Measuring Concrete Crosstie Rail Seat Pressure Distribution with Matrix Based Tactile Surface Sensors

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ABSTRACT

A sustained increase in gross rail loads and cumulative freight tonnages, as well as growing interest in high speed passenger rail development, is placing an increasing demand on North American railway infrastructure. To meet this demand, improvements to the performance and durability of concrete crossties and fastening systems are necessary. One of the typical failure modes for concrete crossties in North America is Rail Seat Deterioration (RSD), and researchers have hypothesized that localized crushing of the concrete in the rail seat is one of the potential mechanisms that contributes to RSD. To better understand this mechanism, the University of Illinois at Urbana-Champaign (UIUC) is using a matrix based tactile surface sensor (MBTSS) to measure and quantify the forces and pressure distribution acting at the contact interface between the concrete rail seat and the bottom of the rail pad. Preliminary data collected during laboratory experimentation has shown that a direct relationship exists between rail pad modulus and maximum rail seat pressure. Additionally, under a constant vertical load, a direct relationship between the lateral/vertical (L/V) force ratio and the maximum field side rail seat pressure has been observed. Given that all preliminary results indicate that various combinations of pad modulus, track geometry, and L/V force ratios create localized areas of high pressure, crushing remains a potential mechanism leading to RSD, as will be discussed in this paper. Through the analysis of rail seat pressure data, valuable insight will be gained that can be applied to the development of concrete crosstie and fastening system component designs that meet current and projected service demands.

INTRODUCTION

Concrete crossties are typically used in locations that place high loading demands on the railroad track structure and/or necessitate stringent geometric tolerances. In North America, they were adopted in response to the inability of timber crossties to perform satisfactorily in certain severe service conditions, such as areas of high curvature, heavy axle load freight traffic, high speed passenger train traffic, high annual gross tonnages, steep grades, and severe climatic conditions including areas of high moisture that would cause accelerated decay of timber ties *(1)*. The cast-in shoulders and molded rail seat of concrete crossties increase their ability to hold gage under these loading conditions *(1)*.

Concrete crossties are not without their design and performance challenges. As reported in surveys conducted by the University of Illinois at Urbana-Champaign (UIUC) in 2008 and 2012, North American Class I Railroads and other railway infrastructure experts ranked rail seat deterioration (RSD) as one of the most critical problems associated with concrete crosstie and fastening system performance *(2, 3)*. Problems that arise from the deterioration of the concrete rail seat surface include widening of gauge, reduction in the clamping force (toe load) of fastening clips, and insufficient rail cant *(2)*. All of these problems have the potential to create unsafe operating conditions and an increased risk of rail rollover derailments *(4)*.

A suspected cause of RSD is high forces acting on the concrete rail seat surface, often in concentrated areas. To address this, a study was performed by the John A. Volpe National Transportation Systems Center on the effect of wheel/rail loads on concrete tie stresses and rail rollover. The study confirmed the possibility of concentrated loads producing stresses exceeding the 7,000 psi (48,260 kPa) minimum design compressive strength of concrete as recommended by the American Railway Engineering and Maintenance-of-Way Association (AREMA) *(4)*.

The combination of static wheel loads and dynamic impact loads impart forces into the rail seat that potentially damage the concrete surface *(5)*. The magnitude of these loads can vary based on track support variations, wheel defects, or rail irregularities *(5)*. Well-maintained concrete crosstie track is typically stiffer than timber crosstie track. According to the AREMA Manual for Railway Engineering, the typical track modulus value for mainline concrete crosstie track is 6,000 lb/in^2 (41.4 N/mm^2), which is approximately twice the typical timber crosstie track modulus of 3,000 lb/in^2 (20.7 N/mm^2) *(6)*. A track superstructure that is stiffer, consisting of the rail, fastening system components, and crossties, produces a less resilient response to impact loads, resulting in higher forces being transferred to the concrete rail seat surface. This assumes that the track substructures, consisting of the sub-ballast and ballast layers, for both concrete and timber crosstie track, provide adequate support conditions for each track type. Despite being a less resilient track superstructure, a study performed to investigate the effect of replacing defective timber crossties with concrete crossties yielded results showing a drastic improvement on the remaining life of other crossties for this given section of track *(7)*.

To better understand the forces acting at this surface, researchers at UIUC are using matrix based tactile surface sensors (MBTSS) as a means to measure load magnitude and distribution. MBTSS have been previously used in experimentation under the tie plates on timber crossties *(8)*; however, researchers at UIUC are using this technology to explore the pressure distribution on the rail seats of concrete crossties.

Background

There are many factors that affect the rail seat pressure distribution, one of which is the transfer of forces at the wheel/rail interface. The transfer of forces from the wheel to the rail is heavily dependent upon frictional characteristics at this interface, such as the presence of top-of-rail (TOR) friction modifiers *(9)*. After the load is transferred from the wheel to the rail, it moves through the web of the rail and into the base of the rail. Next, the load is distributed through the rail pad assembly onto the rail seat of the crosstie. The profile of the wheel and rail (e.g. wear pattern), and the performance of the rail car truck, are some of the variables that can govern the location and angle of the resultant force. The authors of this paper suspect that these parameters can cause significant variation in which areas of the rail seat are receiving concentrated loadings. Additionally, the lateral to vertical (L/V) ratio of this resultant force also

varies greatly depending on track geometry conditions. Lateral forces imparted onto the rail can be significant in horizontal curves or special trackwork. Trains travelling at speeds above or below the balancing speed of a curve can cause shifts in the vertical and lateral load to the high or low rail, respectively. These loads being imparted into the track structure are highly dependent on the speed through which a train is operating through the curve, and it is understood that trains do not always travel at the design balance speed *(10)*. These loading scenarios are especially likely on shared infrastructure, where both freight and passenger trains operate on the same track, typically at different speeds, which can vary as much as 100 mph (161 kph). Passenger trains operating at higher speeds on a track designed primarily for freight traffic would be operating at a cant deficiency, where axle loads are not evenly distributed between even rails, and forces on the high rail and fastening system components are higher. As a result, shared infrastructure presents diverging engineering requirements for track that can accommodate the heavy axle loads of slower speed freight trains with the possibility of high dynamic loads from higher speed passenger trains.

Design of the fastening system components also plays a crucial role in the distribution of pressure in the rail seat. Given the stiff nature of concrete crosstie track, the fastening system must provide some of the resiliency necessary to attenuate loads without damaging the concrete *(11)*. Some of the variables potentially affecting the magnitude and distribution of pressure on the concrete rail seat are explored through laboratory experimentation. Preliminary results from these experiments are documented in this paper.

