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DETERMINING BOND-SLIP CHARACTERISTICS OF PRESTRESSING TENDONS WITH VARYING GEOMETRIES IN TWO CONCRETE MIXTURES

SUMMARY

Untensioned pullout tests were conducted to obtain the bond-slip characteristics of two groups of prestressing tendons used in concrete railroad tie production. The purpose of this testing was to provide empirical data to support numerical methods of predicting splitting and bursting failures in concrete ties. This work was conducted by RJ Peterman & Associates, Inc. (RJPA) between April and December 2017 and was funded by the Federal Railroad Administration (FRA).

The first group of tendons included four 5.32-mm-diameter wires and one 3/8”-diameter 7-wire smooth strand, and the second group included one 7.5-mm-diameter indented wire and four 8-mm-diameter wires with varying indent depths. Two concrete mixtures were made, one utilizing Tucson, AZ, aggregates resulting in a normal modulus concrete, and the other made with weathered granite aggregate from Anderson, SC, which yielded a reduced modulus concrete. Their moduli of elasticity (MOE) and Poisson’s ratios were determined experimentally at three different compressive strengths (3,500 psi, 4,500 psi, and 6,000 psi).

The test results show a stronger bond with increased concrete compressive strength for all reinforcement diameters, indentation depths, and concrete types evaluated. With 8-mm-diameter wires, the bond strength increased with increasing indent depths. Further, the reduced modulus concrete resulted in a lower bond at all concrete compressive strengths. Additional tests are recommended to investigate the bond-slip relationships of tendons in concrete mixtures using the limestone aggregate and a water/cement (w/c) ratio of 0.32.

BACKGROUND

The bond-slip relationship between prestressing tendons and concrete is a key variable when applying finite element analysis (FEA) to predict the splitting or bursting failure of pretensioned concrete crossties (Stuart and Yu, 2018). Many factors can affect bond-slip performance, including the prestressing tendon characteristics, concrete mixture, and concrete release strength. Effectively recognizing and managing these variables can improve the performance of concrete crossties and maximize their service life.

OBJECTIVES

The main objective of this research was to experimentally determine the bond-slip relationships of different prestressing tendons in concrete made with different coarse aggregate sources and having different compressive strengths. The results of this research will improve the performance of FEA models and increase the state of knowledge in the industry. These results can be leveraged to create better performing, longer-lasting concrete crossties.

METHODS

Untensioned pullout tests were completed for each unique combination of concrete mixture, prestressing tendon type, and concrete compressive strength. Each test was replicated 3 times for a total of 135 tests.

Concrete mixtures

Two similar concrete mixtures (Table 1) were used with two aggregate types (Figure 1). The sand used for both mixtures was a local concrete sand from Manhattan, KS. A slump of approximately 6 inches was achieved for both mixtures by adding a high-range water reducer (Glennium 7,700).

Table 1. Concrete mix proportions

Concrete	Material Type	Quantities per 1.0 ft^3
Tucson Aggregates	CA#1	40.0 lb
	CA#2	24.0 lb
	Sand	48.0 lb
	Type III Cement	36.0 lb
	w/c	0.42
	Admixture	Glennium 7,700
Weathered Granite	Weathered Granite	64.0 lb
	Sand	48.0 lb
	Type III Cement	36.0 lb
	w/c	0.42
	Admixture	Glennium 7,700

Figure 1. Aggregates: CA#1 and CA#2 (Tucson, AZ); weathered granite (size 57/67, Anderson, SC)

The MOE and Poisson's ratios of the two concrete mixtures were experimentally determined at three different compressive strengths (3,500 psi, 4,500 psi, and 6,000 psi). Table 2 lists the average MOE and Poisson's ratio results for the concrete mixtures.

Prestressing tendon types

The first group consisted of four 5.32-mm-diameter wires and one 3/8"-diameter 7-wire smooth strand, denoted as WA, WE, WG, WH and SA, respectively, from the original transfer length study conducted at Kansas State University (KSU) (Arnold, 2013). The second group consisted of one 7.5-mm-diameter indented wire from Voestalpine (denoted as VA) and four 8-mm-diameter wires with varying indent depths from Nucor Corporation (denoted as NA, NS, NM, and ND, respectively). Figure 2 shows the surface indent patterns of the second group of wires.

