Quantification of Lateral Forces in Concrete Sleeper Fastening Systems Under Heavy Haul Freight Loads

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SUMMARY

Increasing axle loads of North American heavy haul freight trains have placed significant demands on current rail infrastructure. These new loading demands present numerous engineering challenges related to the design and performance of fastening systems. It is hypothesized that high lateral load demand on the fastening system is a main contributor to fastening system component failures. Due to the lack of understanding of lateral force transfer through the fastening system, lab experimentation was conducted to quantify and map the lateral load path. This was achieved through investigation of the lateral stiffness and global lateral load distribution while varying support conditions of the sleeper as well as rail seat friction coefficient. Analysis of experiment data showed lateral stiffness increased when vertical force increased, the lateral stiffness of a properly supported sleeper is greater than a poorly supported sleeper, and both support conditions and decreasing rail seat friction changes the lateral load distribution through the three sleeper system investigated.

INTRODUCTION

Concrete sleepers are an appealing alternative to conventional timber sleepers for many reasons primarily due to their durability and high load carrying capacity[1]. However, as the annual gross tonnage on North American heavy haul track has increased, concrete sleepers and fastening systems have been experiencing a wide variety of failures that include rail seat deterioration, insulator wear, shoulder deterioration, and worn rail pads[2, 3]. Industry experts have hypothesized that fastening system component failure and deterioration is driven by the lateral load demands placed on the components in heavy haul environments. Although research has been conducted to better understand the lateral load demands placed on track infrastructure by trains[4, 5], the lateral load path through the fastening system and track structure is still not fully understood. Due to this limited understanding, laboratory experimentation was conducted at the University of Illinois Urbana-Champaign (UIUC) as part of a multi-year research effort funded by the Federal Rail Administration (FRA) to better understand the overall performance and quantify the mechanics of concrete sleepers and fastening systems.

OVERVIEW OF LAB EXPERIMENTATION

Various fastening system designs are used in service on North American heavy haul track, but the predominant design used historically has been the Safelok I fastening system[3,4]. Therefore, experiments were performed on Safelok I fasteners to quantify the lateral force transfer through the track superstructure.

Track Loading System

Data analyzed in this report were collected from experiments performed on the full-scale Track Loading System (TLS) at UIUC. The TLS applies loads to a 6.7 meter (22 ft.) long section of concrete sleeper track (**Figure 1**). Track components were assembled on a full depth section of track that included eleven sleepers spaced at 610 mm (24 inches) center-to-center. Static combinations of vertical and lateral loads were applied to the journals of a 914-mm (36-inch) diameter wheel set. Vertical and lateral loads were adjusted separately using a control system. The TLS used two hydraulic actuators mounted vertically and a hydraulic cylinder mounted laterally on a self-reacting steel frame. A special assembly for each journal was designed to attach one vertically-oriented actuator and the horizontally-oriented hydraulic cylinder to one journal and the second vertically-oriented actuator to the opposite journal. The actuator's load cell and linear variable differential transducer (LVDT) were calibrated for both load and displacement.

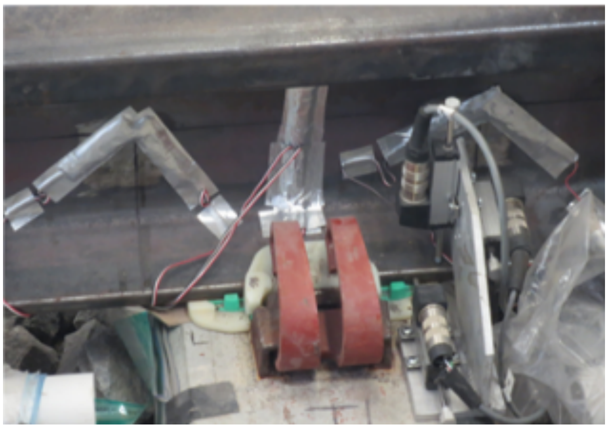
Figure 1. Track Loading System

Lateral and Rail Seat Load Instrumentation

Lateral wheel loads and rail seat loads were measured to quantify the load magnitude entering the rail head as well as the distribution through the track structure. Lateral loads were measured by four strain gauges installed on both sides of rail centered above the rail seat (**Figure 2a**). Strain gauges to measure lateral wheel load were wired in a full Wheatstone bridge and placed on the center five sleepers of the TLS. Rail seat loads were measured by strain gauges embedded in the center five sleepers.