Sensor Technology and Protection

The sensor technology UIUC is currently using for quantifying forces and pressure distribution at the rail seat is the MBTSS manufactured by Tekscan® Inc. In order to protect the MBTSS from shear forces and puncture, it is covered on both sides with thin layers of polytetrafluoroethylene (PTFE) and bi-axially oriented Polyethylene Terephthalate (BoPET) (Figure 1). Calibration of MBTSS is conducted by applying known loads and correlating the loads with the respective raw sum units. Known input loads can also be applied to collected MBTSS data in order to quantify pressure distributions.

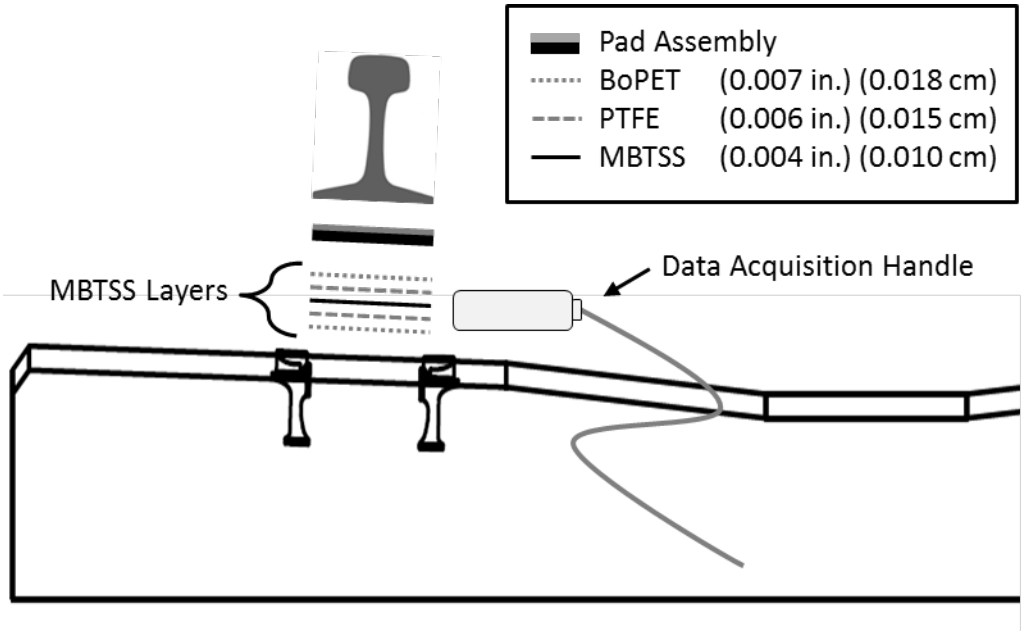

FIGURE 1 Profile View of MBTSS Layers and Thicknesses.

Experimental Setup

UIUC's experimental testing was performed at the Advanced Transportation Research and Engineering Laboratory (ATREL). The Pulsating Load Testing Machine (PLTM), which is owned by Amsted RPS and was designed to perform the American Railway Engineering and Maintenance-of-way Association (AREMA) Test 6 (Wear and Abrasion), as well as other experiments related to concrete crossties and fastening systems, was used to execute the experiments within this paper. The PLTM consists of one horizontal and two vertical actuators, both attached to a steel loading head that encapsulates a 24 inch (610 mm) section of rail. The rail section is attached to one of the two rail seats on a concrete crosstie. Preliminary UIUC research included installing a MBTSS in the concrete crosstie fastening system and loading the tie using the PLTM. Loading inputs for this experimentation are applied to the rail in only the vertical and lateral directions, due to the constraints of the experimental setup. UIUC researchers recognize that moving wheel loads impart longitudinal forces onto the track structure that add a higher level of complexity to analysis of loads on the various track components. Although it is possible that the longitudinal forces would have a large effect on varying the pressure distribution at the rail seat, the ability to simulate such loads with this experimental setup does not currently exist.

RESULTS OF EXPERIMENTATION

Experiments have been conducted by UIUC researchers to collect data on the distribution of pressure on the concrete crosstie rail seat based on expected loading conditions at the rail seat surface. The experimental setup is not meant to replicate the common field loading conditions, but is designed to simulate extreme loading conditions that can occur in the field. Therefore, this experimental setup simulates a single wheel load imparted onto a single crosstie.

These experiments were conducted to analyze and quantify the loading behavior at this interface using a variety of load inputs while varying concrete crosstie fastening system components. The first series of experiments was performed to determine a relationship between the rail pad modulus and pressure distribution at the rail seat. The modulus of a rail pad is often considered to be a proxy for the stiffness of the pad. However, it should be noted that modulus is a property of the material, while stiffness is dependent on both the material properties and the boundary conditions of the component. Another series of experiments was performed to compare two different elastic fastening system clip designs with respect to their ability to distribute pressure over the rail seat. For each series of experiments, various L/V force ratios were explored in an attempt to simulate a variety of rail vehicle and track interaction conditions that could occur at the wheel/rail interface. The overall objective of this experimentation was to determine a relationship between L/V force ratio and pressure distribution at the rail seat while varying different components of the fastening system. The following sections explain the effect of varying L/V force ratios, and present the experimental protocol and results from the aforementioned experiments. There are many variables that can affect the L/V force ratio, including the track geometry (e.g. horizontal curvature), wheel/rail interface conditions and frictional properties, axle loads, railcar truck steering performance, and train speed *(12)*. Researchers at UIUC suspect that a high concentration of field side loading could be seen on the high rail seat on a section of superelevated track with a train operating in an underbalanced condition, and that, inversely, a field side concentration on the low rail seat would be expected for a train operating in an overbalanced condition.

Rail Pad Component Experimentation

Concrete crosstie fastening systems typically include a single or multi-layer rail pad assembly *(13)*. Part of this assembly includes a polymer rail pad, historically made of rubber or polyethylene, to attenuate the load and provide protection for the concrete rail seat *(1)*. Given that concrete crosstie track is often more rigid than the traditional timber crosstie track, concrete crossties can impart higher stresses onto the ballast. An important purpose of the rail pad as an individual component is to provide increased resiliency for the concrete crosstie system. The increased resiliency provides the advantages of dampening the loads experienced by the rolling stock and increasing passenger comfort *(14)*. Rail pads

are manufactured from a variety of materials and molded into different geometries. Their material properties and component geometries govern the modulus and stiffness values for a given design.

Part of the research being conducted at UIUC is investigating the effect of the rail pad's modulus on mitigating high loads imparted on the rail seat while continuing to protect the concrete rail seat. Researchers at UIUC are exploring the possibility that a rail pad of a lower modulus (i.e. softer) will distribute the applied load over a wider area of the concrete rail seat. Although a softer rail pad may better mitigate high impact loads, its high resiliency allows for greater rail deflection, which can increase wear and fatigue of other components of the fastening system *(1)*. The softer pad, in combination with the elastic clips commonly used in concrete crosstie fastening systems, can perform well in moderate traffic loading conditions *(13)*. Under heavier loads, as are becoming increasingly common in North America, excessive lateral movement of the rail base and wear of the fastening system components can occur *(13)*.

