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PRESTRESSING STEEL AND CONCRETE VARIABLES AFFECTING TRANSFER LENGTH IN PRETENSIONED CONCRETE CROSSTIES

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). The project's period of performance was 2011 through 2015. This report highlights advances in understanding the prestressing steel and concrete properties that affect the transfer length (TL) in pretensioned concrete crossties. The full Technical Report can be downloaded from the K-State Research Exchange.

The project experiments included 13 different steel wire reinforcements, with varying indent geometries, and a range of concrete properties. The effort consisted of a lab phase and a plant phase. During the lab phase, pretensioned concrete prisms were fabricated to model plant-manufactured full crossties. In the plant phase, a concrete crosstie manufacturing plant fabricated full concrete railroad ties. KSU researchers measured surface strains of the various prisms and ties to compute the TLs of the various reinforcement and concrete combinations.

This research found a strong correlation between wire indent geometry and concrete strength and the resulting transfer length of the prestressing force. Researchers also developed a correlation function between ASTM 1096 wire test results and concrete tie transfer lengths. These results provide concrete tie manufacturers with a valuable toolset to predict the TL of concrete ties prior to manufacturing.

BACKGROUND

Transfer length, in a pretensioned concrete member, is the length 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 be fully transferred to the concrete outboard of the rail seat. This concept is represented in Figure 1.

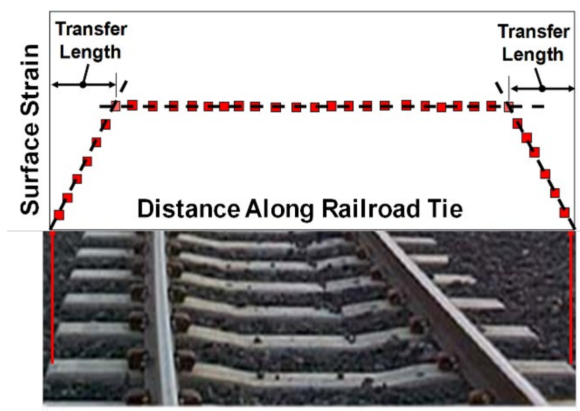

Figure 1: Schematic of transfer length

Concrete ties are relatively short. Most prestressed concrete railroad tie producers use indented wires or indented strands rather than traditional 7-wire smooth strands because these indentations serve to improve the bond between the steel and the concrete, reducing the TL. However, the broad application of these indented reinforcing steels has been limited. U.S. design codes do not yet include recommended design parameters for indented prestressing wire or strands for transfer and development length. Moreover, there is no standardized indent pattern (shape, size, depth of indent, etc.) produced by wire manufacturers for use in concrete ties. Thus, the corresponding bond behavior of these different reinforcements when used in concrete ties is not well established.

OBJECTIVES

The objective of this research was to quantify how prestressing wire parameters and concrete variables change the TL in concrete ties and to identify the best combinations to meet the desired tie properties. A detailed investigation of the influential parameters that affect the TL of a pretensioned concrete tie was completed.

METHODS

The specific parameters investigated in this project included the wire reinforcement indent geometry, concrete consistency (slump), release strength, water-to-cementitious (w/c) ratio, aggregate type, and the presence of viscosity-modifying admixture. Researchers systematically varied the mix design and reinforcement type to quantify the effect of each parameter on TL.

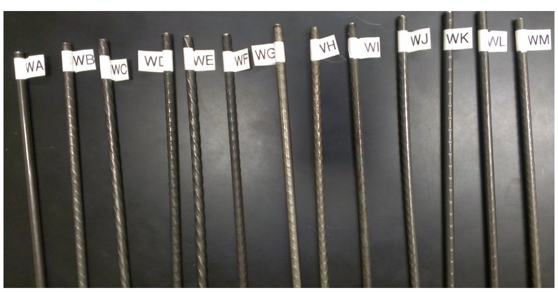

Figure 2: Wire types

This study included 13 different 5.32-mm-diameter prestressing wires (12 indented and 1 smooth) that are used in pre-tensioned concrete railroad ties worldwide. The steel type was low-relaxation, Grade 270 ksi. All wires were labeled from [WA] through [WM] sequentially, based on their date of arrival at the KSU laboratory. The wire types are shown in Figure 2.

