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BOND-SLIP RELATIONSHIPS OF WIRES USED IN PRETENSIONED CONCRETE RAILROAD TIES

SUMMARY

This research was part of a larger project, "Quantifying the Effect of Prestressing Steel and Concrete Variables on the Transfer Length in Pretensioned Concrete Crossties," conducted by Kansas State University (KSU) and sponsored by the Federal Railroad Administration (FRA). This report highlights advances in methods to determine the bond-slip relationships of different prestressing steel wire types. These relationships can predict wire performance in concrete ties and are useful for modeling tie designs. The full technical report can be downloaded from the K-State Research Exchange.

KSU developed special wire testing frames and procedures to measure bond-slip performance of prestressing wires (or strands) in concrete. The test called for applying tension to the wires prior to casting the concrete and then slowly releasing the prestress force into the concrete. Forces and displacements were measured to control the test and develop the results. The results revealed significant variations in the bond-slip relationships for different wires, despite sharing the same diameter and tensile strength. These differences were attributed to both the wire indent characteristics and the amount of concrete surrounding the wire. This research also found a strong correlation between the bond-slip results and the force transfer length in pretensioned concrete prisms with similar wires. These methods and results are useful inputs to the concrete tie design process.

BACKGROUND

Transfer length in a pretensioned concrete member is the distance required to transfer the prestressing force into the concrete member [1]. 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 .

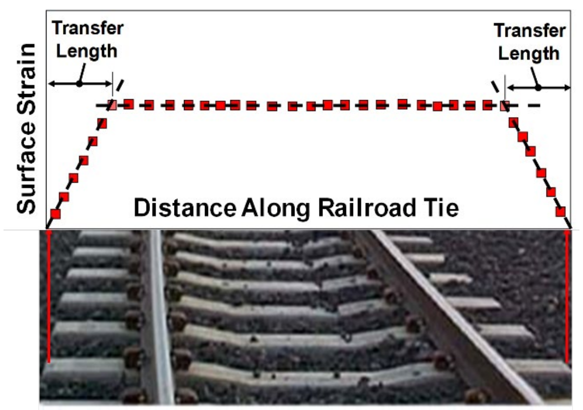

Figure 1: Schematic of transfer length

Prestressing force transfers from the steel wires to the concrete during the detensioning process. The bond-slip relationship between the wires and the concrete mix influences this force transfer and, therefore, the quality of the finished tie. Quantifying the bond-slip relationships of the specific wires and concrete mixtures used for ties will improve the accuracy of tie designs and provide valuable input to finite element (FE) modeling of concrete tie performance under loads.

OBJECTIVES

The objective of this research was to empirically determine the bond-slip relationships for a set of common concrete reinforcement wires.

Researchers developed a unique test method and equipment arrangement for wire reinforcement testing. These tests were modeled after the tensioned pullout tests previously conducted by Abrishami [1] on 7-wire prestressing strands.

The team investigated five different 5.32-mm-diameter wire types in this portion of the study: smooth wire, spiral wire, deep chevron, shallow chevron, and dot-patterned wire.

Figure 2: Five different 5.32-mm-diameter wires with different indentation types were utilized

METHODS

Researchers used three special frames (Figure 3 and Figure 4) to tension the 5.32-mm-diameter wires in the vertical direction to 7,000 lbs each. Cylindrical concrete specimens were cast around the wires using steel molds (Figure 5). These specimens were 2½ inches tall and either 4 inches or 2 inches in diameter. The different concrete diameters were used to measure the effect of cover thickness on the bond-slip relationship. The full report details the results from this part of the research .

The concrete was cured to match the typical compressive strength used in concrete tie manufacturing. Concrete strength at the time of testing was determined from temperature match-cured strength cylinders. Once the concrete reached the desired strength, the mechanical gear jack at the top of the frame slowly released the prestress force into the specimen. Linear variable differential transformers (LVDTs) attached to a fixture clamped to the wire measured the displacement of the wire with respect to the concrete (Figure 6, Figure 7). Load cells recorded the force at the top and bottom of the wire.

