



FIELD MEASUREMENT OF BENDING MOMENTS IN PRESTRESSED CONCRETE MONOBLOCK SLEEPERS

Henry E. Wolf, J. Riley Edwards, Marcus S. Dersch, Yu Qian, David A. Lange.

Rail Transportation and Engineering Center (RailTEC), University of Illinois at Urbana-Champaign, Urbana, U.S.A.

*Contact: mdersch2@illinois.edu

Abstract

As the use of concrete sleepers increases for heavy-haul freight railroad lines in North America, it is becoming more critical to improve the understanding of their flexural behavior. This improved understanding can help to optimize current design and maintenance practices for concrete sleepers, leading to longer service life, lower life cycle costs, and fewer in-service failures. Currently, center cracking is regarded as one of the most common concrete sleeper failure mechanisms in North America. Improving the understanding of sleeper flexure can help reduce the occurrences of center cracked sleepers by ensuring designs are adequate for the field conditions that are encountered. Past work conducted at the University of Illinois at Urbana-Champaign (UIUC) found that sleeper flexure is highly dependent on ballast support conditions and this support can vary greatly from sleeper to sleeper. To measure the bending moments and support conditions experienced in North American heavy-haul freight service, surface strain gauges were mounted to ten concrete sleepers along a high-tonnage, heavy-haul North American freight railroad line. These gauges were used to record strains at five critical locations along each sleeper. These strains were converted to bending moments using a calibration factor found in laboratory testing. Data was collected from over 7,500 axles from fourteen train passes over three site visits. The variation of the measured bending moments were found to be non-normally distributed, with a negative skew, indicating there to be a large number of high bending moments experienced by the sleeper. Although minor cracking was observed at the center of most sleepers in this test section, measured bending moments and strains did not exceed the 1997 industry standard design limits. Ballast support conditions were found to be a major source of variation in sleeper flexure and were found to be highly variable in both the longitudinal and transverse directions.

1. Introduction

Throughout the world, the majority of railroad track infrastructure is supported by ballast. A ballasted track system typically consists of rail, fastening systems, sleepers, ballast, sub-ballast, and subgrade. The most commonly used material for sleepers in the United States is timber, which is used for approximately 90-95% of the sleepers in revenue service (1). Concrete is the second most common material for sleepers, making up most of the remaining 5-10%. Steel and composite sleepers are also used, but they make up a negligible share of the total number of sleepers (1). Typically, concrete sleepers are used in the most demanding service conditions (e.g. high curvature, steep grades, heavy tonnage, high speed passenger traffic, etc.).

According to a survey of railroads, concrete sleeper manufacturers, and researchers from around the world, sleeper cracking from center binding was ranked as the third most critical problem with concrete sleepers (2). North American respondents considered center cracking to be slightly less critical than their international counterparts, ranking it as the fifth most critical issue associated with concrete sleepers. However, North American respondents ranked cracking from dynamic loads as the third most critical issue, one place ahead of international respondents. This survey shows that sleeper cracking is an important issue in railroad track infrastructure and is a failure mechanism that is experienced both domestically and internationally.

