

Comparison of Lateral Load Performance of Concrete Crosstie Heavy Haul Fastening Systems

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ABSTRACT

There are many unique designs of elastic fastening systems used throughout the world that have been developed to meet a variety of design specifications and performance expectations. Historically, the most common types of fastening systems used for concrete crossties in North America are the Safelok I or e-clip systems. However, in recent years, railroads have begun implementing the Skl-style (W) fastening system with concrete crossties in existing and new heavy-haul freight railroad mainlines. To better understand how the Skl-style system performs under the magnitude of lateral loads observed on heavy haul freight railroads, research was conducted by the Rail Transportation and Engineering Center (RailTEC) at the University of Illinois at Urbana-Champaign (UIUC). The focus of this paper is on

laboratory characterization of the lateral load path through the Skl-style W 40 fastening system on a full-scale laboratory setup. These data were then compared to experimentation conducted on the Safelok I fastening system under the same loading conditions. Laboratory experimentation comparison concluded that lateral wheel load is primarily transferred into three crossties for both systems, the lateral wheel load imparted into the angled guide plate of the W 40 system was higher than the lateral wheel load imparted into the shoulder of the Safelok I, and the lateral stress placed on the lateral crosstie bearing area for the W 40 system is lower than the lateral stress placed on the lateral crosstie bearing area of the Safelok I system. It is the authors' intent that the information in this paper will assist the rail industry in improving fastening system design and performance for North American heavy-haul freight railroad applications through the use of quantitative loading data as inputs for the future implementation of mechanistic design.

INTRODUCTION

Concrete crossties are an appealing alternative to conventional timber crossties for many reasons, primarily due to their durability and high load-carrying capacity. However, increasing axle loads, coupled with the demanding loading environment seen in certain portions of the North American rail network, have presented engineering challenges for the design and performance of concrete crossties and their fastening systems. A survey conducted in 2012 by the Rail Transportation and Engineering Center (RailTEC) at the University of Illinois at Urbana-Champaign (UIUC) determined that wear of fastening system components and rail seat deterioration (RSD) are two of the most critical problems observed in concrete crosstie track in North America (1). It is hypothesized that one of the primary contributors to both of these problems is the high lateral load that is expected to occur within the track superstructure in certain heavy haul freight railroad locations. This hypothesis cannot be addressed due to the fact that lateral load performance of track superstructure has not been thoroughly investigated.

There has been progress in recent years in terms of research that was aimed at quantifying lateral forces within the track superstructure (2-6), mostly developing a detailed understanding of the lateral load demands on fastening system components. These initial experiments primarily focused on the performance of a widely-used spring clip system, the Safelok I, but the magnitude of lateral loads imparted on fastening system components and the distribution of lateral forces within the track superstructure are believed to be dependent on the type of fastening system used. In recent years, North

American railroads have begun implementing SkI-style (W) fastening systems with concrete crossties in both existing and new heavy-haul freight railroad infrastructure. Although the systems are performing well in demanding North American track locations, little research has been conducted on SkI-style systems with respect to the lateral load demands placed on the components under heavy haul loads. To improve the current understanding of SkI-style fastening systems, laboratory experimentation was conducted at UIUC to further understand the lateral load performance of the systems. The performance of the SkI-style system was then compared to similar laboratory experimentation conducted on the widely-used Safelok I system in order to better understand how the SkI-style system performs under North American heavy haul freight railroad axle loads.

OVERVIEW OF FASTENING SYSTEMS

W 40 HH AP System

The SkI-style system chosen to conduct lateral load experimentation is the W 40 HH AP fastening system (hereafter referred to as the “W 40” or “W 40 system”) manufactured by Vossloh Fastening Systems (7). The W 40 system is comprised of tension clamps, angled guide plates, a rail pad, and an abrasion plate, and is held together by tie (i.e. lag) screws (Figure 1) inserted into an embedded dowel.

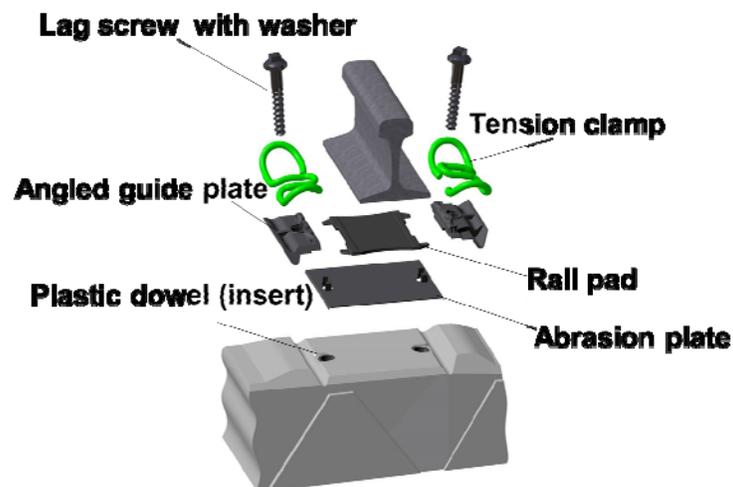


Figure 1. Vossloh Fastening Systems W 40 HH AP fastening system (8)

