PCI Recommended Practice on Strand Bond

by Dr. Jared Brewe, Precast/Prestressed Concrete Institute

The Precast/Prestressed Concrete Institute (PCI) published a new "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand" in the November–December 2020 issue of the *PCI Journal*.[1] This recommended practice culminates many years of research evaluating test methods as well as test repeatability and reliability to provide uniform criteria for the precast concrete industry to use when specifying strand for bonded, pretensioned applications. An article in the same issue of the *PCI Journal*[2] and an article in the following issue[3] summarize the background research on strand bond, current design provisions, and the development of the recommended practice.

Current Design Provisions

The ninth edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[4] provides provisions for the development length of bonded strand in Article 5.9.4.3.2, as follows:

$$l_d \geq \kappa\left(f_{ps} - \frac{2}{3}f_{pe}\right)d_b \qquad (5.9.4.3.2\text{-}1)$$

where

l_d = development length in tension of pretensioned strand (in.)

κ = 1.0 for pretensioned panels, piling, and other pretensioned members with a depth of less than or equal to 24.0 in.

= 1.6 for pretensioned members with a depth greater than 24.0 in.

f_{ps} = average stress in prestressing steel at the time for which the nominal resistance of the member is required ksi

f_{pe} = effective prestress in the prestressing steel after losses (ksi)

d_b = nominal strand diameter (in.)

The development length consists of the sum of the transfer length, which is the length of embedded pretensioned reinforcement required to transfer the effective prestress to the concrete, and the bond length, which is the length of bonded pretensioned reinforcement required to develop the effective prestress used for the strength limit state design. The AASHTO LRFD specifications, Article 5.9.4.3.1, states the transfer length may be taken as $60d_b$.

PCI Recommended Practice

The "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand" establishes two values for ASTM A1081[5] pullout strength: a minimum value and a high-bond value. For the minimum value, the required average pullout strength is 14,000 lb for 0.5-in.-diameter strand. For the high-bond value, the required average pullout strength is 18,000 lb for 0.5-in.-diameter strand. For other strand diameters and strengths, the pullout value is based on a ratio of diameter and specified tensile strength. Thus, for 0.6-in.-diameter Grade 270 strand, the values are 16,800 and 21,600 lb for minimum-bond-strength and high-bond-strength strands, respectively.

The recommended practice provides the following development length equation intended to replace the current AASHTO LRFD specifications equation:

$$l_d = \left(\frac{120}{\sqrt{f'_{ci}}} + \frac{225}{\sqrt{f'_c}}\right)d_b \geq 100d_b$$

where

f'_{ci} = concrete strength at transfer (ksi)

f'_c = design concrete strength (ksi)

The coefficients in the numerators of the preceding equation differ from those published in the recommended practice because they have been converted for use with the AASHTO LRFD specifications, which use kip per square inch (ksi) for concrete strengths rather than pounds per square inch (psi). The change from calculating development length based on strand stress to using concrete strengths is based on research described in National Cooperative Highway Research Program (NCHRP) Report 603,[6] where the preceding equation is given as Eq. (4.5).

Assuming a concrete strength at transfer of 4.5 ksi, design concrete strength of 6.5 ksi, and 0.5-in.-diameter strand results in a development length of 72 in., approximately equal to the current development length assuming f_{ps} = 258 ksi and f_{pe} = 170 ksi. Furthermore, the recommended practice removes the 1.6 multiplier, which results in shorter development lengths than the current AASHTO LRFD specifications equation for typical bridge girders and members greater than 24 in. deep. **Figure 1** illustrates the effect of the recommended practice on development length for 0.5-in.-diameter strand as the concrete strength varies.

