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Laboratory Evaluation of Polyurethane-Treated Ballast for Rail Joints

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Summary

The potential benefits of using polyurethane-treated ballast under rail joints were evaluated by the Transportation Technology Center, Inc. (TTCI) under the Association of American Railroads Strategic Research Initiatives Program. This document discusses the laboratory test results conducted on two types of polyurethane-treated ballast. For rail joint foundation applications, the objectives are to reduce degradation of ballast particles and to increase damping.

The tests showed both types of polyurethane-treated ballast provided about 20 percent higher damping than compacted untreated ballast. It is unclear whether this gain in damping properties (i.e., the ability of the track to absorb energy or reduce oscillations in a vibrating system) will provide significant improvements in rail joint service life. In general, it is believed that rail joints are underdamped. Thus, adding damping will improve performance. It is unclear what level of improvement is needed to significantly increase service life. Sieve analysis results of untreated ballast and treated ballast also showed that the treated ballast particles experienced more degradation than untreated ballast. The laboratory tests were conducted up to 1,000,000 cycles and may not represent long term in-track performance.

The laboratory tests showed that polyurethane-treated ballasts had significantly lower damping than untreated ballast immediately after construction. However, untreated ballast can quickly lose damping after construction or tamping. The tests showed that the three test ballasts had similar damping values after 100,000 load cycles. For the duration of the 1,000,000 cycle load test, the polyurethane-treated ballasts had about 20 percent higher damping than untreated ballast.

Test results showed the loaded deflections were higher in the polyurethane-treated ballast than in the untreated ballast. The apparent reason is deformation of the polyurethane between the ballast particles. Unlike untreated ballast, deflections in treated ballast increased nearly linearly with the number of load cycles. The deflections of untreated ballast remained constant after initial settlement.

Sieve test results before and after loading showed that degradation actually increased in polyurethane-treated ballast.

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INTRODUCTION

This *Technology Digest* discusses the laboratory test results conducted on two types of polyurethane-treated ballast. For rail joint foundation applications, the objective is to reduce degradation of ballast particles and increase damping.

Both types of polyurethane-treated ballast provided about 20 percent higher damping than compacted ballast. It is unclear whether this gain in damping properties will provide significant improvements in rail joint service lives. Sieve analysis results of untreated ballast and polyurethane-treated ballast showed that the treated ballast particles experienced more degradation than untreated ballast. The laboratory tests were conducted up to 1,000,000 load cycles and may not represent long term in-track performance.

BACKGROUND

A rail joint when assembled has joint bars that alter the stiffness of the track at the rail joint location. Also, there is a gap between the ends of the two rails, which changes with ambient temperature variations. The gap causes wheel impacts. Both of these factors accelerate ballast degradation under and around the rail joint, which results in unequal track settlement. Thus, as a result, under the same loading, the track at the joint has higher deflections.

The traditional solutions to this problem do not address the root causes of higher surface degradation rate. They involve “peaking” (i.e., starting with the joint higher than the surrounding track) and more frequent ballast surfacing. Both of these methods are short-term solutions and may actually accelerate the ballast degradation under the joint. Over time, peaking and ballast surfacing cycles become shorter, causing network reliability and capacity issues. Since the surrounding track components also generally deteriorate due to a low joint, a joint bar or rail break has a potential for a higher derailment risk than surrounding track.

Geosynthetics has been studied to improve performance of ballast.[1] Most applications have objectives to mitigate noise and ground vibration. For heavy axle load freight applications, an additional goal of foundation stability is sought.

APPROACH

Three ballast box samples were prepared using untreated ballast, ballast with polyurethane A (Figure 1) and ballast with polyurethane B (Figure 2). Dimensions of all boxes and material volumes were similar. The following tests were conducted on each sample box:

- Cycling load test to evaluate the effect of repetitive loading
- Hammer test to measure damping
- Sieve analysis to measure the extent of particle degradation

Cyclic Loading Test

TTCI conducted cyclic loading tests of three ballast boxes. The tests were performed to evaluate the dynamic repetitive load and deflection relationship. In addition, the data was used to calculate damping characteristics of untreated and treated ballast. The first box contained untreated ballast and served as the control for the test. The other two boxes, Polyurethane Box A and Polyurethane Box B, were treated with two different chemical formulas and consistencies.