During the lab phase, the effect of the following parameters on TL was determined:

- Wire indentation type (13 total types, all 5.32-mm diameter)
- Concrete compressive strength at de-tensioning (3500, 4500, or 6000 psi)
- Concrete consistency (slump) – 3, 6, or 9 inches

Parameter testing utilized 69-inch-long, 4-wire pre-tensioned concrete prisms (Figure 3). The prism cross-sections each contained four wires or strands, and the dimensions were chosen to maintain the same approximate tendon spacing and reinforcement-to-concrete proportions as typical concrete ties. Brass inserts cast into the sides of these prisms at 1-inch spacing facilitated surface strain measurements.

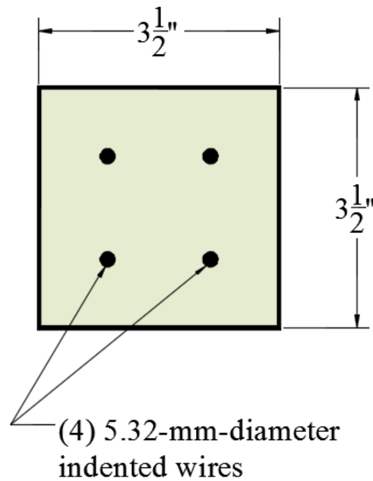

Figure 3: Pretensioned prism cross-sections

The wires were tensioned to 7,000 lbs each, corresponding to a 203.2 ksi stress level. A mechanical (Whittemore) gage was used to measure in-plane concrete surface strains. The instrument was fitted with a digital indicator with a precision of 0.0001 inch (Figure 4).

Figure 4: Measurement of concrete surface displacements using a Whittemore gage

Table 1 lists the average TLs determined for each wire type when the prisms were de-tensioned at 4,500 ± 200 psi. From this table, average TLs varied from 7.43 inches to 18.73 inches. The concrete had a slump of 6 inches and a w/c ratio of 0.32.

Table 1: Average transfer length of each wire type when detensioned at 4,500 psi

Wire Designation	Indentation Type	Average Transfer Length (inches)
WA	Smooth	16.33
WB	Chevron	11.60
WC	Spiral	8.85
WD	Chevron	11.08
WE	Spiral	7.43
WF	Diamond	8.45
WG	Chevron	11.78
WH	Chevron	7.50
WI	Chevron	10.10
WJ	Chevron	9.02
WK	Dot (4 rows)	14.00
WL	Dot (2 rows)	18.73
WM	Chevron	9.83

Figure 5 shows the variation of TL with concrete release strength. These tests utilized wires WA (smooth), WE (spiral), WG (shallowest chevron), WH (deepest chevron), and WL (dot). In every case, increasing release strength resulted in shorter average TL values.

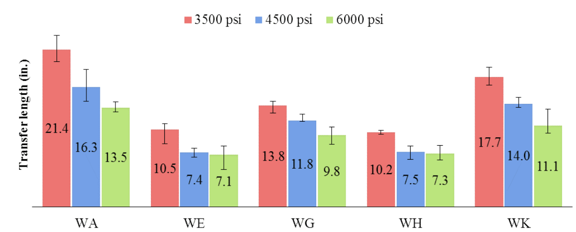

Figure 5: Effect of concrete strength at detensioning on transfer length

Figure 6 shows the effect of concrete consistency (slump) on TL. These prisms had a w/c ratio of 0.32 and a release strength of 4,500 psi. From this figure, concrete slump had little influence on TL values, although TL values for 9-inch-slump concrete were highest for four of the five wire types.