In performing the AREMA Test 6 (Wear and Abrasion) using the PLTM, researchers at UIUC have seen this excessive lateral movement of the rail cause wear on the field side cast-in steel shoulder, which could potentially lead to gauge-widening. In both the 2008 and 2012 surveys of North American Class I Railroads, shoulder/fastener wear or fatigue ranked second behind RSD as the second most critical concrete tie problem *(2, 3)*. Also, UIUC researchers are exploring the possibility that a rail pad with higher modulus will help reduce the stress on the fastening system as a whole, but will place a higher concentration of load on the concrete rail seat surface, and in turn result in increased ballast pressures on the bottom of the crosstie *(13)*.

An experiment was performed to compare the pressure distributions of a higher modulus, medium density polyethylene (MDPE) rail pad, a lower modulus Thermoplastic Vulcanizate (TPV) rail pad, and a more commonly used two-part pad assembly comprising of a Nylon 6-6 abrasion plate and a 95 Shore A Thermoplastic Polyurethane (TPU) pad. The MDPE and TPV rail pads used were cast with a flat surface specifically for this experiment to remove variation in pad geometry. The MDPE pad had a Shore Hardness of 60 on the D scale, with a flexural modulus of 120,000 psi (827.4 N/mm^2). The TPV pad had a Shore Hardness of 86 on the A scale, with an approximate flexural modulus of 15,000 psi (103.4 N/mm^2) (this value is based on a TPV with a similar Shore Hardness of 87A). Although the numerical value for the TPV rail pad Shore Hardness is higher than that of the MDPE, the type A scale is used for softer plastic materials, whereas the type D is used for harder plastic materials. In this instance, the value of 60 for the type D scale indicates a harder material than the values of 86 and 95 for the type A scale.

Loading conditions were consistent for the three series of experiments, having a constant vertical load of 32,500 lb (144.6 kN) and corresponding lateral loads based on the L/V force ratios being simulated. This magnitude of vertical load was chosen because it is the same value as specified for the AREMA Test 6 (Wear and Abrasion), which is designed to simulate a heavy-axle freight car negotiating a sharp curve. To compare the relative performances of the three rail pad components, the maximum loaded frame per L/V force ratio was identified and obtained for each pad (Table 1a). Table 1b is a compilation of the results from this series of experiments. The data collected for each rail pad component is presented side-by-side per L/V force ratio to show the difference in pressure distribution for the various materials under identical loading conditions. Figures 2a, 2b, and 2c are plots of the average pressure per column of data from the MBTSS along the width of the sensor on the rail seat for the TPV, MDPE, and two-part pad assemblies, per L/V force ratio.

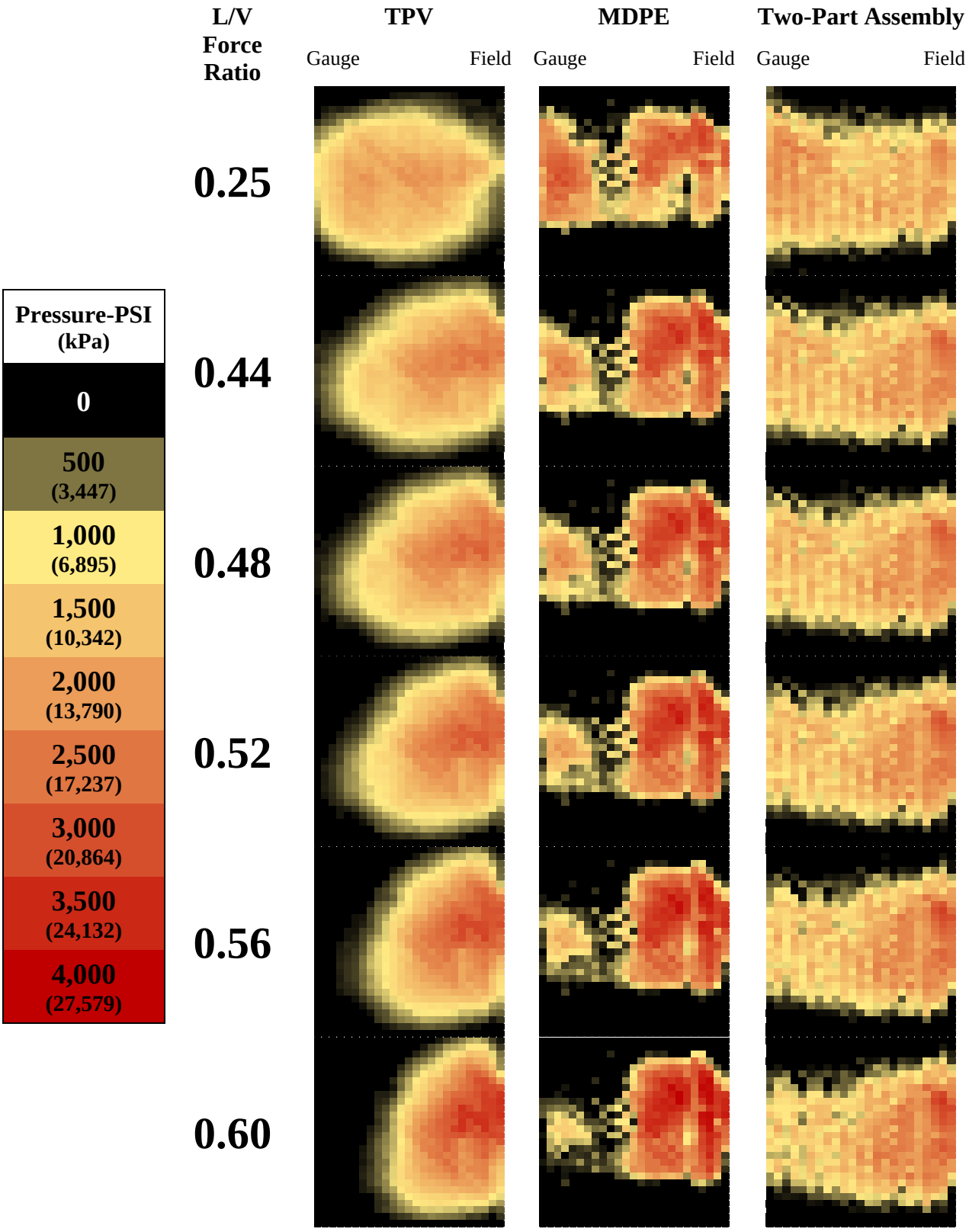

TABLE 1a Rail Seat Pressure Distributions for Rail Pad Assemblies under Varying L/V Force Ratios.

