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Laboratory investigation of the Skl-style fastening system's lateral load performance under heavy haul freight railroad loads

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ABSTRACT

Throughout the international railway community, there are many different designs of elastic fastening systems that have been developed to meet a variety of design specifications and performance expectations. Historically, in North America, the most common types of fastening systems used for concrete crossties are the Safelok I or e-clip systems. 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. The magnitude of lateral force applied to the Skl-style fastening system is important information for both design and application purposes. Despite this importance, the lateral force applied to the Skl-style fastening system in a heavy haul freight railroad environment has never been quantified to date. 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 fastening system using novel instrumentation techniques that are subjected to heavy haul freight railroad loading conditions. The investigation of fastening system performance included an evaluation of lateral load distribution through the track superstructure, and a single fastening system. Laboratory experimentation concluded that lateral wheel load is primarily distributed to three crossties, the relationship between lateral wheel load and lateral force resisted by field side angled guide plate is non-linear, and that the design of the Skl-style fastening system allows lateral force to be transferred into the crosstie below the worst case concrete compressive fatigue strength. The observations from this study will assist the rail industry in improving fastening system design and developing mechanistic track structure design method.

1. Introduction

1.1. Purpose of investigating Skl-style fastening systems

The concrete crosstie fastening system is a set of components that form the structural connection between the rail and concrete crosstie in the track superstructure [1]. These components help to resist movement of the rail, maintain track geometry, and distribute the loads imparted on the rail into the concrete crosstie and track substructure [2]. The loads on the rail that must be resisted by a fastening system are primarily caused by passing trains and temperature changes in the rail [3].

Increasing axle loads on North American heavy haul freight railroads, coupled with the demanding environments in which many of the track infrastructure components are required to perform, have presented engineering challenges for the design and performance of concrete crosstie fastening systems. Historically, in North America, the most common types of heavy haul fastening systems used for concrete crossties are the Safelok I or e-clip systems (Fig. 1a & b). However, in recent years railroads have been implementing Skl-style (W) fastening systems (Fig. 1c) with concrete crossties in both existing and new heavy-haul freight infrastructure. Although the systems are performing well in demanding North American track locations, little research has been conducted on Skl-style systems with respect to the lateral load demands placed on the components under heavy haul freight wheel loads.

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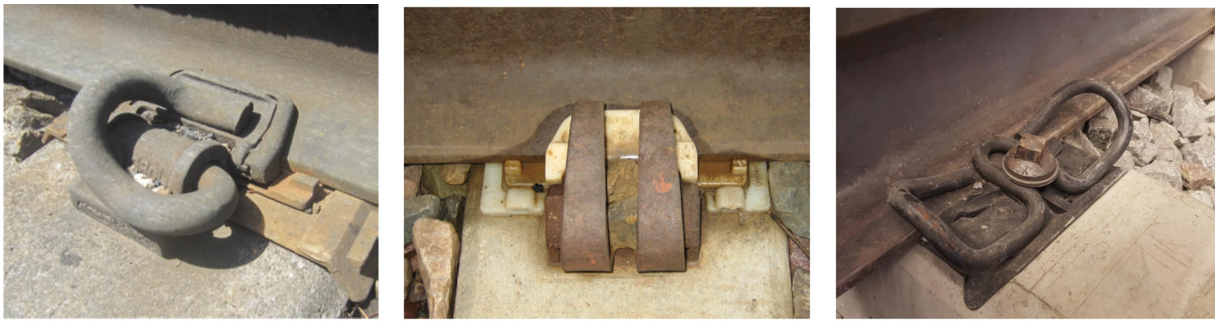


(a) (b) (c)

Fig. 1. Examples of common types of fastening systems on North American heavy haul freight railroad track a) e-clip b) Safelok I c) Skl-style.

Additionally, the variation of lateral load distribution through the track superstructure when equipped with the Skl-style system is a topic of interest to both designers and end users, especially in terms of comparing the performance to that of other systems. To address these voids in the current understanding of Skl-style fastening systems, laboratory experimentation was conducted by the Rail Transportation and Engineering Center (RailTEC) at the University of Illinois at Urbana-Champaign (UIUC) to further understand the performance of the Skl-style fastening systems under lateral load.

1.2. Background

A survey conducted in 2012 by RailTEC 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 [4]. Industry experts have 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. In addition to track component deterioration seen in heavy haul freight loading environments, it has become clear in recent years that train derailments due to gauge widening and rail rollover are principally due to the development of lateral forces that are either excessive or repetitive to the track superstructure [5]. Investigating the ability of a fastening system to transfer lateral force from the rail to the concrete crosstie is therefore important not only in the design of components that can mitigate wear and RSD, but also to help decrease the likeliness of derailments caused by the combination of track superstructure deterioration and high lateral forces seen in demanding heavy haul freight loading environments.

There have been several research endeavors conducted in the past that tried to better understand how the track structure is affected by lateral loading. In 1909, Stetson [6] presented the concept of L/V ratio where L is lateral force and V is vertical force applied to the rail head in an American Railway Engineering Association (AREA) report. In this report he discussed how varying the L/V ratio affected timber track performance and component failure. In 1961, Sato [7] conducted a series of experiments to investigate the lateral strength of timber track. Sato explained that the lateral strength of track can be modeled by three springs: a spring representing transverse displacement of the rail base on the crosstie, a spring representing the lateral displacement of the crosstie on ballast, and a torsional spring representing the reaction of the crosstie and fasteners to the twisting of the rail. In 1977, Zarembski [8] outlined the key laboratory and field experimentation conducted up until that point pertaining to the rail industry's knowledge of track performance under lateral loads. The work outlined in the paper primarily investigated the ability of timber crosstie fastening system to resist rail movement corresponding to applied lateral wheel loads. However, the magnitudes and distribution of lateral forces in the fastening systems or overall track superstructure was not specifically discussed.

In recent years, there has been progress in terms of quantifying lateral forces within the track superstructure. Williams et al. [9–12] presented work on the creation of a novel load cell called "lateral load evaluation device (LLED)" that could be placed inside a fastening system to quantify the lateral loads passing from the rail, into the fastening system and concrete crosstie. Through the use of the LLED, these studies were able to:

- Quantify the difference in lateral load placed on fastening system components by the leading and trailing axles of a truck as observed through field experimentation [9,10].
- Investigate the hypothesis that lateral wheel load applied to the track structure is primarily distributed to less than 5 crossties [9,10].
- Quantify a relationship between lateral wheel load and lateral force on the fastening system shoulder under varying freight train speeds [10].
- Compare the magnitude of lateral forces placed on track components positioned on the high and low rail [11].
- Investigated the importance of friction at the rail pad rail seat interface in resisting lateral load through a single fastening system [12].

