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Effect of Concrete Composition on Splitting Cracks in Prestressed Concrete Railroad Ties

SUMMARY

This research was part of a larger project, "Developing Qualification Tests to Ensure Proper Selection and Interaction of Pretensioned Concrete Railroad Tie Materials." Kansas State University (KSU) conducted this research under contract with the Federal Railroad Administration from 2015 through 2019. This report highlights advances in methods to evaluate the splitting crack growth potential for various mixtures used to fabricate prestressed concrete railroad ties. A full technical report of this research is available on the K-State Research Exchange.

Durable prestressed concrete ties must be resistant to splitting crack growth. In this study, KSU researchers tested the effect of aggregate angularity, coarse aggregate volume, water-to-cement ratios (w/c), and other variables on the crack growth potential of concrete.

KSU researchers conducted fracture toughness (FT) tests on four, 3-point bending concrete specimens for each mixture type. Next, they fabricated pretensioned prisms with varying amounts of concrete covering the reinforcements. The prism strength was 4,500 psi when de-tensioned. Finally, they quantitatively evaluated the splitting cracks in each specimen by direct measurement of the crack lengths. The results indicated a strong correlation between crack length and FT.

BACKGROUND

A typical failure mode of pretensioned concrete crossties is the propagation of longitudinal cracks that intersect the prestressing wires. Durable prestressed concrete ties must prevent existing micro-cracks within the material from growing. Previous research has shown that very high local stresses occur in the concrete around prestressing wires during the prestressing release operation [1].

Cracks will often form during the de-tensioning process when stress transfers from the wires to the concrete but, given sufficient concrete strength and concrete cover over the wires, will not propagate to the surface. However, these cracks can propagate over time due to the additional stress of drying shrinkage, creep, and service loading in track. Some concrete ties are much better able to resist crack propagation than others. This ability to resist crack propagation is referred to as the *fracture toughness* of the concrete.

OBJECTIVES

The KSU team sought to quantify the effect of concrete composition on end-splitting crack propagation in prestressed concrete members. Parameters evaluated included aggregate shape and content, (w/c) ratio, the presence of fly ash, and paste and air void content.

METHODS

KSU researchers used five different coarse aggregate (CA) types from different locations across the U.S. These aggregates are in use, or were previously used, for concrete railroad tie manufacturing. Figure 1 shows the CA types used in this study and the percentage of fractured particles according to AASHTO TP 61 [2].

Figure 1: Coarse aggregates used in the study

Researchers conducted FT tests on 3 in. x 6 in. x 21 in. prisms (Figure 2) based on the two-parameter method proposed by Shah et al. [3]. The procedure employs a clip gauge (Figure 3) to measure the opening of a 1.5 in.-deep saw-cut notch at the midpoint of the specimen. A load was applied at a rate sufficient to maintain a constant crack mouth opening displacement (CMOD) of 0.00015 in. per minute.

Figure 2: Prism under test

Researchers measured the CMOD during both the loading and unloading phases. To cause the crack to close during the unloading phase, they used 15-lb. cantilevered counterweights at the end of the specimens (Figure 2).

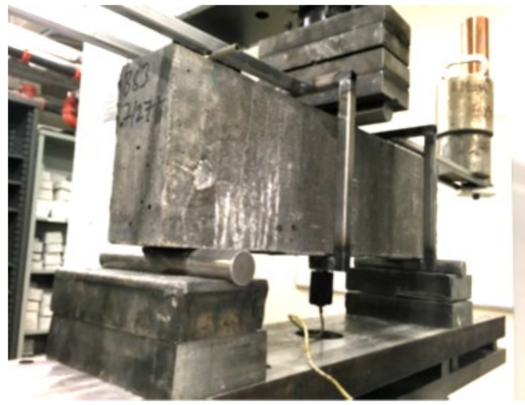

Figure 3: FT specimen with clip gage mounted at bottom

In addition to the FT tests, researchers fabricated pretensioned concrete prisms – four wires in a square pattern, spaced 2.0 inches apart in both directions – using the same concrete mixtures as the FT specimens (Figure 4). Each test included three prisms, each with different amounts of concrete edge distance to the prestressed wires – 0.50, 0.625, and 0.75 in. Concrete edge distance is defined as the distance from the wire center to the prism edge. All wires were from a single source and tensioned to 7,000 lbs each prior to placing the concrete.