TABLE 1b Results of Rail Pad Component Experimentation

L/V Force Ratio	0.25			0.44		
Pad Assembly	**MDPE**	**TPV**	**2-Part Pad**	**MDPE**	**TPV**	**2-Part Pad**
Vertical, kips	32.50	32.50	32.50	32.50	32.50	32.50
Lateral, kips	8.13	8.13	8.13	14.30	14.30	14.30
Contact Area, in^2	20.09	28.75	24.73	19.31	27.93	23.96
Peak Pressure, psi	3,213	2,139	2,460	3,469	2,573	2,821
Contact Area over 3000 psi, in^2	0.34	0	0	1.55	0	0

L/V Force Ratio	0.48			0.52		
Pad Assembly	**MDPE**	**TPV**	**2-Part Pad**	**MDPE**	**TPV**	**2-Part Pad**
Vertical, kips	32.50	32.50	32.50	32.50	32.50	32.50
Lateral, kips	15.60	15.60	15.60	16.90	16.90	16.90
Contact Area, in^2	19.12	27.25	23.91	19.02	25.75	23.86
Peak Pressure, psi	3,546	2,800	2,877	3,721	2,925	2,990
Contact Area over 3000 psi, in^2	2.32	0	0	2.86	0	0

L/V Force Ratio	0.56			0.60		
Pad Assembly	**MDPE**	**TPV**	**2-Part Pad**	**MDPE**	**TPV**	**2-Part Pad**
Vertical, kips	32.50	32.50	32.50	32.50	32.50	32.50
Lateral, kips	18.20	18.20	18.20	19.50	19.50	19.50
Contact Area, in^2	18.63	23.96	23.38	17.76	21.30	23.38
Peak Pressure, psi	3,838	3,162	3,201	4,096	3,400	3,325
Contact Area over 3000 psi, in^2	3.44	0.53	0.10	4.11	1.74	0.29

NOTE: 1 kip = 4.45 kN, 1 in^2 = 6.45 cm^2, 1 psi = 6.89 kPa

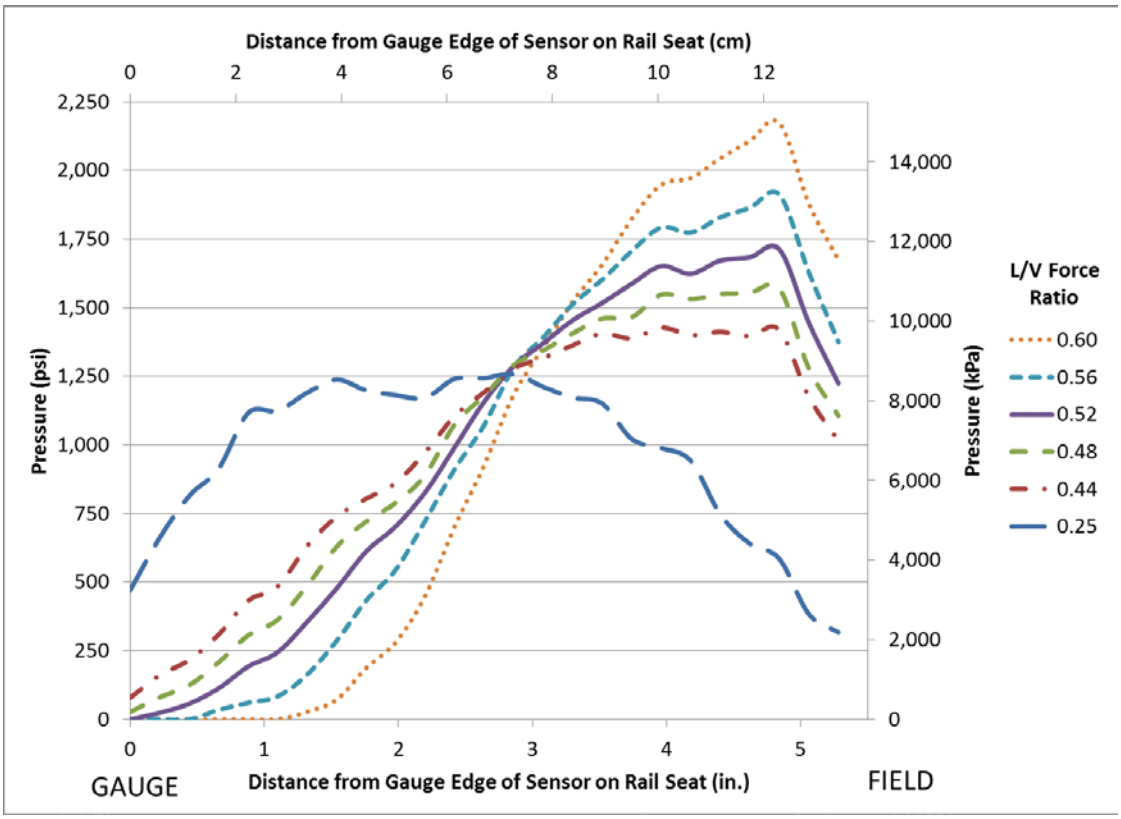

FIGURE 2a Average Pressure Distributions for TPV Rail Pad.