In 2015, Holder et al. [13] studied how crosstie support conditions affect the lateral wheel load distribution through the track superstructure, and investigated how decreasing the coefficient of friction at the rail pad to rail seat interface globally alters lateral wheel load distribution through the track. These past experimentations with the LLEDs have been primarily focused on developing a detailed understanding of the lateral load demands placed on concrete crosstie track equipped with a single type of spring clip fastening system, the Safelok I. It is believed that the magnitude of lateral loads imparted on fastening system components and the distribution of lateral forces within the track superstructure are heavily dependent on the type of fastening system used on the track.

2. Materials and experimentation setup

2.1. Overview of W 40 fastening system

All experiments explained in this paper were performed on concrete crossties equipped with the W 40 HH AP fastening system (hereafter referred to as the "W 40" or "W 40 system") manufactured by Vossloh Fastening Systems, Inc. [14]. The W 40 system is an Skl-style fastening system designed for track with 136 RE or 141 RE rails, which is comprised of tension clamps, angled guide plates, a rail pad, and an abrasion plate, and is held together by lag screws (Fig. 2).

The W 40 system is an Skl-style fastening system comprised of tension clamps, angled guide plates, a rail pad, and an abrasion plate, and is held together by lag screws (Fig. 2).

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 maintain adequate clamping force over time [15]. 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 [15]. The system is also equipped with an abrasion plate designed as a sacrificial element to mitigate RSD, one of the most critical problems with concrete crossties and fastening systems in North America today [4,16].

2.2. Track loading system

Data presented in this paper were collected from experiments 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 (Fig. 3). Track components are assembled on a full depth section of track that included eleven Rocla Vossloh 101L concrete crossties spaced at 24 in. (61 cm) on center. The substructure was prepared according to BNSF Railway track construction standards, having 12 in. (31 cm) of ballast installed underneath the crossties, 34 in. (86 cm) of silty clay subgrade and 10 in. (25 cm) of pea gravel subballast. Static combinations of vertical and lateral loads were applied to the journals of a standard 36-in. (91.4 cm) diameter wheelset. Vertical and lateral loads were adjusted separately using a control system. The loading system includes two MTS servo-hydraulic actuators mounted vertically and a hydraulic cylinder mounted laterally on a self-reacting steel frame that encapsulates the track structure (Fig. 3a). A special steel 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.

2.3. Laboratory instrumentation

2.3.1. Laboratory experimentation objective

The primary objective of this research is to quantify the lateral load path through the track superstructure equipped with the Skl-style system by investigating the global lateral load distribution through the track superstructure, and the lateral force applied to the field side angled guide plate. A parallel objective is addressing the aforementioned items in controlled conditions similar to those found in demanding heavy-haul freight railroad corridors.

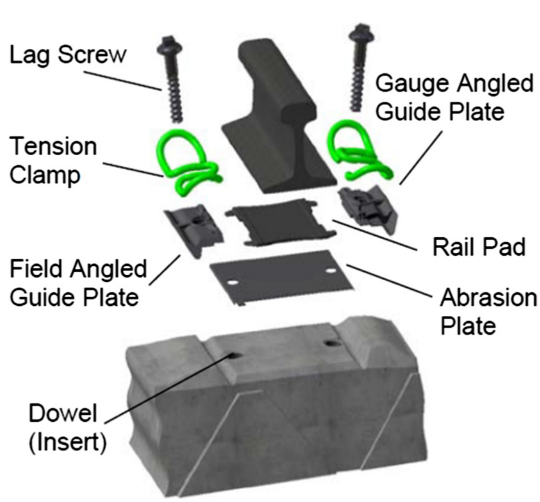


Fig. 2. Vossloh Fastening Systems W 40 HH AP fastening system (8).

2.3.2. Laboratory instrumentation layout

All instrumentation was symmetrically installed on five of the eleven concrete crossties on the TLS, which were centered in the middle of the TLS to avoid any influence of boundary conditions at the ends (Fig. 4). Five concrete crossties were chosen for instrumentation due to past experience of load distribution from field experimentation performed by RailTEC, and established theories on vertical pressure distribution [17,18].

Only one rail was heavily instrumented due to the manner in which lateral force is applied to the wheelset on the TLS (Fig. 4). The horizontally-mounted hydraulic cylinder applies lateral force to 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.

2.3.3. Lateral wheel load and rail seat load measurement

Lateral wheel loads and rail seat loads were measured to quantify the load magnitude entering the rail at the wheel-rail interface as well as measure the distribution of vertical loads through the track structure. Lateral loads were measured using four strain gauges, two installed on each side of the rail centered above the rail seat (Fig. 5). Rail seat loads were measured from two sets of four strain gauges installed 12 in. (305 mm) apart centered over the crosstie, in the longitudinal direction of the track (Fig. 6) [19]. Strain gauge locations are symbolized in Figs. 5 and 6 by the red marks on the rail. Strain gauges to measure both loads were wired in a full Wheatstone bridge and installed above the center five crossties on the TLS.

2.3.4. Measurement of lateral force through fastening system

RailTEC developed the LLED to measure lateral forces imparted on the shoulder of the Safelok I fastening system as a part of earlier research efforts [9–13]. In order to quantify the lateral load magnitude on the field side guide plate in this study, a modified version of LLED was developed that was tailored for the W 40 system. The LLED used in this study employs strain gauges to measure the bending strain of a load cell that is placed into 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. Two LLEDs are installed in the field side guide plate of the W 40 fastening system in order to obtain the total magnitude of lateral force imparted on the face of the guide plate by the rail base. 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 (Fig. 7).

2.3.5. Measurement of rail base displacement

Rail base displacement was monitored during experimentation to investigate track movement during the application of load to the TLS. Rail base displacement was obtained from horizontal potentiometers that were positioned to contact the edge of the rail base on the field side adjacent to the instrumented angled guide plate (Fig. 8). Measurements recorded from both horizontal potentiometers on each side of the field portion of the fastening system were averaged to obtain the rail base displacement during the application of load.

