centered in the fixture holes, the location of potential failure surfaces becomes more difficult to predict because the fixture may be bearing on some anchors but not all of them. Likewise, the spacing between anchors in the direction of the shear load influences whether a full or partial failure surface can develop from a given anchor or anchor row assumed to be in bearing with the fixture.

Assuming which anchors are in bearing with the fixture also influences how the shear load can be distributed on those anchors. ACI 318-19(22) design assumptions consider two anchor rows with one anchor in each row. For anchorages consisting of more than two anchor rows with multiple anchors in each row, these design assumptions must be extrapolated to consider which anchor rows are in bearing with the fixture, permitting the formation of

LOAD DISTRIBUTION ON ANCHORS IN SHEAR – THINGS TO CONSIDER

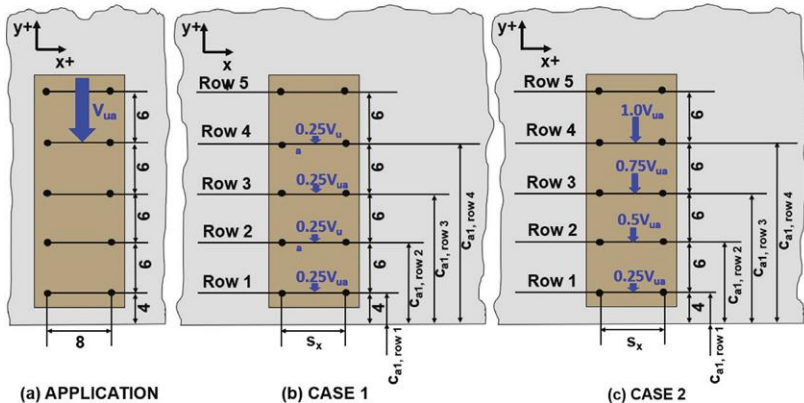


Figure 3 Examples of Potential Load Distribution for Multiple Anchor Rows in Shear.

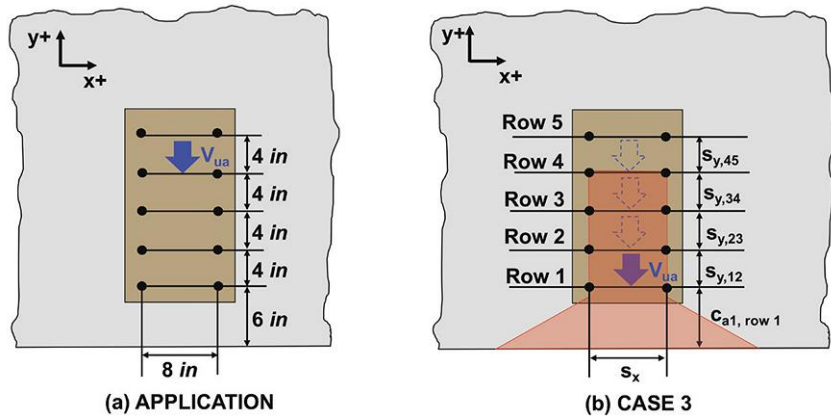


Figure 4 Example of Case 3 Load Distribution for Multiple Anchor Rows in Shear.

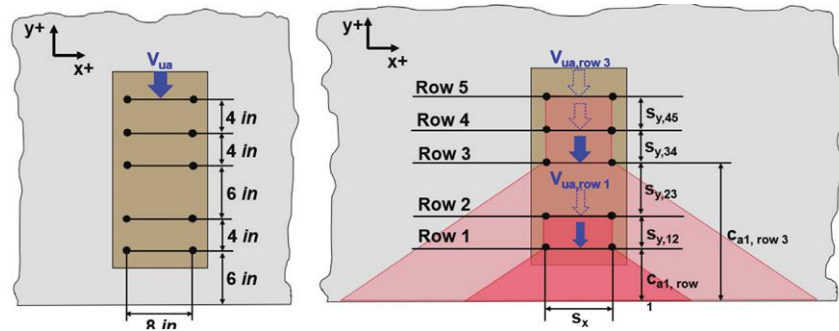


Figure 5 Example of Multiple Anchor Rows Unequally Spaced and Loaded in Shear.

a potential failure surface, and the shear load distribution among these rows.

Load Distribution On Anchors In Shear – Things To Consider

When an anchorage consists of more than two rows resisting shear load, the engineer must decide how the load is distributed on each row. For example, the anchorage shown in Figure 3 consists of five rows. Assume the anchors are not rigidly attached to the plate. Shear load (V_{ua}) acts towards the $-y$ edge. Assuming shear lag, only Rows 1, 2, 3, and 4 will be considered in this example to resist shear load. The edge distance $c_{a1,row 1}$ corresponds to the distance of the anchors in Row 1 to the $-y$ edge (4 inches). Anchor spacing in the x direction (s_x) equals 8 inches, so the anchors in each row act as a group because s_x is less than $3c_{a1,row 1}$. Spacing in the y direction between each anchor row equals 6 inches, which is greater than $c_{a1,row 1}$ so both Case 1 and Case 2 can be considered when calculating the design concrete breakout strength in shear (ϕV_{cbg}). The distribution of V_{ua} among rows 1, 2, 3, and 4 must now be considered. Case 1 assumes equal load distribution per row. Case 2 assumes the total shear load is applied to Row 4; however, consideration could be given to the possibility that some fraction of V_{ua} acts on Rows 1, 2, and 3. Therefore, if Case 2 is considered, ϕV_{cbg} could be calculated for each row using the c_{a1} -value for that row and checked against some fraction of V_{ua} assumed to be acting on that row.

