Shear-Friction Design Provisions of the *AASHTO LRFD Bridge Design Specifications*

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Among the recent questions received by our *ASPIRE*® team are several related to shear-friction design. More specifically, we are hearing from members of the concrete bridge community about current challenges in bridge-widening projects, the design and detailing of precast concrete spliced-girder bridges, and a variety of complex bridge applications. With these issues serving as a backdrop, this article discusses the shear-friction design provisions in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[1] and the performance of those provisions in light of some recent test data for spliced-girder bridges.

What Do the AASHTO LRFD Specifications Say?

Article 5.7.4 of the AASHTO LRFD specifications states the following:

> *Interface shear transfer shall be considered across a given plane at:*
>
> - *An existing or potential crack;*
> - *An interface between dissimilar materials;*
> - *An interface between two concretes cast at different times; or*
> - *The interface between different elements of the cross-section.*

Article 5.7.4.3 of the specifications is devoted to interface shear resistance, as follows:

The factored interface shear resistance, V_{ri}, shall be taken as:

$$V_{ri} = \phi V_{ni} \qquad (5.7.4.3\text{-}1)$$

and the design shall satisfy:

$$V_{ri} \geq V_{ni} \qquad (5.7.4.3\text{-}2)$$

where:

V_{ni} = *nominal interface shear resistance (kip)*
V_{ui} = *factored interface shear force due to total load based on the applicable strength and extreme event load combinations in Table 3.4.1-1 (kip)*
ϕ = *resistance factor for shear specified in Article 5.5.4.2. For the extreme limit state event ϕ may be taken as 1.0.*

The nominal shear resistance of the interface plane shall be taken as:

$$V_{ni} = cA_{cv} + \mu(A_{vf}f_y + P_c) \qquad (5.7.4.3\text{-}3)$$

The nominal shear resistance, V_{ni}, used in the design shall not exceed either of the following:

$$V_{ni} \leq K_1 f'_c A_{cv} \qquad (5.7.4.3\text{-}4)$$

$$V_{ni} \leq K_2 A_{cv} \qquad (5.7.4.3\text{-}5)$$

in which:

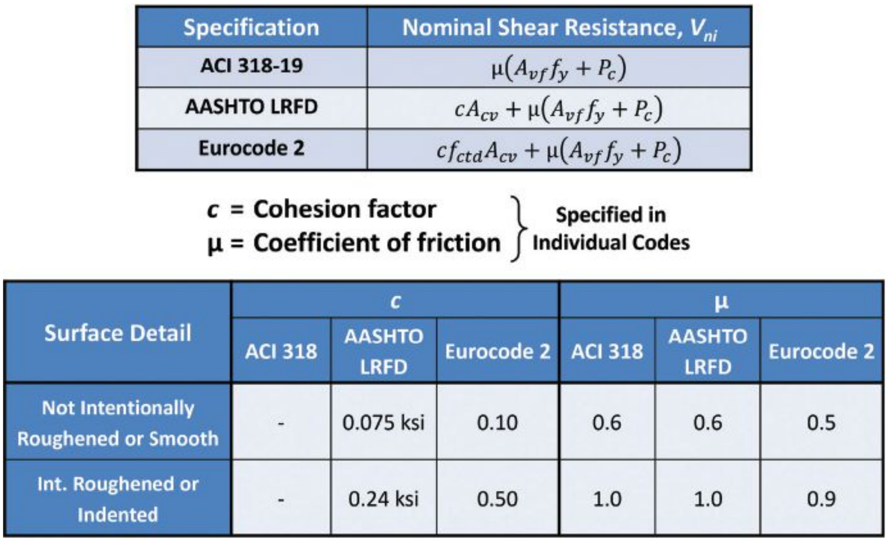
$$A_{cv} = b_{vi}L_{vi} \qquad (5.7.4.3\text{-}6)$$

where:

b_{vi} = *interface width considered to be engaged in shear transfer (in.)*
L_{vi} = *interface length considered to be engaged in shear transfer (in.)*
c = *cohesion factor specified in Article 5.7.4.4 (ksi)*
μ = *friction factor specified in Article 5.7.4.4*
P_c = *permanent net compressive force normal to the shear plane; if force is tensile, P_c = 0.0 (kip)*
f'_c = *design concrete compressive strength of the weaker concrete on either side of the interface (ksi)*
K_1 = *fraction of concrete strength available to resist interface shear, as specified in Article 5.7.4.4.*
K_2 = *limiting interface shear resistance specified in Article 5.7.4.4 (ksi)*

If a member has transverse reinforcement with a specified minimum yield strength greater than 60.0 ksi for flexural shear resistance, interface reinforcement may be provided by extending the transverse reinforcement across the interface zone. In this case, the value of f_y in Eq. 5.7.4.3-3 shall not be taken as greater than 60.0 ksi.

