

Effects of Heavy Axle Load on Settlement and Degradation of Ballast

by
E. T. Selig, R. R. V. Devulapally and S. M. Chrismer
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Summary

Laboratory tests of ballast were performed to determine the amount of increased ballast damage with heavy axle loadings up to 49 tons. These tests show that ballast settlement under HAL is expected to increase only slightly, therefore tamping frequency should not be significantly affected. However, it is expected that ballast life will be shortened somewhat by HAL. The amount of ballast life decrease should be estimated by the percentage of heavy axle loads expected.

Under the AAR Fellowship Program with the University of Massachusetts, repeated load tests were performed in a ballast box using a dolomite ballast material of relatively low abrasion resistance. Loads were imposed on a wood tie segment laid over a six-inch layer of ballast. Simulated axle loads of 23, 33, 39 (static HAL), and 49 tons were used. The 49-ton axle load was used to simulate the effect of static HAL plus a dynamic component.

The amount of tie settlement after 300 Million Gross Tons (MGT) for each axle load was measured. The trend of total tie settlement with axle load increased at a decreasing rate. This is indicated by the damage coefficient between 0.4 and 0.7 depending on the base stiffness used in the ballast box. Because the damage coefficient is less than one, ballast settlement from HAL is less than proportional to the load increase. Gradation analyses, which were performed before and after 300 MGT of loading for each load magnitude, provide a measure of the amount of ballast breakdown. The presence of fouling material rose at an increasing rate with load magnitude. The damage coefficient for breakdown was 1.5. This indicates that the fouling could be expected to increase proportionally more than the increase in loading.



Association of American Railroads
Research and Test Department



INTRODUCTION AND CONCLUSIONS

To investigate the effects of HAL on ballast settlement and degradation, a series of repeated load laboratory tests were performed on a low strength ballast in a test fixture known as a ballast box. Under the various loads applied, the test data showed that both settlement and breakdown increased with loading. But settlement increased in smaller proportion to the increase in loading, while breakdown increased in larger proportion.

This appears to indicate that HAL will not produce a need for significantly more tamping due to large increases in ballast settlement. However, the larger than proportional increase in ballast particle breakdown with load magnitude may mean that ballast life would be significantly shortened.

BALLAST BOX TESTS

Exhibit 1 shows the ballast box construction and dimensions. Sheet metal over rubber strips were placed on the sides and bottom of the box. The sheet metal provided protection to the rubber and the rubber provided resiliency. To determine if base resiliency had an effect on the measurements, a softer base of two layers of rubber pads was also used and the series of tests performed again. Six inches of AREA Gradation 4 ballast were placed over the base. The ballast had an Abrasion Number of 79 (relatively weak). A wood tie segment was placed on the ballast. The cyclic loads were applied to the top of the tie segment.

To quantify the trend of ballast settlement and breakdown with load magnitude, simulated axle loads of 23, 33, 39, and 49 tons were used. Note that two loads were less than HAL (39 tons) and one load was greater. Because only a tie segment was used, the loads on the tie were scaled down to produce the same ballast stress that would result from the simulated axle loads. The test loads used are shown in Exhibit 2.

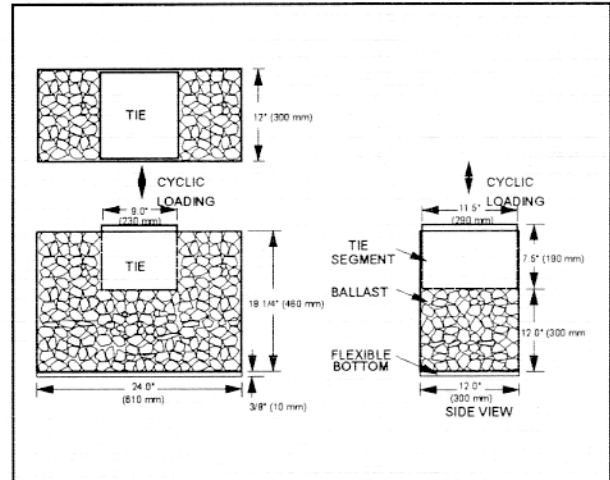


Exhibit 1. Ballast Box.

Car Capacity (ton)	Axle load (ton)	Box Test Load (lb)
70	23	2900
100	33	4200
125	39	4900
Dyn. Effect	49	6200

Exhibit 2. Axle Loads and Box Test Loads for Corresponding Car Weights.

DAMAGE FACTORS

An axle load dependant damage factor is defined as the relative damage associated with increasing axle loads. The damage can be expressed in the form:

$$F = \left(\frac{P}{4200} \right)^n$$



where F is the damage ratio or the ratio of the damage from the box test load (P in lbs) to the reference test load of 4200 lbs. The parameter n is the damage exponent. The other box test loads may be substituted for P in the above equation.

