**Quantification of Concrete Sleeper and Elastic Fastening System Demands
Utilizing Concrete Sleeper Rail Seat Contact Area**

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ABSTRACT

To adequately satisfy the demands placed on North America's railway infrastructure through ever increasing freight tonnages and development of its high speed rail program, the design and performance of track infrastructure, specifically concrete ties and elastic fastening systems, must be improved. Researchers from the University of Illinois at Urbana-Champaign executed an extensive field experimental program at the Transportation Technology Center (TTC) in Pueblo, CO, USA. As a part of this extensive program, Matrix Based Tactile Surface Sensors (MBTSS) were employed to better understand and quantify the load distribution imparted onto concrete sleeper rail seats while additional instrumentation was deployed to quantify the resulting demands placed on the elastic fastening systems. A common failure mode of concrete sleepers in North America is the degradation of the concrete surface of the rail seat, also known as rail seat deterioration (RSD); therefore, researchers at UIUC are attempting to characterize the loading environment at this interface. It is possible that highly concentrated loads at this interface could result in peak pressure values high enough to initiate a failure mechanism such as RSD. This paper will focus on data collected at TTC in tangent track with controlled vertical and lateral loads applied by a track loading vehicle (TLV) to explore the pressure distribution at the concrete rail seat under a variety of loading conditions. The understanding of the distribution of loads imparted onto concrete sleepers will lead to a mechanistic design approach to enhance the robustness and efficiency of the concrete sleeper and fastening system, and help mitigate failure mechanisms such as RSD. The insight gained on rail seat loading conditions in North America can provide benefits in many rail networks around the world where the challenge of operating increasing freight tonnages and high speed rail programs on shared infrastructure exists.

1.   Introduction

The design of concrete crossties and fastening systems for North American railroads presents a unique challenge. These components must provide the strength and resiliency required to attenuate the heavy axle loads imparted by freight trains, while retaining the track tolerances necessary for high-speed passenger rail safety and rider comfort. Shared infrastructure operating scenarios are becoming more common as existing freight lines are being upgraded to allow for higher-speed passenger operation, and these upgrades may include the installation of concrete crossties and elastic fastening systems.

As part of a rail infrastructure research program at the University of Illinois at Urbana-Champaign (UIUC), researchers are striving to improve the design and performance of the track structure by investigating the loading demands placed on concrete crossties and their fastening system components. One of the primary objectives of this research is quantifying the load path from the wheel-rail interface of the rail, through the fastening system assembly, and onto the concrete rail seat surface. The rail seat surface plays a critical role in maintaining the integrity of the railroad track structure; as loss of concrete material at the rail seat, also known as rail seat deterioration (RSD), can lead to problems such as widening of

gauge, reduction in the clamping force (i.e. toe load) of fastening clips, and improper rail cant (Zeman 2010). Any one problem, or combination of problems, can potentially create unsafe operating conditions and increase the risk of derailment from rail rollover (Marquis 2011). In surveys conducted in 2008 and 2012 by UIUC, North American Class I Railroads and other railroad infrastructure experts ranked RSD as the most critical problem associated with concrete crossties and fastening system performance (Zeman 2010, Van Dyk 2012). In the 2012 survey, the prevention and repair of RSD was ranked as the most important research topic in North America (Van Dyk 2012).

To gain a better understanding of how forces are being imparted onto the concrete rail seat surface and further understand the demands placed on the elastic fastening systems, researchers at UIUC are using Matrix Based Tactile Surface Sensors (MBTSS), manufactured by Tekscan® Inc., as a means to measure pressure magnitude and distribution. The data collected by this technology will provide better insight into the mechanisms of RSD by quantifying maximum pressure values and identifying areas of the rail seat receiving concentrated loads under various loading scenarios. Research includes the use of MBTSS in a single-crosstie laboratory study and in field track installations. The results discussed in this paper focus on a portion of experimentation in which the track was subjected to controlled loads.