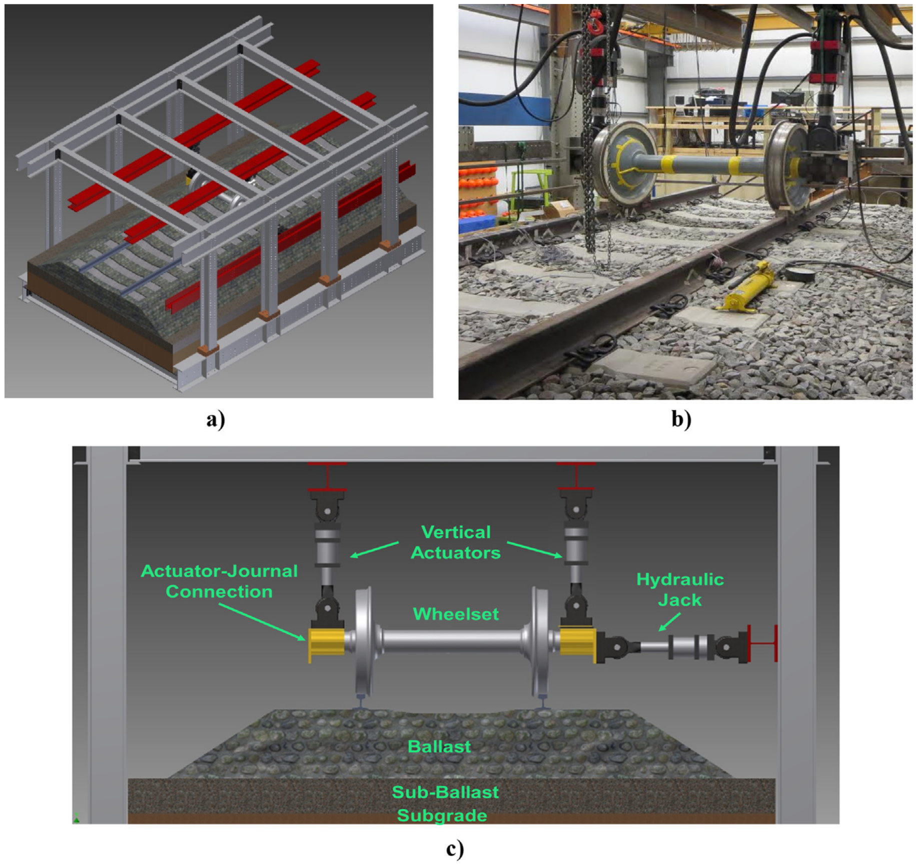


Fig. 3. RailTEC's Track Loading System (TLS) in the Research and Innovation Laboratory (RAIL), Champaign, Illinois, USA a) Schematic drawing of loading system in isometric view b) Angled view of loading system during experimentation c) Schematic drawing of loading system in a cross-sectional view.

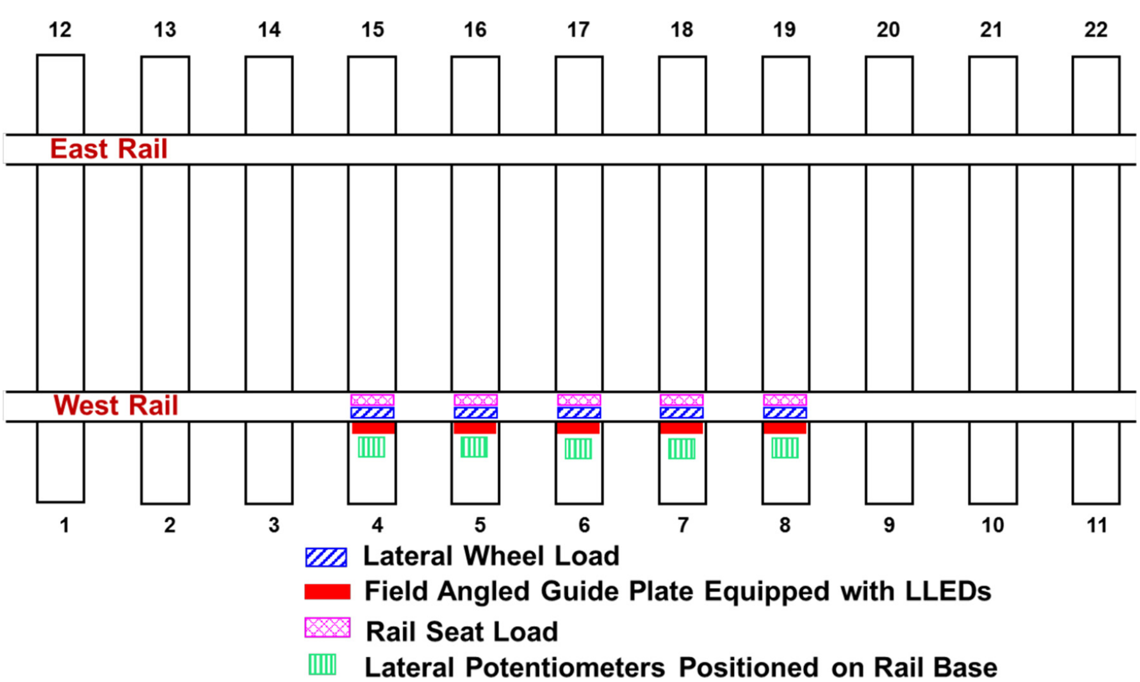


Fig. 4. Laboratory instrumentation map for W 40 fastening system.

2.3.6. Experimentation matrix

The test matrix performed in this study is presented in Table 1. In each loading scenario, a constant vertical force was applied to the wheelset using vertical actuators and a variable lateral force was applied to the wheelset using a hydraulic cylinder to obtain a specific L/V force ratio. The loading scenarios seen in Table 1 were

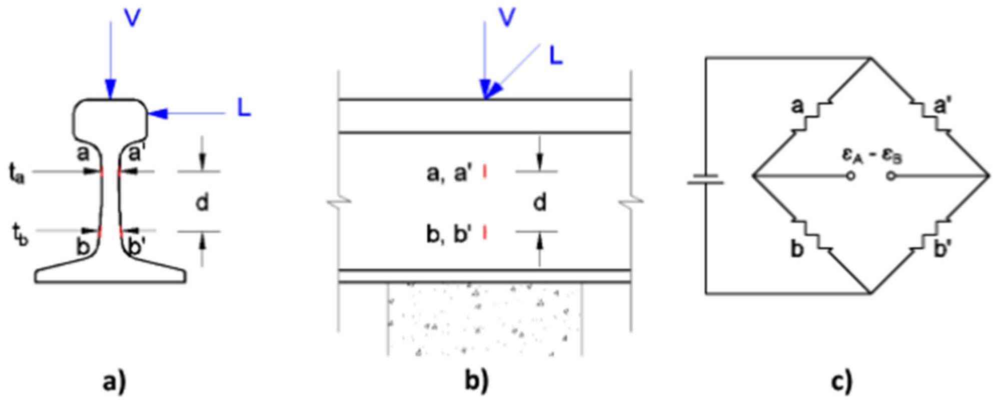


Fig. 5. Strain gauge pattern for lateral wheel load measurement; a) Cross-sectional view b) Elevation view c) Full Wheatstone bridge connection. Note: Red marks symbolize strain gauge locations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