Figure 1. Polyurethane Box A

Figure 2. Polyurethane Box B

Each box was subjected to compressive loads of 29,000 pounds at a rate of 1.5 hertz (Hz). The loading simulates the loading of a 36-ton axle load with a 100 percent dynamic load factor on a single rail seat. The boxes were tested to 1,000,000 cycles. (An accumulated load of 1,000,000 cycles is roughly equal to 36 million gross tons of traffic.) A small concrete tie section was used to transfer the compressive load to the ballast, as Figure 3 shows. The total cycle count was measured continuously throughout the test. Tie deflection as a function of applied loading was measured for 5 minutes at load cycles 10, 100,000, 300,000, 500,000, 700,000, 900,000, and 1,000,000.

Figure 4 is a typical load versus deflection hysteresis and showing one cycle at each of these intervals.

Damping was calculated for the ballast boxes by determining the total energy dissipated during a complete load cycle. Each load cycle in the test produced a hysteresis loop in the load-deflection curve. Assuming that damping was the primary source of energy dissipation in the system, the area encompassed by one cycle of the load-deflection curve equals the energy dissipated by the ballast due to damping.

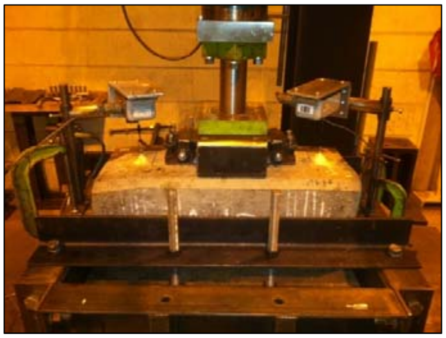

Figure 3. Test Setup in Cyclic Load Machine

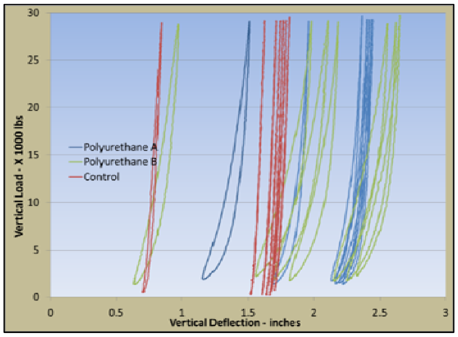

Figure 4. Typical Load-Deflection Hysteresis showing One Cycle at Each of the Intervals

The area encompassed by each hysteresis loop was calculated using trapezoidal approximations of the areas under the loading and unloading curves. Each load-deflection curve consisted of two halves: the upper loading curve and the lower unloading curve. The areas under each half of the loop were divided into smaller trapezoidal areas based on the number of samples in the cycle. Both sets of trapezoidal areas were summed to find the total area under each half of the load-deflection curve. The area inside the hysteresis loop was then determined by subtracting the area under the unloading curve from the area under the loading curve. Figure 5 shows an example of a load-deflection loop.

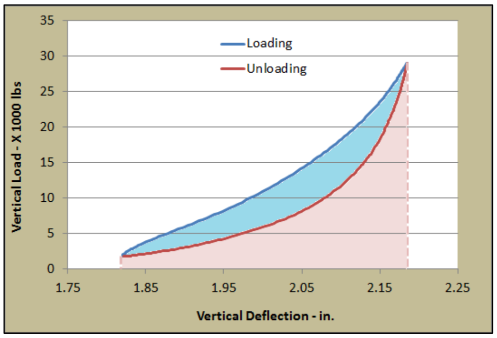

Figure 5. 500,000th Load Cycle for Polyurethane Box B

Ballast damping in the test was assumed to be hysteretic and independent of the load frequency. In real world applications, damping tends to be weakly correlated with frequency, if not completely independent of it.[2] This assumption allows the ballast boxes to be idealized as hysteretic dampers. Thus, the results can be used to compare the three materials in the test.

