Design and Performance of Elastic Fastening System Assemblies and Concrete Sleepers for Heavy-Haul Service

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Abstract

As heavy-haul freight axle loads and cumulative tonnages increase and high-speed passenger rail systems develop, improved concrete sleeper and fastening system performance is becoming increasingly important. In addition to the increased service demands, poor performance of the fastening system is often correlated to the occurrence of rail seat deterioration (RSD), one of the primary maintenance concerns with concrete sleepers on North American heavy-haul railroads. Reducing the life cycle costs of concrete sleeper fastening systems is of paramount importance to the railway industry to ensure the continued acceptance of concrete ties as a viable means of rail restraint. Recent advancements in fastening system design for concrete sleepers in heavy-haul and passenger service stem from research and testing addressing current problems the industry is facing regarding the use of concrete sleepers and fastening systems. This paper includes a brief review of fastening system characteristics and performance. This paper also presents results from full-scale crosstie and fastening system component tests at UIUC. Testing is underway to understand the performance of various components in the fastening system; including surface treatment of rail seat, crosstie pads, insulators, clips, and shoulders. Preliminary results show that epoxy, which is added to some rail seats, is worn away more quickly than previously expected. Additionally, tests have been designed to address moisture conditioning of insulators and its effect on the performance of the fastening system.

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.

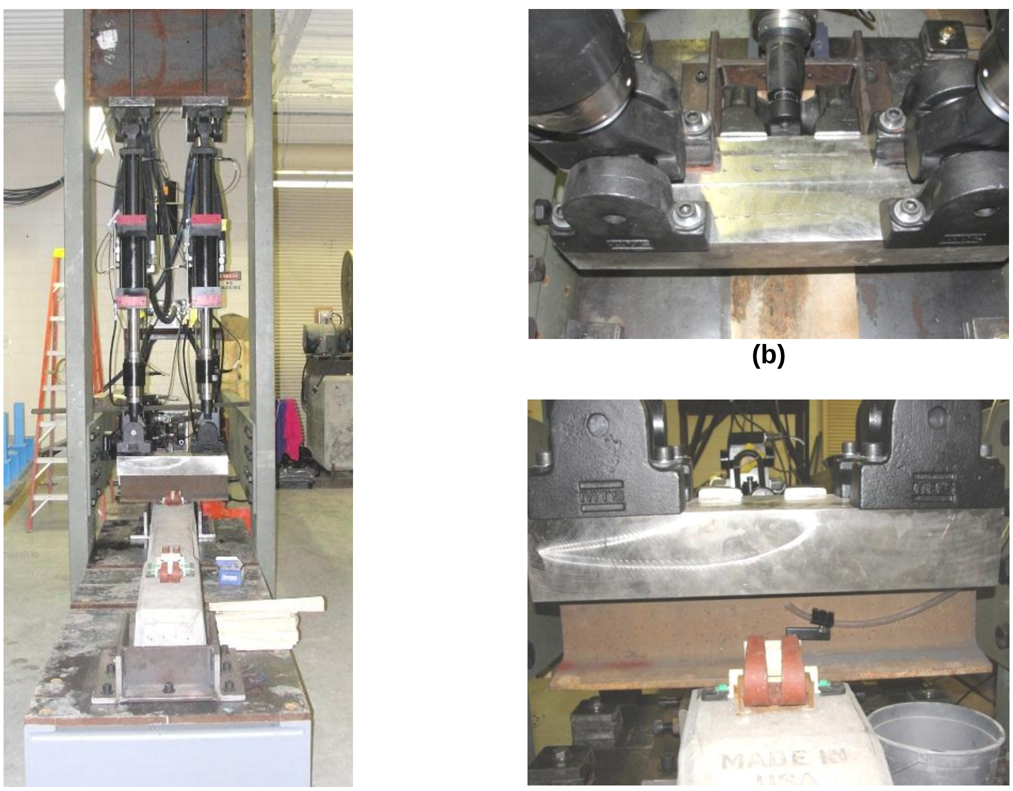
Additionally, modern elastic fastening systems are also designed to operate in conjunction with railway signaling systems. In areas where track circuits are used, the fastening system should provide electrical insulation for the rail (relative to the sleeper) in order to provide electrical impendence, which is accomplished through the use of insulators typically made from high strength polymers and nylons. Sleepers should also facilitate load attenuation to minimize the pressures exerted on the ballast at the bottom of the sleeper and mitigate impacts from vibration, which may lead to abrasion and crushing damage of fastener components and the rail seat.

