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**ANALYSIS OF THE LATERAL LOAD PATH IN CONCRETE
CROSSTIE FASTENING SYSTEMS**

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ABSTRACT

Increasing axle loads of today's North American heavy haul freight trains have presented numerous engineering challenges for the design and performance of concrete crossties and fastening systems. Several research studies have been conducted to understand the path of the vertical load from the wheel/rail interface through the fastening system and into the crosstie with successful results. However, problems arise due to the failure of fastening system components caused by high lateral and longitudinal loads in addition to vertical loads. Failed components are often seen in demanding track environments such as sharp curves or steep grades. It is hypothesized these component failures are caused by high lateral and longitudinal loads, respectively. Until now, attempts to measure lateral forces in the fastening system have been relatively unsuccessful. This study focuses on gaining a better understanding of the lateral load path in concrete crosstie fastening systems through the use of novel instrumentation techniques to quantify the magnitude of lateral forces induced from various types of rolling stock. A thorough understanding of the lateral load path, lateral load

magnitudes, and their impact on failure modes will aid in the future mechanistic design of fastening systems. Ultimately, mechanistic design will lead to fastening system components that are able to withstand heavy axle freight train loads with longer service lives. Preliminary results show that the type of rolling stock and resulting wheel loads greatly affect the magnitude of lateral forces in the fastening system.

INTRODUCTION

The design of components within concrete crosstie fastening systems has historically been an iterative process. Based on individual experiences and anecdotal evidence, these designs lack a clear and comprehensive understanding of how and why certain performance characteristics of these designs exist. Combining measurements at critical interfaces where failures are commonly seen enables researchers to gain a more adequate understanding of the demands components are subjected to under each passing train.

There is large variability among freight trains loads in North America due to a variety of factors. Unlike operating conditions

in other parts of the world, shared corridor usage between heavy axle load (HAL) freight trains and higher speed passenger trains creates a challenging environment for track component design.

Forces at critical interfaces must be quantified under representative loading conditions (i.e. rolling stock weights) commonly experienced in North America to best understand the demands imparted on the fastening system. Wheel impact load detectors (WILD) have been used to measure vertical input loads from passing trains and have been well documented (1). Lateral forces, however, have not been quantified to the same extent. This paper describes lateral forces in the fastening system passing from the rail through the insulator and resisted by the shoulder (Figure 1). Forces at the insulator-shoulder interface must be quantified to better understand performance characteristics of the Safelok I fastening system under various loading conditions. With track infrastructure parameters held constant, lateral forces at the critical insulator-shoulder interface are hypothesized to be influenced by wheel load (e.g. car weight) while speed is hypothesized to have a negative effect (i.e. increasing speed will decrease lateral forces). The results of this study will contribute to a more thorough understanding of the effects of such a varied loading environment, aiding in a mechanistic design approach for future fastening systems.

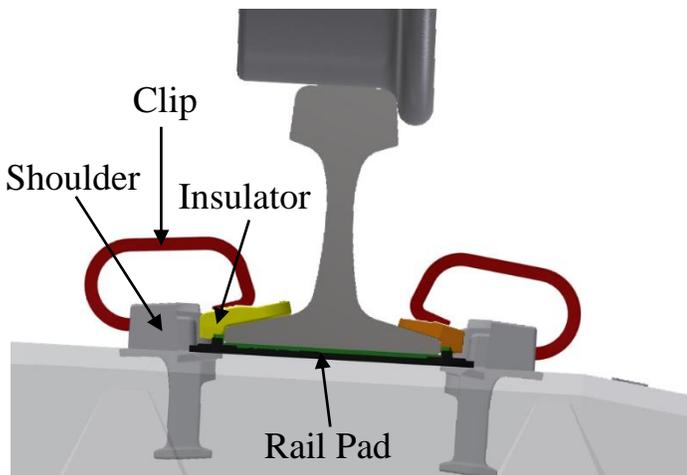


FIGURE 1. SAFELOK I FASTENING SYSTEM COMPONENT DESCRIPTION

MEASUREMENT TECHNOLOGY

Researchers at UIUC developed a technology to measure the lateral force at the insulator-shoulder interface while maintaining the original geometry of a concrete crosstie Safelok I fastening system. Safelok I systems are approximated to be in use on 65% of North American heavy haul concrete crossties. An optimized design of this approach was reached after learning from earlier attempts aimed at measuring the lateral force passing through the insulator post and entering the shoulder. UIUC’s Lateral Load Evaluation Device (LLED) uses strain gauges to measure bending strain of a beam placed in four-point bending. The face

of the shoulder is grinded away using a handheld grinder and straight edge to ensure proper dimensions are maintained. Once the shoulder face is removed, the LLED replaces the removed section. Figure 2 shows an LLED installed during the field experiments described in this paper. The primary advantage of this technology is that the original geometry is maintained, thus clip installation procedures and all fastening system components remain the same. Furthermore, the stiffness of the LLED is similar to that of the original shoulder to ensure equivalent conditions.