Hysteretic damping constants were calculated for each hysteresis loop using measured displacements and estimated energy dissipation. The following equation shows this relationship and was used in the calculations:

$$h = \frac{\Delta U_h}{\pi {x_0}^2}$$

where: h = *hysteretic damping constant*
ΔU_h = *energy dissipation in a single load cycle*
x_0 = *maximum displacement in a single load cycle*[3]

Figure 6 shows a plot of hysteretic damping values calculated for the ballast boxes.

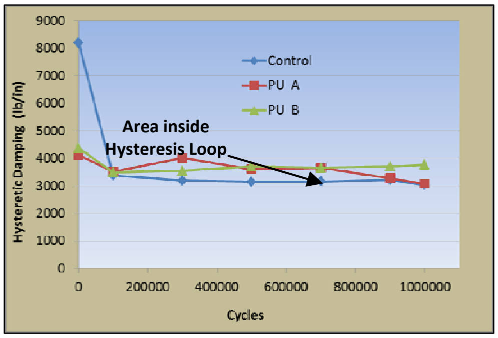

Figure 6. Hysteretic Damping Constants

Hysteretic dampers, similar to the ballast in the cyclic tests, can be represented as equivalent viscous dampers in systems using the following equation:

$$c = \frac{h}{\omega}$$

where: c = *equivalent viscous damping constant*
h = *hysteretic damping constant*
ω = *load frequency*[3]

Equivalent viscous damping constants were computed for the three ballast boxes using previously calculated hysteretic damping values. Figure 7 show the viscous damping values of each ballast box at various cycles. The box containing untreated ballast had much higher damping initially, but decreased by over 50 percent after only 100,000 cycles. Polyurethane Boxes A and B had lower damping initially than the untreated ballast box, but maintained more consistent damping up to 1,000,000 cycles.

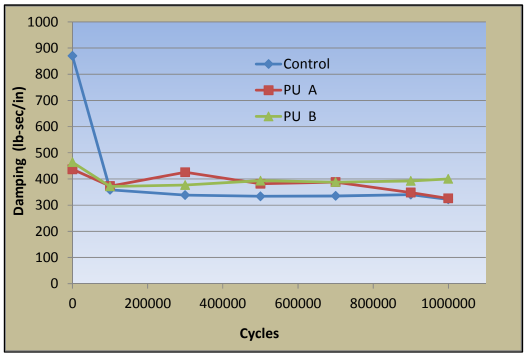

Figure 7. Equivalent Viscous Damping

Damping ratios were calculated for the ballast boxes (Figure 8) using stiffness and damping values from each load cycle. The following equation illustrates this relationship:

$$\zeta = \frac{h}{k}$$

where: ζ *= damping ratio*
h *= hysteretic damping constant*
k *= average stiffness of the hysteresis loop*[3].

The stiffness of the ballast was estimated as the average slope of the hysteresis loop. However, the hysteresis loops of the polyurethane boxes were distinctly nonlinear. The loops usually displayed a stiffness change at the midpoints of the loading and unloading curves (Figure 5). The average slope of hysteresis loops may not accurately indicate the ballast stiffness in these cases. Thus, we can conclude that polyurethane did increase damping over the control ballast. However, differences in damping ratio between Polyurethanes A and B may not be as significant due to the method of measurement.

