NCBC Webinar July 17, 2020: AASHTO 10th Edition Article 5.13 – Attachments with Shear Lugs

Responses to Questions

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. Is ACI considering updates to the concrete breakout provisions for shear lugs, particularly for calculating V_b and A_{vco}? There is a stark reduction in concrete breakout strength for shear lugs in ACI 318-22 (and ACI 349-23) vs ACI 349-13.

   The requirements for shear lugs in ACI 318-25 (the latest edition) are the same as those in ACI 318-19/22. To the best of my knowledge, there are no current efforts to revise the breakout provisions for shear lugs.

2. Is there a minimum requirement on the height of shear lug? Can I design shear lugs of only half inch tall?

   Neither ACI 318-19 nor ACI 318-25 specifies minimum dimensions for shear lugs. AISC Design Guide 1 – Base Connection Design for Steel Structures recommends that the base plate thickness be at least equal to the shear lug thickness, but it does not specify a minimum shear lug height. As a good practice, the shear lug should be embedded at least 2 in. into the concrete support; therefore, the minimum shear lug height should be 2 in. plus the grout thickness.

3. Does that assume that all the shear is taken by the shear lug?

   Shear lugs are typically designed to resist 100% of the applied shear force (V_u). However, when checking the tension-shear interaction for anchors (if applicable), a small portion of V_u is assigned to the anchors welded to the base plate/shear lug assembly – please see slide 26.

4. In slide 40, how can the front lug produce a concrete breakout when the lugs are welded to the base plate. For headed stud anchorages, the concrete breakout occurs at the back stud unless the spacing between the front and back anchor parallel to the shear force is large, which result in a shear lag effect on the anchorage. Are you saying that shear lugs always have a distance between lugs that causes a shear lag?

   ACI 318-19 has the following requirements for multiple shear lugs:

   > *"17.11.3.4 For cases with multiple shear lugs, the concrete breakout strength shall be determined for each potential breakout surface."*
   >
   > *"ACI 318-19 R17.11.3.4 The concrete breakout strength for multiple shear lugs is based on R17.7.2.1 and shown in Fig. R17.7.2.1b Case 1 and Case 2."*

   Case 1 and Case 2 are shown in slide 40.

5. How would you handle a solid circular shear lug welded to a base plate or a circular tube section used as a shear lug?

ACI 318 and AISC Design Guide 1 are silent about such cases. In lieu of a detailed finite element analysis, the following approximate method may be used.

Solid circular shear lugs

We can approximate a solid circular shear lug as an equivalent rectangular shear lug. The width of the equivalent shear lug (b_{sl}) is taken as the diameter of the circular shear lug (D). We can determine an equivalent thickness (t_{eq}) by matching elastic section moduli ($S_{eq,rectangle} = S_{circular}$) to ensure equivalent bending "stiffness."

Equivalent rectangular shear lug (width = D, t_{eq} = equivalent thickness):	*Solid circular shear lug:*
$S_{eq,rectangle} = \frac{Dt_{eq}^2}{6}$	$S_{circular} = \frac{\pi D^3}{32}$

$$S_{eq,rectangle} = S_{circular} \rightarrow \frac{Dt_{eq}^2}{6} = \frac{\pi D^3}{32} \rightarrow t_{eq} = \sqrt{\frac{3}{16}}D = 0.767D$$

The equivalent thickness from matching elastic section moduli is $0.767D$. For simplicity and added conservatism, this is rounded down to $0.5D$.

$$h_{ef,sl} = min\left(h_s, 2t_{eq}\right) = min(h_s, 2 \times 0.5D) = min(h_s, D)$$

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

Hollow circular (round HSS) shear lugs

Concrete bearing pressure acts directly on the front face of a round hollow structural section (HSS). Unlike a solid bar, the thin walls of an HSS can deform locally under bearing pressure – a phenomenon known as ovalization.