Concrete Sleeper and Fastening Research at the UIUC

Research aimed at gaining a greater understanding of the mechanisms behind rail seat deterioration (RSD) is currently underway at the University of Illinois at Urbana-Champaign (UIUC). Specifically, research to investigate the moisture-driven mechanisms including hydraulic pressure cracking, cavitation erosion, and hydro-abrasive erosion have been thoroughly investigated using models and experimental testing (*4, 5, 6, 7*). Future research will be directed at investigating the mechanism of abrasion, thought to be a primary contributor to RSD.

Additionally, full scale concrete sleeper and fastening system research and testing is underway at UIUC's Advanced Transportation Research and Engineering Laboratory (ATREL) (*8).* Concrete sleeper and fastener testing equipment at ATREL includes a Pulsating Load Testing Machine (PLTM), which has the capability of objectively comparing the overall performance of the concrete sleeper and fastening system while changing key variables including the fastening system type, rail pad materials and geometry, rail seat surface treatment, concrete mix design, and the overall sleeper design. This research is sponsored by Unit Rail, Inc., a subsidiary of Amsted Rail, Inc., and focuses on continued development of the captive clip insulator assemblies, which are installed at the sleeper manufacturing plant. In addition, the testing focuses on the post insulator and abrasion resistant rail pad assembly design.

The PLTM consists of three 35,000 pound (lb) actuators with a 10-inch stroke (Figure 2). Its purpose is to simulate severe load conditions on concrete sleepers using AREMA Test 6 (Wear and Abrasion) to test the performance and durability of different fastening system components and determine an optimal level of load attenuation and rail pad durability, while reducing rail seat pressures.



(a) (b) (c)

Figure 2: (a) Full scale concrete sleeper and fastening system testing at UIUC,
(b) Vertical and lateral actuators connected to the loading head,
(c) The loading head at rest of the head of the rail, with the fastening system applied

Preliminary Results

Rail Seat Surface Treatments

Rail seat surface treatments are used for two purposes in North America. The first purpose is to repair the rail seat of a concrete sleeper with RSD using an epoxy or urethane based product to repair ties. The second purpose, adopted by at least one railroad, is to apply a thin membrane of an epoxy-based product at the sleeper manufacturing plant. This thin membrane theoretically seals the rail seat from moisture and abrasive fines, mitigating rail seat abrasion.

Preliminary results from the full-scale concrete sleeper testing and research at UIUC's ATREL, using different types of fastening systems and rail seat treatments, have shown that all rail seat surface treatments have failed to resist wear after extended loading cycles. After completion of each three-million-cycle test with epoxy treated rail seats, the epoxy on the field side has entirely worn away from the rail seat (Figure 3). Once the rail seat surface treatment is worn away from a portion of the rail seat, the fastening system behavior could be adversely affected due to the relative decrease in rail seat height with respect to the fastening system shoulder. This decrease in height could reduce the clamping force, thus leading to increased component movement and subsequent wear. Furthermore, the worn epoxy within the rail seat may also generate abrasive fines that have the potential to cause increased abrasion on rail seat pads and insulators. Further testing is needed to validate the preliminary results described in this section.

Figure 3: Worn rail seat surface treatment on the field side after 3 million cycles

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. 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 or mitigation of RSD.

Future Research

Future research in the area of rail seat deterioration (RSD) on 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, which is currently underway. 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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