The LLED also provides valuable insight into the lateral load path by quantifying the forces at various locations in adjacent fastening systems and components. Frictional forces at the rail-pad and insulator-clip interfaces also resist lateral load and are assumed to be the difference between the input load and LLED measurement. Additionally, lateral rail flexure may resist some small amounts of force, but the resistance is assumed to be negligible based on theoretical calculations that are in agreement with the response of a validated finite element (FE) multi-tie model that is available at UIUC (2). This technology helps track engineers understand how variables associated with friction (e.g. materials and geometry) alter the lateral load path (3).



FIGURE 2. FIELD INSTALLATION OF LLED

Each LLED has two defined points of contact with the shoulder that act as outer supports and two defined points of contact with the insulator that act as inner supports. The four-point-bending beam contains four strain gauges which are wired into a full Wheatstone Bridge to measure the bending action of the beam. These strains are subsequently resolved into a resultant force using calibration curves generated through experiments conducted using a uniaxial loading frame. For calibration, LLEDs were supported on a level plate by two small steel blocks and loaded with a self-leveling loading head to ensure perpendicular loading. Furthermore, frictional forces between the bottom of the LLED and the ground shoulder that would affect the LLED readings are assumed to be negligible because there was no vertical normal force applied to the LLEDs. In laboratory and field installations, a thin steel insert (20 gauge,

0.0359 inches, 0.9119 mm in width) was used between the insulator and the two points of contact on the beam to ensure the points of loading would not penetrate into the relatively soft insulator material (Nylon 6/6). The end result is a load cell at the shoulder-insulator interface that maintains the original geometry and does not alter the lateral load path.

EXPERIMENTAL SETUP

Field experimentation was conducted at the Transportation Technology Center (TTC) in Pueblo, Colorado. Field experiments and results described in this paper were conducted at TTC on a segment of curved track on the Heavy Tonnage Loop (HTL) with a degree of curvature of five degrees, four inches of superelevation, and a 33 mph (53 kph) balanced speed. Different dynamic loading scenarios (e.g. rolling stock weight, train speed) were run on each section to understand how such factors affect lateral forces. Each test section used a 136RE rail section, concrete crossies spaced at 24 inches (610 mm) center-to-center, and premium ballast with an average of 16 inches (406 mm) of shoulder ballast. New fastening system components were used during testing to ensure the uniformity of the fastening system components. LLEDs were installed on the field side of the rail on both rail seats of three adjacent concrete crossies.

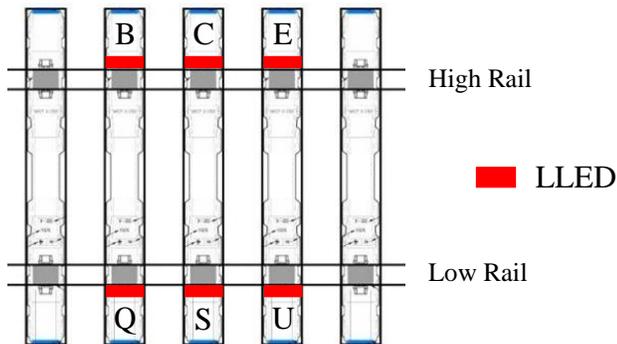


FIGURE 3. PLAN VIEW OF LLED INSTRUMENTATION LOCATION

The field side was selected because most insulator failures occur on the field side. Figure 3 shows the location and naming convention of LLEDs. The installation first required removing the clips and rail pad assembly from the rail seat. Next, the shoulder face was grinded away, and new rail pad assemblies, insulators, and clips were installed. The LLED and steel insert were installed in place of the shoulder face.