To account for this localized flexibility, the effective thickness of an equivalent rectangular shear lug (t_{sl}) is taken simply as the HSS wall thickness (t_w).

$$b_{sl} = D$$

$$h_{ef,sl} = min(h_s, t_w)$$

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

Note:

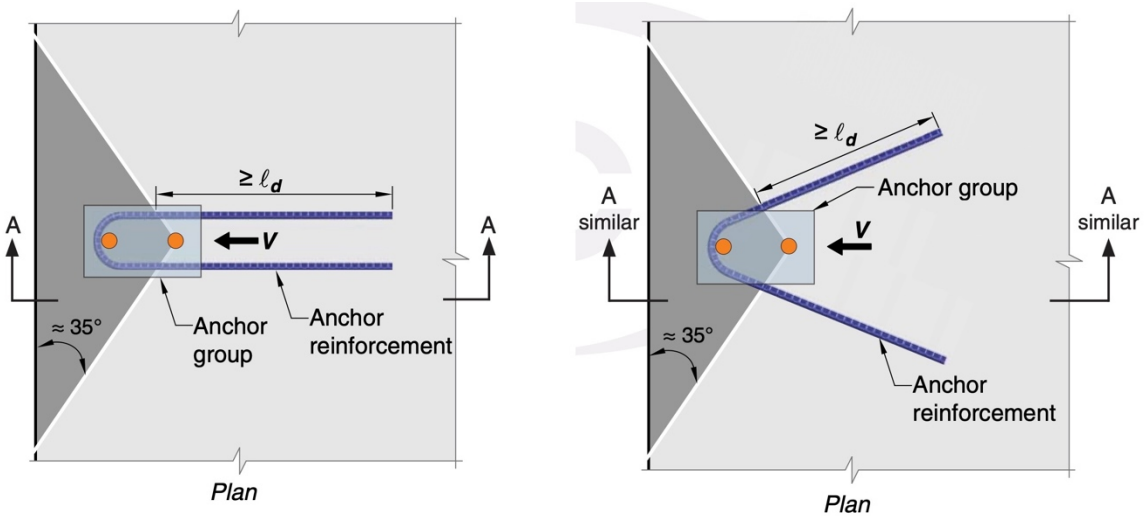
While filling the HSS with concrete reduces ovalization, the concrete infill does not match the stiffness of structural steel. Therefore, ignoring the concrete infill provides a conservative and simplified basis for design.

6. Any Factor of safety used?

   Yes, strength reduction factors (ϕ) and load factors serve as the de facto factors of safety.

7. If reinforcing is provided to bypass the breakout check at what location the bars need to have full development? is this the 35-degree breakout surface?

   Yes, please see the figures shown below. The development length (ℓ_d) starts at the point where the anchor reinforcement crosses the breakout failure surface.



Source: ACI 318-19/ACI 318-25

8. If you have a calc where breakout check has been bypassed because reinforcing is provided, please share for better understanding. Thanks.

   At this point, I don't have a calculation like that available to share.

9. Two questions regarding use of anchor reinforcement in lieu of concrete breakout strength.

   a. Can a reduced breakout strength be used if bars are not fully developed?

      At first glance, using a reduced breakout strength seems logical if we extrapolate the concept of reducing development length by $A_{s,\,provided}/A_{s,\,required}$. The reason for this reduction factor is as follows:

      > *Development length equations are intended to ensure a bar reaches its full yield strength (f_y) under factored design loads. When excess steel is provided, the stress in the reinforcement under ultimate loads remains below f_y, meaning a shorter embedment length is sufficient to develop the required force.*

      Despite this rationale, ACI 318 R17.5.2.1.2 states: "Because development for full f_y is required, the use of excess reinforcement to reduce development length is not permitted for anchor reinforcement." This requirement stems from the following considerations:

I. *Brittle failure prevention: Anchor reinforcement is specifically designed to prevent sudden, brittle concrete breakout failures by transferring the full tension or shear force directly from the anchor into the concrete core.*

II. *Load path integrity: Unreduced development length is required to guarantee complete force transfer across potential breakout surfaces, ensuring ductile behavior regardless of excess steel provided.*

b. 17.5.2.1 requires reinforcement to be developed on both sides of the breakout surface. They apparently do not allow a reduced strength for bar partial development, but instead it must be fully developed. Is that correct?

This is correct: reduced strength is not permitted for partial development of anchor reinforcement. Please see the response above.

10. What if I have a baseplate subjected to a large axial compression in combination with shear and moment. The anchors are not subjected to tension. Much of the axial compression is permanent. Your presentation and Ch. 17 do not permit the inclusion of friction due to the permanent compression as a shear transfer mechanism. Why is that? We are permitted to account for compression when designing horizontal shear transfer at interfaces (e.g., shear friction).

A primary reason for ignoring friction is that ACI 318 does not specify a design coefficient of friction (μ) between a steel base plate and concrete. Friction due to a permanent compressive force cannot be calculated. However, ACI 318 does specify coefficients of friction in Table 22.9.4.2 for shear-friction calculations. These values vary depending on the preparation and characteristics of the contact surface.