U.S. Department of Transportation
Federal Railroad Administration

RESEARCH RESULTS
FRA OFFICE OF RESEARCH, DEVELOPMENT & TECHNOLOGY

RR 24-11 | **September** 2024

RAILROAD SPIKE FAILURE MITIGATION: INVESTIGATION OF TIE PLATE HOLD-DOWN ELEMENTS

SUMMARY

The Rail Transportation and Engineering Center (RailTEC) at the University of Illinois Urbana-Champaign (UIUC) investigated methods to mitigate timber tie spike failures. This research is part of an ongoing investigation sponsored by the Federal Railroad Administration (FRA) that began in 2018.

Through modeling, laboratory study, and field work, RailTEC's team found that maintaining friction between tie plates and ties significantly reduces the spike load (Khachaturian et al., 2022). Installing screw spikes with spring washers can ensure friction is maintained in the fastener; however, the resiliency of the spring washer is critical to achieving long-term performance (Stuart and Dersch, 2022).

This report discusses design recommendations for screw spike spring washers and quantifies the resiliency of alternative spring types. The data show that installation of commercially available springs can overstress the tie leading to premature failure. Alternative springs are available that provide greater resiliency without overstressing the wood tie.

BACKGROUND

Prior research detailed the location and extent of the spike failures, how to inspect for them, and the mechanisms that cause failure (Roadcap et al., 2024). In most instances, the spikes in elastic fastening systems fail in fatigue. A subsequent laboratory investigation found that plate uplift during a train pass reduces plate-to-crosstie friction and can result in spikes handling 100 percent of the longitudinal and lateral loads (Dersch et al., 2020).

Researchers discovered that maintaining a 1,000 lb. hold-down force per spike to maintain friction between the tie plate and tie reduced spike stress by 70 percent. A field test of screw spikes installed with a double-helix fe-6 spring washer revealed improved performance compared to a non-spring washer system after a 170 million gross ton (MGT) dynamic test (Stuart et al., 2020).

Despite this positive test result, one North American heavy axle load (HAL) railroad had previously found broken spikes after installing spring washers. An investigation of these springs revealed a very low (0.05 inch) resiliency when installed. The installation force (15,700 lb.) also exceeded the limits of the wood tie fibers. These characteristics may result in premature failure of the system (Khan et al., 2024b).

OBJECTIVES

This project had two primary objectives. First, the team worked to develop design and performance recommendations for springs used with screw spikes to maintain tie plate to tie friction. Second, the team conducted testing to quantify the resilience (i.e., working range and long-term stress relaxation) of alternative types of spring washers.

METHODS

RailTEC quantified the working range and long-term stress relaxation of 10 spring washers that met the geometric criteria for installation under spike heads. The working range is defined as the spring displacement when unloading from a maximum installation-force to minimum hold-down force (e.g., 5,000 to 1,000 lb.). To quantify the working range, the team completed pseudo-static compressive load experiments and collected force-displacement data, as shown in Figure 1.

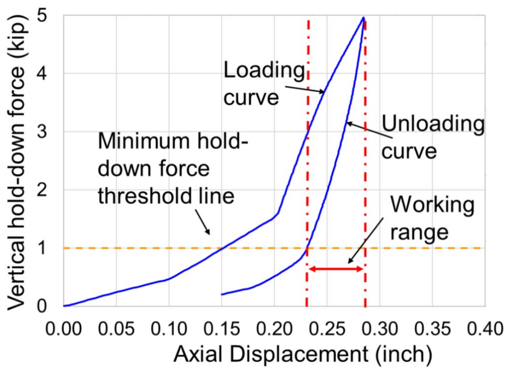

Figure 1. Example force-displacement plot illustrating parameters of interest

To quantify long-term stress relaxation of the spring washers, researchers installed a spike and a spring washer into pre-drilled tie-block holes and recorded the hold-down load over 1,000 hours (Figure 2) (Khan et al., 2024a).

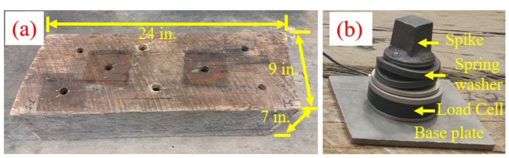

Figure 2. (a) Pre-drilled spike holes in a tie block and (b) Spike installed with fe-6 spring washer and load cell for continuous load measurement

RESULTS

The team established spring washer geometric criteria based on the dimensions of standard screw spikes and tie plates to avoid interference between adjacent spikes. The inner diameter must be at least 1 inch and the outer diameter and installed height must be less than and 2 and 1 ¼ inch, respectively (Khan et al., 2024b).

