



Lateral load performance of concrete sleeper fastening systems under non-ideal conditions

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ABSTRACT: The fastening system is an essential component of the track superstructure that facilitates load transfer from the rail to the sleeper while holding the rail in place. Previous research has focused on investigating the performance of different fastening systems under laboratory and field loading environments when the fastening systems are properly installed. However, with the increased traffic and challenging service environments often experienced in North America, it is likely not all the fastening systems can remain intact throughout their service life of the track, thus missing fastening system components can occur. To date, the performance of different fastening systems under non-ideal conditions, such as track with missing fastening system components, has not been thoroughly investigated. In order to better understand the behaviour of concrete sleeper fastening systems under different non-ideal loading conditions similar to what is seen in the field, an on-going research project is currently being conducted at the University of Illinois at Urbana-Champaign. This paper presents the preliminary laboratory results of the lateral load performance of the Sk1-style fastening system on track with missing fastening system components at one or more sleepers. Lateral load redistribution was quantified for different test scenarios. The results from this study will improve the understanding of lateral load distribution under non-ideal conditions and can be used in future fastening system design and field maintenance practices.

1 INTRODUCTION

The fastening system is an essential component of track superstructure and facilitates load transfer from the rail to sleeper while holding the rail in place. Previous research has studied the lateral load distribution when the fastening systems are properly installed (Holder et al. 2017). However, missing fastening system components on one or more adjacent sleepers can occur in the field, and the performance of track under these non-ideal conditions has not been investigated. To better understand the performance of the fastening system under non-ideal conditions, researchers at the University of Illinois at Urbana-Champaign (UIUC) are conducting an experimental study to investigate the magnitude and distribution of the lateral load through the track superstructure when a portion of the fastening system components are missing. The performance of the fastening system after one or more reinstallations (i.e. clamps and angled guide plates that have been removed and reapplied for multiple times) is also being studied to better understand the loss of clamping force over the service life of the track and how it affects the lateral load distribution and rail rotation. It is the expectation of the authors that the information

in this paper will assist the rail industry in improving fastening system design, performance, and maintenance for heavy-haul freight railroad applications through the use of quantitative loading data as inputs for future practice. The primary objectives of this project are to quantify the clamping forces of the Sk1-style fastening system involved in the removal and reinstallation investigation, as well as to gain a better understanding of the lateral loads distribution under non-ideal conditions when fastening system components are removed.

2 EXPERIMENTATION PLAN

2.1 *Fastening System and Concrete Sleepers*

Experiments were performed using concrete sleepers equipped with Sk1-style fastening systems. The concrete sleepers have dimensions of 2,590 mm long, 279.4 mm wide, and 222.3 mm high. The Sk1-style fastening system is comprised of five major components that ensure the longevity of their performance. These components are the tension clamps, angled guide plates, lag screw/dowel, abrasion plate and rail

pad (see Figure 1). As described by Van Dyk et al. (2015), the tension clamps are designed to have high fatigue strength, which allows them to maintain their clamping ability over extended periods of time. The field and gauge angled guide plate transfer the lateral force experienced by the rail to the concrete sleeper. The lag screw and dowel combination hold the tension clamp to the sleeper and help decrease the transverse stress on the concrete sleeper

The rail pad is designed to provide appropriate resilience while the abrasion plate is a protection layer between the rail pad and the rail seat. Additionally, the rail pad is designed to withstand the high pressures that are associated with heavy haul trains, and the abrasion pad is a critical part in mitigating Rail Seat Deterioration (RSD), a major problem of the concrete sleeper in North America (Greve et al. 2015).