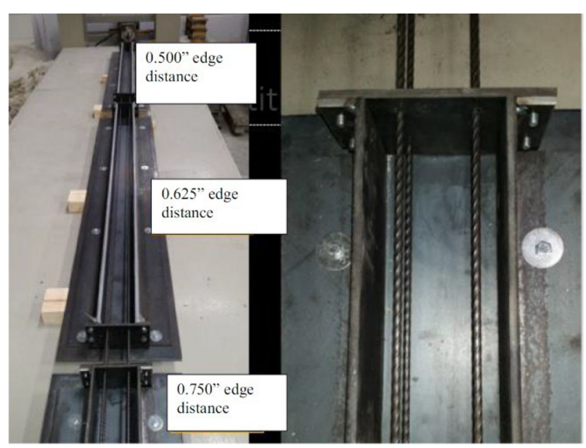

Figure 4: Prism forms with four tensioned

prestressing wires

To control the concrete strength at de-tensioning, researchers employed match-cured cylinders to provide an accurate estimate of the compressive strength of the concrete during the cure process. As soon as the cylinders reached 4,500 psi, they gradually de-tensioned the prisms using a gear jack.

The prisms were left to cure for 90 days to evaluate the long-term behavior of splitting cracks after creep and shrinkage. After curing, the researchers measured the length of all visible cracks using a ruler.

RESULTS

The data from each loop in the load-versus-CMOD graph (Figure 5) was analyzed by calculating FT values for each loop according to the procedure developed by Shah et al. [3].

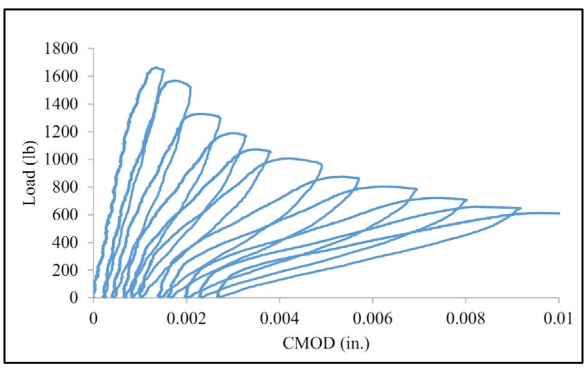

Figure 5: Typical load versus CMOD curves from FT test

The average FT and splitting tensile results for baseline mixtures without supplementary cementitious materials are shown in Figures 6 and 7, respectively. These mixtures each had a CA/fine aggregate (FA) ratio of 1.00 and were not air-entrained. In these figures, the error bars represent one standard deviation.

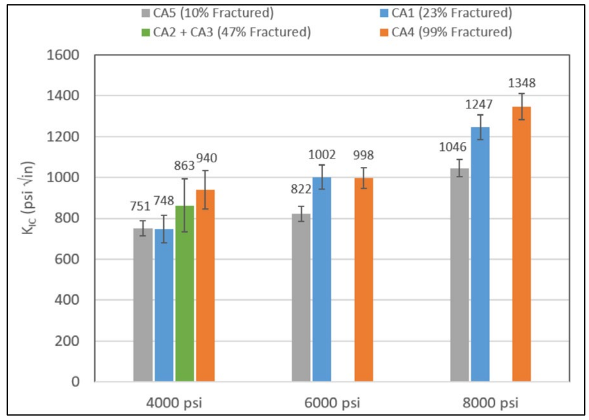

Figure 6: FT results for specimens with different coarse aggregate shape

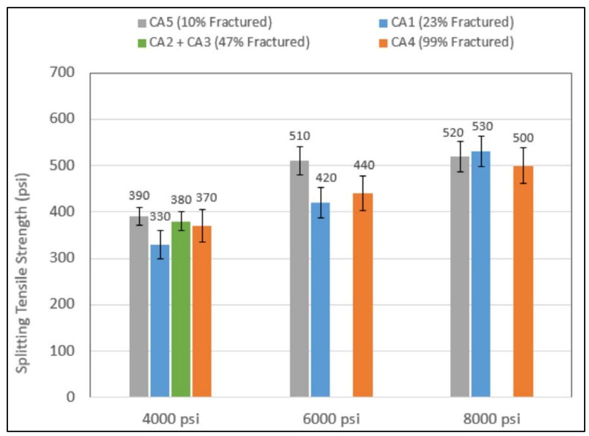

Figure 7: Splitting Tensile Strength results for specimens with different coarse aggregate shape