The recommended practice also provides the following transfer length equation intended to replace the current AASHTO LRFD specifications provisions:

$$l_t = K\left(\frac{120}{\sqrt{f'_{ci}}}\right)d_b \geq 40d_b$$

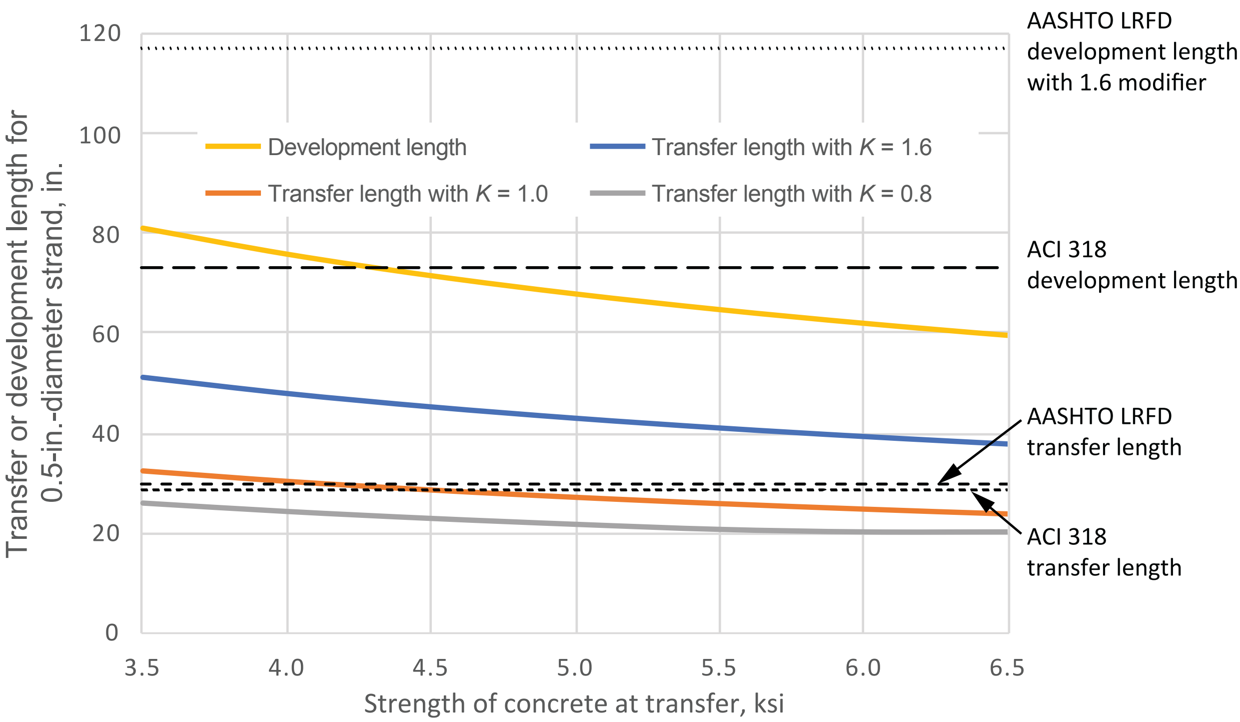

Figure 1. Comparison of transfer and development lengths calculated using the strand bond recommended practice, AASHTO LRFD specifications, and ACI 318. Note: Calculations for transfer and development lengths assume that the design concrete strength f'_c is 1.5 times the concrete strength at transfer f'_{ci}; K = multiplier factor; LRFD = load and resistance factor design. Figure: PCI.

where

K = 1.6 for minimum-bond-strength strand, 1.0 for high-bond-strength strand, and 0.8 for stress calculations at detensioning, shipping, and handling

This equation for transfer length follows the same approach as specified in the American Concrete Institute's *Building Code Requirements for Structural Concrete* (ACI 318-19) *and Commentary* (ACI 318R-19)[7] and in NCHRP 603, where the development length is the total of the transfer length and bond length, rather than the straightforward AASHTO approach of $60d_b$ for transfer length.

For minimum-bond-strength strand (K = 1.6), all common concrete strengths (anything less than 10 ksi) would result in an increased transfer length compared with the current $60d_b$. For high-bond-strength strand (K = 1.0), the transfer length of strand in concrete with a compressive strength at transfer of 4 ksi is equal to the current $60d_b$, but the transfer length is reduced for higher concrete strengths. For calculation of concrete stresses (K = 0.8), transfer lengths are reduced from the current $60d_b$ with the K value less than 1.0, which results in higher calculated fiber stresses at the end of the transfer length near the member's ends.

