Investigation of Concrete Sleeper Rail Seat Pressure Distributions for Varying Fastening Systems and Loading Conditions

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Abstract

Quantifying the load distribution on the rail seat of a concrete sleeper is an important step in understanding and preventing the occurrence of rail seat deterioration (RSD), one of the primary maintenance concerns with concrete sleepers on North American heavy-haul railroads. Proper load attenuation is necessary to reduce vibration impacts, which may lead to deterioration and/or damage of the fastening system components and the concrete rail seat. Additionally, reducing life cycle costs of concrete sleepers and fastening systems through improvements to the rail seat is of extreme importance to the railway industry to ensure the continued acceptance of concrete sleepers as a viable means of rail restraint. This includes a review of the loading path in the concrete tie and elastic fastening system as well as analysis of different loading scenarios for severe service loading conditions typical of heavy-haul service. In addition, the paper reports the latest research results for the measurement of rail seat pressure distribution with varying loading conditions and fastening systems elasticities using Tekscan© pressure measurement sensors. The rail seat pressure distribution study includes an investigation on how load attenuation is affected with pads of different vertical stiffnesses and overall rigidities. The research results were obtained through full-scale severe-service laboratory testing of concrete sleepers and fastening systems at the University of Illinois at Urbana-Champaign (UIUC).

Introduction

The purpose of a railway sleeper is to support and transmit axle loads from the rail to the next layer of the track structure (typically the ballast) with a reduction in pressure. The sleeper, which is embedded in the ballast, anchors the track against lateral, longitudinal, and vertical movement [*1*]. The loads acting on a concrete sleeper depend not only on railcar axle loads and sleeper spacing, but also on the size of the rail, its vertical stiffness, and the properties of the rail fastening system [*2,3*].

Concrete sleeper fastening systems are comprised of various components and materials designed to safely transmit forces exerted by the rail to the concrete sleeper while restraining the rail to the proper gauge and cant as required by the Federal Railroad Administration (FRA) and individual railway engineering maintenance standards. Forces acting on the fastening system are vertical, lateral, rotational (both planes), and longitudinal, and are the result of repeated loading cycles from passing axles, as well as longitudinal stresses in the rail. Fastening system components are constructed from a variety of materials (with variable properties) to securely attach the rail to the sleeper and properly attenuate and/or transfer loads.

Rail Seat Pressure Distribution Measurement

In order to better understand the forces that occur at the rail seat, researchers at the University of Illinois at Urbana-Champaign are currently engaged in a project to measure the pressure distribution at the concrete rail seat. The objective of the study is to measure rail seat pressures and their distribution with different loading conditions (magnitude, L/V) and different fastening systems elasticities. This will enable us to compare the distributions and investigate how rail pads of different stiffnesses affect load attenuation and RSD [*4*] . To accomplish this objective, we are using Tekscan© sensors.

The loads acting on a concrete sleeper depend, not only on railcar axle loads and tie spacing, but also on the size of the rail, track modulus, and the properties of the rail fastening system [*5*]. A change in any of the aforementioned variables would impact the pressure and its distribution at the rail seat. In controlled testing facilities such as UIUC's ATREL and TTCI's FAST, most of the factors affecting the stresses at the rail seat can be determined with great accuracy. In these controlled facilities, for any given load combination the total stress at the rail seat is known and the change in pressure distribution can be measured (using Tekscan© sensors) and studied with slight changes in any of the variables (particularly the fastening system components).

Tekscan© Pressure Measuring System Overview

Tekscan's pressure measuring system provides an array of force sensitive cells that enable the user to measure the pressure distribution between the two contacting surfaces [*6*]. The sensors consists of two thin, flexible polyester sheets which have electrically conductive electrodes deposited in varying patterns [*7*]. The surface of the inner face of one sheet forms a column pattern and the inner surface of the other sheet form a row pattern. The intersection of each row and column creates a sensing cell, (also known as a sensel™). The spacing between the rows and columns varies according to sensor application.

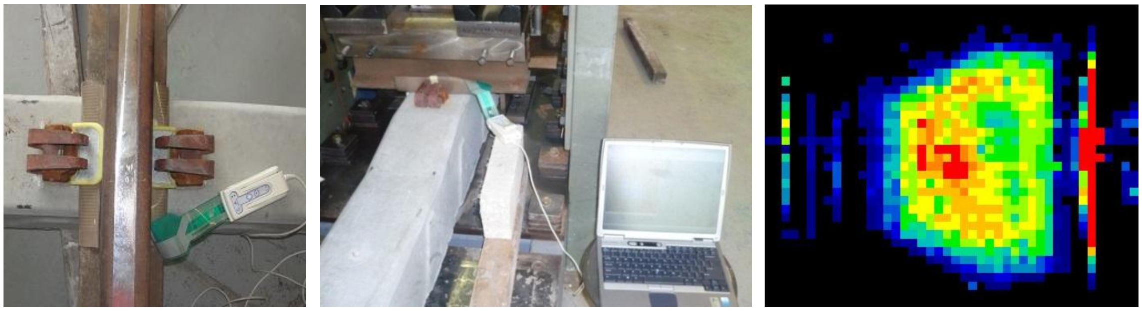
The sensors come in a wide variety of shapes, sizes, and spatial resolutions. The sensors are extremely thin and flexible (e.g. on the order of 0.004 in) and their semi-conductive ink printed in rows and columns varies with the applied force. Sensors can be manufactured for use with a wide range of pressures, including the range found at the rail seat and within the fastening system. Teflon paper and mylar sheets are recommended to be used as general protection of the sensors from shear forces and sharp edges. These protection layers thicken the sensor by 0.012 in, which must be considered when recording and reporting results.