The angled guide plates allow for the distribution of lateral force along the entire length of the rail seat and are designed to stress the concrete crosstie in pure compression (8). Additionally, the system is equipped with an abrasion plate designed to protect the rail pad and to mitigate RSD, one of the most

critical problems with concrete crossties and fastening systems in North America today (1). The geometry of the tension clamp is optimized such that the residual stress within the tension clamp is reduced after typical rail deflection, increasing the fastening system's ability to sustain adequate clamping force (8).

Safelok I System

Lateral load experiments were also conducted on concrete crossties equipped with the Safelok I fastening system, commonly manufactured by Pandrol and Progress Rail Services. This past research effort conducted by RailTEC was funded by the Federal Railroad Administration (FRA), to better understanding concrete crosstie track performance. The Safelok I system is one of the most common fastening systems installed on North American heavy haul concrete crosstie track, and as such, the advantages and disadvantages of this fastening system are relatively well-understood in the North American heavy haul industry. The components of the Safelok I fastening system, and how they are installed on a concrete crosstie can be seen in **Figure 2**.

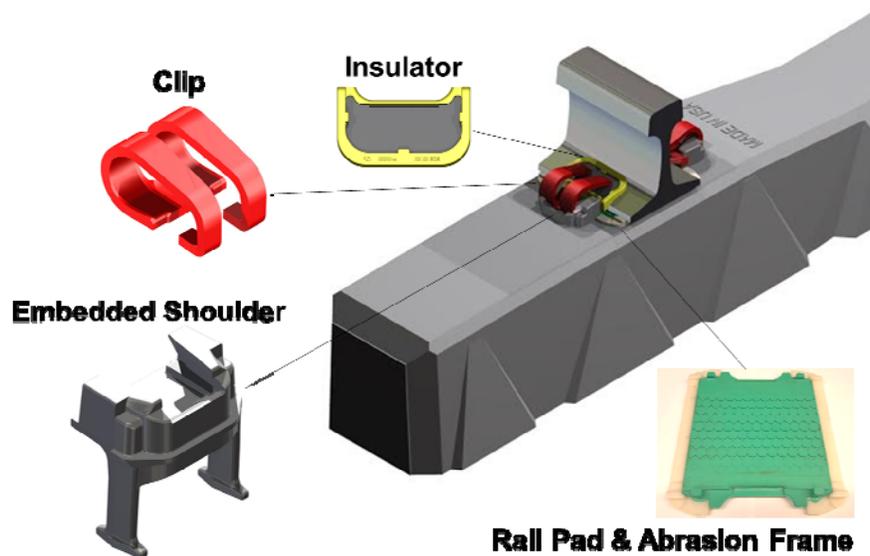


Figure 2. Components of the Safelok I fastening system

Steel shoulders are embedded into the concrete crosstie during casting. Insulators are used to electrically isolate the rail from the clips. A two-part rail pad and abrasion frame is installed underneath

the rail on each rail seat to increase the resilience of the system, and help better distribute vertical and lateral load into the concrete crosstie rail seat.

LABORATORY EXPERIMENTATION

Laboratory Experimentation Objective

The primary objective of this research endeavor is to quantify the lateral load path through the track superstructure equipped with the W 40 system by investigating the global lateral load distribution through the track superstructure, and the lateral force applied to the field-side angled guide plate. The data collected from experimentation with the W 40 system will then be compared with data collected from past experimentation with the Safelok I system. The Safelok I system is widely used within the North American heavy haul freight railroad industry, and provides for a good baseline to better understand the performance of the W 40 system.

Experimentation System

Experimentation for both the W 40 and Safelok I systems was performed on the full-scale Track Loading System (TLS), located in RailTEC's Research and Innovation Laboratory (RAIL) in Champaign, Illinois, USA. The TLS allows for the application of load to a 22-foot (6.7-m) long section of concrete crosstie track (**Figure 3**). Track components are assembled on a full-depth section of track that includes eleven crossties spaced at 24 inches (61 cm) on center. Static combinations of vertical and lateral loads were applied to the journals of a 36-inch (91.4 cm) diameter railcar wheel set. Vertical and lateral loads were adjusted separately using a control system. The TLS uses two servo-hydraulic actuators mounted vertically and a hydraulic cylinder mounted laterally on a self-reacting steel frame that encapsulates the track structure. A special assembly for each journal was designed to attach one vertically-mounted actuator and the horizontally-mounted hydraulic cylinder to one journal and the second vertically-mounted actuator to the opposite journal.