2.   Overview of Previous Experimentation

Prior to use at UIUC, researchers from the University of Kentucky (UK) experimented with the MBTSS technology to measure the pressures under tie plates on timber crossties (Stith 2005). UK researchers proved the feasibility of using MBTSS in the railroad engineering domain. Researchers at UIUC then used laboratory experimentation to prove the feasibility of use on concrete crosstie rail seats. Experimentation at UIUC has consisted of researchers using a bi-axial structural crosstie loading system, referred to as the Pulsating Load Testing Machine (PLTM), to investigate the effect of different rail pad moduli on rail seat pressure distribution under varying L/V force ratios (Rapp 2013). The PLTM is owned by Amsted RPS and is used primarily for conducting AREMA Chapter 30 Test 6 (Wear and Abrasion) (AREMA 2012). Researchers at UIUC have also conducted field testing similar to that discussed in this paper, albeit with a smaller installation.

3.   Field Experimentation Test Site

Field experimentation was performed at the Transportation Technology Center (TTC) in Pueblo, Colorado, USA; a research and testing facility that consists of 77.2 kilometers (48 miles) of railroad track. A section of 15 new concrete crossties was installed on the 21.7 kilometer (13.5 mile) Railroad Test Track (RTT) in a section of tangent track. Eight rail seats, on five crossties, at this site were instrumented with MBTSS. Five consecutive rail seats (near rail seats 1N through 5N) were chosen in an attempt to fully capture the load distribution, and to investigate the effect and variability of support conditions in a group of crossties. Additionally, three consecutive rail seats on the opposite rail (far rail seats 2F through 4F) were selected to provide further information on load transfer, and to examine the variability of support conditions across a single crosstie.
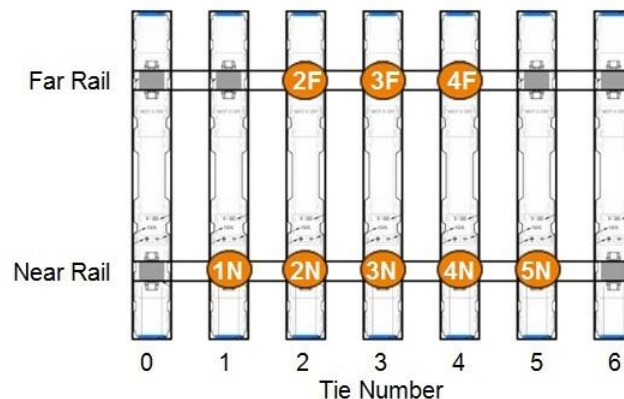

Figure 1. Plan view of MBTSS field installation

4.   Testing Procedure

The loads were applied to the rail using the Track Loading Vehicle (TLV). The TLV is owned by the Association of American Railroads (AAR) and operated by the Transportation Technology Center, Inc. (TTCI) at TTC. The TLV can be used to study a variety of applications including wheel climb derailments, vertical modulus, lateral track strength, gage widening, wheel/rail force relationships, and more (Shust 1997). An instrumented bogie is attached to vertically and laterally oriented actuators, which are attached to the bottom-frame of a modified rail car. All control of the loading apparatus is performed from a computer in the AAR-100 Research Car coupled to the TLV. The TLV's ability to apply controlled vertical and lateral loads to the rail using realistic loading conditions and application made it an ideal tool for the purposes of this experimentation.

The testing procedure consisted of applying loads to the rail with the TLV loading axle centered above each instrumented crosstie. Vertical loads were applied at increasing magnitudes from 0 to 178 kN (40,000 lbs) at 22.2 kN (5,000 lb) increments. At 88.9 kN (20,000 lbs), lateral loads were applied at increasing magnitudes from 0 to 53.4 kN (12,000 lbs) at 8.89 kN (2,000 lb) increments resulting in L/V force ratios ranging from 0 to 0.6. The lateral loads were then reduced to zero and a 178 kN (40,000 lb) vertical load was applied to the rail, at which time lateral loads were applied at increasing magnitudes from 0 to 92.5 kN (22,000 lbs) at 17.8 kN (4,000 lb) increments, with a final increment of 8.89 kN (2,000 lb) resulting in L/V force ratios ranging from 0 to 0.55.