Dynamic train consist runs included both conventional passenger rolling stock and heavy axle load (HAL) freight cars. The passenger train consisted of a six-axle, 390,000 lbs (1,735 kN) locomotive and nine passenger cars averaging just over 86,800 lbs (386 kN). The freight train consisted of three six-axle locomotives averaging 395,000 lbs (1,757 kN), six 263,000 lbs (1,170 kN) cars referred to as “263K” cars, and three 315,000 lbs (1,401 kN) cars referred to as “315K” cars. For the purpose of

this paper, 12 axles will be examined; six from the passenger consist and six from 315K cars. These axles induced the highest peak loads and represented six consecutive axles on each train, enabling investigation into the effects of leading and trailing axles on track forces. Also, this allowed researchers to see how the highest and lowest car weights most commonly used in North America affect in-track forces. Two runs were recorded for each designated speed. Speeds tested for passenger and freight runs were 2 mph (3.2 kph), 15 mph (24 kph), 30 mph (48 kph), and 40 mph (64 kph). An additional 45 mph (72 kph) freight run also conducted..

LATERAL FORCES FROM PASSING TRAINS

All data described in the remainder of this paper is from Railseat U on the low rail (Figure 3). The maximum lateral force and corresponding lateral wheel load recorded during all testing was during a 2 mph run. As speed increased, the maximum lateral forces and lateral wheel loads recorded consistently decreased (Figure 4). This is likely caused by increasing centrifugal force pushing the train away from the instrumented low rail. The maximum lateral forces for passenger cars were constant at a very low magnitude relative to the magnitudes measured from the freight cars. All lateral wheel loads from passenger runs were less than 5,000 lbf (22 kN) and all lateral forces measured by the LLED were less than 1,000 lbf (4.4 kN). At 15 mph, lateral forces measured by the LLED were 618 lbf (2.7 kN) for the passenger consist while the freight consists yielded 6,637 lbf (30 kN), more than an order of magnitude higher than the passenger consist. The small magnitudes from passenger runs were consistent at all speeds. This indicates that passenger trains impart significantly lower demands on track components compared to freight consists. Although the forces from the freight consist were about ten times larger than those from the passenger consist, the freight car weights were only approximately 3.7 times heavier than the passenger cars.

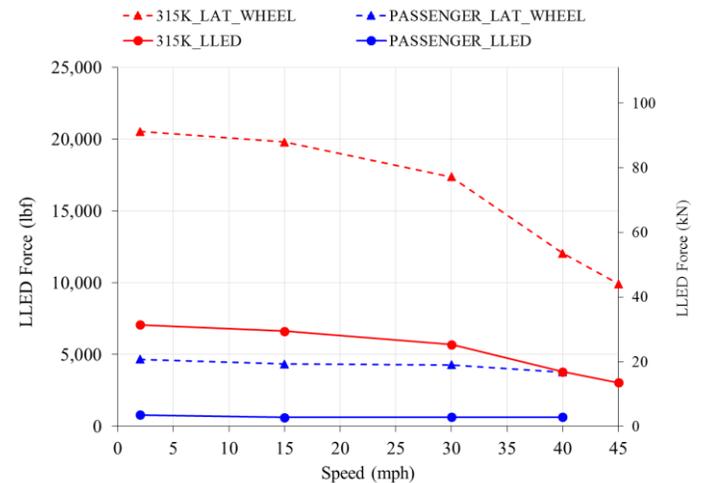


FIGURE 4. MAXIMUM LATERAL WHEEL LOADS AND LATERAL LLED FORCES AT SPEED

This could indicate car weight has a significant influence on the magnitude of the lateral forces imparted on the track.

As the lateral wheel loads decreased, lateral LLED forces decreased proportionally. Although this trend indicates speed is a primary factor that influences lateral forces, the trend only applies for the maximum load scenario. When lateral forces measured by the LLED are plotted versus lateral wheel loads and separated by speed for freight data, it can be seen that lateral forces at the shoulder face are dependent on the lateral wheel load (Figure 5). There is a positive trend between lateral wheel load and lateral forces at the shoulder face, yet the forces at each speed appeared to spread across a wide range of forces. Although the highest lateral force recorded was 6,892 lbf (31 kN) during a 2 mph run, the minimum force during a 2 mph run was 1,503 lbf (6.7 kN), 78% less than the maximum value. The same can be observed for the remaining speeds where minimum lateral forces for 15 mph, 30 mph, 40 mph, and 45 mph were 85%, 83%, 93%, and 80%, respectively, lower than the maximum. Likewise, any given speed induced lateral forces higher and lower than the other speeds (i.e. no one speed induced higher or lower lateral forces than the others).

