PCI Updates the Recommended Practice on Strand Bond

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The Precast/Prestressed Concrete Institute (PCI) Technical Activities Council has published a second edition of the "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand."[1] This second edition—which was published in the January/February 2025 issue of *PCI Journal* with errata published in the September/October 2025 issue[2]—supersedes the first edition that was approved in July 2020.[3]

The new edition of the recommended practice retains the information from the original version that set thresholds for strand bond assessed by ASTM A1081, *Standard Test Method for Evaluating Bond of Seven-Wire Steel Prestressing Strand*,[4] and provided equations for bond and development lengths that include concrete strength as a parameter. The second edition also provides demonstrated bond strength equivalents for prestressing strand diameters other than the two given in the standard test method (0.5 in. and 0.6 in.).

The most important change in the recommended practice is the addition of methodologies to assess the bond characteristics of tensioned strand in a precast concrete producers' product.

ASTM A1081 provides a valuable approach for consistently evaluating strand independent of strand production methods. The ASTM method uses consistent materials and methods to evaluate the untensioned strand in a surrogate grout material, thereby providing the strand user confidence in the bond quality of the produced strand. The methods added to and described in the PCI recommended practice allow for assessment of the concrete-to-strand bond properties in plant-produced precast concrete components. To do this, the tests incorporate standard precast concrete plant production procedures, including tensioning and detensioning methods, concrete mixture design, concrete consolidation techniques, curing conditions, and curing duration. The methods for assessing the bond of tensioned strands in a precast concrete producer's product allow for resolution testing (which is also covered in the new version of the recommended practice) if there are concerns about the quality of bond.

The recommended practice details two testing methods: the pretensioned strand block pullout test and the strand draw-in test, which were both approved by the American Association of State Highway and Transportation Officials (AASHTO) Committee on Bridges and Structures in June 2025 as agenda item 39, to be published in 2027 as Article 5.9.4.3.1 in the 11th edition of the *AASHTO LRFD Bridge Design Specifications*.[5]

The recommended practice also contains an extensive list of frequently asked questions (FAQs) to assist with interpretations of provisions, and two examples illustrating applications to specification requirements.

A Brief History of the Recommended Practice

In a *PCI Journal* article that accompanies the first edition of the PCI recommended practice, Dr. Jared Brewe[6] provides an in-depth history of strand bond and the development of the recommended practice. A brief summary is provided here. (For details, see also Dr. Brewe's article in the Spring 2021 issue of *ASPIRE*®.)

In the late 1980s, a concern developed regarding the quality of the bond between seven-wire prestressing strand and concrete. In 1988, the Federal Highway Administration (FHWA) issued a memorandum[7] that provided a multiplier of 1.6 to the development length equation for fully bonded strands in the *AASHTO Standard Specifications for Highway Bridges*.[8] This multiplier continues to be specified in Article 5.9.4.3.2 of the *AASHTO LRFD Bridge Design Specifications*[9] for members with a depth greater than 24 in. The use of 0.6-in.-diameter strand was also banned for a time. In 1995, PCI issued an alert to producers about possible premature bond failure of untensioned strand used in lifting loops, and the institute published a second alert in 1996 that reiterated the previous concerns and recommended that producers conduct pull-out testing on the strand.

The concerns about strand bond quality led to research by the FHWA, PCI, various state departments of transportation, and North American Strand Producers (NASP). One result of the NASP research was the development of ASTM A1081. Subsequent testing under National Cooperative Highway Research Program (NCHRP) Project 607 and additional testing sponsored by PCI resulted in various recommendations for the threshold value of the pull-out strength assessed by the ASTM A1081 test.

The first edition of the "PCI Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand" set the minimum ASTM A1081 threshold value for prestressing strand to be a demonstrated bond strength equivalent to ½-in.-diameter, 270-ksi strand exhibiting a six-quarter running average value of 14,000 lb with no quarterly test average less than 12,000 lb. Strand manufacturers use this test for quality control, and precast concrete producers use this test and the minimum value when procuring strand for use in pretensioned concrete. In addition, the original PCI recommended practice defined a "high-bond" strand with threshold values of a demonstrated bond strength equivalent to ½-in.-diameter, 270-ksi strand exhibiting a six-quarter running average value of 18,000 lb with no quarterly test average less than 16,000 lb. However, as will be discussed later, the high-bond strand was intended to be used only in certain prestressed concrete components where bond is particularly critical.