5.   Results of Experimentation

The pressure distributions collected for rail seats 3N and 3F under varying L/V force ratios with a constant 178 kN (40,000 lb) vertical load can be seen in Figure 2, with a scale depicting the relative intensity of pressure being imparted on to each rail seat. The distributions for the rail seats are oriented such that the field sides of each are facing opposite directions in order to show the effect of the outward forces applied by the TLV loading frame under increasing L/V force ratios. Immediately, it can be seen that neither rail seat is uniformly loaded. Both rail seats show less initial loading in the center of the rail seat, as compared to the perimeters. This trend is especially evident in rail seat 3N, where the MBTSS registers a significant reduction in pressure near the center of the rail seat. It is also evident that as the L/V force ratio increases, there results a significant loss of pressure on the gauge side of the rail seats at an L/V ratio of 0.3. This trend was found to be representative of all eight rail seats under the same loading conditions.
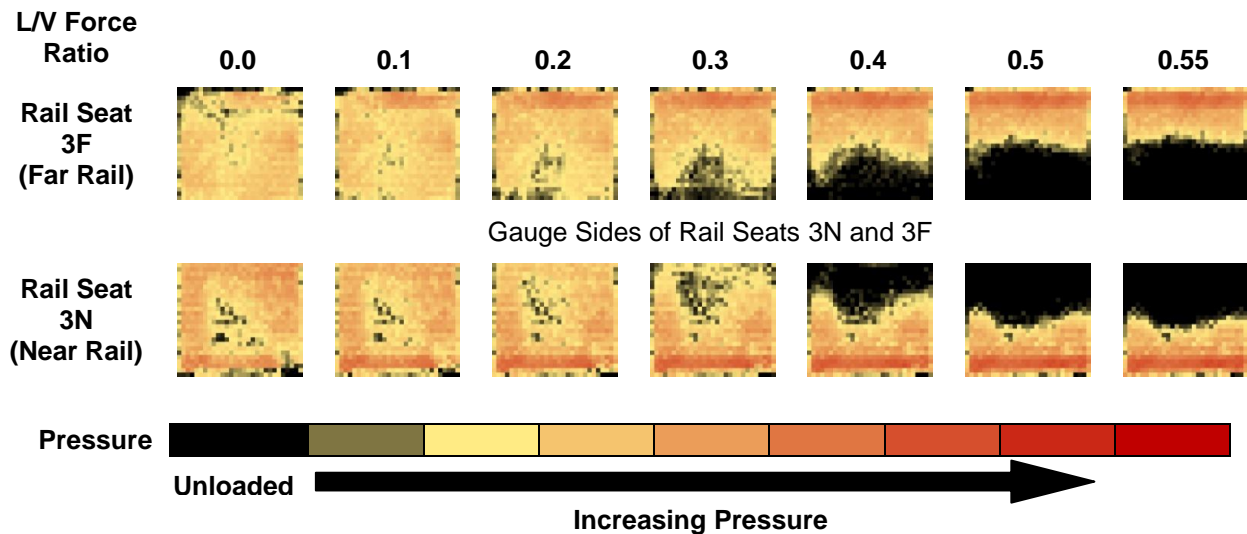

Figure 2. Rail seat pressure distributions under varying L/V force ratios

The reduction of contact area corresponding to an increase in the L/V force ratio, as a result of increasing the lateral load while the TLV was applying a constant 178 kN (40,000 lb) vertical load, illustrated above is a trend representative of all eight rail seats under the same loading conditions. This trend can be quantified and is summarized in Table 1. For each row of data, the TLV is loading the rail directly above the corresponding rail seat.

Table 1. Contact areas in cm^2 (in^2) of loads on rail seats at various L/V force ratios

	L/V Force Ratio						
Rail Seat	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.55**
1N	255.7 (35.0)	232.6 (36.1)	234.2 (36.3)	235.2 (36.5)	232.6 (36.1)	188.3 (29.2)	178.6 (27.7)
2N	223.3 (34.6)	225.7 (35.0)	227.0 (35.2)	223.5 (34.7)	182.4 (28.3)	138.3 (21.4)	127.4 (19.8)
2F	232.6 (36.1)	234.2 (36.3)	235.4 (36.5)	235.4 (36.5)	226.4 (35.1)	157.1 (24.4)	137.1 (21.3)
3N	233.0 (36.1)	233.9 (36.3)	234.2 (36.3)	234.8 (36.4)	183.9 (28.5)	135.8 (21.1)	126.1 (19.6)
3F	231.1 (35.8)	233.2 (36.2)	234.5 (36.4)	233.0 (36.1)	195.2 (30.3)	142.7 (22.1)	129.0 (20.0)
4N	226.1 (35.0)	228.6 (35.4)	229.5 (35.6)	229.5 (35.6)	210.1 (32.6)	155.0 (24.0)	139.5 (21.6)
4F	232.0 (36.0)	233.2 (36.2)	233.9 (36.3)	232.0 (36.0)	214.5 (33.3)	168.9 (26.2)	152.4 (23.6)
5N	233.2 (36.2)	234.8 (36.4)	234.8 (36.4)	235.7 (36.5)	231.4 (35.9)	199.9 (31.0)	179.9 (27.9)

