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NEW TEST TO DETERMINE THE BOND QUALITY OF REINFORCEMENTS FOR CONCRETE RAILROAD TIES

SUMMARY

This report summarizes the development of an un-tensioned pullout test to quantify the bond quality of prestressing wires used in the manufacture of pretensioned concrete railroad ties. Bond quality will vary considerably based on the characteristics of the wire indents. This test provides a practical and efficient method to establish the bond quality of prestressing wires before committing to production.

This effort was part of a larger project, "Quantifying the Effect of Prestressing Steel and Concrete Variables on the Transfer Length in Pretensioned Concrete Crossties." Kansas State University (KSU) conducted this research between 2011 and 2015 and was sponsored by the Federal Railroad Administration.

ASTM International has adopted this un-tensioned pullout test as ASTM A1096 "Standard Test Method for Evaluating Bond of Individual Steel Wire, Indented or Plain, for Concrete Reinforcement" [1]. The full technical report can be downloaded from the K-State Research Exchange.

BACKGROUND

The transfer length in a pretensioned concrete crosstie is the distance required to transfer the prestressing force to the concrete. For concrete ties to have maximum flexural and shear capacity at the rail-seat location, the prestressing force must fully transfer to the concrete outboard of the rail seat. Figure 1 shows this concept.

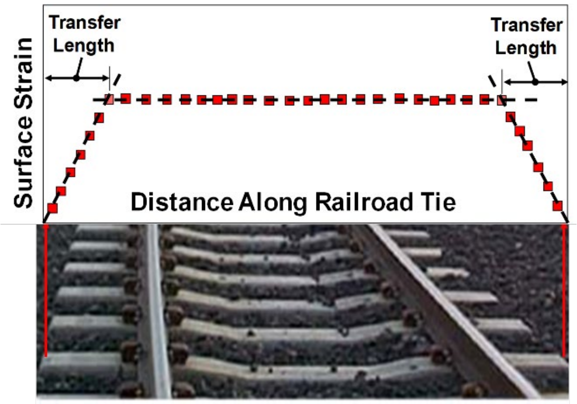

Figure 1: Schematic of transfer length

The bond that develops between the hardened concrete and the steel wires transfers the prestressing force to the concrete during the de-tensioning process. The force transfer length is a variable function of the bond quality determined by the concrete and prestressing steel properties. Accurately determining the bond quality of prestressing reinforcements, independent of the concrete mixture used, helps ensure proper concrete crosstie performance and provides useful quality control information for reinforcement sourcing.

OBJECTIVES

The project team wanted to develop a standard, efficient and practical un-tensioned pullout test for wire reinforcements that reliably establishes the bond quality of various prestressing wires used in the manufacture of pretensioned concrete railroad ties.

The team investigated 12 different 5.32-mm-diameter steel wire types, including 6 chevron indents with varying depths and geometries, 2 dot-patterned wires, 2 spiral wires, 1 diamond indent, and 1 smooth wire (Figure 2).

Figure 2: Researchers used 12 different 5.32-mm-diameter wires with unique indentation types

METHODS

The new wire test adapted a standard un-tensioned pullout test for a 7-wire prestressing strand (ASTM A1081 [2]). Prior testing showed that use of a non-standardized mortar in ASTM A1081 was a likely source of variability between testing labs [3]. Therefore, the project team wanted a standard mortar mixture for this new pullout test. In addition, researchers had to significantly reduce the wire embedment length in mortar from the ASTM A1081 length to limit the bond strength to account for the strength difference between a 7-wire strand and a single, 5.32-mm wire. The goal was to design the test so the wire pulled through the mortar during the test (bong failure) rather than failing in tension due to excessive bond strength.

Numerous trials established the final mortar proportions and the wire embedment length. The mortar mixture consisted of a standard sand conforming to ASTM C778 [4], a sand/cement ratio of 2.0, and a water/cement ratio of 0.427. Researchers systematically reduced the embedment length until the best-bonding wires consistently failed by bond at about 90 percent of their tensile capacity. The final embedment length of 6 inches provided sufficient bond strength to capture the force/slip relationship for the 12 different wires while ensuring the best-bonding wires would still fail by bond slip rather than by tension. Figure 3 shows the final test design.