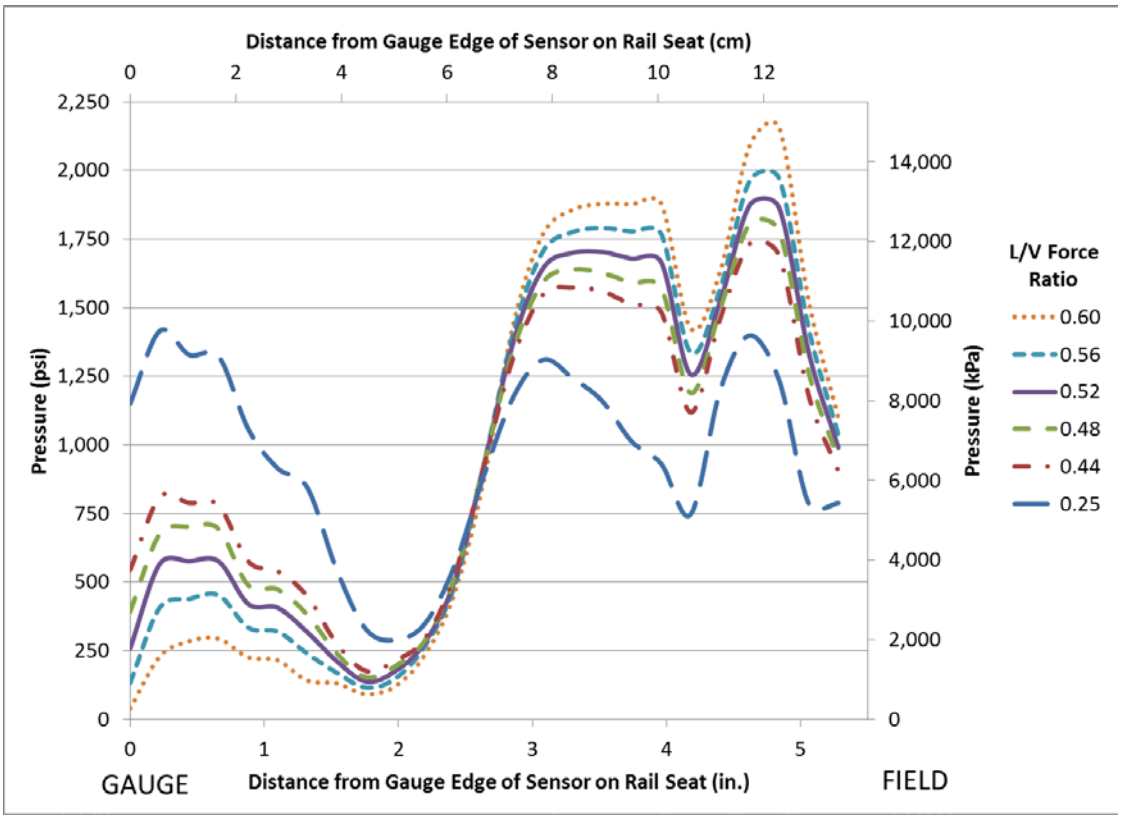

FIGURE 2b Average Pressure Distributions for MDPE Rail Pad.

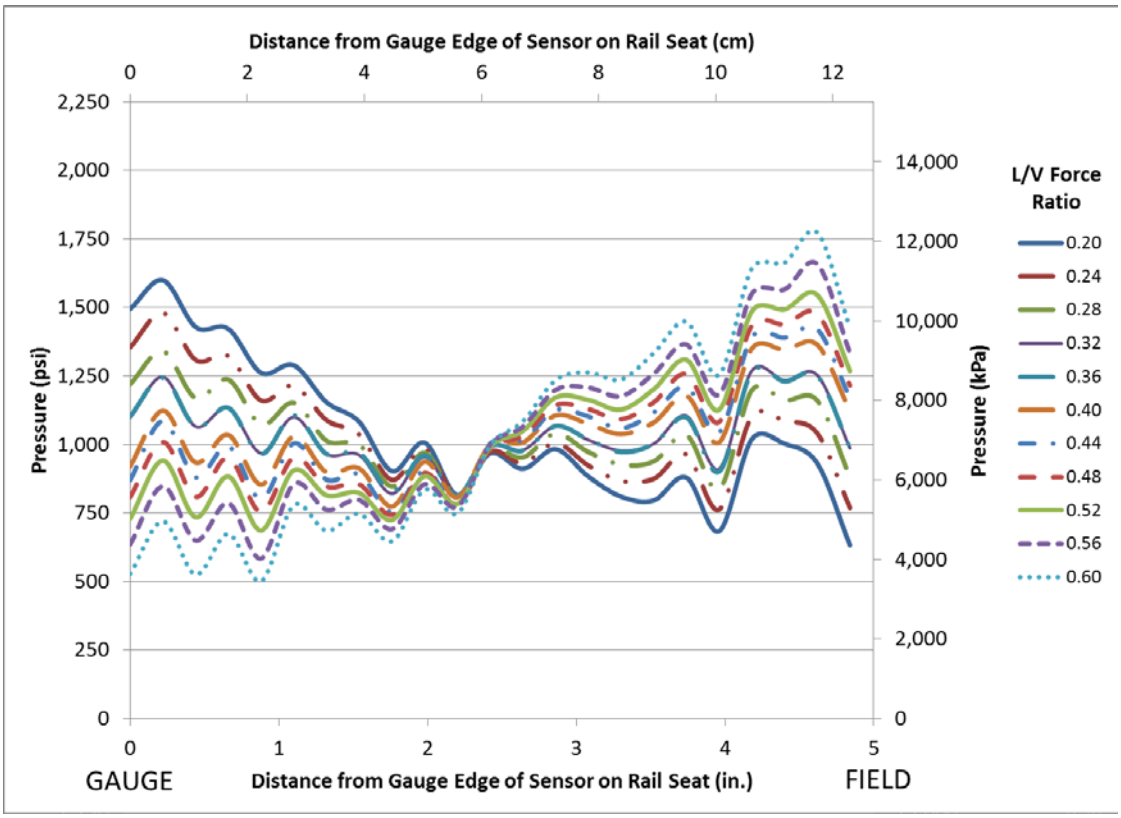

FIGURE 2c Average Pressure Distributions for Two-Part Pad Assembly.

This experiment shows that the MDPE rail pad distributed the same applied load over a noticeably smaller area of the rail seat than the low modulus TPV rail pad or two-part pad assembly. For an L/V force ratio of 0.25, the contact area of the load for the high modulus MDPE rail pad was 20.09 in^2 (129.61 cm^2), only 70% the amount of 28.75 in^2 (185.48 cm^2) of contact area recorded for the low modulus TPV rail pad under the same load, and only 81% the amount of 24.73 in^2 (159.55 cm^2) of the contact area for the two-part pad assembly. Peak pressures for each of the three pad assemblies occurred during the L/V force ratio of 0.60, as it was the same vertical load being applied to smaller contact areas. Of the three pad assemblies used in experimentation, the highest peak pressure recorded was for the MDPE rail pad, with a value of 4,096 psi (28,240 kPa). This value is approximately 20% higher than the peak pressure of 3,400 psi (23,440 kPa) recorded for the TPV rail pad, and 23% higher than the 3,325 psi (22,930 kPa) recorded for the two-part pad assembly. The MDPE pad distributed this same load over 11% less of the rail seat surface than the TPV rail pad, and 17% less than the two-part pad assembly, thus resulting in the higher peak pressures. Furthermore, although the MDPE rail pad had a smaller total contact area, it had a larger amount of area loaded at higher pressures than the two other pad components used in experimentation, as is evident in the rows showing contact area over 3,000 psi (20,680 kPa) (Table 1b).

In Figures 2a, 2b, and 2c, the increase of loading into the field side of the rail seat as L/V force ratio increases can be seen for all three rail pad assemblies used in experimentation. In Figure 2c, a wider range of more uniformly incremented L/V force ratios are presented to better show the transfer of the pressure distributed towards the field side of the rail seat. In all three instances, the decrease of pressure in the area immediately adjacent to the field side shoulder is likely due to the gap beneath the insulator post beyond the width of the base of the rail. The shape of the curves for each experiment could be due to variable material geometry or properties, which can in turn govern the rail base rotation, of each rail pad material under increasing L/V force ratios. Additional experimental replicates are needed to gain further

insight on the shape of the curve on an average rail seat. The curves for the TPV pad are similar to the theoretical triangular distribution pattern noted in previous concrete crosstie rail seat stress research *(4)*. This could be due to the fact that the lower modulus of the TPV pad allows the base of the rail to rotate more under increased lateral loads. The higher modulus MDPE pad, however, would allow less rotation of the rail base, resulting in the distributions shown in Figure 2b. Supporting the possibility that a rail pad component with a lower modulus could allow greater rotation of the base of the rail is the fact that the largest decrease in contact area under increasing L/V force ratio occurred for the TPV rail pad. A decrease of approximately 26% of contact area occurred between the L/V force ratios of 0.25 and 0.60 for the TPV rail pad, as compared to 12% and 5% for the MDPE pad and two-part assembly, respectively.