(a)



(b)

**Figure 3. RailTEC's Track Loading System (TLS) in the Research and Innovation Laboratory (RAIL), Champaign, Illinois, USA a) W 40 experimentation setup
b) Safelok I experimentation setup**

The testing setups on the TLS for the W 40 and Safelok I system experimentations were identical (same crosstie spacing, rail size, ballast depth, etc.). New fastening systems were used in all experimentation conducted on the TLS for both the Safelok I and W 40 systems.

Lateral Wheel Load Measurement

Lateral wheel loads were measured to quantify the load magnitude entering the rail at the wheel-rail interface. Lateral loads were measured using four strain gauges, two installed on each side of the rail centered above the rail seat. Strain gauges to measure loads were wired in full Wheatstone bridges and installed above the center five crossties on the TLS.

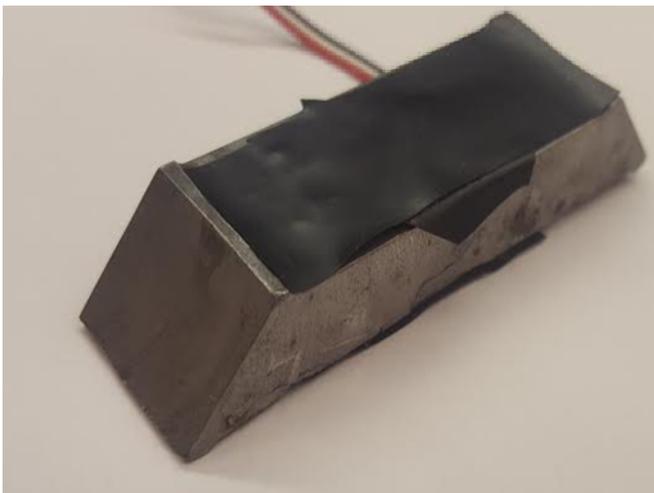
Measurement of Lateral Force through Fastening System

In order to quantify the lateral load magnitude and path through the fastening system, RailTEC researchers developed the Lateral Load Evaluation Device (LLED) (4, 5, 6). A unique LLED was designed for both of the fastening systems compared in this paper. The LLED uses strain gauges to measure the bending strain of a load cell that is placed in four-point bending. Strains measured on the LLED that are induced from lateral loads are resolved into forces using calibration curves generated by

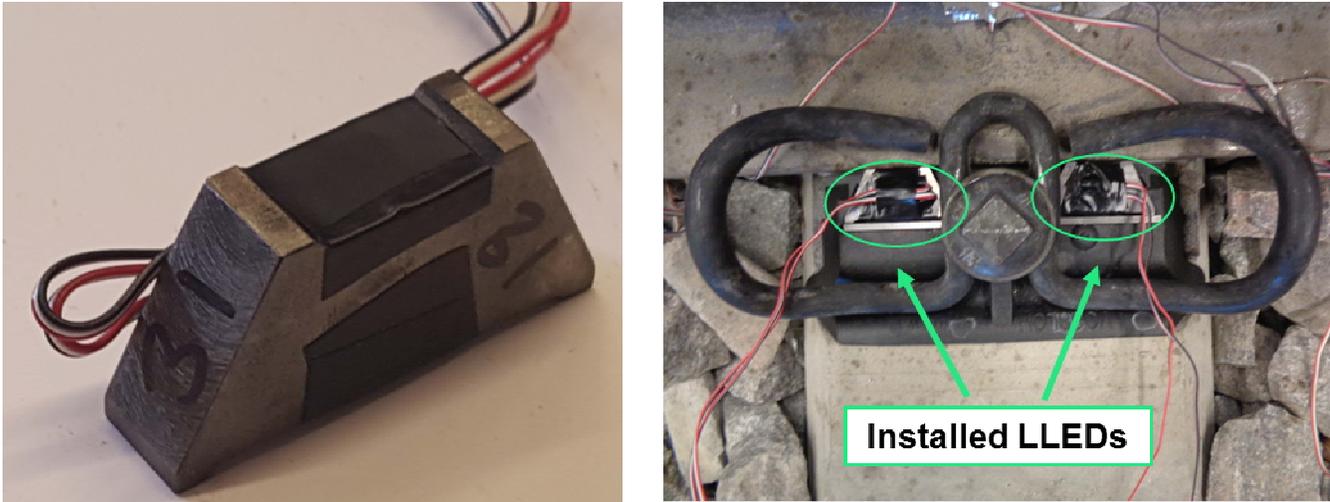
experiments conducted on a uniaxial loading machine.