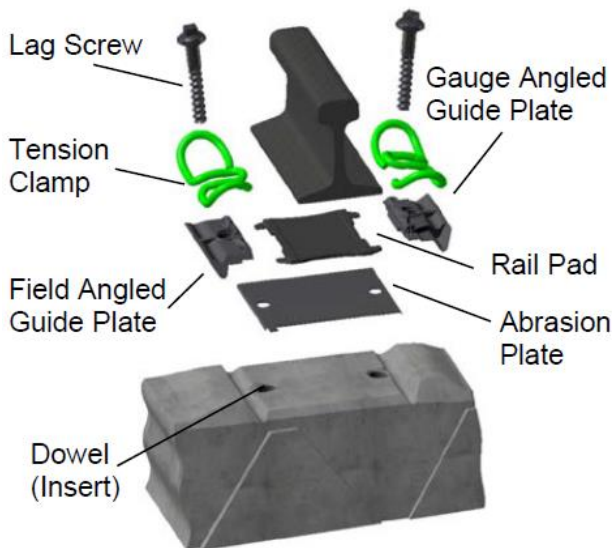


Figure 1. Vossloh Fastening Systems, Inc. W 40 (Van Dyk et al. 2015)

2.2 Lateral Load Path

To better understand the magnitude and distribution of lateral loads through the track superstructure, understanding the load path through the Sk1-style fastening system is important. The load path has not been well defined as of yet, however, based on the results from the past experiments conducted at the University of Illinois, a hypothetical lateral load path is presented in Figure 2 (Williams et al. 2014). When a lateral load is applied to the head of the rail, it is hypothesized that the load is transferred to the base of the rail and is primarily resisted by the field side angled guide plate of the fastening system. For this reason, field side guide plates are often designed to be larger than the gauge side guide plates decrease the compressive stress on the concrete sleeper. UI-

UC researchers also believe that a small portion of the lateral load applied to the rail could possibly be transferred through the tension clamp into the sleeper as well as through frictional forces between the rail pad – rail seat interface.



Figure 2. Hyperthetical lateral load path

2.3 Measuring Lateral Forces

In order to quantify the lateral loads that are applied to the field side angled guide plate, a device called the Lateral Load Evaluation Device (LLED) has recently been developed at the University of Illinois. Strain gauge bridges (applied to the top and bottom sections of the LLED, Figure 3) are used to measure the bending strain of the instrument, which in turn is used to calculate the lateral force experienced by LLEDs with pre-developed calibration curves. Two LLEDs are installed on each of the modified field side angled guide plates to capture any possible uneven loading conditions. The modified field side angled guide plates with LLEDs are also designed to have a similar stiffness of the original guide plate.

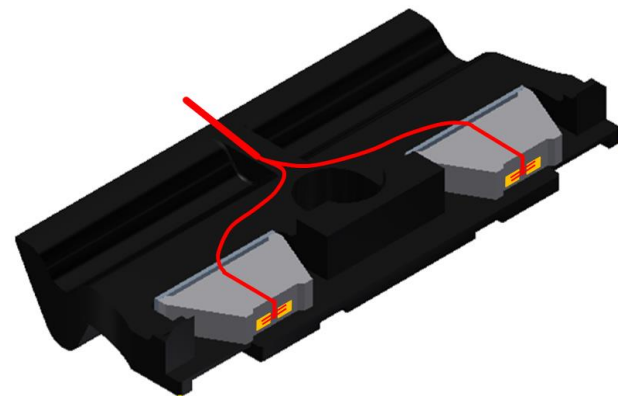


Figure 3. LLED placed in a angled guide plate

2.4 Laboratory Setup

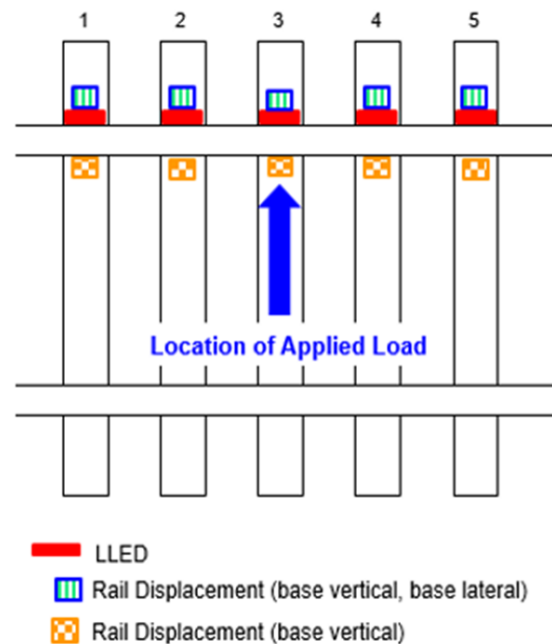
Previous studies have shown that the lateral load primarily is distributed into three sleepers with elastic fastening systems, thus a total of five sleepers were used in the laboratory test setup to be conservative. Figure 4 (a) shows a picture of the test setup