The behavior of the commonly used two-part pad assembly can be seen as a hybrid of the higher modulus MDPE pad and the lower modulus TPV pad. The peak pressure values were on average closer to those of the TPV pad, while undergoing the least change in contact area under increasing L/V force ratio of the three pad components used in experimentation. However, the ability of the two-part pad assembly to resist rotation of the rail base more closely mirrored that of the MDPE pad, as the decrease in contact area under increasing L/V force ratios between these two components was more similar to that of the TPV rail pad. This similarity can also be seen in Table 1a, where under an L/V force ratio of 0.60, both the MDPE and two-part pad assemblies retained contact on the gauge side of the rail seat, whereas this area under the TPV rail pad became unloaded.

For this experiment, and the following clip component experiment, data was not collected in the area immediately adjacent to the gauge side of the rail seat. Figures 2a, 2b, and 2c, show that the width of the sensor on the x-axis is less than the actual full width of the rail seat used for experimentation. This is due to the need to protect the MBTSS by allowing the conductive leads extending from the pressure sensitive area of the sensor to lay flat on the rail seat, rather than bending that area over the base of the rail. Bending of the sensor around the base of the rail was found to cause damage to the sensor in earlier experimentation. Sacrificing data on the gauge side was accepted by the researchers at UIUC, as the pressures near the field side were the primary target of this investigation.

From this experiment, it can be seen that a direct relationship exists between a high rail pad modulus and concentrated loading of the rail seat. Furthermore, a highly concentrated loading of the rail seat could lead to crushing of the concrete surface; although the peak pressure values recorded in this laboratory experimentation did not approach the AREMA recommended minimum 28-day-design compressive strength of concrete used for concrete ties of 7,000 psi (48,260 kPa) *(6)*. It is also possible that highly concentrated loads could be seen in the field because although the maximum vertical load explored in this laboratory experimentation was only 32.5 kips (144.56 kN), wheel impact load detector (WILD) sites in revenue service can record loads of greater than 100 kips (444.82 kN) *(15)*. It is likely that a load of this magnitude would produce pressures on the rail seat in excess of 7,000 psi (48,260 kPa).

Another parameter that could affect the rail pad's ability to evenly distribute pressure is dynamic load attenuation. Under repeated loading cycles, such as those imparted by unit coal trains, the inability for the pad to fully recover elastically between axles could lead to changes in the distribution of pressure on concrete rail seats. Investigation into repeated loadings of rail pads could also lead to discussion of the effect of wear life of this component on rail seat pressure distribution

Fastening Clip Experimentation

Fastening systems for concrete crossties serve the primary purposes of providing vertical, lateral, and longitudinal restraint of the rail and providing load attenuation. A variety of clip designs and rail pad materials result in concrete crosstie and elastic fastening systems with unique stiffness characteristics, which result in a variety of specialized performance capabilities *(13)*. An experiment was performed to investigate pressure distribution on the rail seat while varying the clip component of a concrete crosstie fastening system. Two common North American fastening system clip designs were used for this experiment, which will be referred to as Clip A and Clip B (Table 2a). The design clamping force for Clip A was 4,750 lbs (21.1 kN), with a spring rate of 8,223 lb/in (14.4 kN/cm). The design clamping force

for Clip B was 5,500 lbs (24.5 kN), with a spring rate of 6,286 lb/in (11.0 kN/cm). The spring rate values were determined based on the manufacturer's design clamping force at a given deflection.

The same two-part rail pad assembly was used for each clip to hold that variable constant. It should be noted that a different concrete crosstie was used for each respective clip experiment, as the cast-in steel shoulder design for each fastening system was different (a requirement of different fastening systems). This could result in variability in pressure distributions due to minor differences in the concrete rail seat profile; however, these differences should not be significant.

Loading conditions were consistent for this experiment, having a constant vertical load of 32,500 lb (144.6 kN) and corresponding lateral loads based on the L/V force ratios simulated. Four L/V force ratios were used for this experiment, ranging from 0.25 to 0.60. To compare the relative performances of the two clip designs, the maximum loaded frame per L/V force ratio was obtained for each clip (Table 2a). Table 2b is a summary of results from these maximum loaded frames. Figure 3a is a plot of the average pressure per column of data from the MBTSS along the width of the sensor on the rail seat for Clip A, per L/V force ratio. Figure 3b is the same plot of data collected during the experiment for Clip B.

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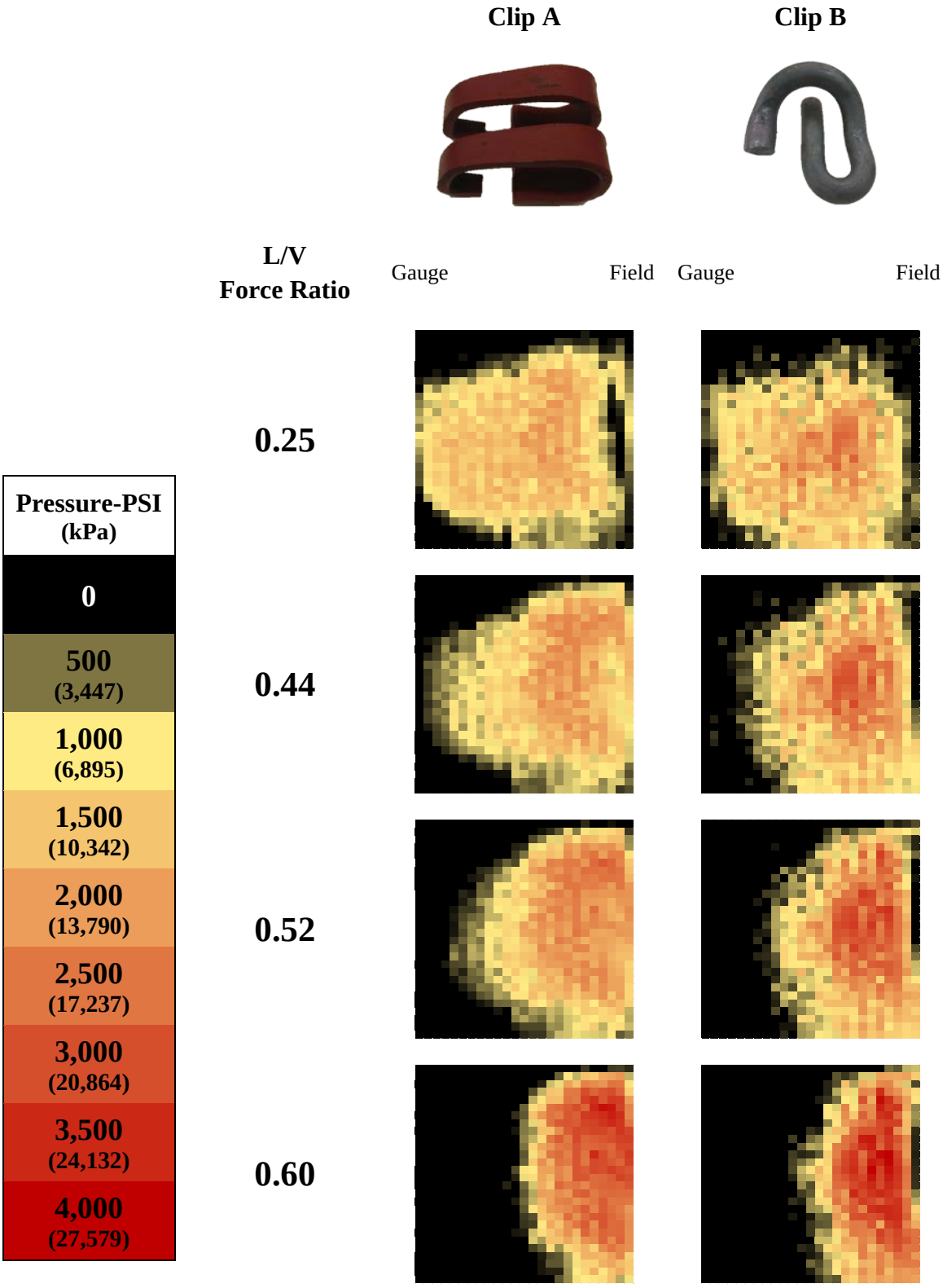