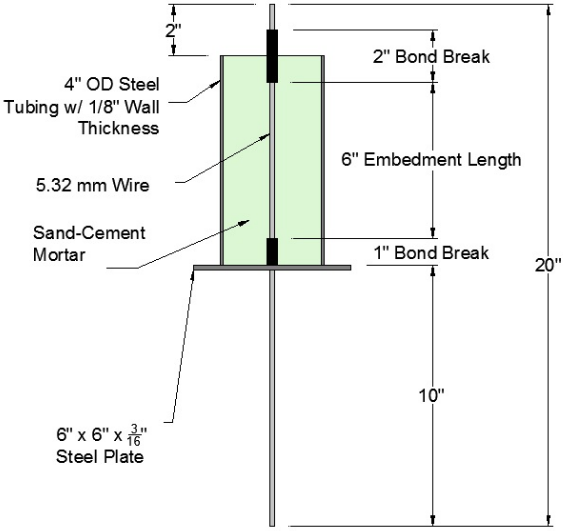

Figure 3: Wire un-tensioned pullout test schematic

The experimental test procedure called for casting and curing the test specimens under controlled conditions. After casting, researchers moved the mortar specimens to a temperature controlled (73.5 °F ± 3.5 °F) curing location until the mortar compressive strength reached 4,500–5,000 psi. They determined mortar strength levels by testing 2-inch mortar cubes that were cast along with the specimens. They then cast six test specimens of each wire type so that a representative average could be obtained. This is similar to ASTM A1081, which also requires six specimens per reinforcement type.

For testing, researchers positioned the pullout specimen in a special fixture mounted in a servo-hydraulic universal testing machine (Figure 4). They supported the specimen on a steel bottom plate and applied a tension load to the wire at a rate of 2,000 lbs per minute until the bond failed and the wire pulled through the mortar more than one inch.

The test procedure called for continuous recording of applied load, actuator displacement, and wire slip data. The testing machine recorded the load and actuator displacement. A linear variable differential transformer attached to the steel tube for recorded the wire displacement at the free-end (top), with respect to the mortar.

Figure 4: Photo showing test setup

RESULTS

The average pullout force versus wire end-slip curves for all wires are plotted in Figure 5. The team generated these curves by averaging the force values for the six wire type replicates at the same end-slip values. This figure highlights the variability in bond performance with wires having the same nominal diameter and tensile strength, but varying indent geometries. Of particular interest is the point at zero end-slip, where all wires overcome initial adhesion. All wire types exhibited a similar response in this region. However, at increasing displacements the force generally increased at varying rates based on the wire type.

The smooth wire and spiral wires behaved differently than the indented wires. For smooth prestressing wire (WA), the diameter of the wire shrinks as tension increases due to the Poisson effect and the wire immediately pulls out of the mortar. The spiral wires (WC and WE) had curves that gradually increased with increasing end-slip and did not appear to have a peak value. Other testing with these spiral wires showed that the pullout force of these wires typically increased with increasing end-slip values until the wire failed in tension.

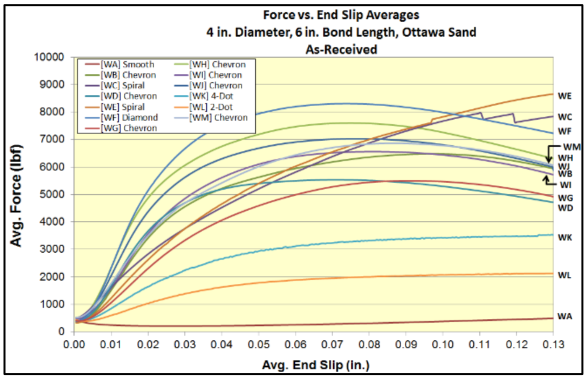

Figure 5: Average pullout force vs. wire-slip curves for the 13 different wire types

Researchers then compared the pullout curves in Figure 5 with transfer length values obtained for the same reinforcements when used to manufacture pretensioned concrete prisms. They conducted this work under a different portion of this study [5]. The prisms were 69 inches long and contained four wires. The team chose the prism cross-section dimensions shown in Figure 6 to represent the same tendon spacing and reinforcement-to-concrete proportions as typical concrete ties. Table 1 lists the average transfer length obtained for the pretensioned concrete prisms cast with the same wire type as those used in the pullout tests.