The first edition of the PCI recommended practice also recognized that bond strength is dependent on concrete strength and recommended alternate equations for transfer and development lengths that contained a term for concrete compressive strength f'_c. To date, these equations remain recommendations and have not been adopted in any of the design specifications.

Additions to the Recommended Practice

The second edition of the recommended practice retains the information from the first edition. The threshold values for prequalifying pretensioning strand are based on 0.5-in.-diameter strand; however, a change was made to clarify and amplify the requirements for testing strands of different diameters with a table that provides equivalent threshold values.

The recommended practice adds two methods for assessing the bond of tensioned strand in concrete. The ASTM A1081 test uses untensioned strand in surrogate material. The surrogate material consists of a mortar composed of only fine aggregate meeting requirements of ASTM C33, *Standard Specification for Concrete Aggregates*;[10] Type III cement; and water. The test is conducted when the mortar has a cube strength between 4500 and 5000 psi. However, in pretensioned concrete applications, the strand is tensioned and embedded in concrete, which results in additional, mechanical contributions to the bond strength that are not evaluated in the ASTM A1081 test. The two methods in the recommended practice for evaluating tensioned strand are the strand block pullout test and the evaluation of strand draw-in.

It is interesting to note that the pull-out test evaluates development length, whereas the draw-in test evaluates transfer length. While not usually necessary, both tests could be used simultaneously to provide an estimate of each quantity.

Strand Block Pullout Test

The pretensioned strand block pullout test consists of pulling a tensioned strand out of a concrete prism with cross-section dimensions of 12 in. × 6.5 in. (**Fig. 1**). The length of the specimen is equal to a bonded length L_b plus a 2-in. debonded length. The bonded length L_b is taken as the transfer length of the strand (60 strand diameters in the AASHTO LRFD specifications).

The pullout force and end slip are measured to quantify the bond capacity. The recommended practice states that "the test specimens are fabricated using standard procedures of the precast concrete producer. These standard procedures include the tensioning and detensioning methods, concrete mixture design, concrete consolidation techniques, curing condition, and curing duration." In the ideal case, the test specimen is made at the end of a bed while the precast concrete producer is manufacturing other products; however, the specimen can be made by itself, using the precast concrete producer's standard procedures.

After the specimen is made and cured, the strand is pulled out of the block using the apparatus setup shown in **Fig. 2.** The strand at the dead end of the specimen is saw cut flush with the face of the specimen and a gauge is used to measure the end slip. The test is performed as follows:

1. The specimen is loaded until the end slip measures 0.10 in., with load and end slip being recorded such that at least 10 data points of load and end slip are collected before the end slip reaches 0.10 in. (A reading of an increased load and no end slip is acceptable as a data point.)
2. The specimen is then loaded until:
   a. a 25% decrease in load is measured, or
   b. the strand fractures, or
   c. a displacement of 0.5 in. is measured at the dead end.
4. The estimated minimum length to fracture the strand L_{ult} (in.) is found from:

$$L_{ult} = \frac{f_{ps} A_{ps}}{F_u} L_b$$

(Recommended Practice Eq. 5.2.1.14)

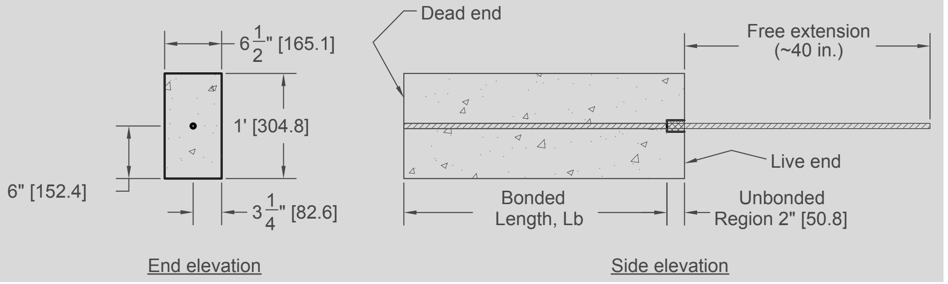

Figure 1. Strand block pullout test specimen.[1] All Figures and Photos: PCI.