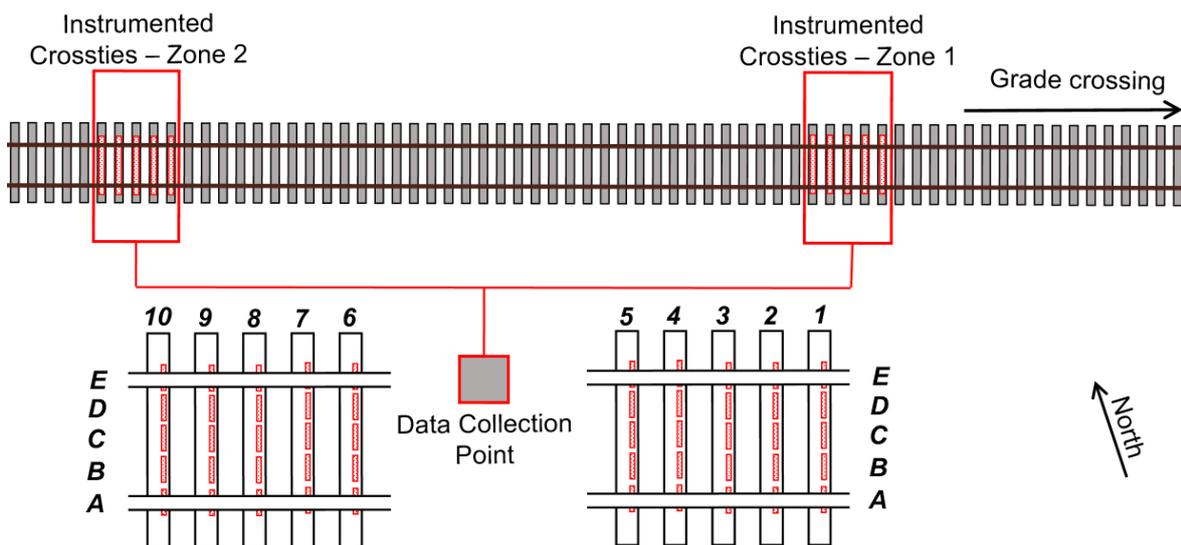
Experimentation Plan

Field experimentation was conducted on a ballasted North American heavy-haul freight line in the western portion of the United States. Because of the high variability of support conditions seen in past

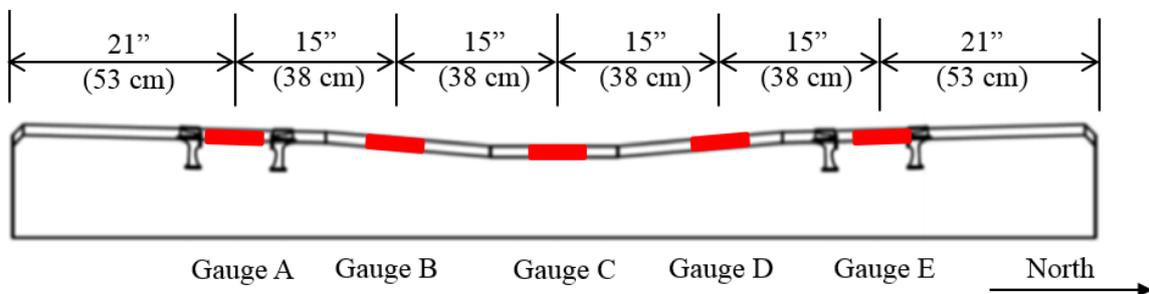
experimentation (3), instrumentation was placed in two locations, or “zones”, of tangent track, spaced approximately 60 feet (18.3 m) apart on centers (Figure 1a). Each zone consisted of five sleepers, based on the widely accepted distribution of vertical load to five sleepers (4) (Figure 1a).

The east zone (Zone 1) consisted of Sleepers 1 – 5 and served as the example for poor support. Zone 1 was located near a group of sleepers that had historically registered cross-level defects during geometry car inspections, which were addressed before the beginning of this experimentation. Additionally, all sleepers in Zone 1 had some level of visible center negative cracking and displayed evidence of ballast pumping. The west zone (Zone 2) consisted of Sleepers 6 – 10 and served as the well-supported or control zone. Sleepers 6, 7, 8, and 9 showed some center cracking, but there was no visible pumping and upon train passes, Zone 2 deflected noticeably less than Zone 1. Finally, there was a grade crossing located approximately 180 feet (55 meters) east of Zone 1. The track at this location consisted of 133RE rail and Safelok I fastening systems. Rail, fasteners, and sleepers were all installed in 1999. As of early 2015, the track was last surfaced in an out-of-face fashion in 2011. The timetable speed at this site was 60 mph (97 km/h), the predominant direction of the traffic on this track was eastbound, and the dominant type of railcar was loaded 286 kip (129.7 tonne) coal cars.

Bending strains along the length of the sleeper were measured to quantify the bending behavior of the sleeper under train loading. Surface strain gauges were applied oriented longitudinally along the chamfer near the top surface of the sleeper. A total of five strain gauges (labeled A – E) were used on each sleeper, with one at each rail seat, one at the center, and another located approximately halfway between each rail seat and center (Figure 1b).



(a) Site layout



(b) Strain gauge placement map
FIGURE 1 Experimentation plan

To relate the measured strains to a bending moment, calibration factors were determined by instrumenting three sleepers of the same model and vintage (a representative Class I standard sleeper manufactured in 1997) as those installed in track with the strain gauge layout shown in Figure 1b. A known bending moment was applied to the sleeper and the corresponding strains were recorded to determine the calibration factor.

Data Analysis Procedure

To quantify the bending moments concrete sleepers experience in revenue service, peaks in the strain gauge signal caused by loading of a sleeper due to an axle load were extracted from the data stream using the “findpeaks” function in MATLAB (5). Before these peaks were obtained, the strain signal was zeroed, smoothed using a moving average filter of five data points, and the baseline was corrected to adjust for any signal drift. Figure 2 shows an example of a typical signal for a center gauge with each peak labeled.