The installation of the LLED in the Safelok I system involves grinding away a portion of the field side shoulder, and replacing it with the LLED (**Figure 4a**). A steel shim was manufactured to cover the front of the device in the Safelok I system to limit possible damage to the insulator and LLED during experimentation. The stiffness and geometry of the LLED is similar to the original shoulder to ensure equivalent conditions.

For the W 40 system, two LLEDs are installed in the field-side angled guide plate in order to obtain the total magnitude of lateral force imparted in the face of the angled guide plate by the rail base (**Figure 4b**). LLEDs are installed in pockets that are machined into the field side angled guide plates and were designed to maintain fastening system geometry and stiffness in a manner that is representative of the un-instrumented fastening system (**Figure 4b**). Steel shims were manufactured and placed at the back of the LLEDs to decrease the possibility of the LLED damaging the guide plate during experimentation.



a)



b)

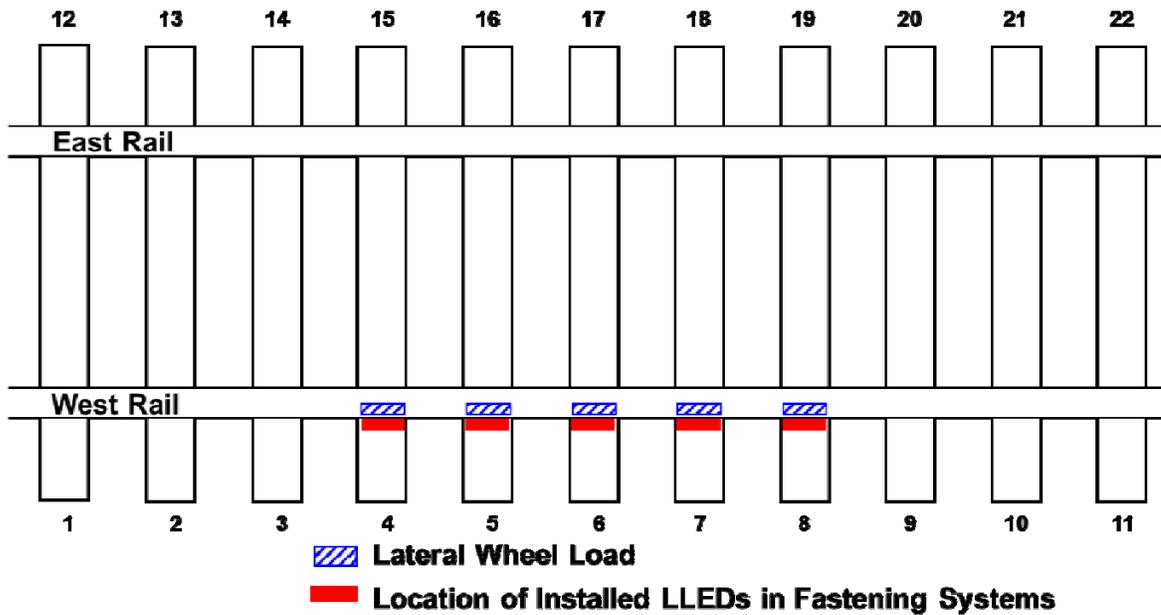
Figure 4. Image of LLEDs and the installation of the instrumentation in fastening system a) LLED designed and installed for Safelok I system b) LLED designed and installed for the W 40 system

Laboratory Instrumentation Layout

For each fastening system, the LLED-equipped systems were symmetrically installed on five of the eleven concrete cross-ties on the TLS. The instrumentation was installed on the middle cross-ties of the TLS to

avoid

any



influence of boundary conditions at the ends (**Figure 5**). The five concrete crosstie installation was chosen for instrumentation due to past experience of load distribution from field experimentation performed by RailTEC, and established theories on vertical pressure distribution (9).

For each fastening system tested, only one rail was heavily instrumented due to the manner in which lateral force is applied to the wheelset on the TLS (**Figure 5**). The horizontally-mounted hydraulic cylinder applies lateral force on the wheelset toward the west rail causing the flange of the wheel to be braced against this rail as lateral load is increased. This causes higher lateral forces to be imparted on the west rail making it the more critical rail to investigate when analyzing lateral load path.

GLOBAL DISTRIBUTION OF LATERAL FORCES

The lateral force distribution through the track superstructure with each fastening system was quantified and compared to investigate how different fastening systems distribute load globally. This distribution was analyzed by applying load directly over each heavily instrumented crosstie on the TLS,

Figure 5. Laboratory instrumentation map

and quantifying the distribution of lateral force resisted by the field side angled guide plates of the W 40 system or field side shoulder of the Safelok I system. An example of the global lateral load distribution observed in laboratory experimentation with both fastening systems tested can be seen in **Figure 6**. In this figure a vertical wheel load of 40 kips (178 kN) was held constant on the TLS track as lateral load was applied (**Figure 6**). The y-axis in this figure was obtained by dividing the lateral force measured from the LLEDs within the field angled guide plate or embedded shoulder of a given crosstie by the lateral wheel load applied to the rail.

