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Understanding the Service Environment of Concrete Crossties and Fastening Systems

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Summary

As a part of research programs funded by the Association of American Railroads (Technology Scanning Committee) and the Federal Railroad Administration, the University of Illinois at Urbana-Champaign (UIUC) is conducting research to understand the mechanisms of rail seat deterioration and to improve the design and performance of concrete crossties and elastic fastening systems for the North American railway service environment. A preliminary test conducted at the Transportation Technology Center, Pueblo, Colorado, has provided findings to improve and validate efforts of a more comprehensive instrumentation strategy that will be implemented in subsequent field tests. Some results drawn from the collected data include:

- Relative rail seat load and contact area increase with train speed
  - The rail base and tie surface contact area and location increase and move to the field side of the rail seat as lateral load increases, respectively
- A relatively low percentage of the crosstie's rail seat has measurable rail contact stress (i.e., is loaded) under train operations (43% or less).
- Relative rail seat loads show good correlation with railcar weight. This finding confirms that the track was well supported and the measurements of rail and tie stresses are typical of mainline track.

The preliminary efforts also showed:

- Plane sections of the rail above and near the concrete tie do not remain plane under train loading
- Fastener clips on the gage side of the high rail showed substantial increases in compressive stresses on the top surface of the clip under loading
- Up to 45 ksi of compressive surface stress due to bending of the field-side rail base was measured under train loading

These findings are important for developing a crosstie/rail interface model and improving crosstie design. They point out where to measure tie/ fastener performance so that it may be most easily modeled. The results also point out potential areas for improvement, namely the gage side clip and the rail seat pad. In future testing, vertical and lateral loads can be determined with strain gages on the rail and adequate calibration. Strains on the clip and rail base will provide an understanding of the relative movement of multiple components in the crosstie and fastener system and fastener clamping forces on the rail. Matrix-based tactile surface sensors (MBTSS) placed on the concrete crosstie at the interface between the rail seat pad assembly and the concrete rail seat surface can collect data on the distribution of the load onto the rail seat, providing insight into the potential failure mode of tie rail seat crushing. This test was also the first time UIUC had installed MBTSS on the rail seats of concrete crossties in the field. Insight was gained regarding the placement and protection of the relatively fragile sensors in the harsh loading environment that can exist in concrete crosstie track under heavy-axle freight train loads.

INTRODUCTION

To better satisfy the demands placed on railway infrastructure from increasing freight tonnages and development of shared passenger and freight rail infrastructure, improved performance of concrete ties and elastic fastening systems is desirable. There are two steps to the process: (1) understanding current failure mechanisms, funded by the Association of American Railroads (AAR) and (2) designing future components using mechanistic standards, funded by the Federal Railroad Administration (FRA). Research funded by the FRA is focused on improving concrete crossties and fastening systems to withstand loading conditions experienced on shared heavy haul and high speed rail infrastructure. As a part of this research, UIUC is developing and implementing a full-scale field test to determine the magnitude of loads and stress distributions within the concrete crosstie and fastening system. This *Technology Digest* describes the preliminary feasibility field study conducted at the Transportation Technology Center (TTC) in November 2011. The tests used strain gages and MBTSS to improve understanding of the system's behavior and to develop a focused field instrumentation plan to implement in future field testing. One of the primary objectives of this field study was to monitor rail seat pressures and determine if the crushing mechanism of rail seat deterioration is feasible, a mechanism that has not been addressed through prior AAR-funded research at UIUC.

EXPERIMENTAL TESTING PROTOCOL

Testing was conducted within tangent and 5-degree curved track (Sections 29 and 3) of the High Tonnage Loop at TTC. The train was made up of the locomotive, a passenger instrumentation car, one loaded 315,000-pound car, two loaded 263,000-pound cars, four more 315,000-pound cars, and an empty car. Trains were operated at speeds of 10, 20, and 40 mph.

RAIL SURFACE STRAINS

From preliminary structural analysis of the rail, the locations of strain gages were determined to capture rail bending near the rail seat. These measurements were synchronously recorded at a frequency of 2,000 hertz for analysis. To understand the changing curvature of the rail, eight strain gages were positioned longitudinally above the faces of the concrete tie; for both the gage and field-side of the rail, two were placed on each side of the crosstie (Figure 1). The bent shape (local vertical curvature) and bending moment of the rail was determined at this location for the test train passing at 10, 20, and 40 mph.

The bending of the rail can be determined with one gage, given the distance to the neutral axis. The bending for two gages in the same vertical plane of the rail did not agree, suggesting that plane sections of rail are not remaining plane under load nearest to the rail seat. This was verified in the finite element model (FEM), and thus these strain gages will be positioned 2 inches farther from the tie in future field testing plans. Strains were also recorded on the rail base, transverse to the direction of the rail. These measurements were taken from immediately above the field- and gage-side rail bases. The strains collected at all three train speeds showed significant bending stresses of the rail base on the field side (as high as 45 ksi). The gage-side rail base showed only 10 to 15 percent of those field-side stresses (no greater than 5 ksi).

