Transportation Test Center

FAST/HAL BALLAST AND SUBGRADE EXPERIMENTS

AAR REPORT R-788
FRA/ORD-91/10

ASSOCIATION OF AMERICAN RAILROADS

U.S. Department of Transportation
Federal Railroad Administration

Facility for Accelerated Service Testing
Heavy Axle Load Program

FAST/HAL BALLAST AND SUBGRADE EXPERIMENTS

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by

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DISCLAIMER

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13. Abstract

The ballast and subgrade experiments were conducted during the first 160 MGT of Heavy Axle Load (HAL) traffic to determine if the increase in axle load, 33-ton to 39-ton, generated a measurable difference in the performance of the four selected ballasts and the typical subgrade found at the Facility for Accelerated Service Testing (FAST), Transportation Test Center, Pueblo, Colorado.

Dolomite, limestone, granite, and traprock were tested to determine their capability of supporting traffic in a 39-ton axle load traffic environment. Track geometry retention and ballast degradation were monitored during the test.

All four ballasts were able to withstand the HAL environment, but the dolomite and limestone required an out-of-face surfacing before the end of the first phase of the HAL program.

The Subgrade Experiment was conducted to determine if an increase in axle load produces a significant increase in subgrade stresses. Data from the test reflected the increase in axle load at the ballast/subgrade interface. The increase varied with the track support condition.

14. Subject Terms

Ballast, Subgrade, Heavy Axle Load

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EXECUTIVE SUMMARY

The increase in axle load from 33-ton to 39-ton may have a dramatic influence on the track and support structure in the railroad environment. Two experiments, the Ballast and the Subgrade, were conducted at the Association of American Railroads, Transportation Test Center, Pueblo, Colorado, to investigate the influence of the increase in axle loads during the first 160 MGT of the Heavy Axle Load (HAL) program. Two of the four ballasts tested (dolomite and limestone) have required an out-of-face surfacing. The axle load increase was also measurable at the ballast/subgrade interface. While the increase in axle load did not cause any subgrade failures at the Facility for Accelerated Service Testing, the measured increase in stresses could be sufficient to cause significant subgrade related maintenance on some typical North American tracks.

Loss of cross level was attributed to out-of-face surfacing of the dolomite and limestone. The dolomite ballast was surfaced after 40 MGT of traffic, while the limestone ballast was surfaced after 70 MGT of traffic. Even though all four ballasts completed the test, the dolomite ballast required more spot tamping where rail anomalies were present. Track geometry retention measurements varied with each type of ballast, while ballast particle degradation of samples removed from track exhibited no substantial amount of degradation in all four ballasts with the accumulated tonnage. However, the particle degradation data collected in the granite and dolomite ballast test bins did show a definite increase in ballast degradation in the dolomite ballast. This degradation is likely due to the cyclic tamping which was part of the maintenance performed on all of the ballast bins.

The significant increase in subgrade stresses due to the increase in axle load varied from 10 percent to 30 percent and was influenced by the vertical stiffness of the track. The largest subgrade stress values recorded were directly under the rail seats. The rail seat load data reflects a similar increase to that of the increase in subgrade stresses measured at the same location. An increase in subgrade deflection due to the increase axle load was also evident at the ballast/subgrade interface.

The four ballasts in test are presently used in revenue service under 33-ton axle load traffic. The quality of the ballasts used ranged from good to marginal. Ballast degradation

and track geometry retention measurements were used to monitor the ability of the ballast materials to withstand the HAL environment. Measurements were taken at predetermined MGT cycles, and before and after surfacing.

Gradation analysis results of the ballast samples removed from predetermined tie locations, and from the ballast test bins were used to determine the ballast degradation. Geometry car data, loaded and unloaded track elevations, vertical track deflection, and ballast density results were used to monitor track geometry retention in the four ballast test zones. Initial laboratory tests were also performed on all four ballast to document size, shape, petrographic properties, hardness, and unit weight of these ballasts materials.

A direct comparison of the ballasts presently in test under 39-ton axle load traffic with the previous 33-ton axle load ballast test results cannot be made due to differences in the ballast properties, and accumulated tonnage. When the present ballast test reaches an accumulated tonnage close to 225 MGT, an attempt will be made to correlate the data with the previous 33-ton axle load ballast test.