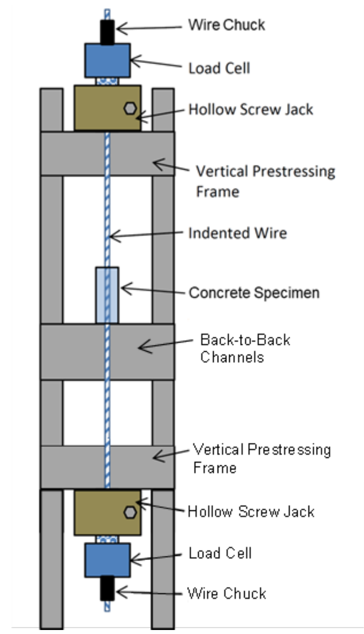

Figure 3: Schematic of test frame

Figure 4: Three vertical prestressing frames

(a) 4" diameter (b) 2" diameter

Figure 5: Concrete specimen molds

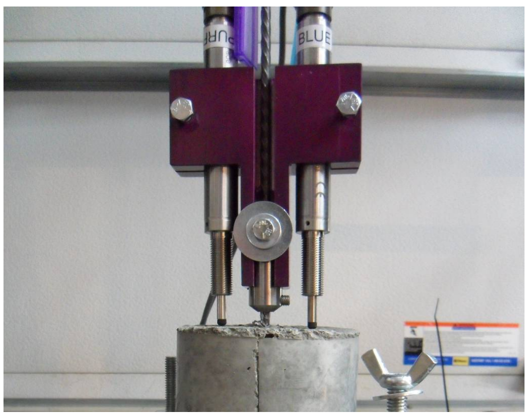

Figure 6: Two LVDTs measuring slip of wire with respect to the concrete at the specimen top

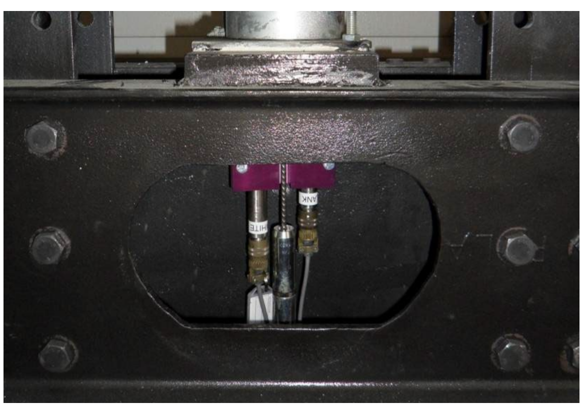

Figure 7: Two LVDTs measure wire slip with respect to the steel bottom plate of the concrete mold

RESULTS

Three tests were conducted with each wire type and specimen diameter. The 2-inch-diameter, unconfined specimens with deeper indentations resulted in some specimens with longitudinal splitting cracks. The 4-inch-diameter, unconfined specimens experienced no cracking, and the bond stress-versus-slip curves were consistent for each wire type (Figure 8, Figure 9).

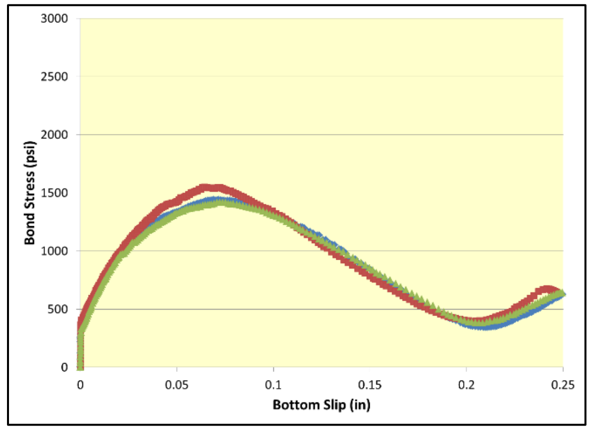

Figure 8: Bond-versus-slip curves for wires with shallow chevron indents

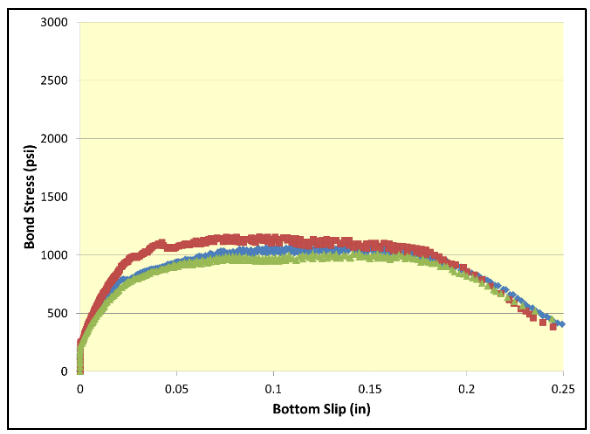

Figure 9: Bond-versus-slip curves for wires with dot-patterned indents

Each of the five reinforcements exhibited a unique bond-slip relationship as the wire was released and slipped through the specimen (Figure 10).