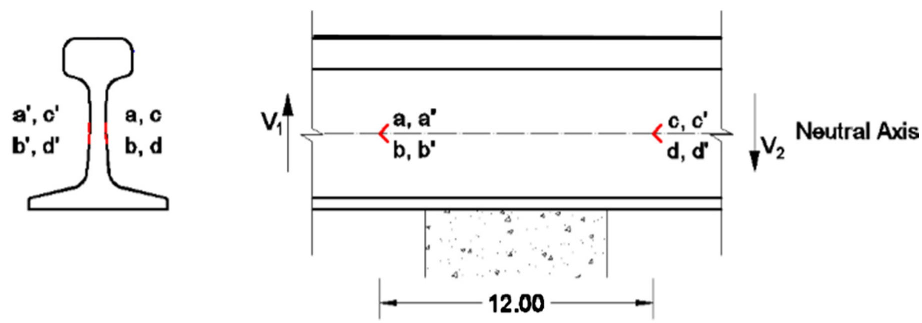
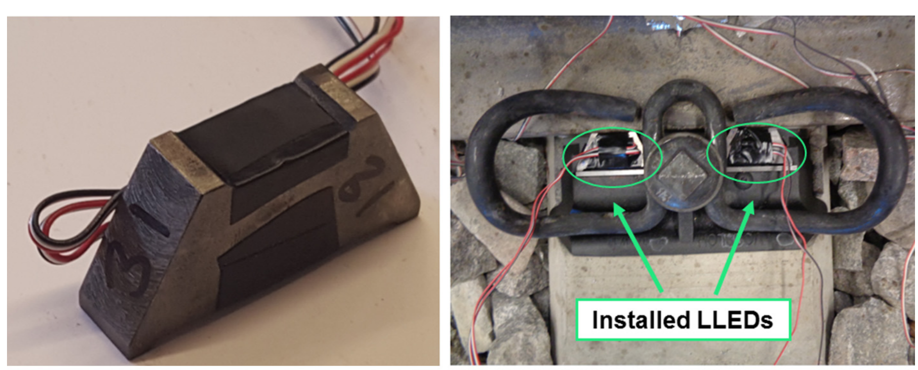


Fig. 6. Strain gauge pattern for rail seat load measurement. Note: Red marks symbolize strain gauge locations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



(a) (b)

Fig. 7. Image of field side of W 40 fastening system with LLEDs installed.

performed with the wheelset positioned directly over each of the five instrumented crossties, thus the matrix was executed five times in total.

3. Test results and discussion

3.1. Global distribution of lateral wheel load

In order to understand the lateral force distribution through the track superstructure, the global distribution of lateral force was investigated. This distribution was analyzed by applying load directly over each instrumented crosstie on the TLS, and quantifying the distribution of lateral force resisted by the field side angled guide plates (obtained from the LLEDs).

An example of the lateral load distribution that was observed when load was applied directly over each instrumented crosstie can be seen in Fig. 9. The t load applied to the track when the data were collected is also shown in Fig. 9a, c, e, g, & i. Fig. 9b, d, f, h, & j are the recorded lateral rail base displacements that correspond to the lateral load distributions seen in Fig. 9a, c, e, g, & i respectively. The y-axis of Fig. 9a, c, e, g, & i was obtained from dividing the summation of lateral force collected from the LLEDs within the field guide plate of a given crosstie by the lateral wheel load applied to the rail.

When load was applied directly over crossties 5, 6, and 7 (Fig. 9c, e, & g) it was observed that lateral load was mainly distributed into the crosstie directly below the point of load application, as well as the two adjacent crossties. The three-crosstie

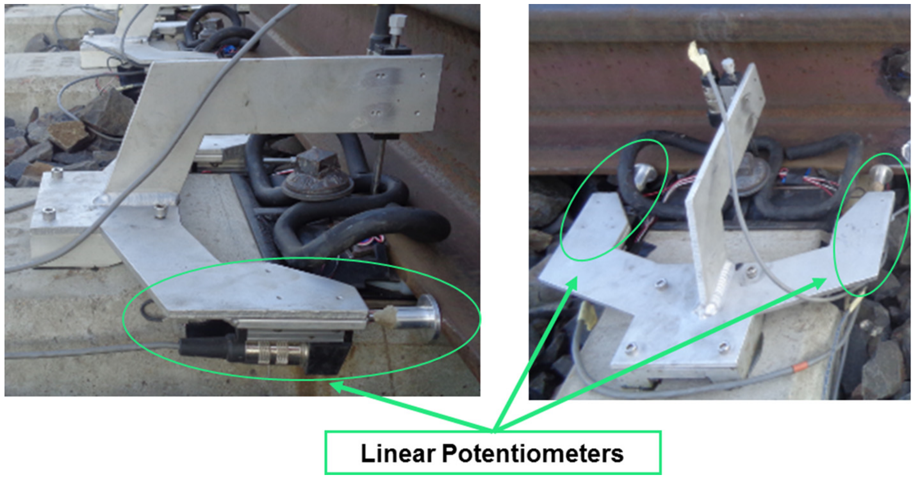


Fig. 8. Image of field side of W 40 fastening system with LLEDs installed.

Table 1
Testing matrix for crossties equipped with fully fastened W 40 fastening systems.

Vertical Load		L/V Force Ratio						
kips	kN	Applied to Wheelset						
10	44.5	0.0	0.1	0.2	0.3	0.4	0.5	0.6
20	89	0.0	0.1	0.2	0.3	0.4	0.5	0.6
30	133	0.0	0.1	0.2	0.3	0.4	0.5	0.6
40	178	0.0	0.1	0.2	0.3	0.4	0.5	0.6

Note: Vertical load specified in test matrix is the vertical load applied by each actuator to the wheelset. Lateral load used to calculate L/V in test matrix is the lateral load applied to the wheelset by the lateral hydraulic jack.

distribution of lateral load is further supported from rail base displacement data collected during testing which showed the rail primarily displacing towards the field side at the three crosstie locations where lateral load was primarily being distributed.