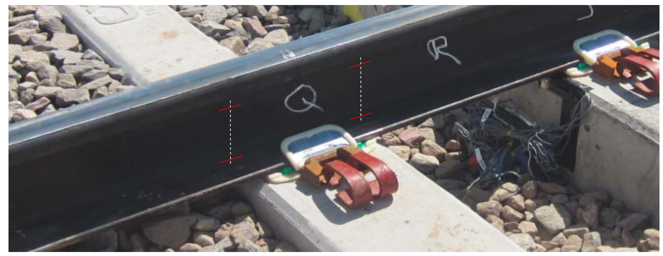


Figure 1. Configuration of Longitudinal Gages

FASTENING CLIP STRAINS

Strain gages were applied to the top surface of the field- and gage-side fasteners (Figure 2). The strains were measured during train operations at all three speeds (Figure 3 shows results at 20 mph), as well as during the clip installation and removal to gain insight into the clamping force. A similar test was conducted on a 2-foot section of rail, which was statically loaded in the laboratory at UIUC with a vertical load of 32,500 pounds and lateral load of 16,900 pounds (a resultant force of 36,600 pounds and L/V ratio of 0.52). With the 36,600 pounds applied to the rail, an additional stress of 7.8 ksi was seen at the top surface of the gage-side clip. In the field, with measured axle loads of 44,000 pounds from a train passing at 20 mph, the gage-side clips showed nearly twice the addition of stress (14.4 ksi), measured as the average of peak strains from each axle, from Figure 3. However, the increase in load was only 20 percent, suggesting that field conditions are much more demanding on the fasteners than laboratory testing has shown within an isolated system.

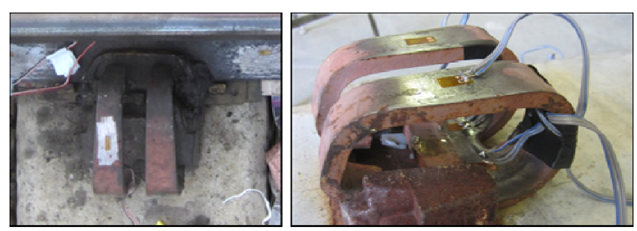


Figure 2. Instrumented Clip at TTC (left) and UIUC. Operational gauges are on top of clip.

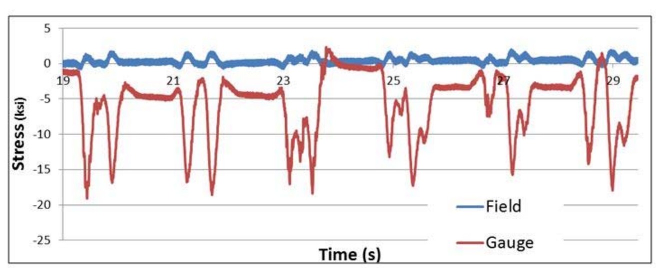


Figure 3. Fastener Clip Stresses from 20 mph Train Pass

At the lowest speed of 10 mph, there was evidence of positive strain (i.e., downward movement of the clip toe) in both of the clips, indicating a relaxation in the stressed clips and, consequently, clamping force. This was also observed in the static load test conducted in the laboratory at UIUC for field-side clips, in which low loads of about 15,000 pounds were applied. There was no relaxation of the gage-side clip in the controlled laboratory setup. It is important to note the rail seat investigated was on the high rail of a 5-degree curve with a balanced speed of 34 mph (4 inches of superelevation), and the runs that showed gage-side clip relaxation were all conducted in an underbalanced situation.

RAIL SEAT PRESSURE DISTRIBUTION

To understand the pressure distribution of the load at the rail seats of concrete crossties, the MBTSS were placed at the interface between the fastening system rail pad assembly and concrete rail seat surface in the laboratory[1] and in the field. In the field, some of the sensors were destroyed as train operation began because of inadequate protection of the “tab” to which the data acquisition connection (i.e., handle) attaches. This issue will be mitigated prior to future field testing.

Calibration files were created in the laboratory before field instrumentation. These files were to be applied to the data after collection in an attempt to calibrate data and provide quantitative output of pressures. However, upon doing so, the output values were not realistic. This attempt at calibration was discarded, as it was determined that the nature of the sensors is such that the known loads applied in the laboratory must be applied with a similar magnitude and in a similar distribution to what will be seen in the field, which at the time was unknown. Instrumentation for future field testing will include a method of determining the load carried by a single rail seat using a strain gage on the rail above that rail seat or other type of loading calibration equipment. This calculated load can then be used to quantify the rail seat pressures.