and Figure 4 (b) gives the schematic drawing. The five sleepers were secured to the floor with space of 609.6 mm (24 in.) between each other. A section of 136 RE rail with the length of 2590 mm (102 in.) was installed on one side of the sleepers with the Skl-style fastening systems properly tightened according to the supplier's guidance. Other than the aforementioned two LLEDs installed in the field side guide plate, customized aluminium brackets were installed in each sleeper to measure rail movement. The gauge and field brackets were equipped with vertical potentiometers to measure rail rotation, while two other potentiometers were installed laterally on the field side brackets to measure rail base displacement. A hydraulic jack aligned with the center of the middle sleeper was used to apply lateral load from rail head. All loads were applied at this location and were controlled manually using a hand pump. Due to the limitation on length, this paper will present the results LLEDs only. Rail deflection and rotation will be discussed in future publications.



(a) Laboratory test setup

the typical case for a new installation. Figure 5 shows the percentage of lateral wheel load resisted by the field angled guide plate on the y-axis and its corresponding sleeper on the x-axis. The percentage of lateral wheel load resisted by the field angled guide plate is calculated by dividing the summation of the lateral load measured by the two LLEDs installed in each field angled guide plate by the lateral load applied from the hydraulic jack. The summation of the percentages may not be 100% due to the fact that not all the applied lateral force was transferred into the field angled guide plate. A portion of the applied lateral load is assumed to be transferred into the sleeper through the tension clamps, and the friction between the rail and fastening system components. Each of the five trials have been plotted in Figure 5 to show the repeatability of this tests. Mean value and the standard deviation are also provided in Table 1. It is redundant to plot all the repeated test results like Figure 5 for all the types of tests. Instead, the standard deviation between all five trials for each sleeper under different test scenarios are provided in



(b) Schematic drawing of the test setup

Figure 4. Laboratory test setup

3 PRILIMINARY RESULTS

3.1 Repeatability of test

In order to ensure the accuracy and reliability of the data, all experiments were repeated five times. For the five repeated trials, the test setup remains intact without disassembling any components. Figure 5 gives an example of the results from the five repeated tests under the fully fastened condition. The fully fastened test represents how the fastening system performs when there is no missing component, as is

Table 1. It should be noted that the largest standard deviation manifested between five trails is only 3.07; therefore, suggesting that the tests performed are both replicable and accurate. All the graphs presented in this paper later are the averaged results from the five trials for each type of tests.

Table 1. Mean value and standard deviation of lateral load percentage for all test

Sleeper	1		2		3		4		5	
	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev	Mean	Std dev
Fully Fastened	1%	0.22	8%	0.29	39%	0.13	27%	0.40	3%	0.35
Missing Center Clamps	2%	0.23	16%	0.57	33%	0.13	26%	0.28	7%	1.71
Missing Center Plates	0%	0.07	22%	0.13	0%	0.02	39%	0.79	49%	0.73
Missing Adjacent Clamps	7%	0.14	23%	0.66	45%	0.46	34%	3.07	0%	0.00
Missing Adjacent Plates	13%	0.51	0%	0.02	62%	0.03	0%	1.59	0%	0.00
5 Replacements	0%	0.00	20%	0.14	34%	0.07	26%	0.54	0%	0.00
10 Replacements	0%	0.00	20%	0.14	34%	0.07	26%	0.54	0%	0.00
15 Replacements	0%	0.00	22%	0.19	34%	0.04	28%	0.23	0%	0.00