Table 2. Concrete elastic properties

Concrete		MOE (psi)	Poisson's Ratio
Tucson Aggregates	3,500 psi	2.87E+06	0.203
	4,500 psi	3.26E+06	0.204
	6,000 psi	3.78E+06	0.211
Weathered Granite	3,500 psi	2.19E+06	0.186
	4,500 psi	2.60E+06	0.185
	6,000 psi	3.02E+06	0.205

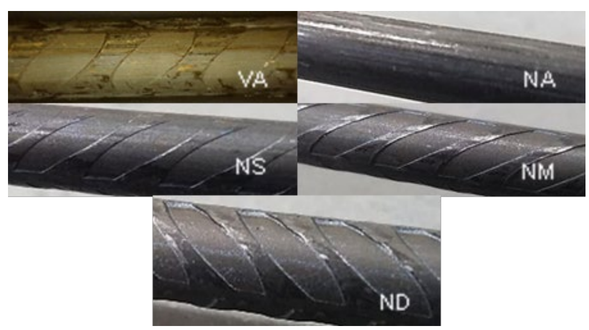

Figure 2. Surface indent patterns of the five larger diameter wires: VA (indented), NA (smooth), NS (0.12-mm-deep indents), NM (0.17-mm-deep indents) and ND (0.22-mm-deep indents)

Test setup

Figure 3 shows the schematic and actual photo of the untensioned pullout test setup. All pullout tests conducted in this study utilized a load frame, servo-hydraulic controller and 4-inch-diameter x 8-inch long reusable steel molds. A tension force was applied to the bottom end of the tendon at a rate of 2,000lbs per minute while the top (free end) of the tendon was monitored for slip with respect to the outer steel tubing. The applied load (or pullout force) and the tendon's unloaded end slip were recorded until pullout failure occurred, and the pullout force versus unloaded end slip curves were generated for all tests.

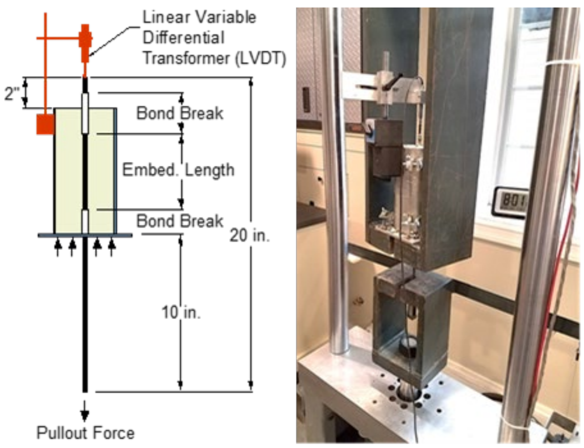

Figure 3. Schematic and photo of the untensioned pullout test setup

RESULTS

To compare the pullout results among tendons with different diameters and embedment lengths, the pullout forces were divided by the calculated nominal bonding areas to obtain the bond stresses. The resulting bond stress-unloaded end slip curves were then averaged for each test.

Figure 4 shows the average bond stress versus end slip curves for each 5.32-mm-diameter wire (WA, WE, WG, and WH) and the 7-wire smooth strand (SA) tested with the Tucson, AZ, aggregate concrete.

Figure 5 shows the average bond stress versus end slip curves for VA, NA, NS, NM and ND with the Tucson, AZ, aggregate concrete.

Figure 6 shows the average bond stress versus end slip curves for WA, WE, WG, WH, and SA with the Anderson, SC, aggregate concrete. Figure 7 compares the responses for prestressing wires WG and WH using the two different aggregate sources. The reduced modulus concrete produced lower average bond stresses compared to normal modulus concrete. This trend may be attributed to a lower confining pressure imposed on the prestressing tendon by the reduced MOE mixture, and/or a lower abrasion resistance provided by the weathered granite aggregate as the tendons are being pulled through the concrete.

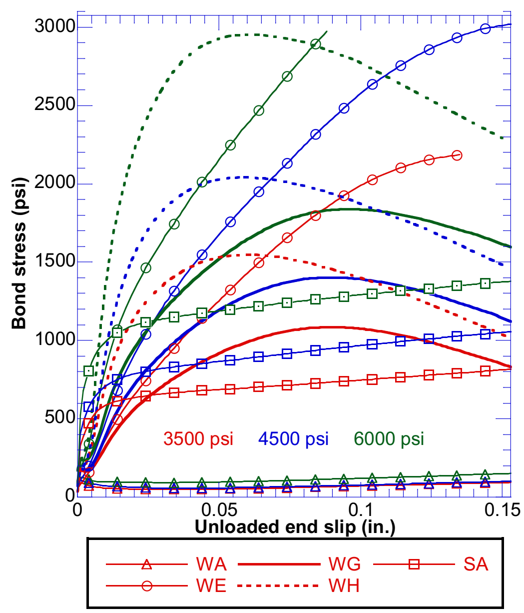

Figure 4. Bond stress-unloaded end slip curves (Tucson, AZ, aggregates)

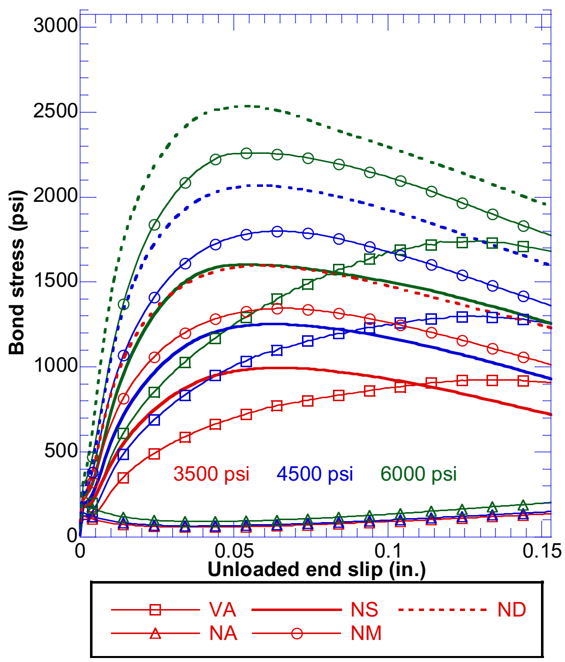

Figure 5. Bond stress-unloaded end slip curves (Tucson, AZ, aggregates).