In total, 7,508 loaded axles were recorded on 10 sleepers at 5 locations along each sleeper from 14 train passes, for a possible 75,080 peak strains at each gauge location. To focus on the current design regions for concrete sleepers, bending moments measured at Gauge B and D are not presented. These data should represent bending moments in spring track conditions which has historically been considered to be a demanding season in terms of track structure loading (6). Currently, data are expected to be collected for 16 months, providing a means of understanding seasonal effects on the flexural performance of concrete sleepers.

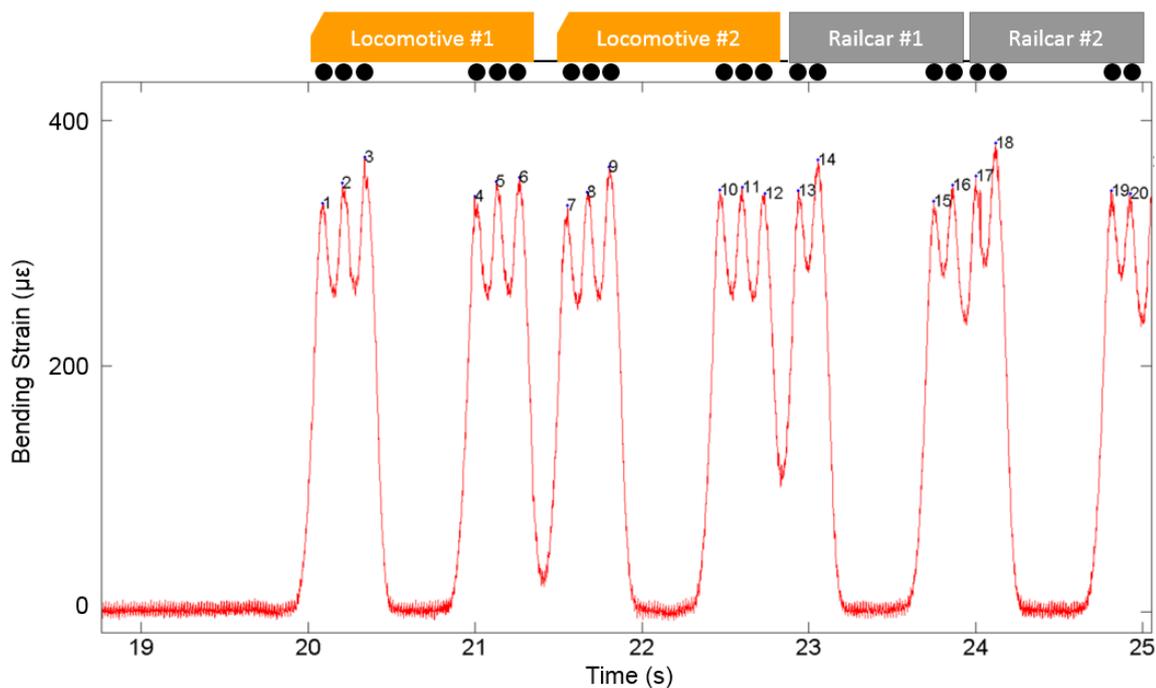


FIGURE 2 Typical strain signal captured under the passage of a loaded train

2. Results

Variation of measured bending moments

To aid in the quantification of bending moments experienced by concrete sleepers in North American heavy-haul freight service, peak bending moments for the site were analyzed by gauge, sleeper, and zone. One of the first observations was that the peak bending moments recorded did not follow a normal distribution. For Gauge A, C, and E, the peak bending moments for each sleeper were typically skewed to the right, with a mean larger than the median (7). This trend held true for both zones and over the entire site.

Bending strains and moments versus strength limit states

When comparing the measured bending moments with the design limits set for concrete sleepers in Chapter 30, Section 4.4 of the American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual of Railway Engineering (MRE) (300 kip-in (33.9 kNm) for rail seat positive bending, 201 kip-in (22.7 kNm) for center negative bending), it is found that the measured bending moments fall within these limits (8). This suggests that cracking of the sleeper should not occur. Sleepers 4, 5, 6, 7, and 9 all experienced moments of at least 175 kip-in, with the maximum of 190 kip-in found at Sleeper 4. While this is still 10 kip-in from the AREMA design limits, this sample consists of 14 trains. It is possible that with effects of fatigue, vibration, center-binding, and wheel flats, this cracking limit could still be exceeded.