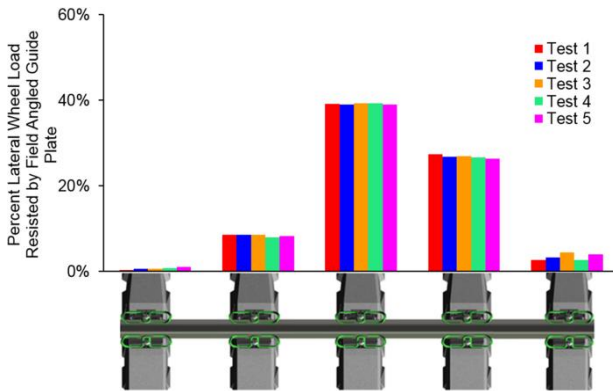


Figure 5. Fully fastened condition

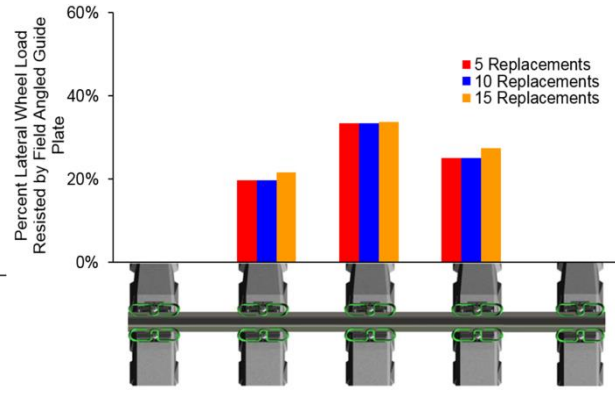


Figure 6. Loss of clamping force

3.2 Reusability of component

To investigate the role that lateral forces have on the Skl-style tension clamps under different test scenarios, components such as tension clamp and angled guide plate need to be removed and reinstalled several times. However, the reusability of those components has not been thoroughly investigated in the literature. In this study, the reusability of the components for the skl-style fastening system was investigated. Experiments were performed by completely removing each fastening systems and re-installing them. After the first five removals and installations were completed, lateral force was applied to the rail and the lateral load distribution was recorded. Load was applied again after an additional 5 removals and re-installations.

Figure 6 presents all three-replacement tests results. Mean values and standard deviations are also provided in Table 1. It is clear that the differences between each of the three tests are minor, especially when the five and ten replacement tests are compared. The test results shown in Figure 6 and Table 1 indicate the components for the Skl-style fastening system can be reused for at least 15 times under the loading magnitude in this study without significant loss of clamping forces.

3.3 Missing Center Clamps

As briefly discussed previously, properly installed fastening systems with no missing components can represent new installation scenario. However, with the accumulation of tonnage during service life, fastening systems with no missing components are not the only scenario found in the field. It is possible for some components to experience failure caused by fatigue, fracture, or crushing which can lead to missing fastening system components on the track superstructure. Thus the performance of the fastening system under non-ideal conditions is worth being investigated. Various possible non-ideal conditions were simulated and tested as listed in Table 1.

The first test performed is the “missing center clamps” test. For this test, the tension clamps on both sides of the center sleeper were removed and the angled guide plates were left with screws tightened on the concrete sleeper. Figure 7 shows the percent lateral load for each sleepers under the “missing center clamps” scenario. On that same graph, the averaged fully fastened test results are also provided for comparison. Figure 7 shows that once the clamps are removed, the percent lateral load resisted by the center sleeper was reduced from 39% to 33%, the percent lateral load resisted by one of adjacent sleeper (sleeper 4) also reduced by a