From experimentation conducted on the TLS with each fastening system, it was observed that lateral load was primarily distributed into the crosstie directly below the point of load application, as well as the two adjacent crossties. As seen in **Figure 6**, the W 40 systems were better able to globally distribute lateral force from the rail into their angled guide plates than the Safelok I system was able to distribute lateral force into its embedded shoulders.

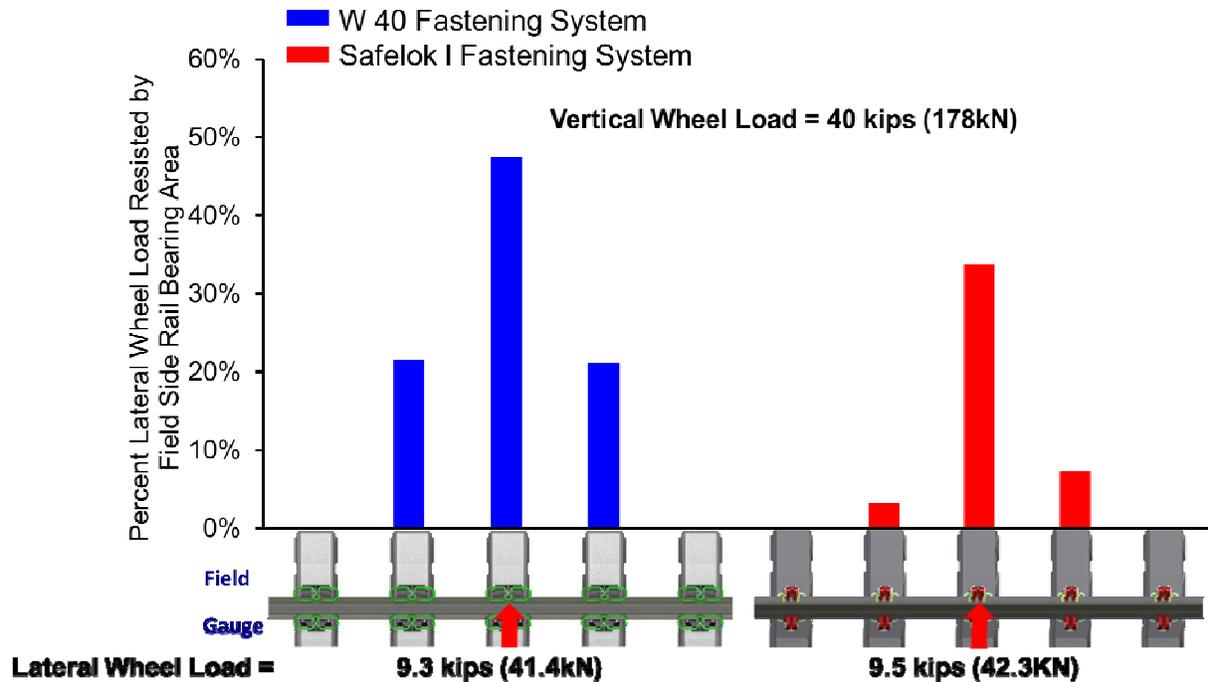


Figure 6. Global distribution of lateral wheel load in track installed with the W 40 and Safelok I systems

Figure 6 also shows that the lateral load measured by the LLEDs installed in the shoulders of the Safelok I systems were considerably lower than the lateral force applied to the rail. In the particular case shown in **Figure 6**, the LLED-measured lateral load only accounts for 63% of the lateral wheel load applied to the rail for Safelok I system, and 90% for the W 40 system. It is hypothesized that this occurs due to the lateral frictional forces at the rail seat playing a more significant role in resisting lateral wheel load for the Safelok I system in comparison to the W 40 system. In the case of the W 40 system, the lack of reliance on lateral frictional forces at the rail seat to transfer lateral wheel load into the concrete crosstie is also hypothesized to make this system less abrasive to the concrete rail seat which could help mitigate the initiation of RSD.

LATERAL FORCE THROUGH FASTENING SYSTEM

Quantifying the lateral force applied to the field side angled guide plate of the Ski-style fastening system has never been performed before, and is an important step to further the understanding of the demands placed on this component. Additionally, quantitative lateral force data provide insight on how the lateral

force is transferred from the rail head to the different components within the fastening system and track superstructure.