For all rail seats, the average loss of contact area was 36.3% of the initial contact area observed under the 178 kN (40,000 lb) vertical load at an L/V force ratio of 0. Of the eight instrumented rail seats, rail seat 1N experienced the smallest reduction, losing 20.9% of the initial contact area, while rail seat 3N experienced the greatest reduction, losing 45.8% of the initial contact area. Figure 3 summarizes the percent of initial contact area observed at the various L/V force ratios for each respective rail seat. In the figure, solid lines are used to represent data from the near rail and dashed lines are used to represent data from the far rail. Further, each color corresponds to a single crosstie. For each data set, the TLV is loading the rail directly above the corresponding rail seat.
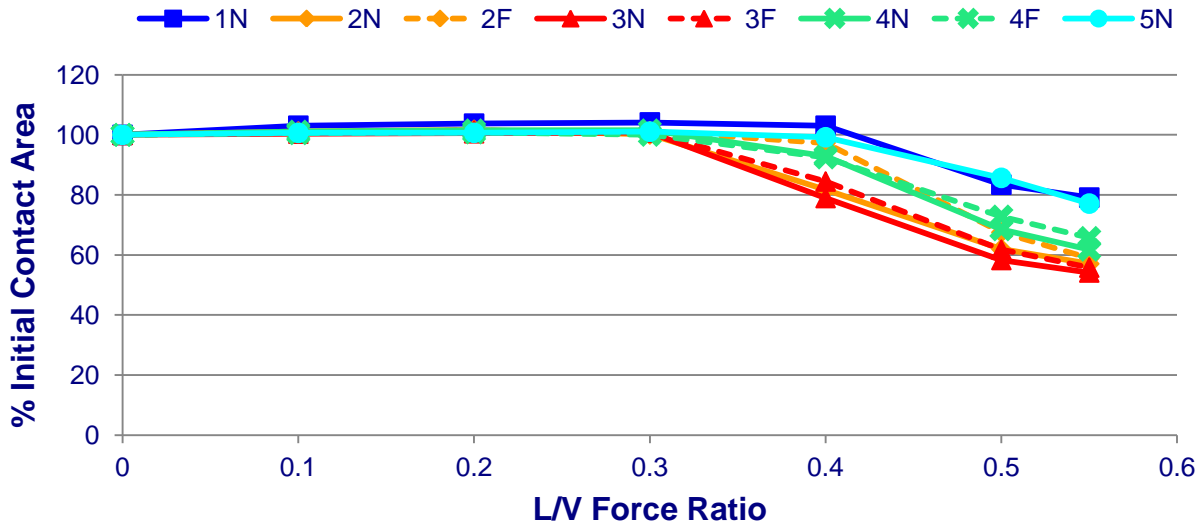
Figure 3. Contact area as a function of L/V force ratio with 178 kN (40,000 lb) vertical load