As seen in the examples of data collected to investigate the global distribution of lateral forces within the track superstructure (Fig. 9c, e, & g), 100% of the lateral wheel load was not accounted for from the summation of all forces imparted on the LLEDs installed in the guide plates of the five heavily instrumented crossties. From the loading experiments conducted over crossties 5, 6, and 7 at the highest lateral and vertical wheel loads applied on the TLS, the percentage of the lateral wheel load accounted for from the summation of forces collected from all LLEDs in the heavily instrumented crossties ranged from 63% to 94% under varying vertical loads (Table 2). These percentages were calculated from data that was zeroed to remove any lateral force caused by the application of pure vertical load to the wheelset. It is hypothesized that the discrepancy between applied lateral load and lateral load measured by LLEDs was transferred into the track by a combination of lateral force transfer through the tension clamps, frictional forces within the fastening system resisting rail movement, and possible frictional forces through the anti-tilting nose found on the face of the field side angled guide plate.

It is important to note that the three crosstie distribution of lateral force was observed on crossties spaced at 24 in. (61 cm) center-to-center. Varying crosstie spacing and support conditions may cause a variation in the amount of crossties over which the lateral wheel load is distributed.

3.2. Lateral force through fastening system

Quantifying the lateral force applied to the field side angled guide plate of the Skl-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.

Fig. 10 shows the magnitude of lateral force applied by the rail base to the field side angled guide plate as lateral wheel load was increased under various vertical loads. Using the TLS, lateral force was applied to the wheelset while keeping vertical force constant on each journal at 20 kips (89 kN), 30 kips (133 kN), and 40 kips (178 kN), respectively. The lateral wheel load applied to the rail was quantified using strain gauge bridges attached to the rail directly over the crosstie being investigated. The data shown in Fig. 10 were collected from all five instrumented crossties on the TLS when the point of load application was directly over the crosstie being investigated.

During experimentation conducted on the TLS, it was observed that a small portion of the vertical load applied to the wheelset was transferred into the rail as lateral force. This is due to the conicity of the wheel, the cant (inclination) of the rail seat, and the location of the contact patch between the wheelset and the rail head. In order to take out this variability from the data collected when load was applied over each instrumented concrete crosstie, all data seen in Fig. 10 were zeroed to remove the lateral force caused by the application of pure vertical load to the wheelset.

When the lateral wheel load applied to the track structure increased, the magnitude of lateral force resisted by the angled guide plate also increased. A polynomial trend line was fitted to the data collected from all five instrumented crossties under 20 kips (89 kN), 30 kips (133 kN), and 40 kips (178 kN) vertical loads. There is significant overlap of the data collected with increasing vertical loads. From the static experiments performed on the TLS, increasing the vertical load between the 20 kips (89 kN) and 40

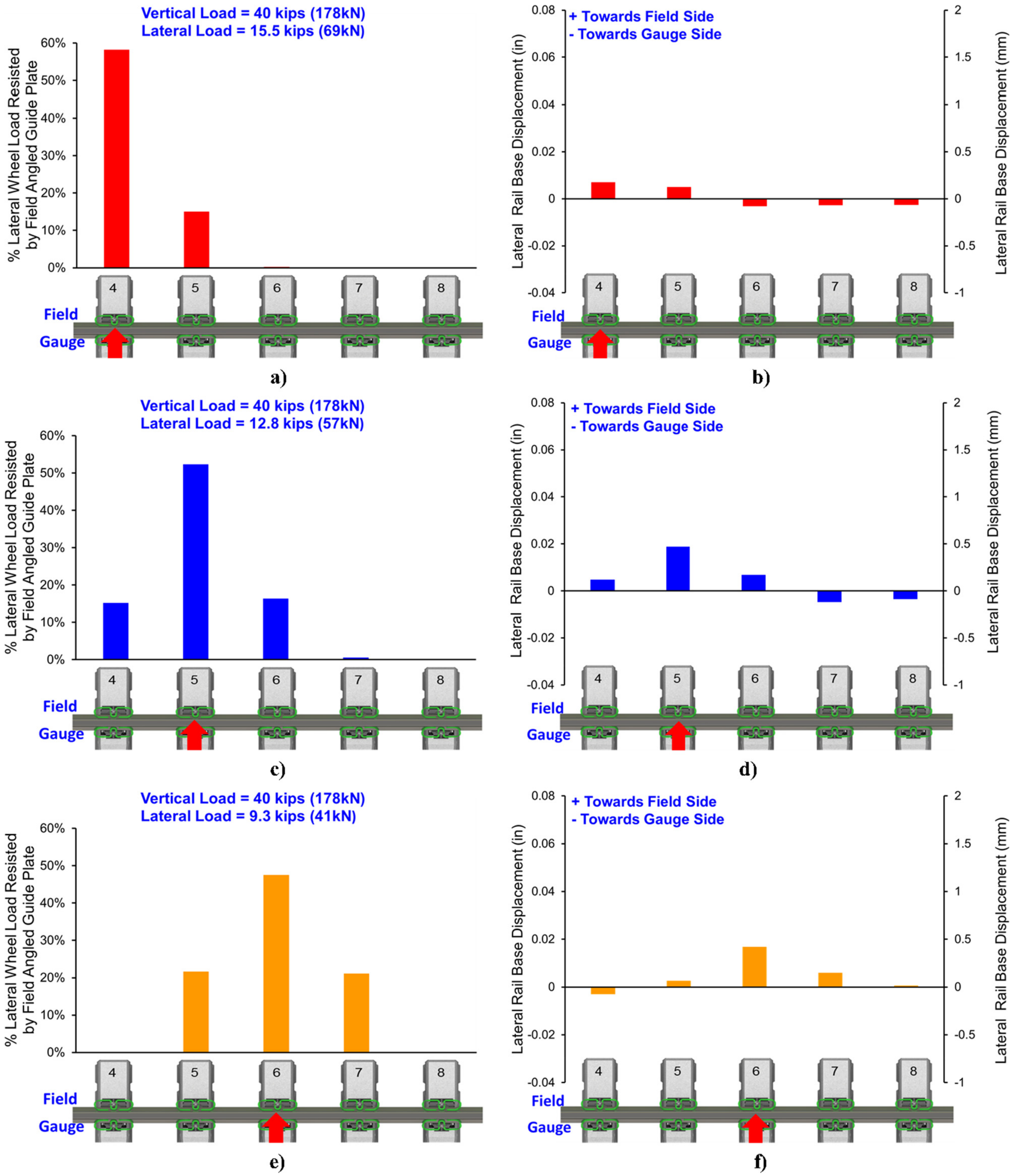


Fig. 9. a) Global distribution of lateral wheel load (wheelset placed at crosstie 4) b) global rail base displacement due to lateral wheel load (wheelset placed at crosstie 4) c) global distribution of lateral wheel load (wheelset placed at crosstie 5) d) global rail base displacement due to lateral wheel load (wheelset placed at crosstie 5) e) global distribution of lateral wheel load (wheelset placed at crosstie 6) f) global rail base displacement due to lateral wheel load (wheelset placed at crosstie 6) g) Global distribution of lateral wheel load (wheelset placed at crosstie 7) h) global rail base displacement due to lateral wheel load (wheelset placed at crosstie 7) i) global distribution of lateral wheel load (wheelset placed at crosstie 8) j) global rail base displacement due to lateral wheel load (wheelset placed at crosstie 8).

kips (178 kN) range did not seem to have a significant effect on the magnitude of the lateral wheel load applied to the field side angled guide plate. The percent of lateral wheel load resisted by angled guide plate directly below the point of load application under all loads ranged from 28 to 55%.