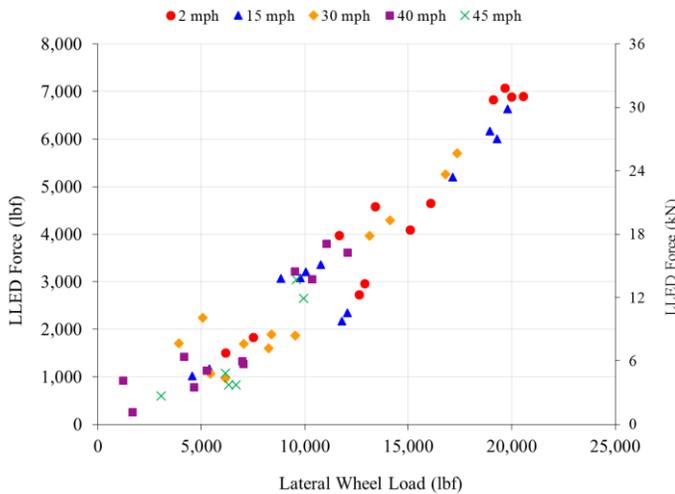


FIGURE 5. LATERAL LLED FORCE AT SPEED - FREIGHT CONSIST

However, it should be noted that lead and trailing axles of trucks produced dissimilar results during the same runs. Lead axles always yielded a higher magnitude of lateral force than the trailing axle on the same truck. Figure 6 shows differences in magnitudes of lateral force between lead and trailing axles at 15 mph on the three trucks under examination. Although Figure 6 shows LLED data for one run at 15 mph, the same trend is observed throughout all runs during testing. The magnitude of lateral forces induced from trailing axles on trucks 1, 2, and 3 were 54%, 50%, and 50% less than the lead axles on the same trucks during the same run. This is likely due to the track being unable to recover from the initial lateral impact of the lead axle before the trailing axle arrives and indicates that the lead axle of

a truck will likely induce a lateral force on the track structure approximately two times higher than the trailing axle.

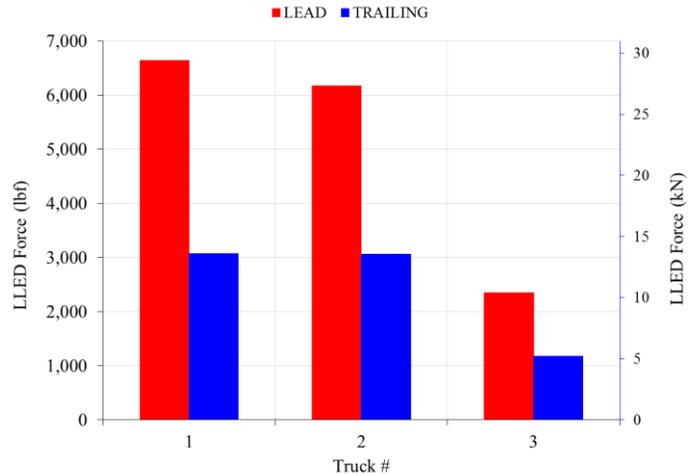


FIGURE 6. LEAD AND TRAILING AXLE LLED FORCES AT 15 MPH

POSSIBLE IMPLICATIONS: RAILSEAT REACTION (RSR) RATIO

The vertical load has been widely accepted to be distributed among five or more ties (5). However, the lateral load has been recently investigated and found to be distributed among three ties (6). Combining higher lateral forces with dissimilar lateral and vertical tie-to-tie distribution may result in a critical loading scenario.

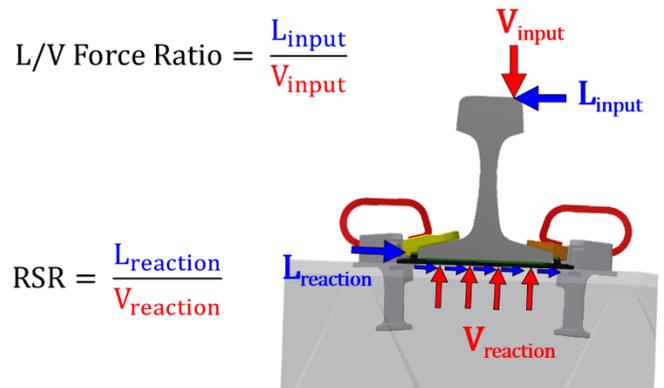


FIGURE 7. THEORETICAL RAILSEAT REACTION (RSR) RATIO

Assume vertical load is distributed to five ties with 50% of the applied load going to tie directly beneath the point of load application, 15% each to the two adjacent ties, and 10% each to two ties away. Also, lateral load is distributed to three ties with