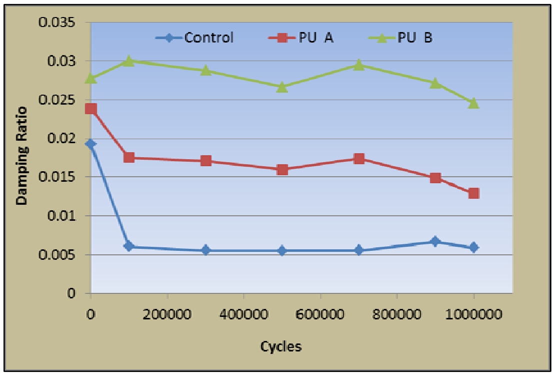

Figure 8. Damping Ratios

Hammer Test

TTCI also conducted hammer tests of the three ballast boxes to determine the damping of each ballast mixture. A steel block section was placed on top of the ballast in the box to simulate the presence of a tie. The block was vertically preloaded with 5,000 pounds by compressing two springs located at each end. An instrumented hammer was used to measure the excitation force, and four accelerometers were used to measure the vibrational response of the system. Figure 9 shows the accelerometers placed in an L-shaped array on top surface of the steel block.

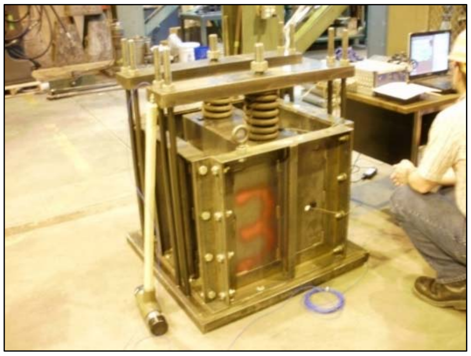

Figure 9. Hammer Test Setup

Each instrumented hammer strike impacted the center of the tie's top surface with approximately 3,000 pounds of force. Excitation results of the hammer was a bell curve for Polyurethane Boxes A and B. However, the untreated box showed a blip, which divided the bell curve into two. This was likely due to the stiffness difference of hammer box fixture, and it made the damping calculation unusable for comparing materials in this test.

Sieve Analysis

In order to measure ballast degradation, sieve analysis of all three boxes was conducted before and after 1,000,000 load cycles. Polyurethane Boxes A and B were kept at 1,000 °F until all the polyurethane was burnt off. The cooled ballast was then sieved. Figure 10 shows the results. There is an increase in particles passing the 1-inch sieve in the control ballast (from nil to 15 percent). However, the increase in particles passing the 1-inch sieve was about double (to 30 percent). These particles were produced from breakage of larger particles.

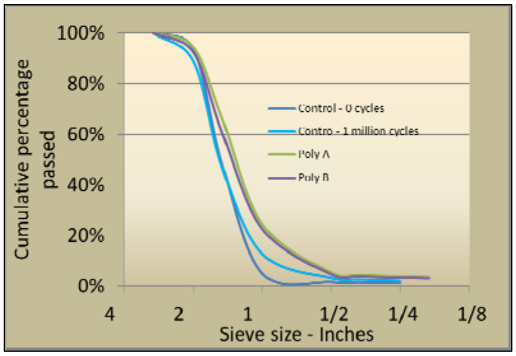

Figure 10. Ballast Particle Size Distribution after 1,000,000 Load Cyles

Conclusions

The laboratory tests showed that polyurethane-treated ballasts had significantly lower damping than untreated ballast after construction. However, untreated ballast can quickly lose damping after loading or tamping. The tests showed that the three test ballasts had similar damping values after 100,000 load cycles. For the duration of the 1,000,000 cycle loading test, the polyurethane-treated ballasts had about 20 percent higher damping than ballast alone.

Test results showed the loaded deflections were higher in the polyurethane-treated ballast than in the untreated ballast. The apparent reason is deformation of the polyurethane between the ballast particles. Unlike untreated ballast, deflections in treated ballast increased nearly linearly with the number of load cycles. The deflections of untreated ballast remained constant after initial settlement.

Sieve test results before and after loading showed that degradation actually increased in polyurethane-treated ballast.

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