From Figures 6 and 7, both splitting tensile strength and FT values tended to increase with increasing compressive strengths. However, there was no clear distinction in splitting tensile results with different aggregates. Conversely, FT values for mixtures with CA4 containing 99 percent fractured particles were always greater than mixtures with CA5 (only 10 percent fractured). Note that the CA2+CA3 specimen was not tested at the higher release strengths because the results at 4000 psi were not significantly different than the other mix types.

The KSU research team conducted similar testing and comparisons with other mixture variables, and the following factors were shown to increase FT:

- Increasing CA angularity (up to a 25 percent increase in FT)
- Increasing CA/FA ratio from 1.0 to 1.5 (up to 16 percent increase in FT)
- Reducing w/c from 0.38 to 0.28 (up to 30 percent increase in FT at 4,000 psi, negligible effect at 6,000 and 8,000 psi)

The team also found that the use of Class F fly ash, the presence of air entrainment, and increasing paste content had little or no effect on FT within the ranges of parameters evaluated.

Based on the FT findings, additional pretensioned concrete prisms were fabricated with a new mixture ("Super Mix") that used the characteristics that improved FT, as noted above. Specifically, the mixture used aggregate CA4 (with 99 percent fractured particles), a CA/FA ratio of 1.5, and a w/c ratio of 0.32. Researchers compared the results from this mixture with the baseline mixtures in Figure 8. They then measured these crack lengths after 90 days.

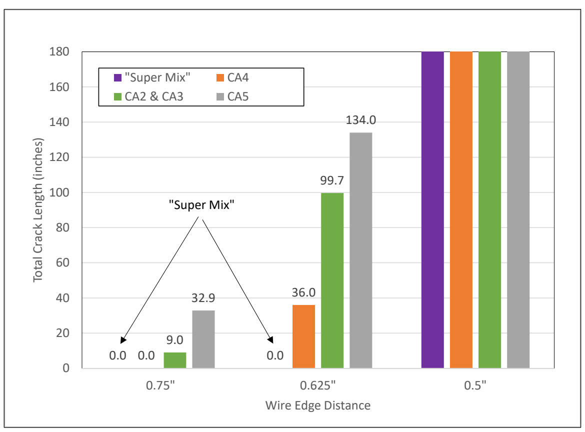

Figure 8: Results from pretensioned concrete prism tests with different mixtures

From Figure 8, prisms fabricated with the Super Mix had zero cracking in prisms with 0.75-in. and 0.625-in. of concrete cover. This was the only mixture to be crack-free at the 0.625-in. cover distance. At 0.5-in., all mixtures cracked.

CONCLUSIONS

The research results indicate that there was a direct correlation between the FT of the concrete mixtures and the splitting resistance of these mixtures when used in the manufacture of pretensioned concrete members. Additionally, FT testing revealed beneficial improvements to the mixture design that were not apparent from direct splitting tensile tests. Researchers found the greatest improvements when de-tensioning at compressive strengths less than 6,000 psi, increasing CA angularity and CA/FA ratios, and reducing the w/c ratio. The work also confirmed that the reinforcement edge distance was the most crucial parameter in the resistance to longitudinal splitting in pretensioned concrete ties (refer to Figure 8).

RECOMMENDATION

KSU researchers do not recommend FT testing as a practical means to evaluate new mixtures for pretensioned concrete ties. The test is difficult to perform and requires many samples to achieve reliable results. A better test is found in the newly approved AREMA Splitting Resistance Test [4], developed as part of this research program. This test provides direct feedback on the robustness of the overall tie design (including the concrete mixture) in resisting longitudinal splitting cracks.

REFERENCES

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Chapter 30 Section 4.2.4.1 Splitting Resistance Test (SRT).

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