50% of the applied load going to tie directly beneath the point of load application and 25% each to the two adjacent ties. A disproportionate ratio of lateral to vertical forces in the fastening system will exist. Traditionally, fastening systems are designed to withstand lateral load to vertical load ratios (i.e. L/V ratio) applied at the wheel-rail interface. However, assuming a three tie lateral load distribution and a five tie vertical load distribution with equal percentages of loads going to the fastening system directly beneath the point of load application (i.e. L/V = RSR at that tie), fastening systems on adjacent ties will experience a RSR ratio higher than the L/V ratio. If the applied L/V Ratio is 0.5, such a scenario described above would produce a RSR ratio on the adjacent railseats of 0.83, much higher than the assumed value of 0.5. This could mean fastening systems not directly beneath the point of load application may experience higher demands than fastening systems directly beneath the load, which is counter intuitive to conventional engineering judgment.

Further investigation must be done on the RSR ratio to gain a deeper understanding of this concept. The stability of the rail is paramount to track safety and fastening system component performance. If the fastening system is not designed for the actual demands seen in the field, problems in these areas may contribute to the current track maintenance challenges.

CONCLUSIONS AND FUTURE WORK

UIUC's LLED is a successful tool for understanding track component forces, and has led to the following conclusions based on preliminary field data obtained through testing at TTC:

- As hypothesized, the magnitude of lateral forces entering the shoulder appears dependent on the input lateral load at the wheel/rail interface
- As hypothesized, train speed has a negative effect on lateral forces on the low rail. However, train speed does not appear to be a consistent parameter by which lateral forces in the fastening system can be predicted
- Passenger consists impart very low lateral forces on the track superstructure at the shoulder-insulator interface, consistently less than 1,000 lbs (4.5 kN) during testing implying very little demand is placed on the infrastructure
- Freight consists can apply approximately ten times higher lateral forces than passenger consists. The maximum lateral forces measured by the LLED were 618 lbf (2.7 kN) for the passenger consist while the freight consists yielded 6,637 lbf (30 kN)
- Lead axles impart approximately twice the lateral force than trailing axles at the insulator-shoulder interface
- The railseat reaction ratio could be a valuable way to understand the effects of unequal lateral and vertical load distribution on rail stability

Future revenue service testing on a Class I mainline with concrete crosstie track will provide researchers with insight on lateral forces imparted in the track from passing revenue trains

to obtain real world values and allow operating railroads to interpret the performance of their infrastructure. Revenue service testing will also allow us to investigate the effects of rail friction modification, gauge width, and other variables on lateral forces.

Additionally, in-depth laboratory experimentation will be conducted on UIUC's Full Scale Track Loading System to gain a better understanding on lateral load distribution in a controlled environment and will initiate an in-depth investigation into the theorized RSR.

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REFERENCES

- (1) Van Dyk, B., "Quantifying Shared Corridor Wheel Loading Variation Using Wheel Impact Load Detectors JRC 2013," *Proceedings of the 2013 Joint Rail Conference*, Knoxville, Tennessee, April 2013
- (2) Chen, Z., M. Shin, B. Andrawes. 2013. Finite Element Modeling of the Fastening Systems and the Concrete Sleepers in North America. *Proceedings of the 2013 International Heavy Haul Association Conference*. New Delhi, India, (February 2013).
- (3) Czichos, H. 1978. *Tribology: a systems approach to the science and technology of friction, lubrication and wear*, Elsevier North-Holland, Inc., New York, NY.
- (4) Van Dyk, B., J.R. Edwards, C.J. Ruppert, and C.P.L. Barkan. 2013. *Considerations for Mechanistic Design of Concrete Sleepers and Elastic Fastening Systems in North America*.

Proceedings of the 2013 International Heavy Haul Association Conference. New Delhi, India, (February 2013).

- (5) Grasse, J. 2013. *Field Test Program of the Concrete Crosstie and Fastening System*. University of Illinois at Urbana-Champaign, Urbana, IL.

- (6) Williams, B., R. Kernes, J. R. Edwards, C. P. L. Barkan. 2014. Lateral Force Measurement in Concrete Fastening Systems. Proceedings of the 2014 Transportation Research Board Annual Meeting. Washington D.C., United States of America, (January 2014)