Researchers recommend a maximum spring washer hold-down force of 5,000 lb. to protect the timber against excessive stress. This is based upon the Railway Tie Association (RTA) guidance for spike retention, actual tie pullout strengths, and long-term load retention data. The team found that the fe-6 washer (14 replicates) applied excessive hold-down force when installed at the manufacturer-recommended installation level of 0.08-inch gap between the spring coils. This force exceeded the pullout values obtained from three sources: lab tests (blue in Figure 3), design values from National Design Specifications for wood construction (green), and textbook values from *Wood Engineering* by Gurfinkel (orange).

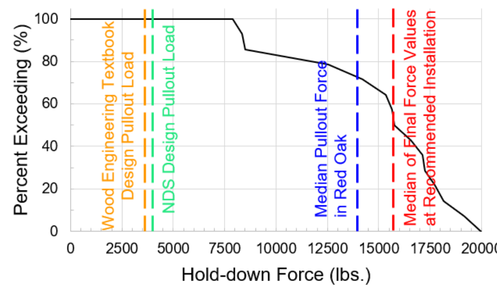

Figure 3. Hold-down force distribution of fe-6 spring washers using recommended installation procedures

The team also recommends a 1,000 lb./spike minimum hold-down force since it provides a ~70 percent reduction in spike stress (Dersch et al., 2020). To maintain adequate friction over time and accommodate plate cutting, typical wear, and screw loosening, a minimum working range of 1/8 inch is recommended.

Figure 4 shows the working ranges of all spring washers tested. The fe-19 and polyurethane washers outperformed other washers by offering 0.093, 0.106 (single) and 0.215 (double-stacked) inch working ranges. When compared to the fe-6 washer, the fe-19 and double-stacked polyurethane increased the working range by 69 and 300 percent, respectively, while also reducing the stress by 67 percent.

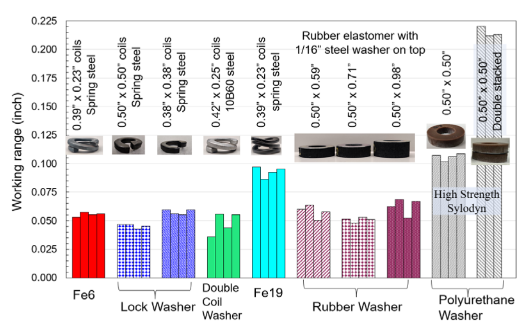

Figure 4. Working range of potential spring washers (each bar with same color & pattern represents test replicates)

Stress relaxation experiments quantified the effects of timber tie species, spring washer type, and installation loads individually. Figure 5 presents the load retention at the end of the 1000-hour period as a percentage of initial load.

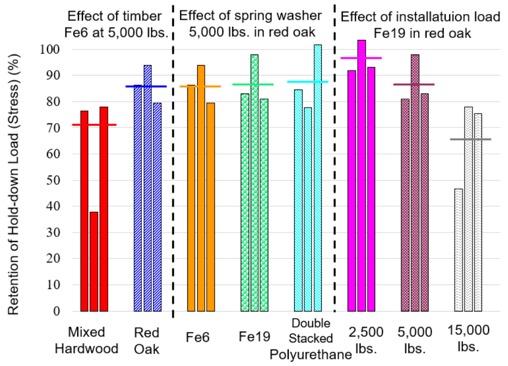

Figure 5. Hold-down load retention 1,000 hours after installation (horizontal lines indicate mean values)

Some of the results revealed significant differences. The red oak ties outperformed the mixed hardwood with 86 percent load retention versus 71 percent. As the installation loads for red oak increased, the load retention values decreased from 96 to 67 percent, indicating a measurable sensitivity in the system.

The effect of the spring working range was insignificant. Small, medium, and high working range springs all retained approximately 87 percent of their hold-down loads.

The 1000-hour (42 days) period is very short. Figure 6 illustrates the decay of the hold-down load of an fe-19 washer in red oak over the first approximately 100 days after installation at 15,000 lb. The relaxation of the system continued with time. Assuming a logarithmic trendline, the relaxation is expected to continue for 340 days with a residual load of approximately 4,060 lb., or 27 percent of the installed load).

