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CONCRETE TIE PERFORMANCE IN DEGRADED TRACK CONDITIONS

SUMMARY

This research provides insight into how concrete crossties perform in locations with poor track support. Specifically, the project documented critical support conditions for concrete track, the effect of center binding and cracking conditions on tie performance, and the effect of water on tie crack propagation rates. Researchers acquired data through industry surveys, laboratory experiments, and finite element (FE) modeling, and the results are incorporated into industry reference documents. RailTEC at the University of Illinois at Urbana-Champaign performed this work between January 2015 and April 2019. This research report provides a partial summary of the project results; full technical reports are linked in the conclusions section

BACKGROUND

Several derailments have occurred in locations where track support conditions are not ideal. While much effort has been made to model problematic rail infrastructure locations, there has been little experimental or modeling work aimed at understanding how concrete crossties perform in these locations (Figure 1). This project focused on quantifying the effects of poor support conditions on the stress state of concrete ties and understanding how the ties perform under these conditions. This information will help inform design, maintenance, and regulatory practices to ensure the safety of the rail system.

OBJECTIVES

The mission of this project was to investigate how concrete crossties and fastening systems perform when they are poorly supported or worn. Specific interests were to determine metrics for performance and failure and to develop design changes that promote improved safety and longer life cycles. The project objectives were to:

- Quantify the stress state of track superstructure to determine stress states when conditions are degraded.
- Study the influence of wear and deterioration on the stresses in track components and the overall behavior of the system.
- Investigate the interface between crossties and ballast to improve the current state of knowledge regarding the distribution and magnitude of forces.
- Identify improvement opportunities within the industry standards and Federal safety standards.

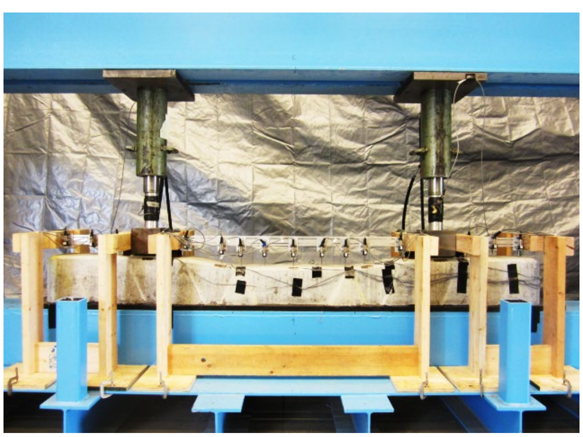
- Quantify the effect of cyclic loading and water intrusion on concrete crosstie service life.

METHODS

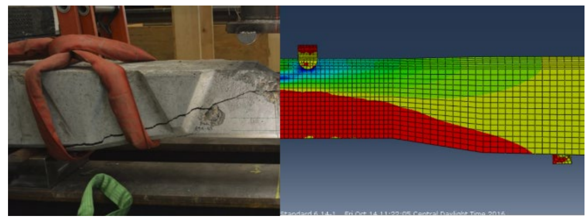
This project incorporated a review of available literature, expert opinion survey, laboratory work, and analytical modeling to fulfill the objectives and build on prior research on concrete crossties and fastening systems.

Initial work included gathering relevant background information to determine the most common types of track conditions that could lead to derailment risks. The project team communicated with railroads and other industry experts to understand what failure types are most common and determine the condition of components at these failure locations. This information guided the laboratory study at RailTEC and the development of an FE model designed to study the impact of deteriorated service conditions on tie performance.

Laboratory experimentation simulated good and poor concrete tie support conditions to determine the tie performance bounds. Researchers set up lab experiments, varying the load, support, and track component (Figure 2). In addition, several concrete crossties were tested in bending to determine the flexural performance of typical crosstie designs used in North America.



The FE analysis leveraged existing, validated models developed by researchers at Illinois. Using the FE model, researchers ran parametric analyses to quantify the effect of support conditions, loss of prestress, and loss of section depth on stresses present in the crosstie (Figure 3).



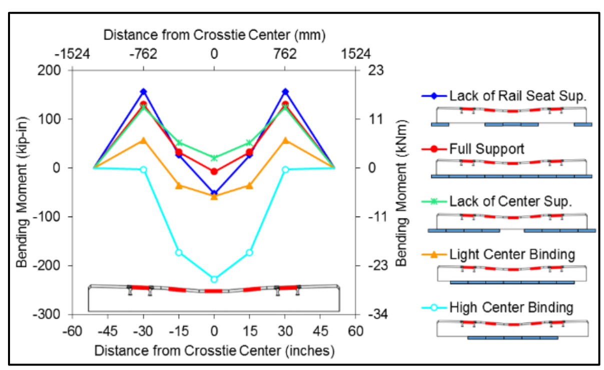
RESULTS

Some key results of this project include:

Center Binding Support and Center Cracking

FRA accident data, results from a focused industry survey, and findings from literature demonstrate that center binding and center cracking are critical problems for concrete crossties.