3.3. Lateral stress on bearing areas

An important design parameter of the W 40 angled guide plates is the large rail lateral bearing area and concrete lateral bearing area implemented into the guide plate design to decrease the lat-

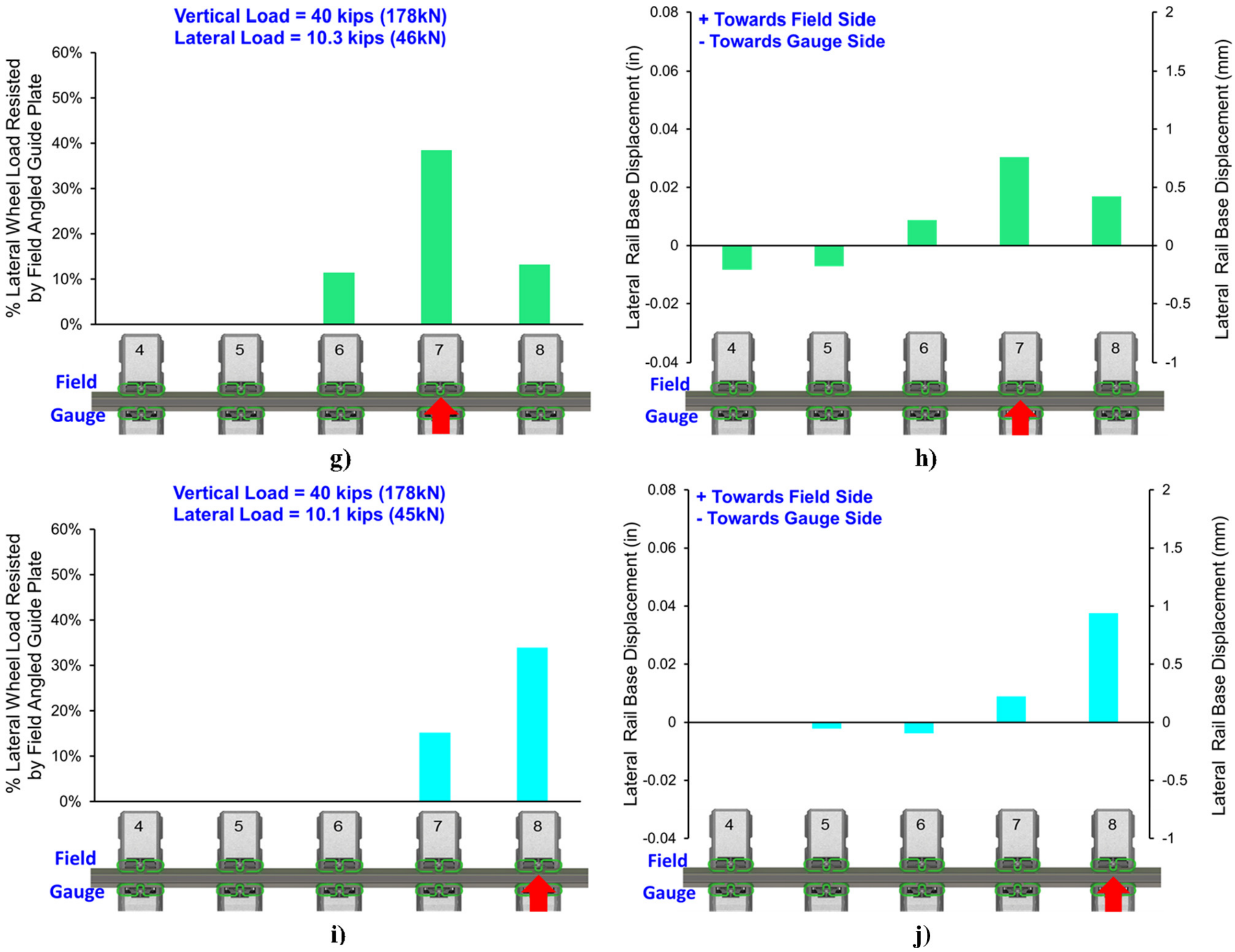


Fig. 9 (*continued*)

Table 2
Maximum percent of lateral wheel load accounted for by LLED summation.

Vertical Load		Point of Load Application		
kips	kN	Tie 5	Tie 6	Tie 7
10	44.5	68%	86%	68%
20	89	78%	85%	67%
30	133	75%	94%	63%
40	178	84%	90%	90%

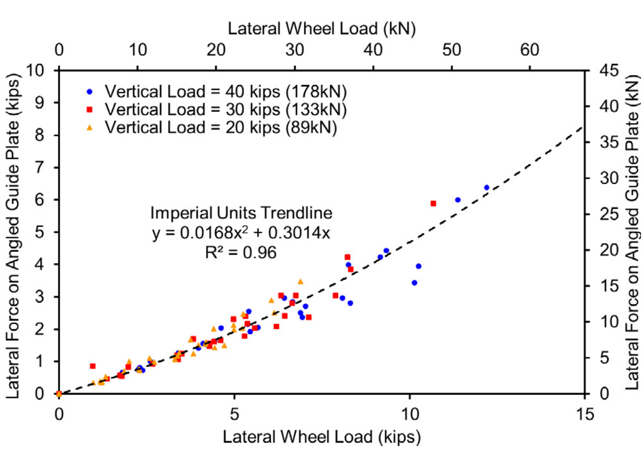


Fig. 10. Lateral force on W 40 system angled guide plate versus lateral wheel load.

eral stress on the concrete crosstie. To investigate the importance of these parameters in the distribution of the lateral force into the concrete crosstie, the lateral stress on the rail lateral bearing area and concrete lateral bearing area were calculated as follows:

$$Lateral\ Stress = \frac{LLED\ Force}{Bearing\ Area\ For\ Lateral\ Force}$$

where LLED force is the force obtained from the summation of LLED's in the angled guide plate directly below the point of load application, and bearing area for lateral force is the cross sectional area of the field-side angled guide plate in contact with the rail or crosstie as shown in Fig. 11.