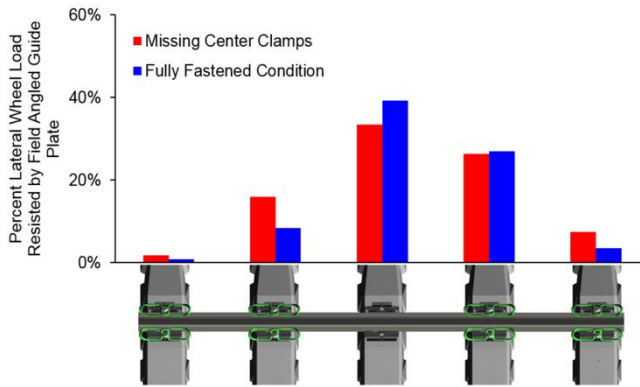


Figure 7. Missing center clamps

small portion, from 27% to 26%. However, the percent lateral load resisted by sleeper 1, 2, and 5 all increased, from 1% to 2%, 8% to 16%, and 3% to 7%, respectively, which means the lateral forces become more evenly distributed for the missing center clamps scenario than the fully fastened scenario. The change of lateral force distribution may be caused by the change of lateral stiffness at the center when the clamps were removed. However, the majority of the lateral load was still resisted by the middle three sleepers. It was observed that there was more rail rotation at the center sleeper, which will be discussed in future publications.

3.4 Missing Center Clamps and Plates

The second test performed was for missing center sleeper tension clamps and angled guide plates. For this test the tension clamps and angled guide plates were completely removed for the center sleeper. Since there are no angled guide plates in either the field or gauge side of the sleeper, there will be no lateral load measurement at this location, but lateral resistance from the friction is still possible. Figure 8 shows the percent lateral load for each sleepers under the missing center clamps and plates scenario. After removing the center clamps and plates, the percent lateral load clearly transferred into the adjacent sleepers. The percent lateral load for sleepers 2 and 4 increased from 8% and 27% to 22% and 39%, respectively, while the values for sleeper 1 remained similar. It is interesting to see that there is no value of percent lateral load for sleeper 5 after removing the center clamps and plates in Figure 8. This may be due the significant reduction in lateral restraint at the center sleeper which allowed the rail more freedom to twist or move, causing the field side angled plate of sleeper 5 to lose contact with the rail as load was being applied. This scenario may also happen in the field considering the longitudinal stiffness of rail is relatively low.

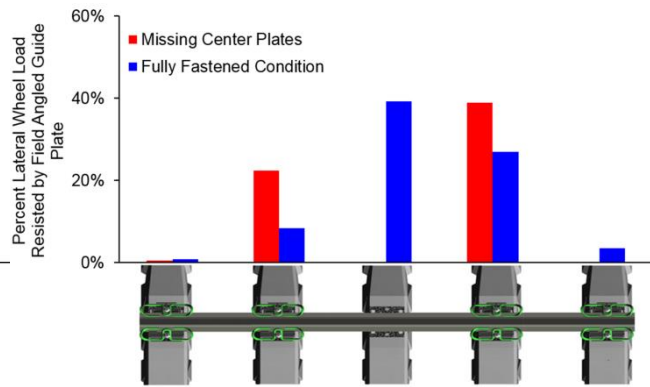


Figure 8. Missing center plates

3.5 Missing Adjacent Clamps

In order to help this study to cover a wide range of possibilities, it was important not only to include the non-ideal conditions on the center sleeper but also considering the two adjacent sleepers. Figure 10 illustrates the distribution of lateral loads when the two adjacent sleepers have had their tension clamps removed, representing a possible failure mode for both adjacent sleepers. When two out of five sleepers had missing clamps, the total percent of lateral load resist by angled guide plate increased from 79% to nearly 100%. The reason that the portion of lateral load resisted by the angled guide plate increased was possibly due to the loss of clamping force when the two adjacent clamps were missing. Similar to missing the clamps for the center sleeper only in which case the percent lateral load on the center sleeper reduced (from 39% to 33%, see Figure 7), the percent lateral load for sleeper 3 decreased from 39% to 38%. Sleepers 1, 2 and 4 increased, 1% to 6% for sleeper 1, 8% to 20% for sleeper 2 and 27% to 29% for sleeper 4 (Figure 9). One interesting observation is the percent lateral load of sleeper 5 reduced to 0 after clamps were removed from sleeper 2 and 4, while a considerable percent lateral load increased from 1% to 6% for sleeper 1.