The Tekscan system includes the sensors, the handle and the software. The handle provides a connection between the sensor and computer converting the sensor output to a digital image. The handle uses pogo pins to clamp over the lead of the sensor and make individual contact with each of the silver leads. The software serves as the primary means of evaluating and viewing the data and allows the user to control how the data is collected. The software additionally enables different sensor sensitivities for more accurate data collection.

Calibration of the sensor is an important step to validate any results. The level of precision of the final pressure values will strongly depend on how well the calibration process was carried out. Generally, calibration is conducted before the actual tests, but it could be completed after testing is complete. Calibration is completed by applying a known force to the system, using areas and surface geometries that are representative of the ones that will be tested. The raw values obtained by the sensor are then matched with the known values. A calibration factor is obtained and is used for future tests with that particular sensor type.

Tekscan Sensors at Rail Seat and Fastening System Pad Interface

The thin sensors are placed at the rail seat and fastening system pad interface. Then the fastening system is fastened and the sensor is able to record the applied toe load and the weight of the rail section above it. Figure 6 shows how a sensor is placed at the rail seat, with the handle protruding on the right. It is important to select the correct sensor size to accurately cover the entire rail seat area. For this initial feasibility study, the sensor model 5150 was used. This sensor can accurately measure pressures of up to 1500 psi.



(a) (b) (c)

Figure 1: (a) Tekscan sensor bent along the base of the rail,
(b) Proof-of-concept test with sensor on PLTM,
(c) Sample frame of pressure distribution obtained during proof-of-concept test

Challenges to Rail Seat Pressure Measurement

Thus far, precise calibration of the system was our biggest challenge, and it plays a major role in achieving valid results. Our second challenge at the early stages of the investigation was that the type of sensor used at the beginning of the investigation was larger than the rail seat area and had to be bent along the base of the rail (Figure 1). Applying large forces while having the sensors bent on sharp edges (e.g. base of the rail, edge of post insulators, etc) caused damage to a considerable section of each sensor in every proof-of-concept test. As a result, the sensor reading will not have the accuracy level required for this investigation and a precise calibration is also compromised.

A smaller sized sensor which fits the rail seat flat without being bent will be obtained for future testing and research. The Tekscan© sensor model that meet this requirement is model 5150N. The sensor model 5150N will allow us to better compare the repeatability of the results. Also, using a smaller sensor will keep sensors from getting damaged in every trial run.

Conclusions

As freight railcar axle loads increase in North America, the need for improved performance of concrete sleepers and fastening systems is becoming increasingly important. The occurrence of rail seat deterioration (RSD), one of the primary maintenance concerns with concrete sleepers on North American heavy-haul railroads, can also be correlated with the performance of the fastening system and concrete sleepers. Significant research has been undertaken by universities, testing laboratories, and sleeper and fastening manufacturers, aimed at increasing fastening system component durability while making installation and maintenance more cost effective. Also, laboratory research has focused on understanding the mechanisms behind RSD and finding practical ways to prevent the occurrence of RSD. By using the Tekscan© sensors to measure pressures and the distribution of these pressures at the rail seat with different loading conditions (magnitude, L/V) and different fastening systems elasticities, we would be enabled to compare pressure distributions and investigate how pads of different stiffnesses affect load attenuation and RSD. To meet the needs of the railway industry, extensive research and advancements are still needed, and they will most likely focus on the areas of fastening system component durability, concrete sleeper and fastening system cost effectiveness, and prevention of RSD.

Future Research

Future research in the area of fastening system elasticity will include laboratory validation and field experimentation of our rail seat surface treatment and rail seat pressure distribution investigations. It is important to understand and validate how surface treatments can affect the fastening system performance. Another important step in concrete sleeper and fastening system research is determining how the rail seat surface pressure distribution measurements will help us understand how the loading path of the rail infrastructure is affected with different fastening systems. Also, an analysis of how the pressure distribution underneath the concrete sleeper is affected with varying fastening systems elasticity will be conducted. Using the results obtained in the aforementioned future research, we propose the development of a stiffness model to classify the fastening systems according to their elasticity and recommend the optimum stiffness for a pad in order to properly attenuate the load to maximize component durability.

Future research in the area of rail seat deterioration (RSD) in concrete sleepers will include the study of the crushing and abrasion mechanisms thought to contribute to RSD. The abrasion mechanism will be addressed through modeling and experimental testing. Research on this mechanism will lead to a better understanding of how concrete mix designs, sleeper pad materials, and other materials and sleeper design choices relate to one another and will help to maximize the effectiveness of the overall design of the sleeper and fastening assembly.

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