Measurement of Force through Shoulder

In order to quantify the lateral load path and lateral load demands through the fastening system, researchers at UIUC developed a technology to measure the lateral force at the insulator–shoulder interface of the Safelok I fastening system[5]. The Lateral Load Evaluation Device (LLED) uses strain gauges to measure the bending strain of a beam placed in four point bending[6]. Installation of the device involves grinding away a portion of the shoulder, and replacing it with the LLED itself (**Figure 2b**). The stiffness and geometry of the LLED is similar to the original shoulder to ensure equivalent conditions[5]. This device allows for the measurements of lateral load resisted by the shoulder of the Safelok I fastening system.



a)

b)

Figure 2. a) Gauge Side lateral wheel load strain gauges b) Installed LLED[6]

Modifying Rail Seat Friction

Past research conducted at the University of Illinois has found that the presence of sand and moisture at the rail pad – rail seat interface may lead to a decrease in the coefficient of friction at this location[7]. It is also believed that current track remediation practices to mitigate rail seat deterioration alter the friction resistance at the rail seat surface. Examples of these remediation practices include steel abrasion frames and rail seat epoxy. Altering the coefficient of friction at this interface is hypothesized to change the magnitude of lateral load demand on the insulator and shoulder of installed fastening systems. During lab experimentation on the TLS, the friction coefficient between the rail pad and rail seat was decreased to gain a better understanding for how friction at this location contributes to the distribution of the lateral forces through the track structure. Friction coefficient was decreased by installing multiple layers of BoPET (Biaxially-oriented polyethylene terephthalate) film to create a low friction layer at the rail seat surface prior to installation of the Safelok I fastening system

OBJECTIVE

The primary objective of this research is to quantify the lateral load path by investigating the lateral stiffness and global lateral load distribution through the fastening system by varying vertical load, sleeper support conditions, and friction at the rail seat-tie pad interface.

LATERAL STIFFNESS

Lateral stiffness of a given fastening system is a parameter used to quantify the performance of the fastening system under lateral load demands. Lateral stiffness of the fastening system ($\text{Lat. Stiffness}_{\text{FS}}$) is defined as:

$$\text{Lat. Stiffness}_{\text{FS}} = \frac{\text{Lateral Force Resisted by Shoulder}}{\text{Rail Base Displacement}}$$

During the lab experimentation, lateral force resisted by shoulder was measured using LLEDs, and rail base displacements were measured by linear potentiometers. A fastening system with a high lateral stiffness must resist a larger percentage of the lateral load bearing on the insulator post and shoulder face[4]. This parameter helps in investigating a fastening system's ability to hold gauge as well as investigate how lateral force is transferred through the rail and into the remaining track structure.

Varying Vertical Load

Increasing axle loads of North American heavy haul freight trains have presented numerous challenges for the performance of fastening systems[3,4]. Because of this, laboratory experiments were conducted to investigate how lateral stiffness is affected by increasing vertical force. Using the TLS, lateral force was applied to the wheel set while keeping vertical force constant on each journal at 89 kN (20 kips), 133 kN (30 kips) and 178 kN (40 kips). The lateral stiffness of a single fastening system installed on a properly supported sleeper directly underneath the applied load of the wheel set is quantified in **Table 1,** and graphically displayed in **Figure 3**. Lateral stiffness is the slope of each curve seen in **Figure 3**. Increasing the vertical force increased the lateral stiffness of the fastening system. This may be due to the fact that as vertical force increases, lateral frictional forces within the fastening system itself begins to play a more significant role in resisting rail base movement. There was a 16.9% increase in lateral stiffness as vertical load increased from 89 kN (20 kips) to 133 kN (30 kips), and 17.9% increase in lateral stiffness when vertical load increased from 133 kN (30 kips) to 178 kN (40 kips). This shows that lateral stiffness increases at a relatively constant rate with increasing vertical load. In each vertical load case there is a slight change in slope as displacement increased. This slight increase in stiffness is hypothesized as the point where all excess slack between the shoulder, insulator and rail was removed.