Table 1. Shear-friction design provisions



Specification	Nominal Shear Resistance, V_{ni}
ACI 318-19	$\mu(A_{vf}f_y + P_c)$
AASHTO LRFD	$cA_{cv} + \mu(A_{vf}f_y + P_c)$
Eurocode 2	$cf_{ctd}A_{cv} + \mu(A_{vf}f_y + P_c)$

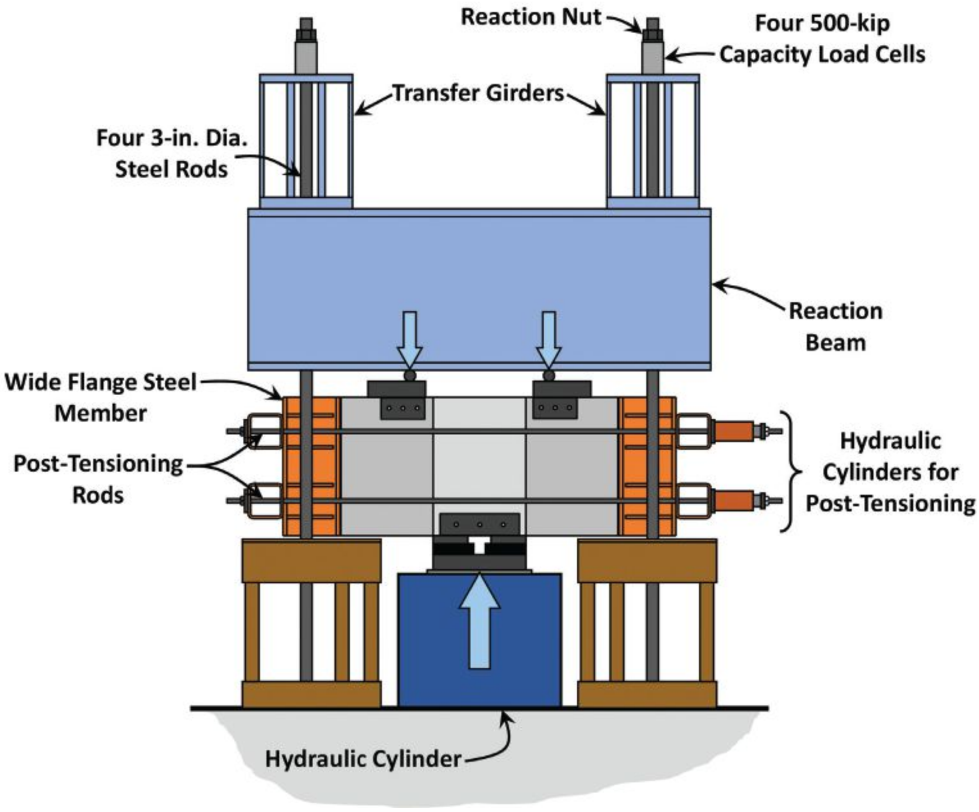
$$\left.\begin{array}{l} c = \text{Cohesion factor} \\ \mu = \text{Coefficient of friction} \end{array}\right\} \text{Specified in Individual Codes}$$

Surface Detail	c			μ		
	ACI 318	AASHTO LRFD	Eurocode 2	ACI 318	AASHTO LRFD	Eurocode 2
Not Intentionally Roughened or Smooth	-	0.075 ksi	0.10	0.6	0.6	0.5
Int. Roughened or Indented	-	0.24 ksi	0.50	1.0	1.0	0.9

Design codes around the globe have design provisions similar to those in the AASHTO LRFD specifications. To provide a basis of comparison in light of some recent experimental data, we will focus our attention in this article on the relevant provisions of the American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary (ACI 318R-19)*[2] and *Eurocode 2: Design of Concrete Structures*,[3] in addition to the AASHTO LRFD specifications. **Table 1** succinctly summarizes the applicable design expressions for nominal interface shear resistance. For brevity, additional design provisions are not repeated herein, and readers are directed to the original design references. Note that some of the terminology in Table 1 has been modified from the original references to match the terms used in the AASHTO LRFD specifications.