For the Subgrade Experiment, a section of tangent track was instrumented to measure the vertical load generated at the rail seat, and subgrade stresses and strains generated at the ballast/subgrade interface. Pressure cells, extensometers, and instrumented tie plates were used to collect the data on the selected tangent section of the Heavy Tonnage Loop. Measurements were taken at three predetermined MGT cycles. The train consist used when the data was being collected was made up on an equal number of 33-ton and 39-ton cars. The testing of the 33- and 39-ton axle loads simultaneously allowed a direct comparison of data without the influence of weather, instrumentation drift, operating conditions or train speed. The consist was operated and data collected at three different time intervals.

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INTRODUCTION

The ballast and subgrade experiments were conducted at the Facility for Accelerated Service Testing (FAST), Transportation Test Center (TTC), Pueblo, Colorado, during the first 160 MGT of heavy axle load traffic to determine if the increase from the present 33-ton to 39-ton axle load traffic generated a measurable difference in the performance of four selected ballast types and the FAST subgrade.

Certain ballast materials, with their varied mineral characteristics, may prove to be impractical or incapable of supporting traffic for a suitable length of time in a heavy axle load environment. Ballast breakdown significantly contributes to track fouling, which plays a critical role in determining maintenance cycles.[1] This information led to a ballast experiment under heavy axle load traffic at FAST (see Appendix A). The quality of the four ballasts used in the test ranged from good to marginal. The ballast materials tested were granite, traprock, limestone, and dolomite. These ballasts are presently used in revenue service under 33-ton axle load traffic. Ballast degradation and track geometry retention measurements were monitored at selected MGT cycles for each of the test ballasts.

The Subgrade Experiment was conducted to determine if the increase in axle load from 33-ton to 39-ton produced a significant increase in subgrade stresses. Also, if a significant increase was apparent, was the increase proportional to the increase in applied load. Pressure cells, extensometers, and instrumented tie plates were used to collect the data on a tangent section of the High Tonnage Loop (HTL) track. The Ballast Experiment is presented as Part I of this document, and the Subgrade Experiment is presented as Part II.

PART I - BALLAST EXPERIMENT

1.0 OBJECTIVE

Evaluating the ability of selected ballast materials to withstand an increase in loads from 33-ton axle load traffic to 39-ton axle load traffic and comparing their performance under 33-ton axle load traffic were the objectives of the Ballast Experiment. Dolomite, limestone, traprock, and granite were the ballast materials provided for testing.

The gradation specification for the granite and limestone ballasts was an AREA #3 modified. The traprock specification was an AREA #4, and the dolomite was an AREA #24. Standard AREA laboratory tests[2] were performed on all four ballast materials. The results are shown in Table 1. See Appendices C, D, E, and F for the initial ballast gradations, additional laboratory tests, and analysis.

Table 1. AREA Ballast Laboratory Tests

AREA Test	Ballast Type			
	Dolomite	Granite	Limestone	Traprock
Soundness of aggregate (% loss) Magnesium Sulfate	0.23	0.24	0.24	0.56
Sodium Sulfate	0.26	0.20	0.23	0.13
Los Angeles abrasion (% loss)	34.1	18.5	29.7	10.2
Clay lumps and friable particles (% loss)	3.37	0.8	0.29	0.14
Scratch hardness of coarse aggregate (% soft particles)	no loss	20.7*	no loss	no loss
Unit Weight of Aggregate (cu. ft./lb)	104.8	101.8	93.8	106.9

* Loss due to soft mica

2.0 TEST LAYOUT

The test zones were located in Section 03, a 5-degree curve on the Heavy Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST), Transportation Test Center, Pueblo, Colorado. Figure 1 shows the track layout of the four test zones, each containing a different ballast material.