One measure of damage was tie settlement resulting from ballast compression under repeated load. The damage ratio F_s is thus the settlement under load P divided by the average settlement under the 4200 lb load. The settlement damage ratio is plotted against the load ratio in Exhibit 3. A linear regression on a log-log plot was performed to obtain the best fit value of the damage exponent, n .

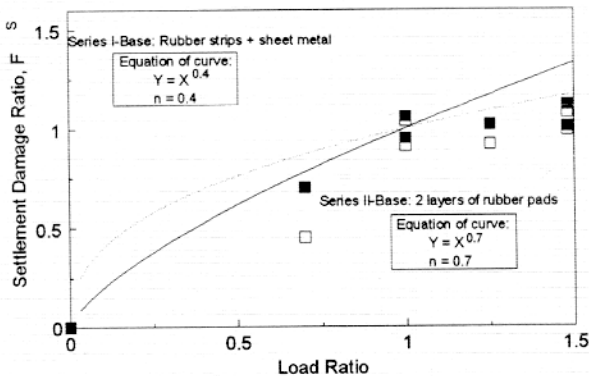


Exhibit 3. Total Settlement Normalized with the Average Total Settlement of Test with 4200 lb Load.

The damage exponent for ballast settlement was 0.4 for the stiffer base and 0.7 for the softer base materials, showing in both cases that settlement increased at a decreasing rate with increasing load magnitude. This suggests that the more flexible the base, the greater is the damage produced with respect to settlement. However, as examination of the data plots suggests, the trends for the two test series are essentially the same. The difference in the damage exponent values appears to be a result of data scatter and may be misleading.

A second measure of damage was ballast breakage

under repeated load. The damage ratio F_d is thus the breakage under load P divided by the average breakage under the 4200 lb load. The breakage damage ratio is plotted against the load ratio in Exhibit 4. The damage exponent of 1.5 shows that fouling material generated increased at an increasing rate with increasing load magnitude.

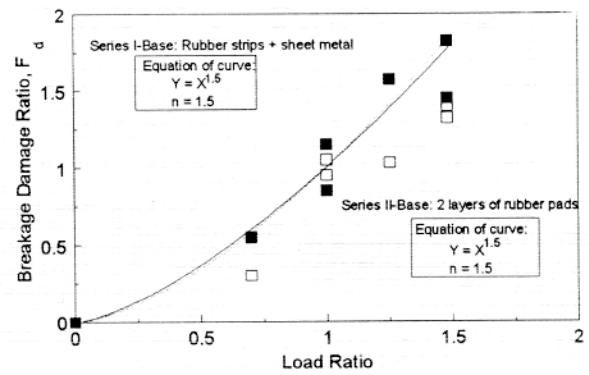


Exhibit 4. Fouling Material Normalized with the Average Fouling Material of Test with 4200 lb Load.

There was no apparent difference between the gradation changes of the two ballast box test series with different base flexibilities. Base stiffness as represented by the two bases used may not be a factor in the breakage of ballast. It is useful to review what other researchers have found regarding increased loading and track maintenance. In some field tests conducted by British Railways, no significant difference in track settlement was observed between 44 and 55,000 lb axle loads. In tests in their track laboratory, British Railways found that settlement increased approximately in proportion to load in the range of 22 to 66,000 lb axle loads.

The German railroad has studied the effect of ballast pressure on maintenance cost and found that the cost increases with the 4th power of ballast pressure. This finding led to the practice of decreasing tie spacing to lower ballast pressure. This reportedly



increased the time between required tamping cycles from 1-2 years to 4-5 year intervals.

The German railroad experience of a maintenance cost increase greater than the load increase may be due to the need to maintain track to a higher standard. If tolerances of track settlement are very small, then a small increase in ballast pressure can result in the situation shown in Exhibit 5. If maintenance is required when a given cumulative strain level is reached, then the maintenance life is proportional to, and the maintenance cost is inversely proportional to, the number of cycles to reach the designated strain. As shown in Exhibit 5, the number of cycles decreases much more rapidly than the stress increases. Therefore, maintenance cost increases much more rapidly than ballast pressure.

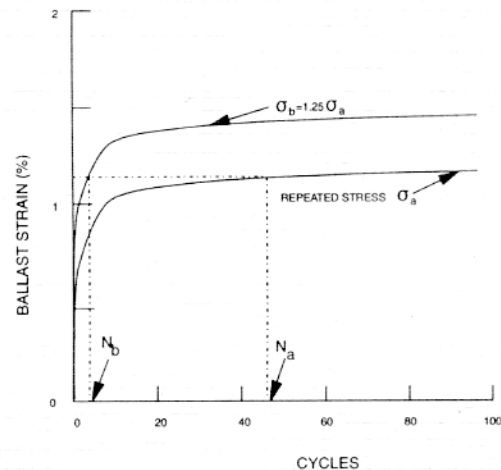


Exhibit 5. Illustration of Nonlinear Relationship Between Ballast Stress and Load Cycles for Common Cumulative Strain.

Note: Contact Steven M. Chrismer (312) 808-5848 with questions or comments about this document.

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