Static, four-point bending experiments with eight crosstie designs showed that U.S.-made crossties have a high reserve capacity relative to ultimate flexural failure (Figure 4).



Laboratory results indicated that tie bending resulted in a maximum gauge widening of 0.139 inch (3.53 mm) at rail seat loads of 20 kips (89 kN). The experimental results also indicated the bending moments at the crosstie center were more sensitive to changes in support conditions than at the rail seat. Static laboratory experimentation showed that high center binding support conditions can induce flexural cracks (Figure 5). These relatively shallow cracks, however, did not affect crosstie structural performance. The FE models predicted similar cracking patterns (Figure 6).

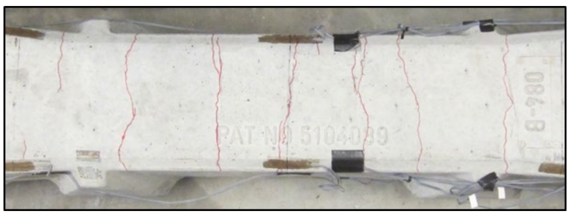


Figure 5. Flexural cracks in test tie

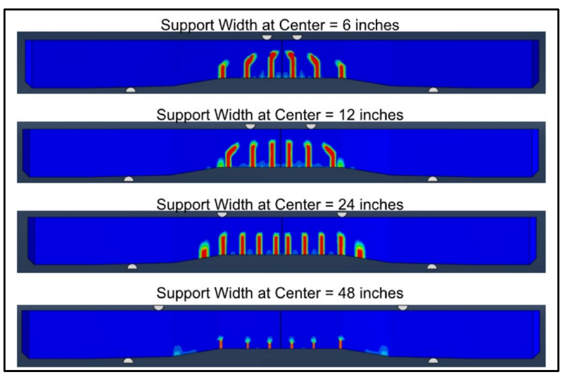


Figure 6. Modeled cracking patterns with varying support conditions

The project team tested several crossties to failure to characterize their ultimate bending capacity at the center, including bottom-abraded ties. To predict the center-negative flexural capacity of concrete crossties, the team generated a statistical model. This model can help railroads determine the actual capacity of their crossties (new or worn). In the model below, M_n is the ultimate capacity in *kip-in*; *I* is the area moment of inertia of the crosstie center section in *inches*^{4}; and *t* is the total number of tendons present in the crosstie.

$$M_n = [15.68 + (8.48 \times 10^{-5})I^2 + (2.32 \times 10^{-3})t^2]^2$$

Consequences of Water on Cracked Crosstie Service Life

Shallow center flexural cracks do not pose a risk by themselves, but they do open the way for water to enter the crosstie. Cyclic loading in laboratory experimentation showed that water speeds up deterioration and can lead to reduced flexural capacity for pretensioned concrete crossties. An FRA Research Results provides more detail on this aspect of the research.

Impacts of Crosstie Bottom Abrasion

Crosstie bottom deterioration is a common degradation mode for concrete crossties. Laboratory and FE simulation results showed a large loss of flexural capacity because of the loss of concrete bottom cover. A crosstie design with four layers of tendons lost 30 percent of its capacity while a design with five layers lost 35 percent.

CONCLUSIONS

This research resulted in revisions to the *AREMA Manual of Railway Engineering* (Chapter 30 – Ties) and to FRA's *Track and Rail and Infrastructure Integrity Compliance Manual*. The findings have also been broadly disseminated and resulted in: 1 M.S. thesis, 1 Ph.D. dissertation, 7 journal articles, and 17 presentations at major conferences. Given the impracticality of including all results in this document, readers are encouraged to refer to the following references, which contain details of this project.

- J.C. Bastos, *Analysis of the Performance and Failure of Railroad Concrete Crossties with Various Track Support Conditions*. M.S. thesis, University of Illinois at Urbana-Champaign, Urbana, IL, 2016.
- Federal Railroad Administration, Impact of Water on Cracked Concrete Crosstie Service Life. Research Results DOT/FRA/ORD-19/11, 2019.
- J.C. Bastos, *Flexural Distress and Degradation Mechanisms in Pretensioned Concrete Beams and Railroad Crossties*.

Ph.D. dissertation, University of Illinois at Urbana-Champaign, Urbana, IL, 2020.

FUTURE ACTION

Additional research is recommended to clearly define what constitutes a failed crosstie and what metrics can best characterize tie degradation. This will help inform FRA track safety standards and industry best practices for maintenance of concrete tie track.

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KEYWORDS

Concrete crossties; crosstie degradation; center cracks; cyclic loading; flexural performance

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