Case 1, shown in Figure 3b, assumes ϕV_{cbg} is calculated using $c_{a1,row 1}$, and V_{ua} is distributed equally among Rows 1, 2, 3, and 4. $\phi V_{cbg,row 1}$ is checked against $(0.25 V_{ua})$. Case 2, shown in Figure 3c, illustrates how the total shear load is assumed to act on Row 4, while some fraction of V_{ua} is assumed to act on Rows 1, 2, and 3. $\phi V_{cbg,row n}$ is checked against $V_{ua,row n}$ for each row.

The percent utilization for Case 1 ($0.25 V_{ua} / \phi V_{cbg,row 1}$) must be checked against the highest percent utilization for Case 2 ($V_{ua,row n} / \phi V_{cbg,row n}$).

The largest value controls the design.

For the anchorage shown in Figure 4, assume the anchors are not rigidly attached to the plate. Due to shear lag, only Rows 1, 2, 3, and 4 will be assumed to resist shear. The edge distance $c_{a1,row 1}$ equals 6 inches and the spacing in the y direction between each anchor row equals 4 inches. The spacing s_x equals 8 inches, so the anchors in each row act as a group because s_x is less than $3c_{a1,row 1}$. Case 3 applies because the spacing in the y direction between all anchor rows is less than $c_{a1,row 1}$; therefore, a full failure surface can only develop from the anchors in Row 1 because the failure surfaces for the other anchor rows merge with each other. The total shear load ($1.0 V_{ua}$) is assumed to act on Row 1, and the design concrete breakout strength (ϕV_{cbg}) calculated using $c_{a1,row 1}$ is checked against V_{ua} .

Now consider the anchorage shown in Figure 5. Assume five rows of anchors not rigidly attached to a plate are subjected to a shear load (V_{ua}) acting towards the $-y$ edge. No shear lag is assumed, so all five rows can resist shear load. Assume $c_{a1,row 1}$ equals 6 inches. The spacing s_x equals 8 inches, so the anchors in each row act as a group because s_x is less than $3c_{a1,row 1}$. The spacing s_y between each row varies. Assuming which anchor rows resist shear load becomes more challenging, and it can be difficult to implement the load distribution assumptions of Cases 1, 2, and/or 3.

The spacings $s_{y,12}$, $s_{y,34}$ and $s_{y,45}$ shown in Figure 5 are less than $c_{a1,row 1}$ so Case 3 is relevant to calculating concrete breakout with respect to Rows 1 and 2, as well as Rows 3, 4, and 5. Case 3 assumes the failure surface

from Row 2 merges into the failure surface for Row 1, and the failure surfaces from Rows 4 and 5 merge into the failure surface for Row 3. However, $s_{y,23}$ shown in Figure 5 is equal to $c_{a1,row 1}$, so Case 2 is also relevant to calculating concrete breakout with respect to Rows 1 and 3. Therefore, the design must consider concrete breakout strength for failure surfaces originating from Row 3 ($\phi V_{cbg,row 3}$) and Row 1 ($\phi V_{cbg,row 1}$). If Case 3 is considered for these rows, then V_{ua} could be assumed to act on either Row 3 or Row 1, and ($V_{ua} / \phi V_{cbg,row 3}$) would be checked versus ($V_{ua} / \phi V_{cbg,row 1}$). If Case 2 is considered for these rows, then some fraction of V_{ua} could be assumed to act on each row, and ($V_{ua,row 3} / \phi V_{cbg,row 3}$) would be checked versus ($V_{ua,row 1} / \phi V_{cbg,row 1}$). Finally, the Case 2 results would need to be checked versus the Case 3 results, and the highest percent utilization ($V_{ua,n} / \phi V_{cbg,n}$) would control the design. As can be seen, the complexity of the anchor configuration influences where potential failure surfaces can develop, as well as the shear load distribution on the anchors assumed to be resisting shear load.

Summary

ACI 318-19(22) provides three design assumptions to calculate shear concrete breakout strength for anchors. Each assumption only considers two anchor rows having one anchor in each row. This article explained how these three design assumptions could be extrapolated to design anchorages consisting of multiple anchor rows with multiple anchors in each row. Consideration must be given to edge distances in the direction of the shear load, and shear load distribution on anchor rows. •

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