Figure 7 shows a comparison of lateral force resisted on rail bearing area for the W 40 and Safelok I systems with increasing lateral wheel load and under a constant vertical load of 40 kips (178 kN) on each journal. The data shown in this figure were collected from instrumented crossties on the TLS when the point of load application was directly over the crosstie being investigated. All data seen was zeroed to remove any lateral load caused by the application of vertical load to the wheelset.

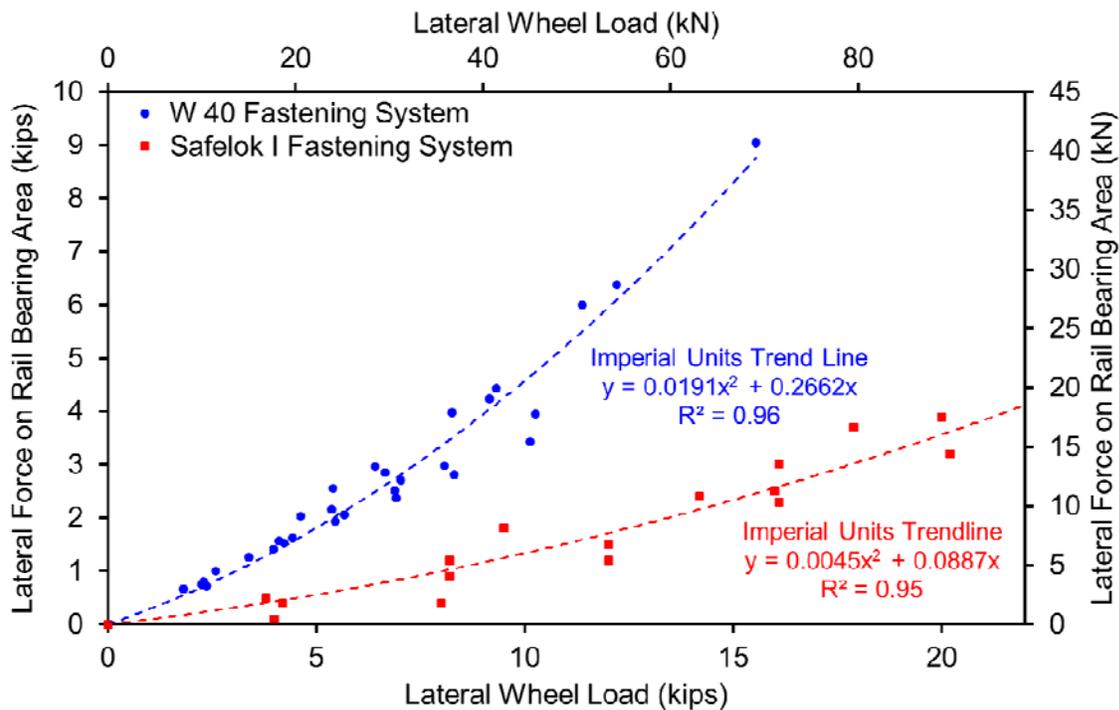


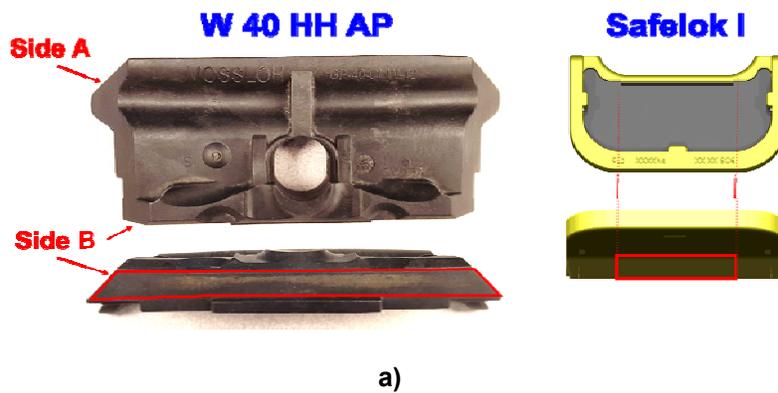
Figure 7. Lateral force resisted on rail bearing area for W 40 and Safelok I systems under a vertical load of 40 kips (178 kN)

As seen in **Figure 7**, as lateral wheel load increased the lateral force on rail bearing area also increased. **Figure 7** also shows that under similar lateral wheel loads, the magnitude of lateral force resisted by the rail bearing area of the Safelok I system was lower than the lateral force resisted by the W 40 system. The higher lateral force resisted by rail bearing area of the W 40 system is possibly due to the fact that, when compared to the Safelok I, the W 40 system relies less on lateral frictional forces at the rail seat as a medium to transfer lateral wheel load into the concrete crosstie.