Table 1. Lateral Stiffness Values Varying Vertical Force

Vertical Load (kN)	Lateral Stiffness (kips/in)	Lateral Stiffness (kN/mm)	R^2 Value
178	176.3	30.9	0.98
133	149.6	26.2	0.98
89	128.0	22.4	0.94

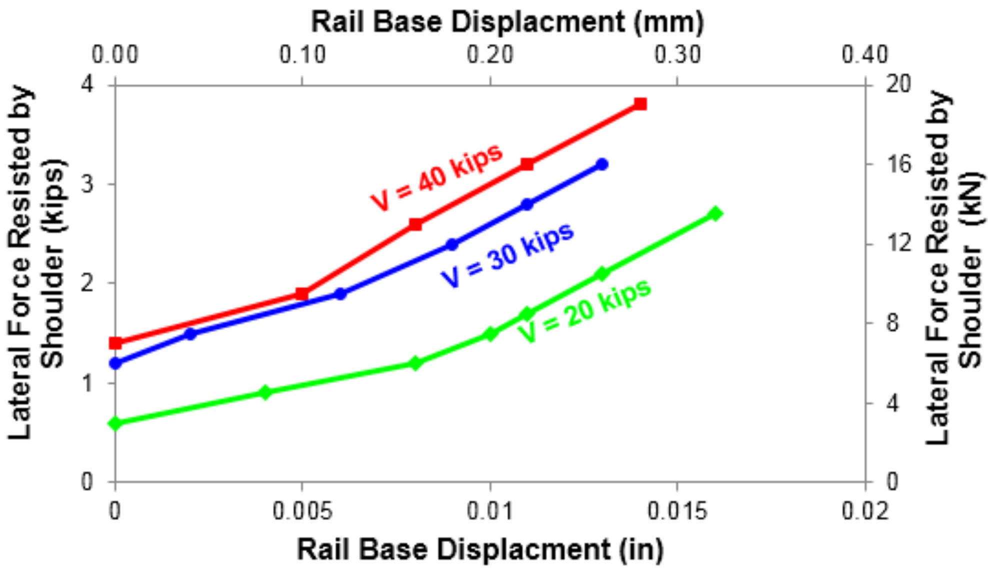


Figure 3. Lateral Stiffness with changing Vertical Force

Varying Support Conditions

Researchers at UIUC suspect that, as track quality degrades, its influence on track component deterioration is compounded. In order to better understand how a decrease in track quality with respect to the support conditions of sleepers effect lateral load performance of the Safelok I fastening system, lab experimentation was conducted to investigate the change in lateral stiffness with changing support conditions. Varied support conditions were achieved through the installation of sleepers with gaps between the base of rail and rail seat. After securing the fastening system, a gap was present at the sleeper to ballast interface, representing a hanging sleeper, and serving as a proxy for simulating poor support conditions. **Figure 4** shows a comparison of lateral stiffness between a poorly and properly supported sleeper under a constant vertical load of 133 kN (30 kips) and 178 kN (40 kips). The lateral stiffness of a poorly supported sleeper under a constant 133kN (30 kips) and 178 kN (40 kips) vertical load was 10.78 kN/mm (61.6 kips/in) and 14.0 kN/mm (80.1 kips/in) respectively. In both cases the lateral stiffness was less than half of what was observed in experiments performed on properly supported sleepers.

During experimentation it was also observed that as vertical load was applied over a poorly supported sleeper, the majority of the vertical force was distributed to adjacent properly supported sleepers. **Figure 5** shows the percent of vertical wheel load supported by three sleepers, where the center sleeper (Location A-A) was poorly supported and the location where the vertical load was applied. Due to this observation, it is hypothesized that the lack of vertical load resisted by a poorly supported sleeper caused a decrease in lateral friction force resistance in its fastening system. This led to an increase in rail base displacement and decrease lateral stiffness.

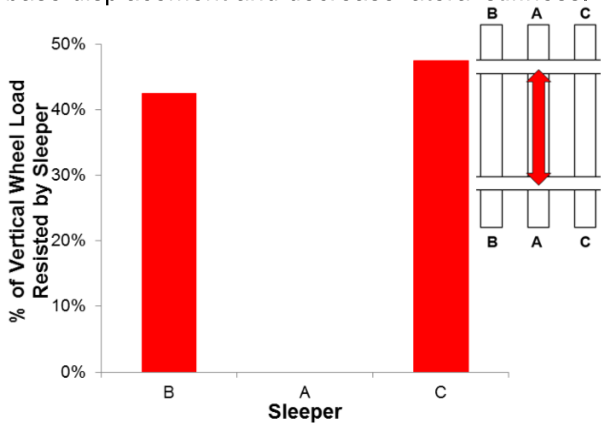


Figure 5. Three Sleeper Distribution of Vertical Wheel Load over Poorly Supported Sleeper