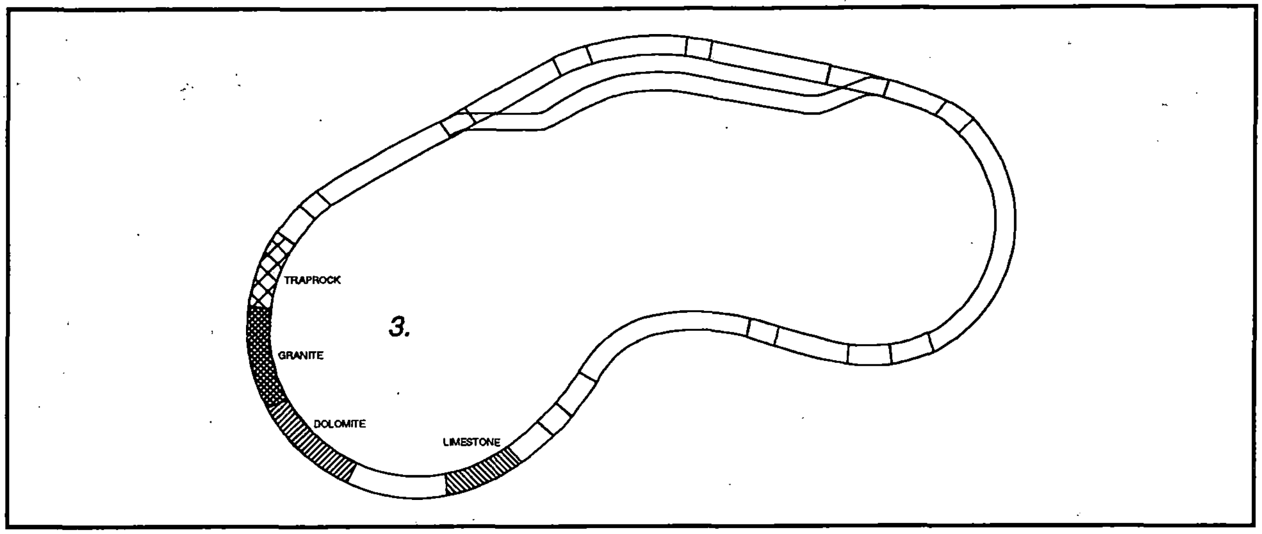

Figure 1. Ballast Test Layout

To construct the test sections, the track was undercut down to the ballast/subgrade interface and a sub-ballast material was installed. Dolomite fines, 8 inches deep, were used as the sub-ballast material in all four test zones. Ballast sections have a depth of approximately 18 inches below the bottom of the tie on the low rail. Average ballast depth, measured after eight trenches were excavated through Section 03, is shown in Figure 2.

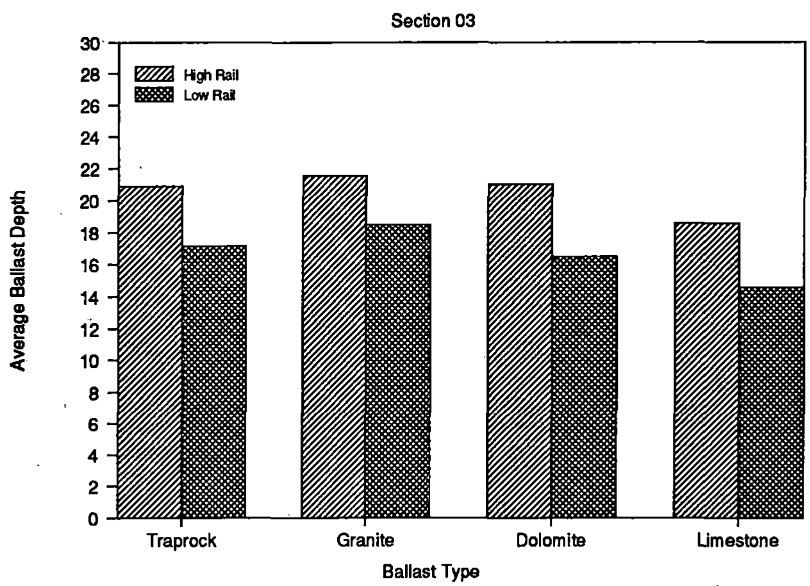

Figure 2. Average Ballast Depth

Each test zone was subdivided into two measurement subsections. One subsection was used to measure track geometry retention, and the other one was used to remove ballast samples for the ballast degradation analysis. The measurement zone was isolated from the ballast sampling zone to avoid changes to the track geometry when the ties were removed to collect ballast samples. Figure 3 is a typical test zone configuration.