In order to properly compare the performance of the W 40 system to the Safelok I system, the data collected from the laboratory experimentation must be normalized to account for the difference in fastening system designs, particularly related to bearing area. Normalizing the data was conducted by calculating the lateral stress on the lateral rail bearing area and lateral crosstie bearing area. Lateral stress on these bearing areas is defined as:

$$\text{Lateral Stress} = \frac{\text{Lateral Load Evaluation Device Force}}{\text{Lateral Force Bearing Area}}$$

The location of the lateral rail and lateral crosstie bearing areas used to calculate the lateral stress distribution through the fastening system can be seen in **Figure 8**.



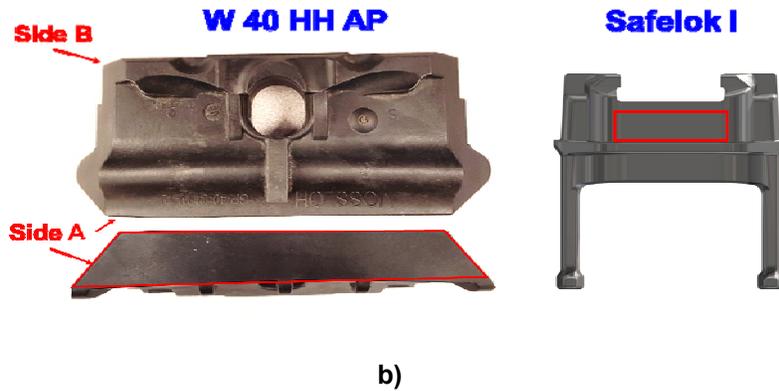


Figure 8. a) Lateral rail bearing area b) Lateral crosstie bearing area

Figure 9 compares the lateral stress on the lateral rail bearing area of both fastening systems as lateral wheel load was increased and a constant 40-kip (178-kN) vertical load was applied to the wheelset. To better explain the data values portrayed on **Figure 9**, a black dashed line was inserted to show the 95th percentile lateral wheel load from a locomotive in North America. The value of the 95th percentile lateral wheel load from a locomotive was obtained from past research work conducted by RailTEC on the analysis of truck performance detector (TPD) data obtained on curves that were 6 degrees or less located on heavy haul mainlines (10). For the calculations of lateral stress on lateral rail bearing area for each system, it was assumed that 100% of the lateral rail bearing area was in contact with the rail. Due to the wide overlapping and scatter of data obtained from each system, RailTEC researchers concluded that the normalized lateral stress on the lateral rail bearing area for each system is

comparable.