Table 2a Comparison of Rail Seat Pressure Distributions for Two Differing Fastening Clips.

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336 **TABLE 2b Results of Fastening Clip Experiment**
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L/V Force Ratio	0.25		0.44	
Clip Design	**Clip A**	**Clip B**	**Clip A**	**Clip B**
Vertical, kips	32.50	32.50	32.50	32.50
Lateral, kips	8.13	8.13	14.30	14.30
Contact Area, in^2	28.36	27.59	26.57	24.54
Peak Pressure, psi	2,188	2,744	2,327	3,067
Contact Area over 3000 psi, in^2	0	0	0	0.24

338

L/V Force Ratio	0.52		0.60	
Clip Design	**Clip A**	**Clip B**	**Clip A**	**Clip B**
Vertical, kips	32.50	32.50	32.50	32.50
Lateral, kips	16.90	16.90	19.50	19.50
Contact Area, in^2	23.62	21.01	16.55	17.18
Peak Pressure, psi	2,872	3,385	3,809	4,083
Contact Area over 3000 psi, in^2	0	0.92	2.13	3.53

339 *NOTE: 1 kip = 4.45 kN, 1 in^2 = 6.45 cm^2, 1 psi = 6.89 kPa*
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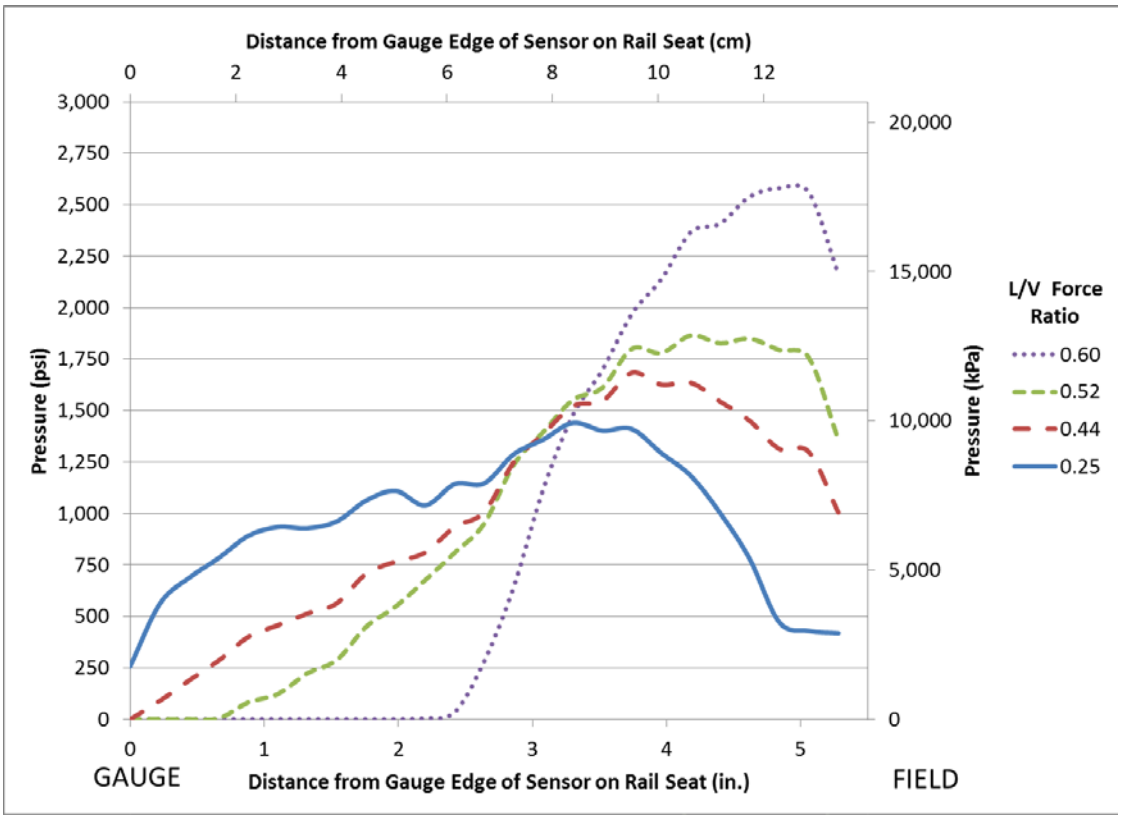

FIGURE 3a Average Pressure Distributions for Clip A.

