

## Measurement of Damping Characteristics for Ballasted Track with Subgrade Improvement Layers

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### Summary

Tests measuring the damping characteristics of ballasted track test sections with various subgrade improvements indicate that Geoweb™ offers higher damping characteristics than hot mix asphalt or reinforced slab concrete. The tests were conducted by Transportation Technology Center, Inc. (TTCI) under a project to improve the performance of special track work sponsored by the Association of American Railroads.

TTCI evaluated the effect of typical foundation improvements under turnout and crossing diamond frogs on damping. Previous work has suggested that optimizing the track damping under high-angle frogs could reduce the maximum vertical loading by up to 30 percent from the conditions thought to exist in the field.<sup>1</sup> Subgrade improvement layer test sections included a reinforced concrete slab, hot mix asphalt (HMA) pavement, a subballast cellular confinement system (Geoweb), and a subballast control section.

There are differences in the damping characteristics of the four test sections. The Geoweb section had the highest damping; but this section still had less damping than the theoretical optimal value. TTCI has developed and refined a method for field measurement of damping in ballasted track. The method uses an impact hammer and accelerometer system to excite the track and measure its response. Modeling of the track response in NUCARS, TTCI's vehicle-track dynamics model, to reproduce the field data provides an estimate of the damping characteristics of the track.

#### Suggested Distribution:

- Maintenance of Way
- Planning & Analysis
- Track Maintenance
- Safety



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## INTRODUCTION AND CONCLUSIONS

The life expectancy of conventional crossing diamonds operated under HAL traffic is dramatically shortened compared to that under 100-ton or mixed-freight operations. Testing at FAST, under 39-kip wheel loads, has shown that conventional diamonds have very short lives (i.e., 5-15 MGT). Unlike turnouts, the use of premium components in conventional designs does not restore the average life to what it was under 33-kip wheel loading. Thus, methods to reduce impact loading are considered essential to improving the life cycle costs of crossing frogs under HAL traffic.

One method being explored to reduce dynamic loading at high angle frogs involves foundation design. Using TTCI's vehicle-track dynamics model NUCARS, TTCI determined the effects of track stiffness and damping on maximum vertical dynamic loading for high-angle crossing diamonds.<sup>1</sup> The effect of track stiffness on maximum vertical load for a loaded freight car going over an unsupported flangeway gap is relatively small. However, the effect of track damping is more significant, with up to a 30 percent reduction in maximum load likely over the range of values expected in the field.

Little data exists on the actual damping characteristics of track. However, in an earlier study, an attempt was made to estimate the damping resistance of railway tracks.<sup>2</sup> The model used then was a "beam on Kelvin foundation"; i.e., the rail was assumed to be continuously supported as against the discretely supported rail ("on Winkler foundation") as it really is. Also, the frequency range was low (up to 80 Hz). Moreover, the track damping was assessed as damping ratio; i.e., a percentage of critical damping. As such, extent of the mass of the track participating in a certain vibration mode was unknown. Practical methods to measure ballasted track damping in the field were unknown.

TTCI developed a method of measuring damping for ballasted track using an impact hammer, track response measuring accelerometers, and track response modeling. While this system is not a real time production measurement device, it is a useful research tool that will assist the industry in developing special track work foundation design policies.

In 1999, TTCI built four track sections in the High Tonnage Loop of FAST for special track work foundation tests. These sections consist of a subgrade improvement layer between the ballast and native subgrade. The test sections were constructed on the existing sandy silt subgrade. Each test section has 6 inches

of compacted subballast underlying the test layer. The test layers are 8 inches of HMA rolled and compacted in two lifts, 12 inches of reinforced concrete cast in place, 8 inches of subballast reinforced with a Geoweb cellular confinement system, and 8 inches of conventional subballast. Twelve inches of ballast was placed above the test layers in all sections except the concrete slab. This section received 8 inches of ballast to account for the extra 4 inches of test layer. Conventional hardwood ties and 136RE rail were placed above the ballast layer. The rails were fastened with eight cut spikes per tie.