GLOBAL LATERAL LOAD DISTRIBUTION

Varying Support Conditions

Analysing the lateral load distribution from the wheel-rail contact point to the sleeper is important in quantifying the lateral load demands on fastening system components. **Figure 6** shows the percent of lateral wheel load applied to the rail passing through the fastening systems of 3 adjacent sleepers. In both support conditions cases, the wheel set was above the center sleeper (location A-A), and a constant vertical force of 178 kN (40 kips) was applied to the wheel set. Lateral force at the shoulder of the fastening system was recorded from the LLEDs. A three sleeper distribution was investigated due to prior field experiments that concluded lateral force is primarily distributed over three sleepers[5,6].

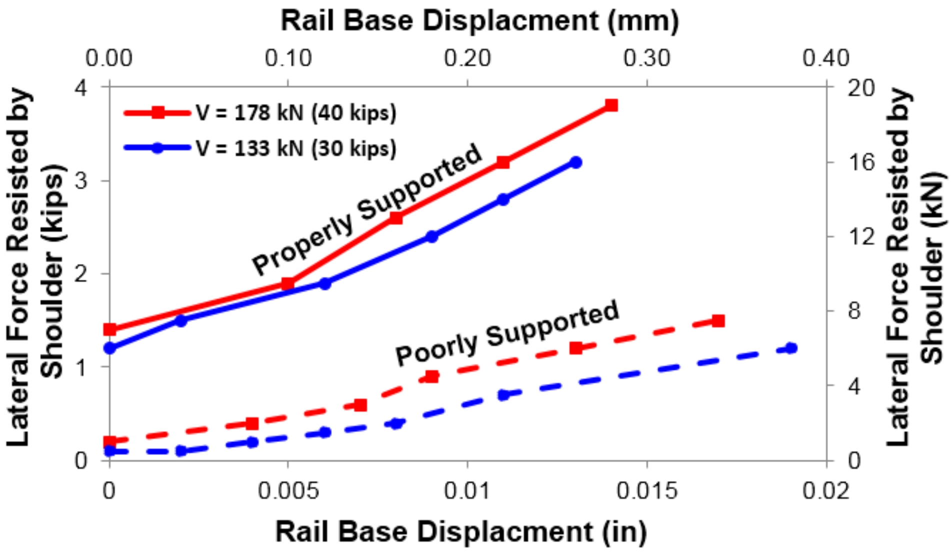


Figure 4. Comparison of Lateral Stiffness between Properly and Poorly Supported Sleepers

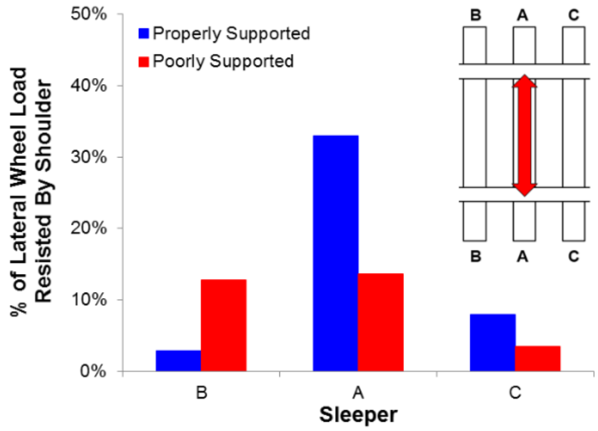


Figure 6. Three Sleeper Distribution of Lateral Wheel Load varying support conditions

During experimentation performed on the properly supported sleeper, roughly 33% of the lateral wheel load applied to the rail was resisted by the shoulder of the fastening system directly under the wheel set (location A-A), and a total of 43% of the lateral wheel load was resisted by the three adjacent sleepers being investigated. During experimentation performed on the poorly supported sleeper, roughly 13.5% of the lateral wheel load was resisted by the shoulder of the fastening system directly under the wheel set (location A-A), and a total of 30% was resisted by the three adjacent sleepers. The lateral wheel load not accounted for by shoulder resistance is assumed to be resisted by frictional forces within the fastening system itself, as well as minor resistance from adjacent fastening systems in the track structure. It is important to note that a portion (approximately 5.3kN (1.2 kips) at a 178kN (40 kip) vertical load) of the lateral wheel load passing through the fastening system into the shoulder is due to lateral load contributions from the vertical load applied to the wheel set.