As is the case in most structural engineering applications, the devil is in the details. That is to say, the presence or absence of cohesion terms, the actual value of the terms and coefficients, and the assumptions that go into calculating the net compression acting on the shear-friction interface are all important. In this context, I will reference a recent project we completed at the Phil M. Ferguson Structural Engineering Laboratory at the University of Texas and some shear-friction tests we conducted in an effort to define the best practices that can be employed in detailing the cast-in-place closure pours in precast concrete spliced-girder bridges.[4–7] As part of our comprehensive research effort, we conducted several tests to study the behavior of the splice region in spliced-girder bridges. **Figure 1** illustrates the test setup used to determine the structural capacity of a variety of cold-joint details and clamping forces through active (applied force) and passive (reinforcement) means. In all, we tested 11 assemblies in 2 series (or sets). **Figure 2** shows the details of the joints examined in series 1 test specimens that were used to examine the geometry of the interface details. Series 2 was devoted to testing the performance of the design expressions for cases in which the active clamping force (applied by using hydraulic rams) across the boundary and passive clamping force provided by mild reinforcement were employed in various combinations. All series 2 test specimens had a single shear key and a sum of active and passive clamping forces between 61 and 251 kips acting across the boundary (**Fig. 3**). Figure 3 shows that, in some cases, the clamping forces across the boundary were provided by different percentages of active and passive components. The passive clamping forces were adjusted by varying the quantity of reinforcement that crossed the interface, and active clamping forces were adjusted by varying the active post-tensioning force, where applicable. Williams[6] provides complete details of the test specimens, which are explained concisely in Williams et al.[7] The summary provided herein serves to establish the backdrop for the discussion on various design expressions in the AASHTO LRFD specifications, ACI 318 and Eurocode 2.

Figure 1. Test setup. All figures: C. S. Williams and Phil M. Ferguson Structural Engineering Laboratory researchers at the University of Texas at Austin.[4–7]



As can be observed in **Fig. 4**, the shear-friction design expressions in the AASHTO LRFD specifications provide the most accurate strength estimates with the least scatter for the 11 test specimens considered in our study. Eurocode 2 expressions display a similar performance to those in the AASHTO LRFD specifications but are more scattered. Interestingly, both the AASHTO LRFD specifications and Eurocode 2 have a "cohesion" term, cA_{cv} and $cf_{ctd}A_{cv}$, respectively, which I personally like to call "concrete contribution to shear friction." Adhesion of two concretes to each other in the boundary (commonly understood to be cohesion) must be overcome to activate the contribution of the reinforcing steel crossing that boundary. At this point the "cohesion" term references aggregate interlock. In my view, the phrase "concrete contribution" seems more appropriate than the term "cohesion" since that "contribution" remains active after the cohesion is overcome and "sliding" becomes activated—that is, both the reinforcement crossing the boundary and the aggregate interlock across a rough surface concurrently exist. In Eurocode 2, f_{ctd} refers to the design value of the direct tensile strength of concrete. With semantics and terminology left aside, and unlike the provisions in the AASHTO LRFD specifications and Eurocode 2, ACI 318 provides a more conservative estimate, likely due to the absence of the cohesion term and perhaps because additional considerations likely went into