Previously reported results showed that available subgrade improvement techniques are effective at stiffening the track.<sup>3</sup> Additionally, there are differences in the damping characteristics of the four test sections. The Geoweb section had the highest damping; but this section still had less damping than the theoretical optimal value. While the Geoweb layer increased damping by 24 percent, it only moved the track section 14 percent closer to the predicted optimal value.

TTCI has developed and refined a method for field measurement of damping in ballasted track. The method uses an impact hammer and accelerometer system to excite the track and measure its response. Modeling of the track response in NUCARS to reproduce the field data provides an estimate of the damping characteristics of the track.

Significant findings include:

- Typical ballasted track has a damping value of 111 lbs/in/sec per tie. This is below the predicted optimal value of 300 lbs/in/sec/tie needed to minimize frog flangeway gap dynamic loading.
- Of the typical subgrade improvement methods tested, the Geoweb was able to increase track damping (as compared to the control section) the most, by about 27 lbs/in/sec, or 24 percent to a total of 138 lbs/in/sec. The 8-inch HMA pavement did not significantly affect track damping (110 lbs/in/sec) and the 12-inch concrete slab decreased damping by 30 percent to 78 lbs/in/sec.
- The impact hammer/ accelerometer field measurement method combined with NUCARS simulation is effective in determining the damping characteristics of ballasted track. A preload is needed for wood tie, cut spike fastener track to eliminate any track structure gaps (e.g., between rail and tie).

- Three vertical track vibration modes were found:
  - Vibration of rail and ties on the ballast (rail-tie in-phase) at about 200 Hz.
  - Vibration of rail on the ties (rail-tie anti-phase) at about 500 Hz.
  - Vibration of rail due to its own elasticity (pinned-pinned) at about 1300 Hz.
  
- The dynamic stiffnesses of the test sections, as instantaneous response to the velocity shock from hammer impact, were considerably higher than the static stiffnesses. Static stiffness, on the other hand, arises from a gradual application of load. Measured static track moduli were 2600 to 3500 lbs/in/in for the four test sections. Calculated dynamic moduli were from 18,000 and 22,000 lbs/in/in.

**TRACK DAMPING MEASUREMENTS**

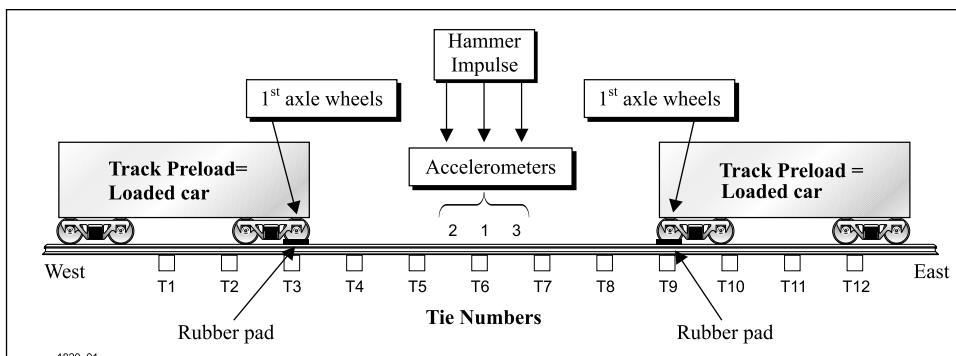
Measurements of the track response were made using an instrumented impact hammer and a system of 11 accelerometers, as Exhibit 1 shows. While 11 accelerometers are not needed to determine the response of the track, the track preload is essential. This preload takes the “slop” out of the track, making the actual track more like the track in the dynamics model used.