Impact on Design

AASHTO Technical Committee T-10 is considering whether to implement the PCI recommended practice into the AASHTO LRFD specifications. The modified development length equation, while not a trivial change, will have a marginal effect on the design of most current prestressed concrete components for service limit state and strength limit state flexural checks. Components that may have previously required additional reinforcement to develop flexural strength within the development length may now be considered adequate. The shorter development length for members greater than 24 in. deep could have some effect on the strand length that a designer chooses to debond.

However, the modified transfer length equation requires careful consideration. The straightforward calculation of transfer length using $60d_b$ is appealing for its simplicity. Similar transfer lengths can be calculated for high-bond-strength strand, which could be used in members with critical transfer or bond lengths, such as deck slabs, but that would depend on the precast concrete plant purchasing, and their strand supplier providing, the strand with higher pullout values. For girders designed with a simplified assumption of minimum-bond-strength strand, the transfer length will affect the tension tie and shear strength of the shear-critical end region. Debonding then becomes a complex, interrelated topic. The end region shear strength depends on strands fully transferring prestress to the girder. If a typical girder has debonded strands to meet fiber stress limits at the service limit state, the unshielded strands may not provide sufficient tension tie force due to the increased development length. This could dictate a design with less strand debonding to meet strength requirements; however, the shorter transfer length may increase fiber stresses near the ends, which could dictate additional strand debonding to meet stress limits at the service limit state.

Effect on PCI Plant Certification

Effective July 1, 2020, the PCI Plant Certification Program approved an addendum to the *Manual for Quality Control for Plants and Production of Structural Precast Concrete Products* (MNL-116) requiring at least annual ASTM A1081 test results from the strand supplier for all strand sizes in use at the plant.[8] PCI committees are currently working on additional guidance following the new recommended practice requirement of quarterly ASTM A1081 test results for 0.5-in.- and 0.6-in.-diameter strands.

Additionally, Section 5, Quality Assurance, of the recommended practice states, "Through appropriate testing, it is recommended that the precast concrete producer confirm that the strand and concrete combination in use produces product performance that meets or exceeds predicted behavior." However, a particular test is not specified. Possible test methods include the flexural beam test, the Peterman beam test, the Moustafa pullout test, the direct pull test, and strand draw-in measurements for sawed ends. Most of these methods require additional specimens for the strand and concrete combination, while strand draw-in measurements provide direct measurements on a fabricated component without additional specimens. Additional guidance and commentary to further clarify the intent of the recommended practice is currently being developed.

References

1. Precast/Prestressed Concrete Institute (PCI) Strand Bond Task Group. 2020. "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand." *PCI Journal* 65 (6): 33–34.
2. Brewe, J. 2020. "Background for the New PCI Recommended Practice on Strand Bond." *PCI Journal* 65 (6): 27–32.
3. Osborn, A., M. Lanier, and N. Hawkins. 2021. "Bond of Prestressing Strand to Concrete." *PCI Journal* 66 (1): 28–48.
4. American Association of State Highway and Transportation Officials (AASHTO). 2020. *AASHTO LRFD Bridge Design Specifications*. 9th ed. Washington, DC: AASHTO.
5. ASTM International. 2015. *Standard Test Method for Evaluating Bond of Seven-Wire Steel Prestressing Strand* (ASTM A1081/A1081M-15). West Conshohocken, PA: ASTM International.
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7. American Concrete Institute (ACI) Committee 318. 2019. *Building Code Requirements for Structural Concrete* (ACI 318-19) *and Commentary* (ACI 318R-19). Farmington Hills, MI: ACI.
8. PCI. 2020. "ASTM A1081 Strand Bond Testing Rule Effective July 1." *PCI Journal* 65 (3): 9.

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