Variation of support conditions

Since the wheel loads experienced by each sleeper were nearly identical with the exception of the occasional higher-impact wheel load, the primary source for the difference in bending strains is assumed to be the ballast support conditions. The variability in these support conditions is evident in Figure 3 where the upper whisker is the upper limit for outliers, the top line of the box is the Q3, the middle line is the median, the bottom line is the Q1, and the lower whisker is the lower limit for outliers. There is very high sleeper-to-sleeper variability in support conditions, even between adjacent sleepers. For example, although Sleeper 9 and 10 are adjacent to one other, the center support is different enough to cause Sleeper 9 to experience a bending moment that is nearly 60 kip-in (6.8 kNm) higher than Sleeper 10.

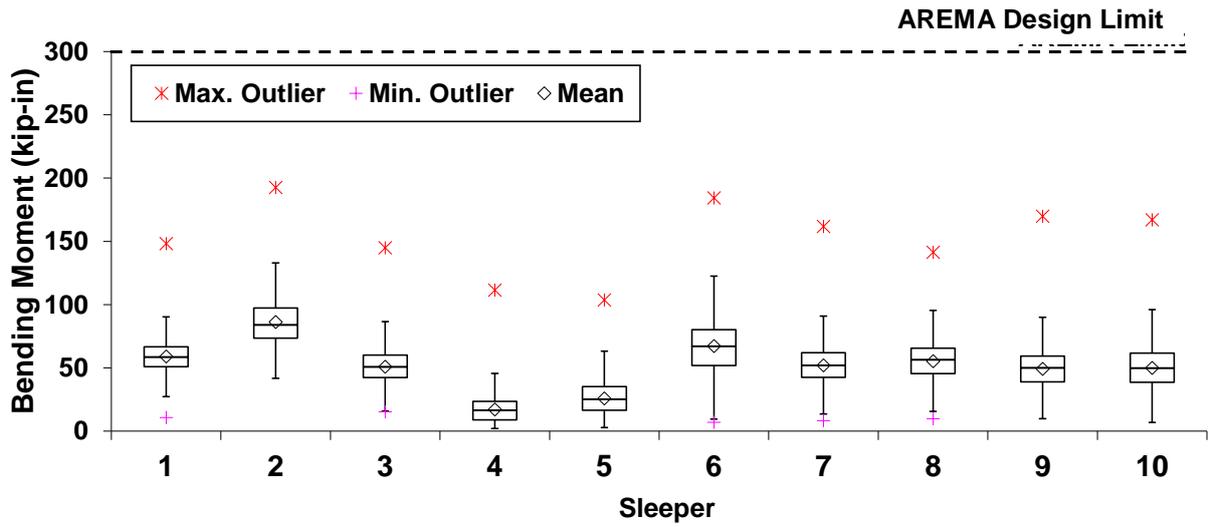
The support conditions were also found to be inconsistent in the transverse direction. This is seen by comparing the boxes of Gauge A and E (Figure 3). Some of the sleepers, such as Sleeper 10, showed symmetric support, with similar medians for Gauge A and E. Despite these similar medians, the IQR and outlier magnitudes varied greatly. More often, Gauge A and E showed different behaviors, as seen in Sleeper 4, where Gauge A's low bending moment suggests that the rail seat is poorly supported.

When comparing the bending moments along the length of each sleeper general trends can be observed. Lower rail seat positive bending moments are accompanied by higher center negative bending moments, and vice versa, following assumptions that are rooted in basic statics. The comparison between rail seat and center bending moments can indicate whether the sleeper is primarily transferring applied loads in bearing at the rail seats or in bending at the center. Using wheel load data, assumptions can be made about the rail seat loads and theoretical estimates of support conditions can be back-calculated and used to improve design recommendations.