Modifying Rail Seat Friction

In order to investigate the role friction at the rail seat surface plays in the distribution of lateral forces, laboratory experiments that involved decreasing the coefficient of friction at the rail pad-rail seat interface were conducted on the TLS. Comparison of lateral load distribution with and without the low friction layer on a properly supported sleeper is shown in **Figure 7.**

When the low friction layer was installed, approximately 47% of the lateral wheel load applied to the rail was resisted by the shoulder of the fastening system directly under the wheel set (location A-A), and a total of 64% of the applied lateral wheel load was resisted by the three adjacent shoulders being investigated.

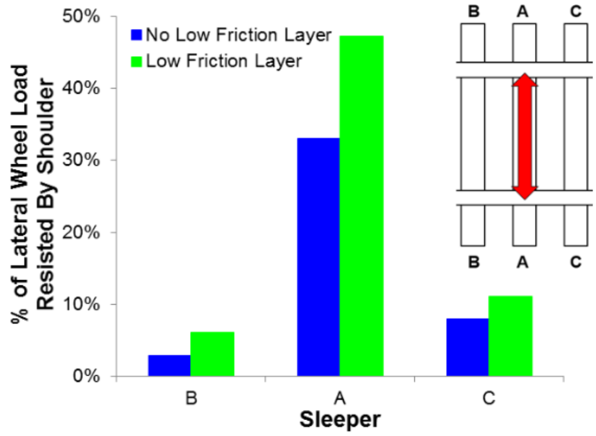


Figure 7. Three Sleeper Distribution of Lateral Wheel Load Varying Rail Seat Friction

The results showed that the installation of the low friction layer increased the lateral load demand on the shoulder of the fastening system. It is hypothesized that this occurred because the lateral friction force at the rail seat, which help resist lateral load applied to the rail, was decreased. As with the comparison of poorly and properly supported load distribution, the lateral wheel load not accounted for by shoulder resistance is assumed to be resisted by frictional forces within the fastening system itself, as well as minor resistance from adjacent fastening systems in the track structure.

CONCLUSION AND FUTURE WORK

This study used the Track Loading System (TLS) setup at UIUC to evaluate the influence of several parameters on the lateral load path through the Safelok I fastening system under static loading conditions. Specifically, the influence of support conditions and frictional characteristics at the rail seat were evaluated. The following conclusions were drawn from the results of the experimental investigation:

- Lateral stiffness of the Safelok I fastening system increased with an increase in vertical wheel load.
- Lateral stiffness of the fastening system on a properly supported sleeper is greater than the lateral stiffness on a poorly supported sleeper.
- Lateral wheel loads are primarily distributed to the sleeper directly beneath the axle applying the force in proper support conditions.
- A poorly supported sleeper directly beneath the axle applying force resists less of the lateral wheel load than a properly supported sleeper.

- Decreasing the friction coefficient between rail pad and rail seat increases the magnitude of lateral bearing force against shoulder in a three sleeper distribution.

The conclusions made from experiments performed are based on a limited number of properly and poorly supported ties analyzed. More experiments must be conducted in order to investigate if the results outlined in this report are repetitive.

Data analyzed in this report were collected from experiments performed on track with fastening systems installed via manufacturer specifications and typical field installation. Future work will include investigation of lateral load path through the track superstructure with missing fastening system components. Comparison between the performance of Safelok I and SKL type fastening systems under lateral load demands will also be investigated.

ACKNOWLEDGMENTS

This project was sponsored by funding from the Federal Rail Administration (FRA), part of the United States Department of Transportation (US DOT). The published material in this report represents the position of the authors and not necessarily that of the DOT. The authors would like to acknowledge Sihang Wei, Thiago Bizarria, Christopher Rapp, Justin Grasse, Kartik Manda, Michael Yang, Matthew Greve, Darold Marrow, Tim Prunkard and the UIUC machine shop for their help in experimentation setup. The authors would also like to thank the support and guidance received from industry partners: BNSF Railways, Union Pacific Railroad; National Railway Passenger Corporation (Amtrak) Amsted RPS/ Amsted Rail Inc, Vossloh ; GIC Ingenieria y Construccion; Hanson Professional Services Inc; and CXT Concrete Crosstie.

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