The figure shows that for seven of the eight rail seats, the contact areas remain relatively unchanged for L/V force ratios in the range of 0 to 0.3. The remaining rail seat, 1N, shows an increase in contact area in this range, indicating that it may be carrying more load as the L/V force ratio increases. Beyond an L/V force ratio of 0.3, a decrease in contact area occurs for all rail seats. This trend is delayed in rail seat 1N, which does not experience a significant contact area reduction until an L/V force ratio of 0.4. It is hypothesized that in this region of loading, significant rail base rotation occurred to such an extent that the gauge side of the rail seat was no longer loaded, as suggested by the concentration of loading on the field side of the rail seats shown in Figure 2. The concentration of the rail seat load on as little as 54% of the initial contact area at high L/V force ratios, as in the case of rail seat 3N, may contribute to pronounced rail seat deterioration (RSD) on the field side of rail seats in use on North American railroads.
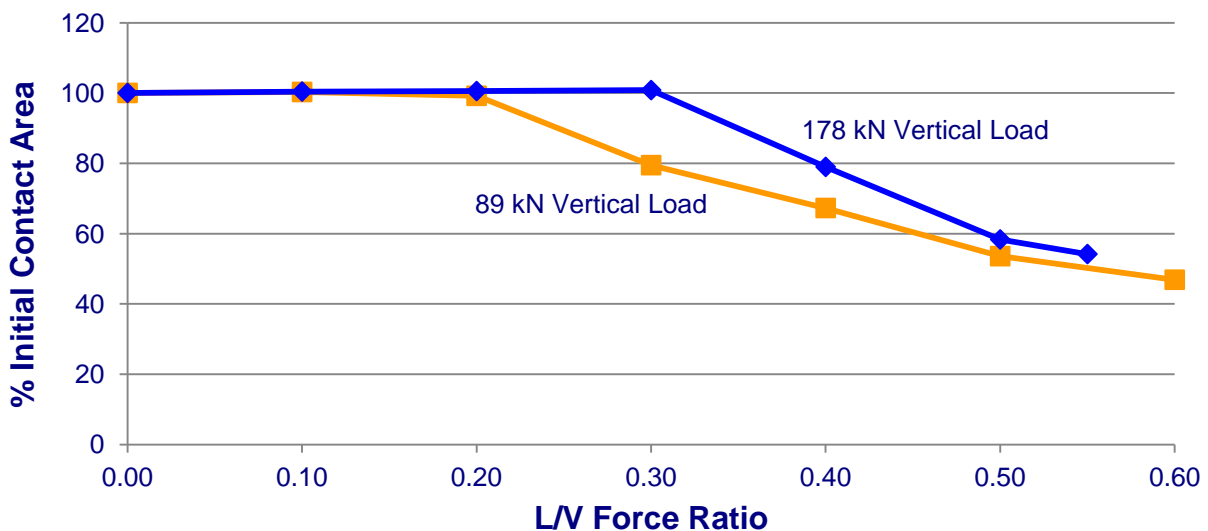
Figure 4. Contact area per L/V force ratio with 178 kN (40,000 lb) and 89 kN (20,000 lb) vertical loads

Figure 4 shows the contact area of rail seat 3F as a function of L/V force ratio at both 89 kN (20,000 lb) and 178 kN (40,000 lb) vertical loads. The figure shows the contact area remaining largely unchanged at 178 kN (40,000 lb) until the threshold L/V force ratio of 0.3, beyond which it decreases. The contact area shows a similar pattern at 89 kN (20,000 lb), but with two significant differences: the threshold L/V is reduced to 0.2, and the subsequent reduction in area is larger than that experienced at 178 kN (40,000 lbs). This trend was observed in all eight rail seats and indicates a greater concentration of forces at lower vertical loads. This may produce a more damaging scenario than higher vertical loads, depending on the maximum pressure.

6.   Conclusions

The following conclusions can be drawn from the analysis of data collected from field experimentation using MBTSS and controlled TLV loads:

- Rail seat pressure distributions are not uniform across a rail seat.
- High L/V force ratios lead to a concentration of the rail seat load on the field side of the rail seat.
- Rail base rotation at high L/V force ratios can lead to a complete unloading of the gauge side of the rail seat.
- Force concentrations on the field side of the rail seat can become more severe at the same L/V force ratio when lower magnitude vertical loads are applied.
- A threshold L/V force ratio at which these force concentrations become significant exists and is variable depending on the vertical load applied.

It is evident that higher demands are placed on the field side of the rail seat and each component of the rail pad assembly. Furthermore, because of the rail base rotation at high L/V force ratios, there is an increased demand placed on the gauge side elastic fastener. Because of these findings, it is hypothesized that these increased demands can lead to the increased rate of wear and deterioration of these components.

7.   Future Work

Future work at UIUC will focus on investigating the specific effect caused by the higher demands placed on these components; specifically, how the pressures measured relate to the formation of RSD. Furthermore, researchers will investigate how clamping force and stiffness of the gauge side clip effects rail rotation and pressure distribution at various L/V force ratios. And lastly, researchers will quantify how non-uniform loads affect the demands placed on the bending capacity of the crossties.

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