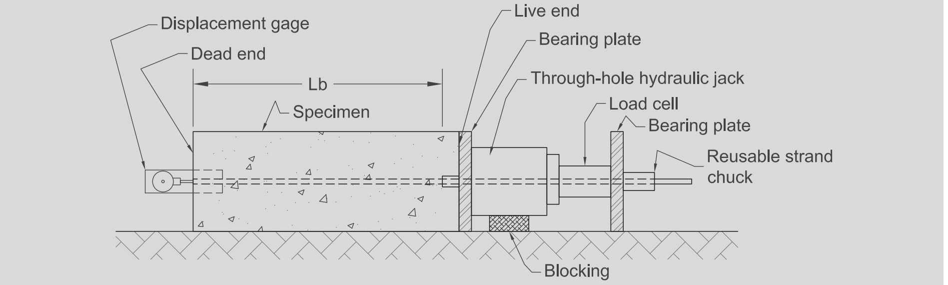

Figure 2. Strand block pullout test setup.[1]

where

f_{ps} = minimum tensile strength of the strand, ksi

A_{ps} = area of the strand, in.^{2}

F_u = average force to achieve an end slip of 0.10 in. at the dead end for three specimens, kip

L_b = bonded length of the strand, in.

According to the commentary for the recommended practice, L_{ult} provides a best estimate of the in-place development length of that combination of strand and concrete. For fitness-for-service design evaluations, these estimates of development length should be taken as more representative values than those obtained from design equations for development length.

If the value of L_{ult} is less than the development length provided by a code-based equation, the pretensioned fabrication conditions exceed specification estimates. This test is not intended to justify the use of a development length that is shorter than specification estimates, and shorter lengths are not allowed in the forthcoming Article 5.9.4.3.1 of the AASHTO LRFD specifications.[5] If the value of L_{ult} is greater than the development length provided by a specification-based equation, the required development length may not be achievable and the value of L_{ult} obtained from Recommended Practice Eq. (5.2.1.14) should be communicated to the designer and used as the development length.

Although the pretensioned strand block pullout test provides an assessment of the bond quality needed to provide an adequate development length, it can be assumed that strand with an acceptable value of L_{ult} will also have adequate transfer length.

Strand Draw-in Test

The second method for evaluating the bond of tensioned strand is the strand draw-in test. This method uses the strand slip from the cut face of a concrete member or prism to assess bond. Some prestressed concrete producers have used this method informally for many years to assess the bond in hollow-core precast concrete elements.

Figure 3 shows a typical case of strand slip and a gauge for measurement. Movement of the outer six wires with respect to the cut concrete face is measured. The slip of the center wire is not measured because that wire is not directly bonded to the concrete.

Figure 3. An example of a strand draw-in measuring device.[1]

This test can be performed two ways: on a concrete member that is detensioned by saw cutting, such as a hollow-core precast concrete component, or by creating a prism. As with the pull-out test, the prism can be cast at the end of the bed during the production of another product or cast separately. In either case, the precast concrete producer's standard procedures of tensioning and detensioning methods, concrete mixture design, concrete consolidation techniques, curing conditions, and curing duration must be used.

A prism for the strand draw-in test has the same cross section and strand placement as a specimen for the pull-out test (Fig. 1), but the specimen length is a minimum of 240 times the strand diameter d_b. The prism is saw cut at midspan. Measurements should be taken within 24 hours of saw cutting.