Fig. 12 shows the calculated lateral stress on the rail lateral bearing area and concrete lateral bearing area from data collected under a constant 40 kip (178 kN) vertical wheel load with increasing lateral wheel load. In both cases calculations were conducted assuming that 100% of the possible rail lateral bearing area and concrete lateral bearing area is being used to distribute lateral force through the track superstructure. The calculations of lateral stress on concrete bearing area neglects any lateral resisting contributions from frictional forces underneath the angled guide plate and through the lag screw in order to give the highest possible lateral stress that would be applied to the concrete through the field side angled guide plate.

To better explain the data portrayed in Fig. 12, a black dashed line was inserted to show the 95th percentile lateral wheel load from a locomotive in North America, and a red dashed line was

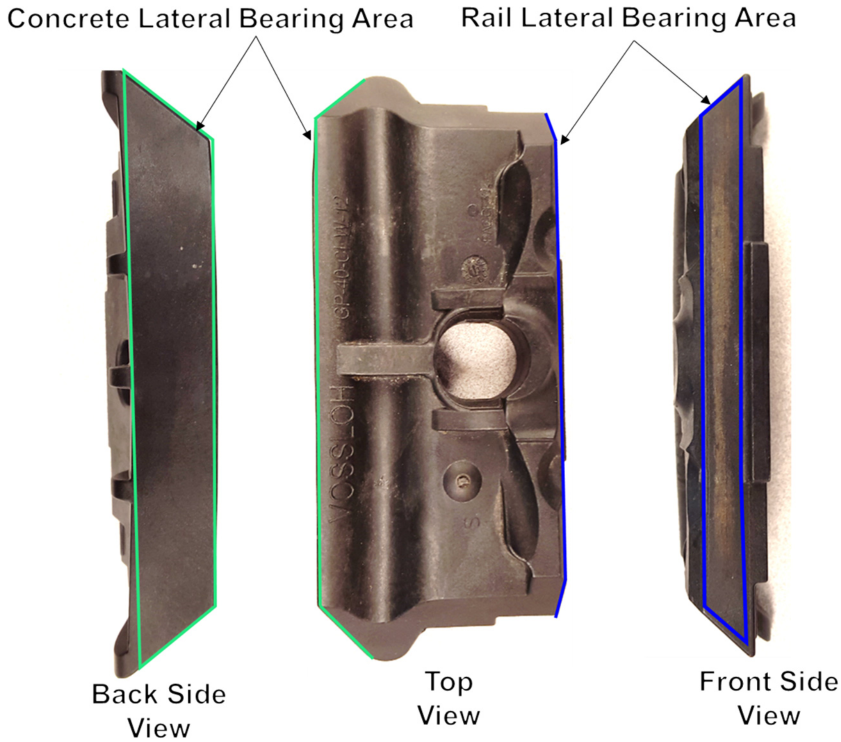


Fig. 11. Rail and concrete lateral bearing area used to calculate lateral stress.

inserted to show the worst case concrete fatigue compressive strength of a concrete crosstie manufactured in North America. The value of the 95th percentile lateral wheel load from a locomotive was obtained from past research work on the analysis of truck performance detector (TPD) data obtained from North American heavy haul freight railroad track [20]. The worst case fatigue strength value was based on the generally accepted value of fatigue strength of concrete after a life of 10,000,000 cycles in compression, which is approximated as 50% of the static ultimate strength [21]. The value of minimum strength of concrete ($f'_{c(\min)}$) used to calculate worst case concrete fatigue compressive strength was taken as 7000 psi (48.3 MPa), which is the minimum compressive strength of concrete recommended by American Railway Engineering and Maintenance-of-Way Association (AREMA) for use in concrete crossties [18].

As seen in Fig. 12, by making some conservative assumptions about the load path through the fastening system, the LLEDs can be used to quantify the lateral stresses passing from the rail into the concrete crosstie under increasing lateral wheel loads. It can also be seen that due to the design of the W 40 fastening system, the lateral stress placed on the concrete crosstie is significantly lower than the worst case concrete fatigue compressive strength at the 95th percentile lateral wheel load from a locomotive on North American heavy haul freight railroad.

In demanding heavy axle freight railroad loading environments, it is possible to have fastening systems poorly installed, and as such the load path through the field angled guide plate is not uniformly distributed across the rail and concrete lateral bearing area. Because of this possibility, an analysis was conducted to investigate what the effect of a non-uniform stress on the rail bearing area would have on the concrete crosstie. The analysis can be seen in Fig. 13, where an assumption was made that the lateral load applied to the angled guide plate from the rail was transferred into the concrete crosstie by 50–100% of the concrete lateral bearing

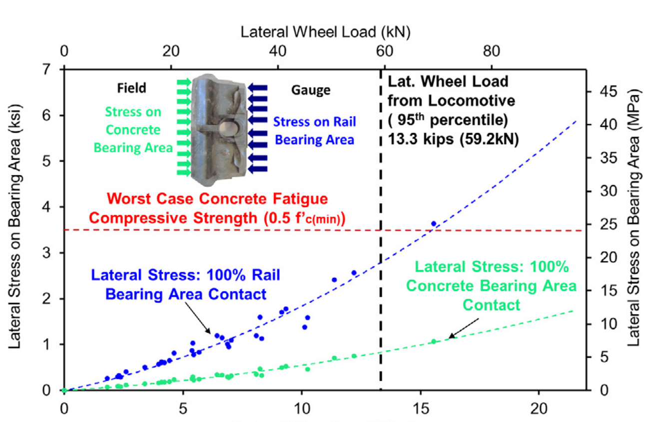


Fig. 12. Lateral stress on rail bearing area and concrete bearing area for the W 40 fastening system.