These data appear to support the experience the HAL railroad encountered after installing spring washers (as noted in the Background section above); however, this behavior warrants further study.

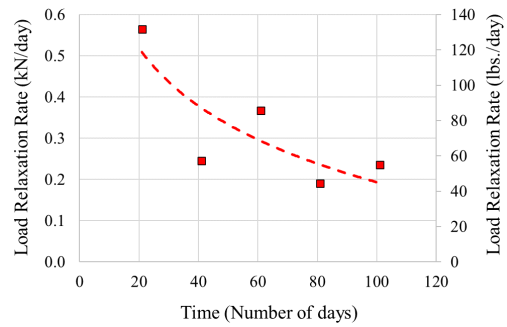

Figure 6. Decay of load reduction rate of a fe-19 washer-loaded spike in a red oak tie block

CONCLUSIONS

The RailTEC team established geometric design and performance criteria for spring washers and identified two spring alternatives with improved resiliency. The fe-19 and double-stacked polyurethane washers offered 0.093 and 0.215 inch of working range, respectively. Tie species and installation load level variables significantly impacted the residual hold-down force after 1000 hours. Red oak ties and lower installation loads produced better results. An initial analysis of long-term relaxation performance indicated that these spring systems continue to relax over time, which may negatively impact the system's ability to maintain the tie-to-plate friction that is critical to reducing spike loads.

FUTURE ACTION

RailTEC researchers developed a unique plate hold-down device that retains the plate to the tie without over-stressing the wood fibers. This device will validate the laboratory results that indicate the critical role plate-to-tie friction plays in reducing spike loads. Future plans include installation of this system along with a selection of spring washers in a controlled test on revenue service track.

REFERENCES

Dersch, M.S., Khachaturian, C., & Edwards, J.R. (2021). Methods to Mitigate Railway Premium Fastening System Spike Fatigue Failures Using Finite Element Analysis. *Engineering Failure Analysis, 121*, 105-160.

Khachaturian, C., Dersch, M.S., Edwards, J.R., & Trizotto, M. (2022). Quantification of Longitudinal Fastener Stiffness and the Effect on Fastening System Loading Demand. *Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit*, *237*(3), 347-355.

Khan, R.M., Dersch, M.S., & Dunn, A.C. (2024a). Quantification of Stress Relaxation in a Timber Fastening System: A Railway Focused Study. *European Journal of Wood and Wood Products, 82*, 1213–1225.

Khan, R.M., Dersch, M.S., & Dunn, A.C. (2024b). Design and laboratory evaluation of spring washers as railway baseplate hold-down method to mitigate spike failures. *Engineering Failure Analysis, 164*.

Roadcap, T., Dersch, M.S., & Edwards, J.R. (2024). *Mechanistic Investigation of Timber Crosstie Spike Fastener Failures – Phase I: The Magnitude of The Spike Failure Challenge* (Report No. DOT/FRA/ORD-24-06). Federal Railroad Administration.

Stuart, C. & Dersch, M.S. (2022). *Screw Spike and Spring Washer Hold-Down Force and Resiliency Investigation* (Report No. RR 22-30). Federal Railroad Administration.

Stuart, C., Dersch, M.S., & Edwards, J.R. (2020). *Timber Crosstie Spike Fastener Failure Investigation: Field Evaluation of an Alternative Fastener* (Report No. RR 20-24). Federal Railroad Administration.

ACKNOWLEDGEMENTS

The authors thank Norfolk Southern, Union Pacific, BNSF, CSX, Pandrol, CN, Vossloh North America, and Progress Rail for their industry partnership.

CONTACT

Cameron Stuart
Program Manager
Federal Railroad Administration
Office of Research, Development, and Technology
1200 New Jersey Avenue, SE
Washington, DC 20590
(202) 493-6384
cameron.stuart@dot.gov

Marcus Dersch, Ph.D., P.E.
Senior Principal Research Engineer
RailTEC at UIUC
Civil and Environmental Engineering
205 N. Mathews Ave, rm 1243
Urbana, IL 61801
mdersch2@illinois.edu

Rahat Mahmud Khan
Graduate Research Assistant
RailTEC at UIUC
Civil and Environmental Engineering
205 N. Mathews Ave, rm B118
Urbana, IL 61801
rmkhan2@illinois.edu

KEYWORDS
Broken spikes, spring washers, spring specifications, hold-down load, resiliency, elastic fasteners, stress relaxation

CONTRACT NUMBER
693JJ6-22-P000006