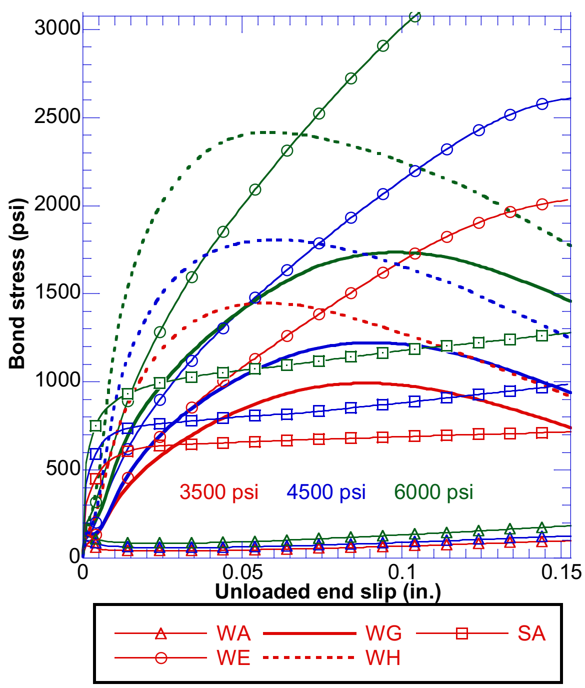

Figure 6. Bond stress-unloaded end slip curves (Anderson, SC, aggregates)

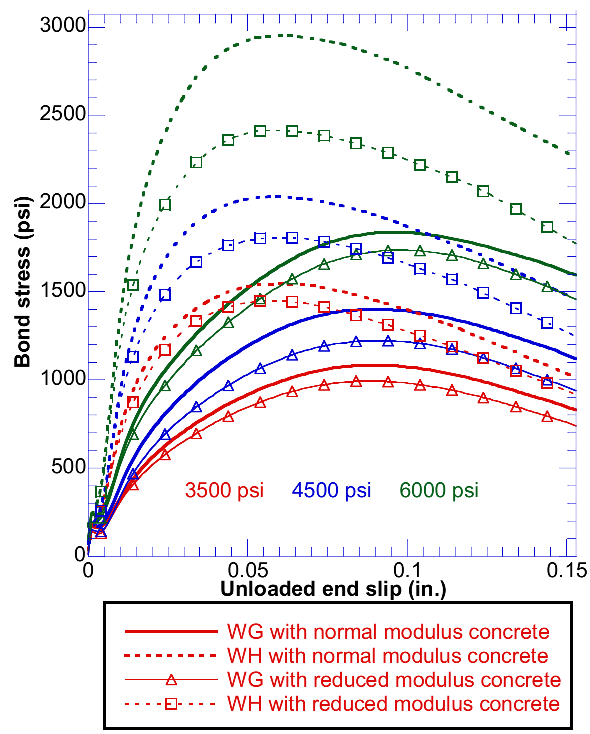

Figure 7. Bond stress-unloaded end slip curves for prestressing wires WG and WH in normal and reduced modulus concrete

CONCLUSIONS

The bond strength increased significantly with increased concrete compression strength. This was consistent for all reinforcement diameters, indentation depths, and concrete types with normal or reduced MOE concrete. Further, pullout tests utilizing 8-mm-diameter wires with different indent depths indicated that the bond consistently increased with increased depth of indent.

FUTURE ACTION

Limestone aggregates are also used to produce concrete crossties. It is recommended that similar pullout tests be conducted on the same prestressing tendon sources, but with concrete using a limestone coarse aggregate.

In this study, a w/c ratio of 0.42 was used to slow the concrete strength-gain rate to permit testing of five specimens within each targeted strength window. Concrete railroad tie plants typically use a w/c ratio of 0.32 (Bodapati et al., 2013) to accelerate the concrete strength-gain rate. The bond strength development rate with this w/c ratio has not been determined. Additional tests are recommended to obtain the bond strength development data with concrete mix using the w/c ratio 0.32.

REFERENCES

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KEYWORDS

Untensioned pullout test, bond-slip relation, prestressing tendon, surface indent, concrete mixture, coarse aggregate, water-to-cement ratio, concrete release strength, concrete compressive strength, concrete railroad tie.