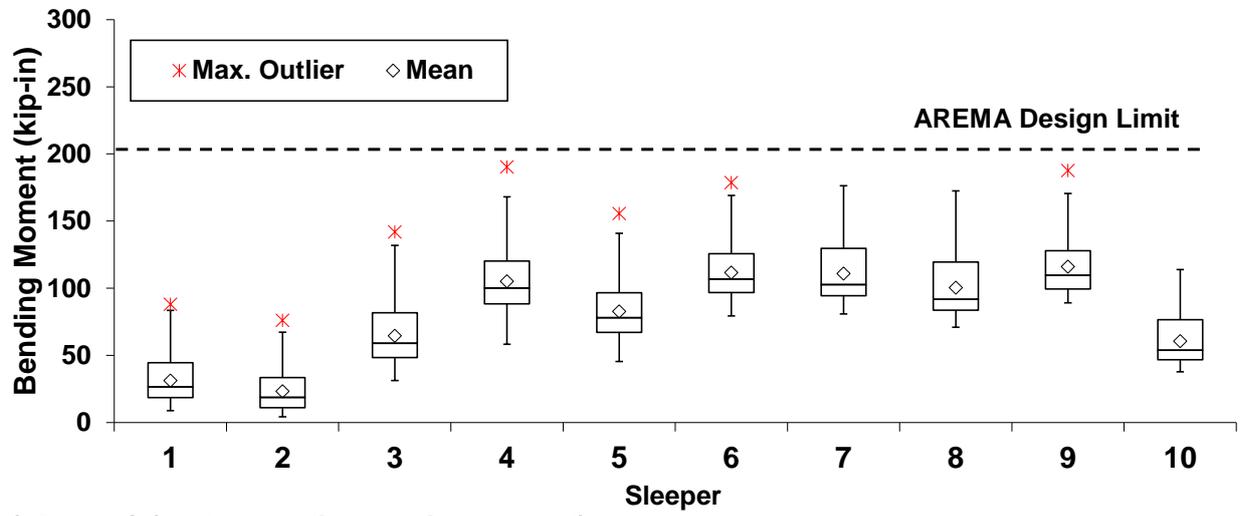
3. Conclusions

Overall, this project was successful in measuring the bending strains and moments experienced currently in North American heavy-haul freight traffic. The effectiveness of surface-mounted concrete strain gauges in measuring sleeper bending behavior was demonstrated. From this work, several conclusions were drawn relating to the flexural behavior of concrete sleepers in revenue heavy-haul freight service:

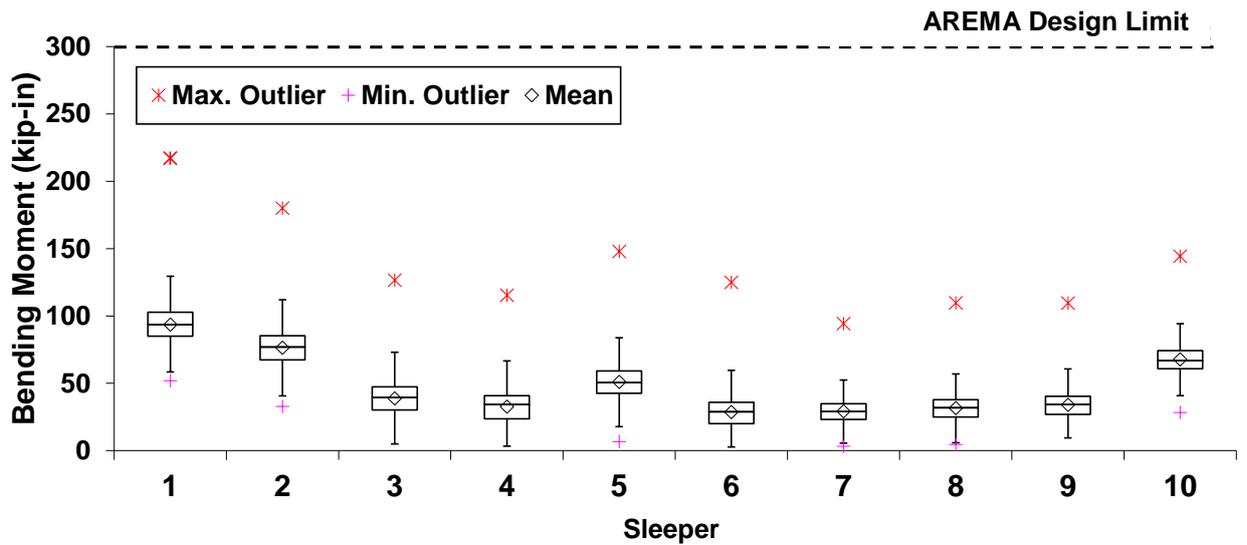
- Bending strains measured in North American heavy-haul freight traffic do not follow a normal distribution. They show moderate to significant negative skew. This skew is likely caused by upper outliers that are generated by high impact wheel loads.
- Bending strains measured at the sleeper rail seat are less variable than those experienced at the center. This could be due to more direct loading from the wheel, less sensitivity to support conditions, or more uniform support conditions under the rail seat.
- Bending moments measured at this test site did not exceed the 1997 AREMA MRE design limits, the recommendations to which these sleepers were designed.
- Bending moments measured at this test site show a high degree of variability in support conditions. Differing bending behavior under similar wheel loading suggests that support conditions can be significantly different in both the longitudinal and transverse directions, even between adjacent sleepers.



(a) Gauge A (rail seat positive bending moment)



(b) Gauge C (center negative bending moment)



(c) Gauge E (rail seat positive bending moment)

FIGURE 3 Box-and-whisker charts of measured bending strains

4. Acknowledgements

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