Despite these challenges, some useful qualitative analyses of data were performed in order to better understand the loading conditions seen in the field and prepare for future field testing. Figure 4 shows a plot of a single train passing at 20 mph from a MBTSS placed on the high rail seat of the curved track. Though the forces remain in uncalibrated “raw sum units,” the relative magnitudes of rail seat loads from the consist can be seen, with the leading locomotive followed by the instrumented passenger car, freight cars with increasing weights, and finally the empty freight car. There is a slight decrease in rail seat load immediately preceding a railcar wheelset, likely due to uplift of the rail occurring under the “wave” action of the rail often seen under train operation.

Table 1 is an example of a set of two-dimensional pressure distribution data collected. This data was collected on a crosstie in a section of tangent track and shows pressure distributions for an unloaded (in situ) scenario followed by train operation at 20 and 40 mph. This rail seat had been repaired with a nonuniformly applied epoxy coating, which likely resulted in the higher (i.e., saturated red) areas of pressure shown on the distributions. The color scale applied to these images is such that black is unloaded area, while the yellow regions increase to red under high pressures. The areas of dark red are locations where peak pressures were high enough to saturate the sensor at the selected sensitivity. Table 1 shows that both the contact area and total area of saturated pressures increase under loading at increased speed, an expected behavior.

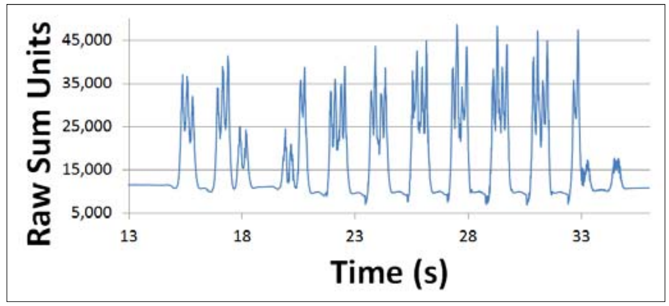
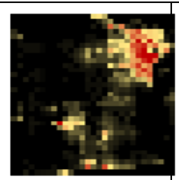
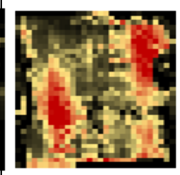
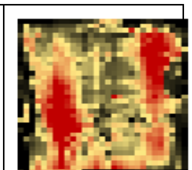


Figure 4. Loading for High Rail Seat on a 5-degree Curve for a Train Operating at 20 mph

Table 1. Pressure Distributions for Tangent Track at TTC

	 Field Gage	 Field Gage	 Field Gage
Train Speed, (mph)	N/A: In-Situ	20	40
Rail Seat Contact Area (in^2)	22.07	40.70	42.98
Total Raw Sum	16,036	60,833	82,765
Sensor Saturated Area (%)	1.54	4.64	9.46

The total raw sum units also increase per distribution under increasing train speed. The in-situ loading situation, which consists mostly of rail self-weight and clamping force, produced a raw sum value of 16,036, whereas the maximum loading of this rail seat under train operation of 20 mph was 60,833 raw sum units, an increase of approximately 279 percent.

Under train operation of 40 mph, the sensor on this rail seat recorded 82,765 raw sum units, an increase of approximately 36 percent from the 20-mph loading. Though these raw sum values may not carry much worth individually, some insight is still gained in comparing the increase in this nominal load unit under increasing train speeds.

FUTURE WORK

UIUC is developing an experimental program that will help to better understand and quantify the behavior of the concrete crosstie and fastening systems. As in this preliminary proof of concept testing discussed here, there will be instrumented clips, with a single strain gage at various locations (field and gage-side clips in adjacent rail seats). There is also an effort to utilize longitudinal strain gages to understand rail shear forces, and potentially input loads.

In addition, the instrumentation plan will utilize linear potentiometers for displacement measurements. These displacements include the vertical rail displacement, lateral web displacement, and lateral translation of the base, all near the rail seat. Synchronized loading measurements will also be taken (vertical and lateral) using strain gages in conventional full-bridges on the rail. Also, we have instrumented several crossties with 2x2 embedment gages at various rail seat areas. This will provide data on the response of concrete within the rail seat (load transfer and induced rotation). From the accumulation of all these measurements over three field tests, we intend to define the mechanics of the system. This data will also progress a comprehensive FEM, which will allow for efficient parametric analyses of varying crosstie and fastening system designs and operating conditions.

ACKNOWLEDGMENTS

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1. Rapp, C.T., et al. April 2012. "Measuring Concrete Crosstie Rail Seat Pressure Distribution with Matrix Based Tactile Surface Sensors," *Proceedings of the 2012 Joint Rail Conference*, Philadelphia, PA.