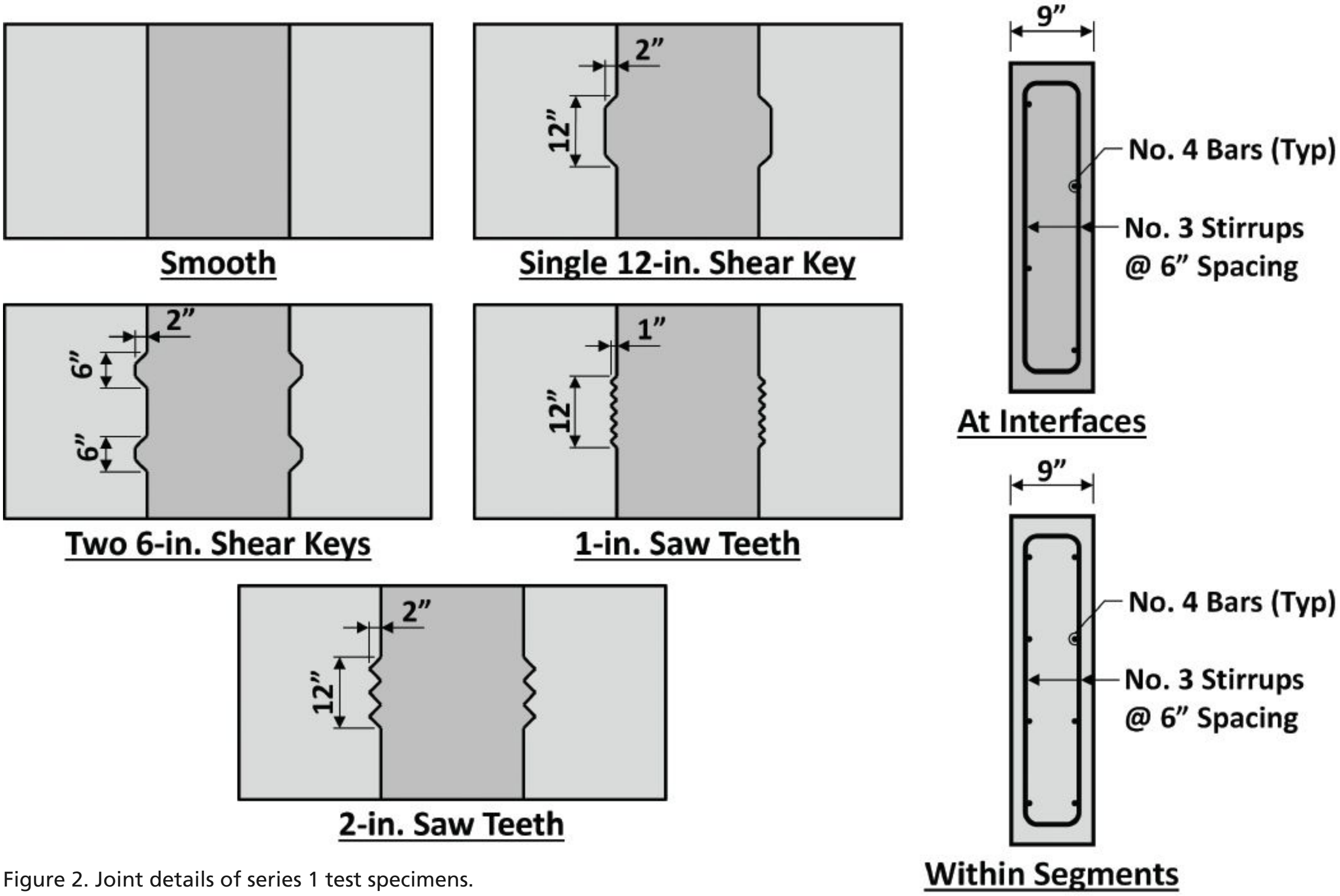
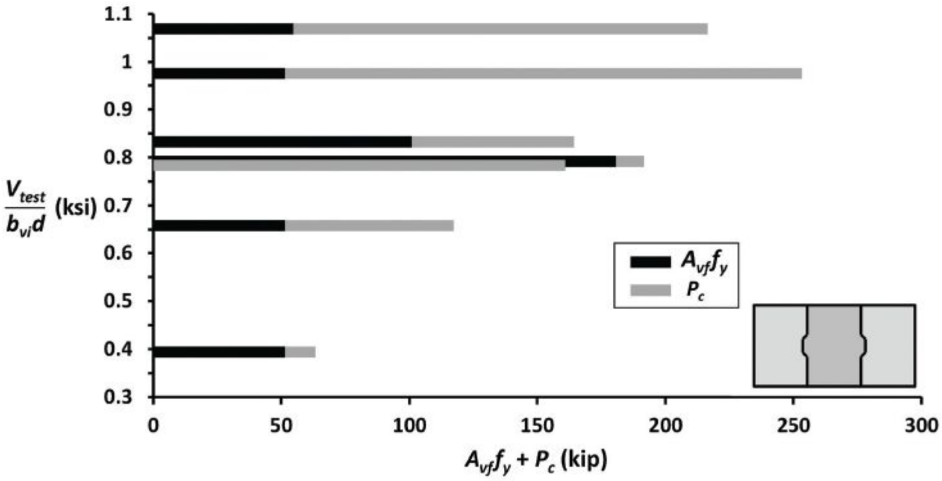


Figure 2. Joint details of series 1 test specimens.

calibrating ACI 318 provisions, such as simplicity of the equations, calibration of load factors, strength reduction factors, and so on.