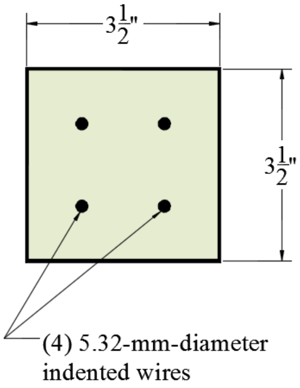

Figure 6: Pretensioned prism cross-sections

Table 1: Table 1: Average transfer length for similar wires in pretensioned concrete prisms

Wire Designation	Indentation Type	Average Transfer Length (in.)
WA	smooth	16.3
WB	chevron	11.6
WC	spiral	8.8
WD	chevron	11.1
WE	spiral	7.4
WF	diamond	8.5
WG	chevron	11.8
WH	chevron	7.5
WI	chevron	10.1
WJ	chevron	9.0
WK	dot (4 rows)	14.0
WL	dot (2 rows)	18.7

To establish the correlation between the curves in Figure 5 and the transfer length values in Table 1, researchers investigated several aspects of the curves. The analysis focused on the initial slope of the curves, the values of end-slip at specific pullout forces, and the values of pullout force at specific end-slip values. The team obtained the highest degree of correlation for all 12 wires when using the maximum pullout force occurring at an end-slip less than or equal to 0.10 inch. This resulted in a coefficient of determination, R^2, of 0.882. As noted above, the smooth and spiral wires behaved quite differently than the indented wires did during the pullout test. Eliminating the smooth and spiral wire data gave a R^2, of 0.916 (Figure 7).

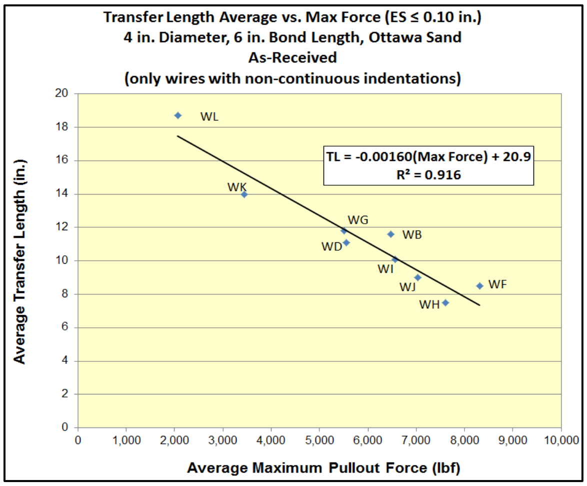

Figure 7: Plot of average transfer length values vs. maximum pullout force (avg. of 6 values) at an end-slip less than or equal to 0.10 inches

CONCLUSIONS

This research successfully developed a practical and efficient un-tensioned pullout test to determine the bond quality of steel reinforcement wires. The test produces results that strongly correlate with transfer lengths in pretensioned concrete members. ASTM International has formally adopted the test as ASTM A1096 and it is now also recognized in Section 4.2.4.3 of the 2021 AREMA Manual for Railway Engineering. The project team recommends that pretensioned concrete tie producers use this test as part of their ongoing quality control efforts.

FUTURE ACTION

Future research includes the development of correlation equations between ASTM A1096 pullout values and the transfer and development length of larger-diameter prestressing wires currently used in the manufacture of pretensioned concrete railroad ties.

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Concrete railroad ties, bond, ASTM A1096, pullout test, transfer length, transmission length, prestressed concrete, indented wire

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