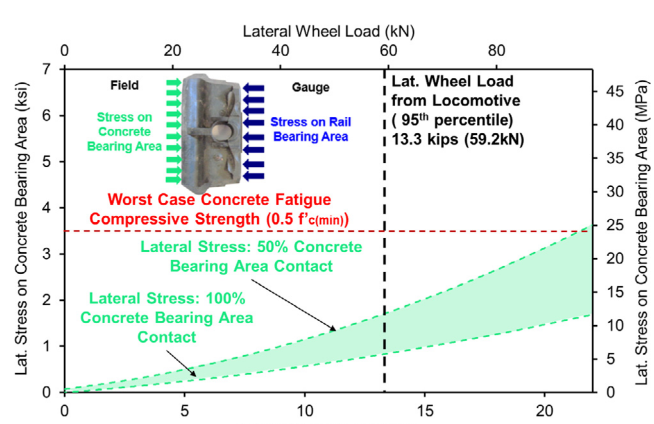


Fig. 13. Lateral stress on concrete crosstie with decreased crosstie bearing area contact for the W 40 fastening system.

area. In this analysis, data were taken when 40 kips (178 kN) of vertical wheel load was applied directly over the crosstie being investigated as lateral wheel load was increased. The calculations of lateral stress on concrete lateral bearing area neglects any lateral resisting contributions from frictional forces underneath the angled guide plate and through the lag screw in order to give the highest possible lateral stress that would be applied to the concrete through the field side angled guide plate. As with Fig. 12, to better explain the data values portrayed on Fig. 13, a black dashed line was inserted to show the 95th percentile lateral wheel load from a locomotive [20], and a red dashed line was inserted to show the worst case concrete fatigue strength of a concrete crosstie manufactured in North America [21].

As seen in Fig. 13, even when this possible worst case loading scenario is considered, the estimated lateral stress applied to the concrete crosstie through the angled guide plate in the range of loads investigated is well below the worst case fatigue compressive strength of a concrete crosstie used in North America.

4. Conclusions

This study used RailTEC's TLS at RAIL to evaluate the lateral load path through the W 40 Skl-style fastening system 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 W 40 system. This paper also investigated the lateral load demands placed on the concrete crosstie under possible worst case loading scenarios that can be observed on heavy haul freight railroad track. The following conclusions were drawn from the results of the laboratory experimental investigation based on the specific test setup and conditions in this study:

- Between 63% and 94% of the lateral wheel load is transferred into the track through three crossties.
- The relationship between lateral wheel load and lateral forces resisted by field side angled guide plate is non-linear.
- Between the range of 20 kips (89 kN) and 40 kips (178 kN), vertical load does not seem to have a significant effect on the magnitude of lateral force resisted by the field side angled guide plate.
- From laboratory experimentation with the Skl-style system, between 28 and 55% of the lateral wheel load is transferred into the angled guide plate directly below the point of load application.
- Due to the design of the angled guide plates in the W 40 fastening system, the lateral stress placed on the crosstie is below the worst case fatigue compressive strength of the concrete crosstie in the range of lateral wheel loads investigated assuming uniform distribution of load over 100% of the crosstie bearing area. This conclusion still holds if the lateral wheel load is uniformly distributed over only half (50%) of the crosstie bearing area.

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References

[1] Esveld C. Modern railway track. 2nd ed. Zaltbommel, The Netherlands: MRT-Productions; 2001.
[2] Bizarria do Carmo T. Multifaceted approach for the analysis of rail pad assembly response, thesis, presented to University of Illinois at Urbana, IL, in partial fulfillment of the requirements for the degree of Masters of Science; 2014.
[3] Selig ET, Waters JM. Track geotechnology and substructure management. London, United Kingdom: Thomas Telford; 1994.
[4] Van Dyk BJ. Characterization of the loading environment for shared-use railway superstructure in North America, thesis, presented to University of Illinois at Urbana, IL, in partial fulfillment of the requirements for the degree of Masters of Science; 2014.
[5] Leeper J, Allen R. Guidelines to best practices for heavy haul railway operations: management of the wheel and rail interface. Omaha, NE: Simmons-Boardman; 2015.
[6] Stetson EE. A study of rail pressures and stresses in track produced by different types of steam locomotives when rounding various degree curves at different speeds. Proceedings of the AREA, vol. 10; 1909.
[7] Sato Y. On the lateral strength of railway track. Railway Technical Research Institute; 1961. Quarterly reports, 2 (Quart. Rpt).
[8] Zarembski AM. Rail rollover-the state of the art. Proceedings of the AREA, vol. 79; 1909.
[9] Williams BA, Kernes RG, Edwards JR, Barkan CPL. Lateral force measurement in concrete crosstie fastening systems. Transportation research board 93rd annual conference, Washington, D.C.; 2014
[10] Williams BA, Edwards JR, Kernes RG, Barkan CPL. Analysis of the lateral load path in concrete crosstie fastening systems. The 2014 joint rail conference, Colorado Springs CO; 2014.
[11] Williams BA, Edwards JR, Dersch MD, Barkan CPL, Kernes RG. Experimental field investigation of the effects of lateral load distribution on concrete crosstie track. The American railway engineering and maintenance-of-way association annual conference, Chicago, IL; 2014.
[12] Holder DE, Williams BA, Dersch MD, Edwards JR, Barkan CPL. Quantification of lateral forces in concrete sleeper fastening systems under heavy haul freight loads. The 11th international heavy haul association conference, Perth, Australia; 2015.
[13] Williams BA, Dersch MD, Edwards JR, Barkan CPL. Quantification of lateral forces in concrete crosstie fastening systems. Transportation research board 94th annual conference, Washington, D.C.; 2015.
[14] Rail fastening system for concrete sleepers on heavy-haul lines – system W 40 HH (Heavy Haul), Vossloh Fastening Systems, Inc. Available from: <http://www.vossloh-fastening-systems.com/media/downloads/pdfs/prospekte/2012/System_W40HH_HHAP_GB_mo.pdf>.
[15] Van Dyk B, Bosterling W, Harrass M, Wiethoff N, Wroblewski A. Rail fastening system design considerations to reduce the stress within haul track supersstructure. In: International heavy haul conference fastening system session, Perth, Australia; 2015. p. 1308–1315.
[16] Greve MJ, Dersch M, Edwards JR, Barkan CPL, Thompson H, Sussmann T, McHenry M. Examination of the effect of concrete crosstie rail seat deterioration on rail seat load distribution. Transportation Research Record – Journal of the Transportation Research Board, No. 1580; 2015.
[17] Hay WW. Railroad engineering. 2nd ed. New York, NY: John Wiley and Sons; 1982.
[18] American Railway Engineering and Maintenance-of-Way Association. AREMA manual for railway engineering. Landover, MD; 2014.
[19] Grasse' JS, Wei W, Derch MS, Kuchma DA, Riley JR, Lange DA. Investigating the concrete crosstie and fastening system load path through field instrumentation. In: The American railway engineering and maintenance-of-way association annual conference, Indianapolis, IN; 2013.
[20] Scheppe AJ, Edwards JR, Dersch MS, Barkan CPL. Quantifying lateral wheel loading variation using truck performance detectors. In: Proceedings: the 11th international heavy haul association conference, Perth, Australia, June 2015; 2015.
[21] Mohsen SE, Barrington B. Fatigue of partially prestresses concrete. J. Struct. Eng. 1986;112(3):524–37.