Each test section was modeled in NUCARS to replicate the track response measured in the field. By varying the damping in the model, the actual track

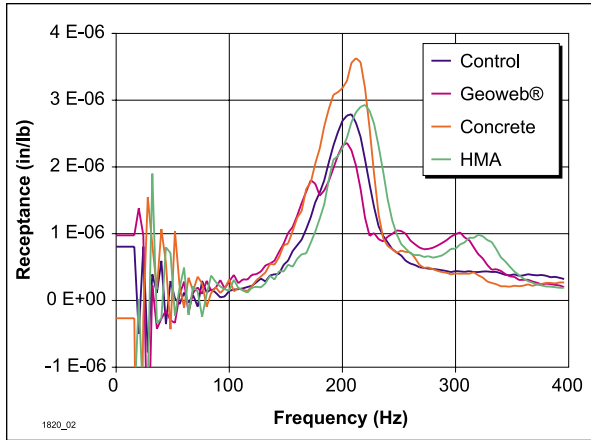
response was obtained. In this manner, the damping of each section was estimated.

**DAMPING TEST RESULTS**

Subgrade improvement affects the ballast characteristics. Since the rail-tie in-phase vibrations are affected mainly by the ballast characteristics, a comparison of receptances (track deflection per unit load) pertaining to this fundamental mode of track is given in Exhibit 2. These receptances were obtained by analyzing the data of vertical track vibrations in the hammer tests. The resonant frequency in this fundamental mode varies from about 204 Hz for the track with Geoweb layer to about 224 Hz for the track with HMA pavement. Stiffer track vibrated at a higher frequency. Even though the differences in the resonant frequencies are quite small, it can still be seen from the results in this exhibit that the Geoweb layer rendered the track somewhat softer in comparison to the control track, while both the concrete slab and HMA pavement made the track relatively stiffer. HMA pavement appeared to make the track stiffest. Tracks with HMA pavement had a 12-inch-thick layer of ballast in contrast to the 8-inch-thick layer of ballast for track with concrete slab. Also, it appears that the grip between ballast and HMA pavement is greater than that between ballast and concrete slab; i.e., the ballast confinement was greater on HMA pavement than the concrete slab.

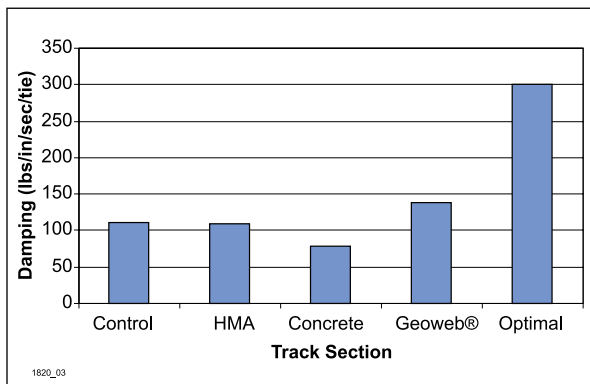


**Exhibit 1. Track Damping Impact Test Setup**



**Exhibit 2. Test Results of Rail-Tie In-Phase Vertical Vibrations: Comparison of Receptances on Crib Location (Position 2) due to Hammer Hit on Crib Location (Position 2)**

Since damping mainly affects the magnitude of the receptance, it is obvious that track with the Geoweb layer provided more damping than the control track. On the other hand, tracks with concrete slab and HMA pavement resulted in less damping. Track with concrete slab appeared to provide the least damping.



**Exhibit 3. Track Damping Measurement Results**

Exhibit 3 shows calculated damping values for each section. The results suggest that the Geoweb subgrade reinforcement system added damping to the track; whereas, the concrete slab reduced damping. The HMA section had damping characteristics similar to the subballast control section.

### FUTURE WORK

All test sections have damping values below the predicted optimal value. Thus, additional methods of increasing track damping will be explored. These include modifications to the track superstructure, such as tie pads.

### REFERENCES

1. Singh, Satya and Davis, David, "Reducing Impact Forces on High-Angle Crossing Diamonds," AAR *Technology Digest* 98-021, August 1998.
2. El-Sibaie, "On the Component of Track Damping Resistance and Related Damping Measurements," AAR, Report No. R-753, January 1990.
3. Davis, David, Singh, Satya, and Guillen, Don, "Evaluation of Foundations for Special Track Work," AAR *Technology Digest* 00-023, November 2000.

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