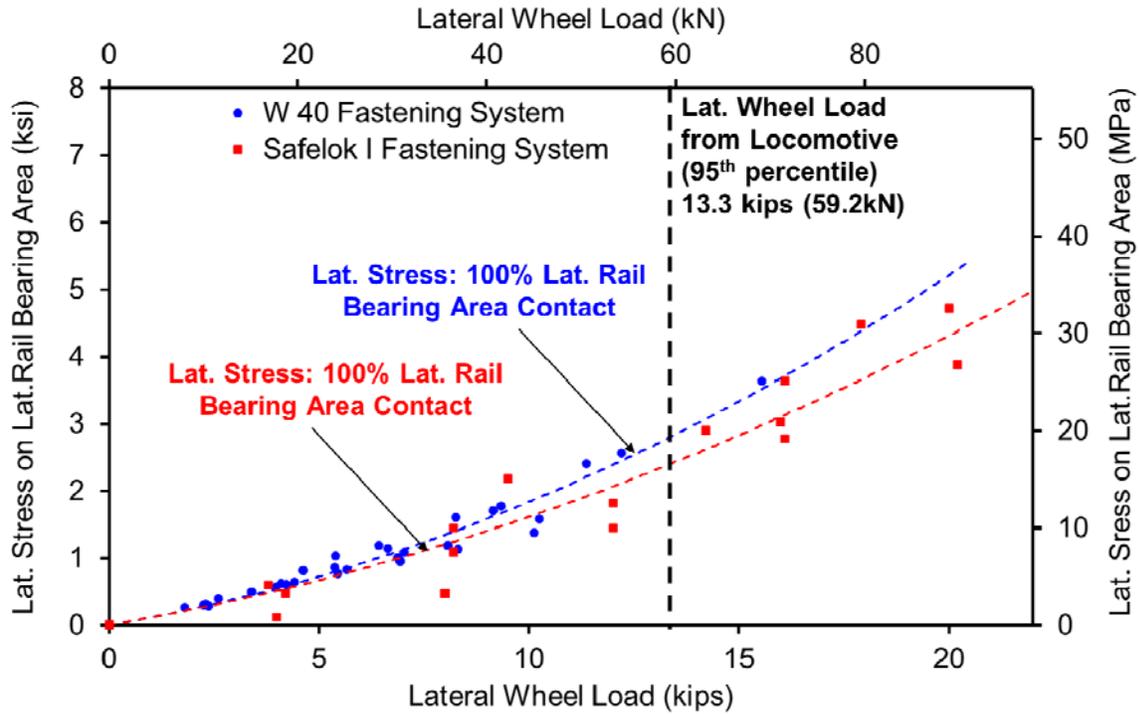


Figure 9. Lateral stress on lateral rail bearing area

Figure 10 compares the lateral stress on the lateral cross-tie bearing area of both fastening systems as lateral wheel load was increased and a constant 40-kip (178-kN) vertical load was applied to the wheelset. For the calculations of lateral stress on lateral cross-tie bearing area for each system, it was assumed that 100% of the cross-tie bearing area was in contact with the cross-tie. As seen in this figure, due to the larger cross-tie bearing area of the W 40 system, the lateral stress on the cross-tie is less than the Safelok I system. It is also important to note that, for the W 40 system, the lateral load is transferred into the concrete cross-tie purely as a compressive stress. The Safelok I system design, due to the geometry of the embedded shoulder, ultimately transfers the lateral stress into the cross-tie as a combination of compressive, shear, and tensile stresses.

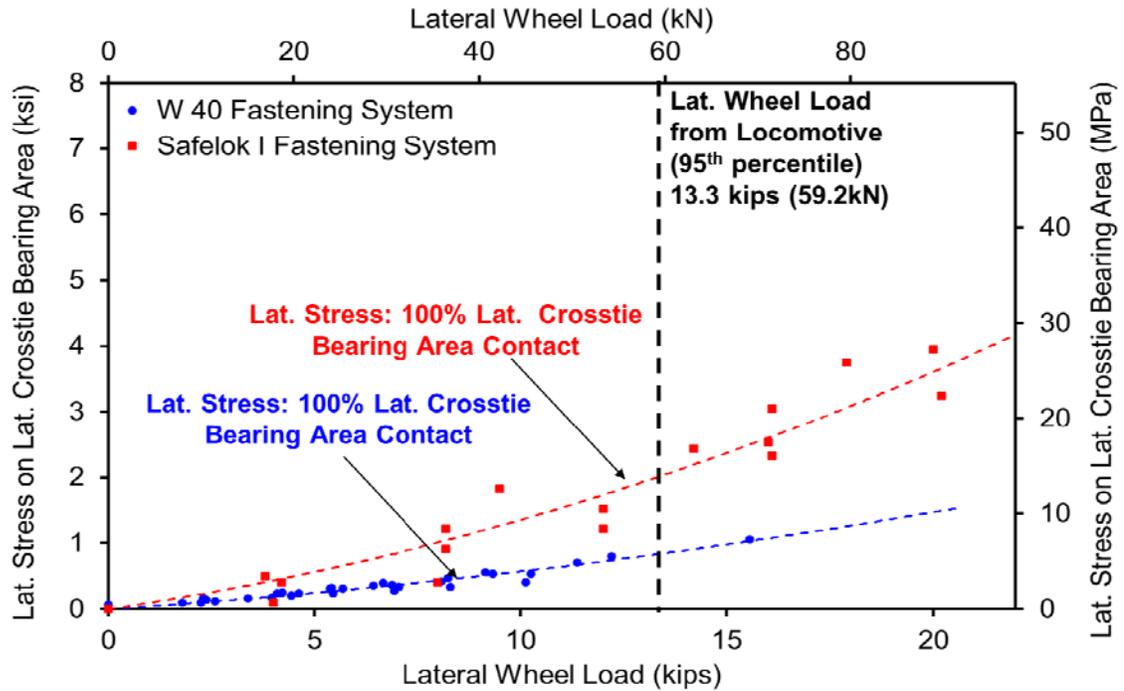


Figure 10. Lateral stress on lateral crosstie bearing area

CONCLUSIONS

This study used RailTEC's TLS at RAIL to evaluate the lateral load path through the W 40 and Safelok I systems under static loading conditions that were representative of revenue service loading magnitudes. Specifically, this paper investigated the global distribution of lateral load through the track superstructure, as well as the lateral load path through a single fastening system. The following conclusions were drawn from the results of the laboratory experimental investigation:

- Lateral wheel load is mainly transferred to three crossies for both fastening systems investigated.
- The relationship between lateral wheel load and lateral forces resisted by the field-side angled guide plate or field side shoulder is non-linear.
- The lateral wheel load resisted by the angled guide plate of the W 40 system directly below the point of load application is higher than the lateral wheel load resisted by the shoulder of the Safelok I system.
- When lateral force is normalized to account for the differences in fastening system rail bearing areas, the lateral stress on the lateral rail bearing area for both fastening systems is comparable.

- When lateral force is normalized to account for the differences in fastening system crosstie bearing areas, the lateral stress on the lateral crosstie bearing area of the W 40 system is lower than the Safelok I system.

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