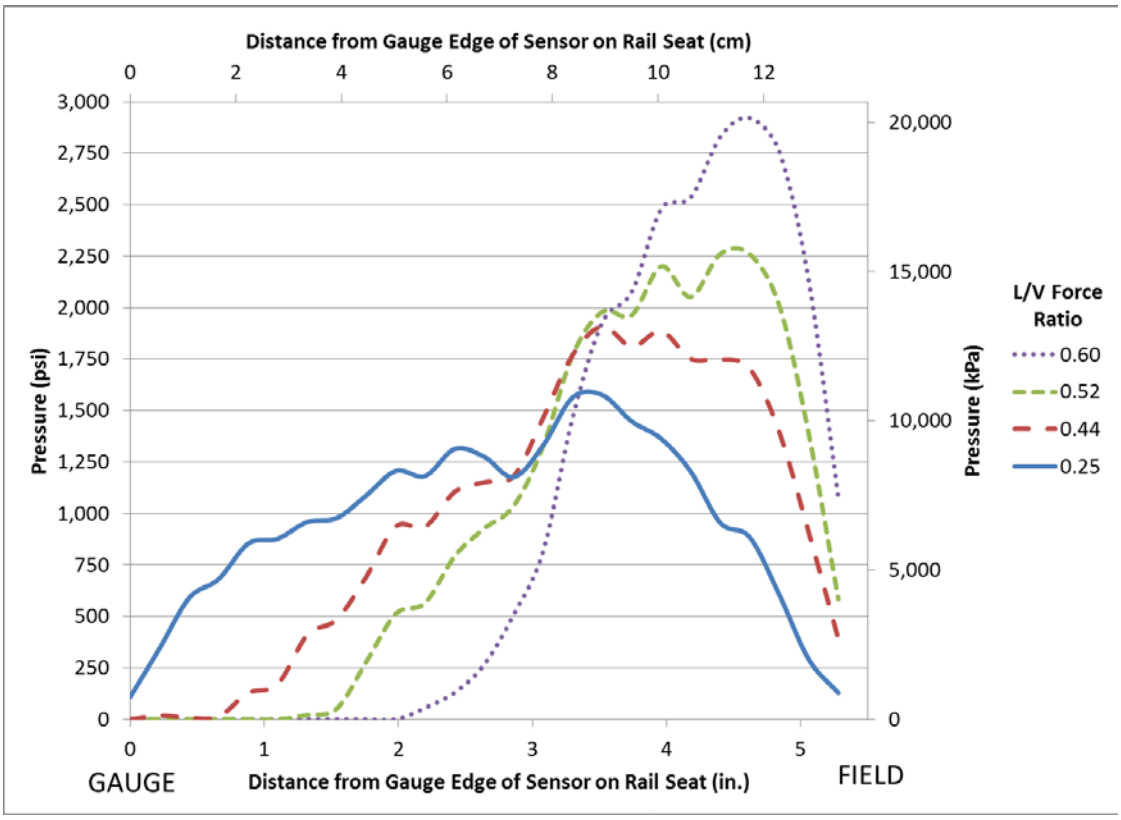

FIGURE 3b Average Pressure Distributions for Clip B.

Results from this experiment show a lower magnitude of variability between these two fastening system components than results from earlier experimentation with different rail pad moduli. The general trend was that Clip A distributed the pressure over a slightly larger area, thus producing lower peak pressure values. The greatest difference in contact area between the two clips was 2.61 in^2 (16.84 cm^2), at an L/V force ratio of 0.52. At the most extreme L/V force ratio of the experiment, the difference in peak pressures was only 274 psi (1,890 kPa), with the value for Clip B being 7.2% higher than that of Clip A.

A notable difference between the results from the two clips is the shape of the pressure distributions. It appears that the geometry of each clip effects where load is concentrated on the rail seat, but it should be noted that no replicates using additional crossties or fastening systems have been conducted. In all of the pressure distribution frames for Clip B, a central area of concentrated pressure is noted, and the design of this clip is such that there is one point of contact between the clip and in the insulator resting on the rail base, as can be seen in Table 2a. For Clip A distributions, the peak pressures appear to be concentrated over a wider area of the rail seat, and not concentrated on a single area like Clip B. This appears logical, as the design of Clip A has two points of contact between the clip and insulator, as can be seen in Table 2a. This concept is also supported by the fact that the Clip B experiments showed higher peak pressures being imparted into the rail seat, while having smaller contact areas than Clip A for all but the L/V force ratio of 0.60. Whether these same pressure distributions are seen in the field is not yet known, which researchers at UIUC intend to investigate through future field experimentation.

CONCLUSIONS AND FUTURE WORK

The following conclusions can be drawn from the analysis of data collected in these preliminary experiments using MBTSS:

- Lower modulus rail pads distribute rail seat loads over a larger contact area, reducing peak pressure values and mitigating highly concentrated loads at this interface
- Higher modulus rail pads distribute rail seat loads in more highly concentrated areas, possibly leading to localized crushing of the concrete surface under extreme loading events
- A more commonly used two-part pad assembly comprising of both higher and lower modulus materials can provide the benefits of reducing peak pressure values while maintaining a more constant contact area under increasing L/V force ratios and reducing rail base rotation
- A lower L/V force ratio of the resultant wheel load distributes the pressure over a larger contact area
- A higher L/V force ratio of the resultant wheel load causes a concentration of pressure on the field side of the rail seat, resulting in higher peak pressures
- The design of the clip component of the fastening system affects the shape of the pressure distribution on the rail seat
- No large differences in peak pressure or contact area values were seen between the two clip designs used in experimentation

Given the projected increase in the use of concrete crossties in the North American railroad industry, research will continue at UIUC to develop a comprehensive laboratory and field instrumentation plan to better understand interactions at this interface. The experiments described in this paper were theoretical in nature, with the loading conditions chosen by researchers based on expert opinion and working knowledge of rail seat loads.

Future laboratory experimentation planned by researchers at UIUC includes installing MBTSS on rail seats of concrete crossties with various models of fastening systems to further view the effect that variations in clip design have on rail seat pressure distribution. Additional rail pad component experimentation will take place to better understand the material properties of this component and the effect it has on mitigating rail seat pressures. Experiments with rail pads of varying thicknesses will also be performed to better understand the effect on rail seat pressure distribution, as rail pad thickness was not

a variable in the initial pad component experimentation. Since a load applied to a larger contact area appears to result in lower peak pressure values, experiments will also be conducted on crossties with various rail seat dimensions and degrees of deterioration and/or repair via epoxy or other materials. Future experimentation using more intermediate L/V force ratio values, such as those seen in Figure 3c, will aid the understanding of the transition of pressure from the gauge to field side under an increasing lateral component of the resultant wheel load.

Having run several preliminary experiments in the laboratory, as well as developing a means to modify and protect the sensor for more accurate data collection, researchers at UIUC plan to instrument MBTSS on concrete crossties in the field. Field experimentation will allow analysis of actual loading conditions on the concrete rail seat surface with varying configurations of train loads, speeds, and track geometry. Another variable that we propose to investigate in field testing is the effect of TOR friction modification on the distribution of loads onto the rail seats of concrete crossties.

Field experimentation will also play a crucial role in guiding the future of laboratory experimentation. A good working relationship between field data and experimental data is expected as the pressure distribution data collection process is refined, and field conditions are better simulated in the laboratory.

In summary, the use of MBTSS appears to be a feasible, non-intrusive means to instrument concrete crossties to measure rail seat pressure distributions. Furthermore, results from this work will be leveraged, as the data collected from MBTSS in the laboratory and field will be used as an input for rail seat loads into finite element model (FEM) analysis of the concrete crosstie and fastening system currently being performed at UIUC.

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