The draw-in of the strand (outer six wires) is measured from two cut faces to at least the nearest 1⁄64 (0.016) in. The average draw-in of the outer wires on each face is determined, and the average of the two face measurements is the average draw-in value Δ_s. The maximum allowable value of Δ_s in inches is found from:

$$\Delta_{s,max} = \frac{L_{ti} f_{pi}}{2E_{ps}}$$

(Recommended Practice Eq. 5.2.2.9)

where

L_{ti} = transfer length of the strand, in.

f_{pi} = initial stress in the strand, ksi

E_{ps} = modulus of elasticity of the strand, ksi

Specimens or components with an average draw-in value less than the maximum value obtained by Recommended Practice Eq. (5.2.2.9) can be assumed to have adequate transfer and development lengths. Specimens or components with an average draw-in value greater than the maximum value obtained by Recommended Practice Eq. (5.2.2.9) require additional investigation.

It is important to note that the draw-in approach is sensitive to the accuracy of the measurement. As an example, if we have a typical pretensioned concrete component with 0.5-in.-diameter strands with initial prestress of 65% of the strand's 270-ksi guaranteed ultimate tensile strength, elastic modulus of 28,500 ksi, and a transfer length of $60d_b$, the allowable $\Delta_{s,max}$ is 0.0924 in. For that magnitude, a 1⁄64 in. measurement results in an accuracy of 17% of the allowable value. If the measurement drops to the nearest $\frac{1}{32}$ in., this accuracy decreases to an unacceptable 34% of the allowable value. If additional accuracy is desired, micrometers that can measure to the nearest 0.001 in. are inexpensive and readily available, and they provide accuracy within 1% on the allowable draw-in value.

Resolution Testing

The recommended practice notes that the pull-out test or the draw-in test can be used for resolution testing if a strand does not meet the requirements of ASTM A1081. The precast concrete producer should cast six specimens for either the pull-out test or the draw-in test to evaluate the quality of the strand bond. The recommended practice explains that development or transfer lengths determined by either the pull-out test or the draw-in test are more representative of the in-service quality of the strand bond than the ASTM A1081 test because the pull-out test or the draw-in test uses tensioned strand in the precast concrete producer's concrete mixture. The recommended practice also notes that, in some cases, development length and/or transfer length may not be controlling for design, and that the results of either the pull-out test or the draw-in test may yield results that are still acceptable to the owner.

Proper Use of High-Bond Strand

The first edition of the recommended practice defined two classes of strand bond quality: standard bond and high bond. Unfortunately, this classification caused some confusion about when to specify high bond in the industry. New language in the second edition will help clear up this confusion.

The class of high-bond strand was created for use only in those products where the strand bond is particularly critical. One example is lightly prestressed hollow-core slabs. The fabrication method for hollow-core slabs generally does not allow for transverse (shear) reinforcement to be used; thus, the shear strength of the member is controlled by the shear strength of the concrete and the strength provided by the longitudinal reinforcing steel (tension tie). The absence of transverse reinforcement means that the strand bond quality is critical to ensure the integrity of the tension tie. Other cases where high-bond strand is appropriate are those where there is limited internal redundancy or where there are fewer than three strands in a section, web, or stem.

For most designs, standard-bond strand is adequate. When the high-bond class was introduced, some designers assumed that "high bond" must be superior to "standard bond" and began to specify it. However, this assumption is not necessarily true. Consider the end of a precast, prestressed concrete beam. The designer will use the assumed transfer length of 60 strand diameters ($60d_b$) to determine the number of harped strands and/or the number and length of debonded strands. If the transfer length is significantly shorter than assumed, the stresses at the end of the girder will not be calculated correctly, and there is an increased possibility of cracking.

When standard-bond strand is properly manufactured and meets the requirements of ASTM A1081, it will provide acceptable transfer and development lengths for the majority of precast, prestressed concrete component designs. Specifying high-bond strand when it is not necessary adds cost and may create unnecessary compliance problems.

Conclusion

The intent of the updated "Recommended Practice to Assess and Control Strand/Concrete Bonding Properties of ASTM A416 Prestressing Strand" is to inform structural designers, strand manufacturers, precast concrete producers, and owners on the methods of assessing strand bond performance. In this way, strand bond–related processes from design to production of a product, with due consideration given to quality control and quality assurance, can be performed consistently. The recommended practice describes processes and testing methods that can be used for fitness-for-service analysis, which accounts not only for the bonding characteristics of the strand but also for a precast concrete producer's plant processes.

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