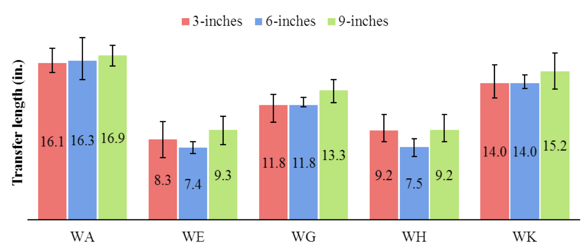

Figure 6: Effect of concrete consistency (slump) on transfer length at 4500 psi release strength.

During the plant phase, a concrete crosstie manufacturer fabricated 20-wire pre-tensioned full-size ties using wires from the same coil as the ones used in the lab phase.

Longitudinal concrete surface displacement measurements were made on 25 concrete ties which allowed for the determination of 50 TLs with each wire type. The ties evaluated were selected to statistically determine the TLs occurring in ties cast along the entire prestressing bed. Researchers measured the TLs with two non-contact, laser-speckle imaging (LSI) measurement systems (Figure 7). These systems compute surface displacements from digital image correlation of speckle patterns painted on the concrete surface.

Figure 7: LSI surface-strain measurement system

RESULTS

The results from both phases demonstrated excellent agreement (Figure 8). Transfer length values for different wire types showed the same trend in both prisms and full ties. The values for wire WL were significantly lower during the plant phase due to a higher concrete release strength.

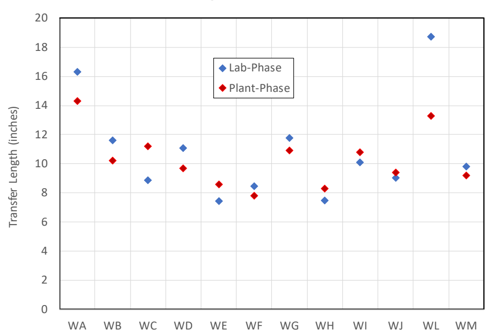

Figure 8: Average transfer lengths from lab phase (at 4,500 psi release) and plant phase

Correlation with Pullout Values

Transfer length values from the lab phase were correlated with pullout test results from ASTM Standard A1096, “Standard Test Method for Evaluating Bond of Individual Steel Wire, Indented or Plain, for Concrete Reinforcement.” (Figure 9) From this correlation, the following expression was developed:

$$TL = 34.2 - \frac{f'_{ci}}{300} - \frac{(A1096\ value)}{\left[1250 - f'_{ci}\left(0.4 - \frac{f'_{ci}}{16{,}000}\right)\right]}$$

where:

TL = Transfer length in inches

f'_{ci} = Concrete compressive strength at de-tensioning in psi

A1096 value = ASTM A1096 pullout value (6-specimen average) in pounds

This expression results in a coefficient of determination, R^2, of 0.954 when compared with the experimental data in the lab phase where concrete strengths at detensioning were precisely controlled.

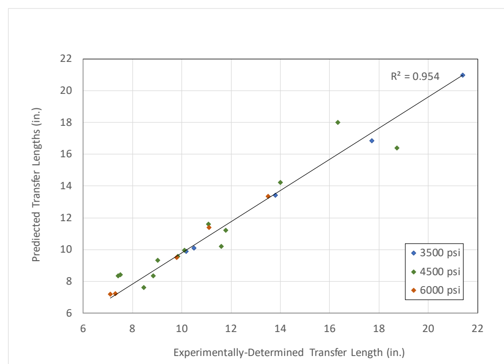

Figure 9: Comparison of actual and predicted transfer lengths

CONCLUSIONS

Transfer length values in pretensioned concrete ties are highly dependent on the type of wire indentation pattern used and the concrete strength at the time of detensioning. ASTM Standard A1096 pullout values and the correlation expression developed in this study can accurately predict the resulting TL.

FUTURE ACTION

The development of a strategy to optimize the wire indents for pretensioned concrete railroad ties is underway. This strategy will include the recent correlations for bond (TL) and splitting propensity (crack length) as a function of the key indent parameters.

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