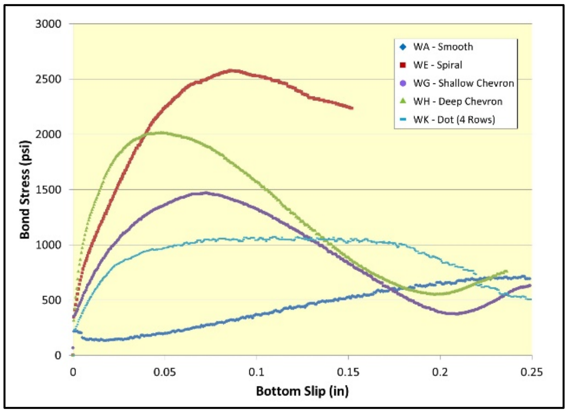

Figure 10: Average curves for each wire type

Wires with indent patterns caused bond stresses to increase much faster than those with smooth wire. Bodapati et al. [2] also observed this increase in bond behavior in their work with pretensioned prisms using the same wire types. Researchers plotted bond stress at various slip values with transfer lengths obtained from Bodapati. Transfer lengths from the prisms were then compared with the average bond-slip curves and correlations determined for bond stress at different slip values. Bond stresses values measured at a bottom slip value of 0.05 inch produced the best correlation to the transfer length, with a coefficient of determination, R^2, of 0.979 (Figure 11).

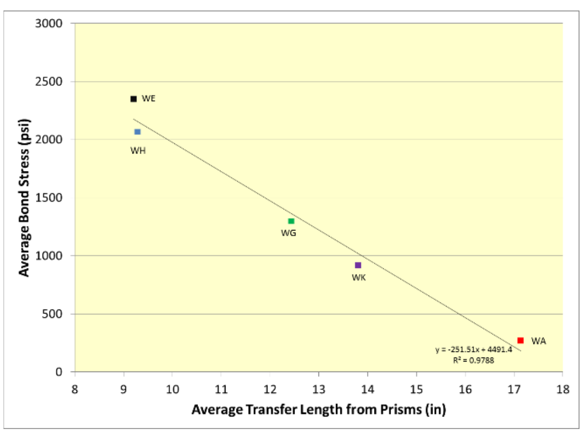

Figure 11: Correlation of bond stress values at 0.05 inch of slip (during tensioned pullout tests) with transfer length from pretensioned prisms

CONCLUSIONS

This research successfully quantified the bond-slip relationships for 5.52-mm-diameter wires with different indentation patterns. The results showed that these relationships were consistent and unique for each wire type, but varied considerably based on indent patterns. In addition, researchers found a strong correlation between wire indent geometry, concrete strength, and the resulting transfer lengths of pretensioned members manufactured with similar wire types. These data will support the development and use of accurate FE models for pretensioned concrete tie design efforts.

FUTURE ACTION

Future research includes the development of a wire-indent optimization strategy for pretensioned concrete railroad ties. The strategy will incorporate the recently quantified correlation between bond performance and splitting propensity as a function of key wire indent parameters.

REFERENCES

[1] Abrishami, H. H. (1994). Studies on Bond and Cracking of Structural Concrete. Ph.D. dissertation, McGill University, Montreal.

[2] Bodapati, N. B., Peterman, R. J., Zhao, W., Wu, C.-H. J., Beck, B. T., Haynes, M., & Holste, J. (2013). Influence of Indented Wire Geometry and Concrete Parameters on the Transfer Length in Prestressed Concrete Crossties. 2013 Joint Rail Conference. Knoxville, TN: American Society of Mechanical Engineers.

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CONTACTS

Cameron D. Stuart
Program Manager
Federal Railroad Administration
Office of Research, Dev., & Technology
1200 New Jersey Avenue, SE
Washington, DC 20590
(202) 493-6384
cameron.stuart@dot.gov

Dr. Robert J. Peterman
Professor
Kansas State University
Civil Engineering
2118 Fiedler Hall
Manhattan, KS 66506
(785) 532-7612
bob@ksu.edu

Dr. B. Terry Beck
Professor
Kansas State University
Mechanical and Nuclear Engineering
1701 B Platt St
Manhattan, KS 66056
(785) 532-2604
tbeck@ksu.edu

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Concrete railroad ties, crossties, bond, pullout test, transfer length, transmission length, prestressed concrete, pretensioned concrete, indented wire

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