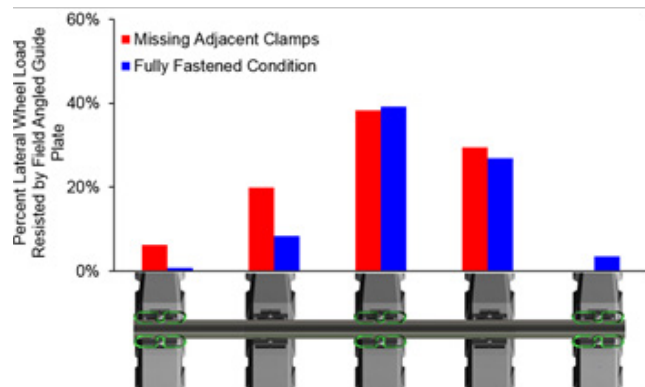


Figure 9. Missing adjacent clamps

One possible reason for this behavior could be that the rail moved during the application of load and one side (sleeper 1 and 2) of the test setup became more engaged. This can also be confirmed by comparing the total percent lateral load changed for sleeper 1 and 2 was 17%, while the values for sleeper 4 and 5 was 1%.

3.6 Missing Adjacent Clamps and Plates

Figure 10 illustrates the distribution of lateral loads when the two adjacent sleepers have had both the tension clamps and angled guide plates removed. This test is the most “severe” scenario in this study. With two sleepers lose ability to restraint lateral movement dramatically, the total percent lateral load measured by LLEDs changed from 79% to 89%. The percent lateral load restrained by the angled guide plate of the center sleeper increased from 39% at the fully fastened scenario to 62%, while the value at the missing adjacent clamps was 38%. A similar increase at sleeper 1 was from 1% at the fully fastened scenario to 13%, while the value at the missing adjacent clamps was 6%. This is because when sleeper 2 and 4 significantly lose their ability to sustain lateral load, fastening system at sleeper 1 and 3 became more engaged. Similar as the missing adjacent clamps test, no noticeable lateral load was measured from sleeper 5.

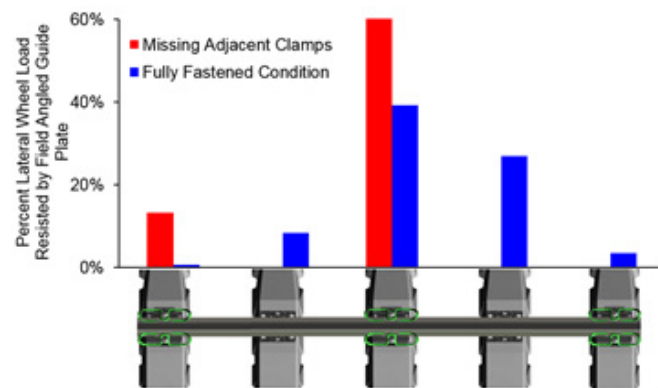


Figure 10. Missing adjacent clamps

4 CONCLUSIONS AND FUTURE WORK

This paper presents an experimental study focused on characterizing lateral load distribution with the SkI-style fastening system under non-ideal conditions. These non-ideal conditions include missing one or more components at one or more sleepers. Lateral load was measured and analysed for each sleeper under different test scenarios. The following conclusions can be drawn based on the preliminary results from this study:

The performance of the SkI-style fastening system was consistent under the specific test conditions in this study. Loss of clamping force during reinstallation for multiple times was not observed. SkI-style fastening system relies more on the angled guide plate to resist lateral load than frictional forces. The majority of the lateral load is distributed into three sleepers under single point lateral load. Missing components will redistribute the lateral load considerably, especially when the angled guide plate is missing. When some component or components are missing, lateral load will mainly be transferred into two adjacent sleepers. However, depending on the initial position of the rail, the redistribution of the lateral load could influence up to five sleepers.

5 ACKNOWLEDGMENTS

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