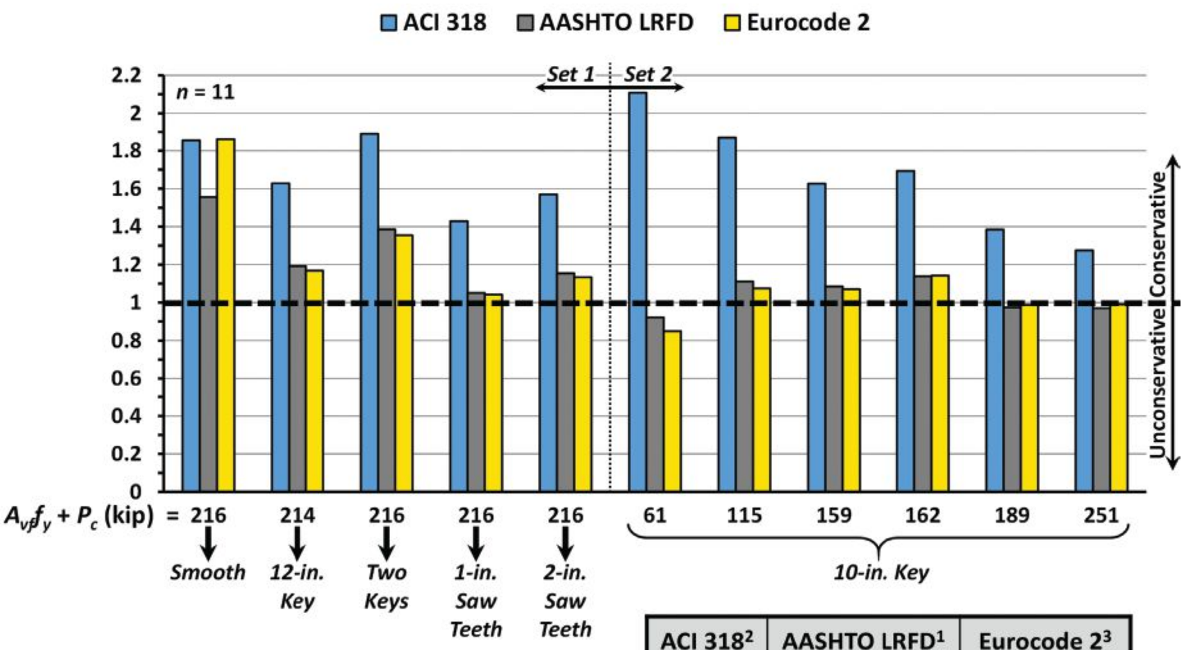
It is important to appreciate that the 11 test specimens considered in our study[4–7] were not intended to be exhaustive of all cases. Instead, they were representative of the spliced-girder details employed in various jurisdictions. With that disclaimer, it is comforting to note the superior performance of the design expressions from the AASHTO LRFD specifications. The overall calibration of design expressions would require more than just the 11 tests and was considered beyond the scope of our efforts. However, overall examination (or reexamination) of shear-friction expressions in the AASHTO LRFD specifications must consider tests that are representative of bridge applications.

Figure 3. Active (force) and passive (reinforcement) contributions to the “clamping” force of each series 2 test specimen.



As we go from experimental observations to a design setting, it is important to appreciate that the calibration of each design code differs. For the AASHTO LRFD specifications, we should keep in mind that if the factored loads are applying both a “clamping effect” (capacity side) and a “factored shear load” (demand side) on the boundary (for example, a cold joint), we must use the applicable load factors. Permanent loads acting on the boundary deserve a different load factor when they appear on the capacity (less than 1) or demand (greater than 1) side of the expressions from the AASHTO LRFD specifications.

This article is not intended to cover all of the articles and commentary that apply to shear-friction (Article 5.7.4 of the AASHTO LRFD specifications). Instead, the focus is placed on the conservativeness and accuracy of the relevant design provisions as



	ACI 318[2]	AASHTO LRFD[1]	Eurocode 2[3]
Mean	1.67	1.14	1.15
Standard Deviation	0.24	0.18	0.25

Figure 4. Comparison of shear-friction design expressions and test results for the 11 test specimens.

they apply to typical joints used in precast concrete spliced-girder bridges. Overall, our recent testing validates both the theoretical basis and the calibration of relevant design expressions in the AASHTO LRFD specifications.

References

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