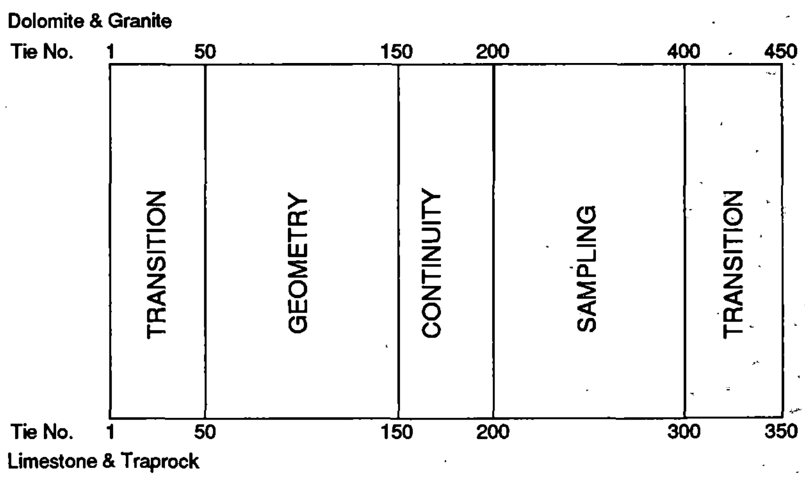

Figure 3. Typical Ballast Test Zone Layout

3.0 MEASUREMENT DESCRIPTION

Measurements that were taken to monitor geometry retention in the geometry zone included loaded and unloaded track profiles, ballast density, vertical track modulus, geometry car, and instrumented wheel set force data. Gradation analysis was used to monitor ballast particle degradation.

3.1 LOADED PROFILE

Loaded track profile, a measurement of track settlement as a function of accumulated tonnage, was accomplished by reading the elevation of a short survey rod that was permanently attached to the bearing adapter of the A-end of an overloaded 100-ton car (Figure 4).

The measurement was recorded when the wheel set was spotted directly above each selected tie. The A-end of the car was loaded to a 39-ton axle load capacity, thus reflecting the static loaded profile under 39-ton axle load traffic. Since the loaded profile measurement applies a 39-ton axle load to measure the profile, it exhibits a more realistic track geometry response than the available geometry measurement car, which applies only a 15-ton axle load.

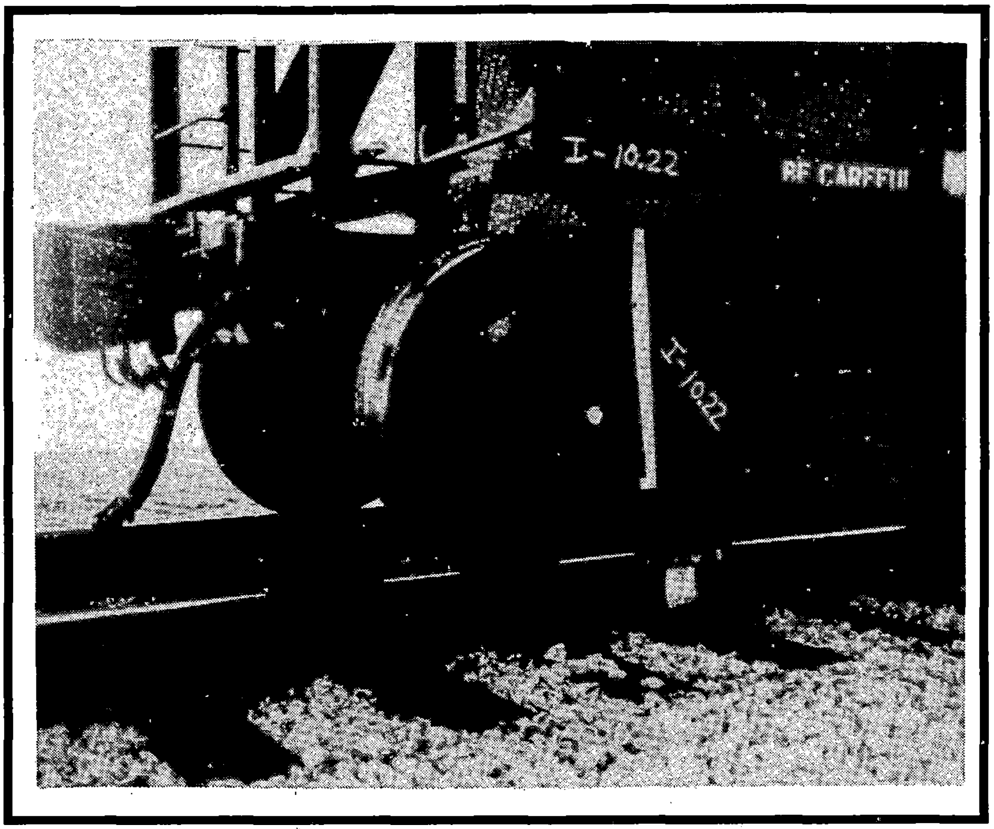

Figure 4. Loaded Profile Measurement Car

The loaded track profile measurement depicts the loaded deflection experienced by the track due to dynamic action of traffic. The loaded track profile data also shows settlement due to track abnormalities, such as joints and battered welds. The loaded profile data is also used to calculate track roughness by computing the standard deviation in the measurement area. Some researchers[3] have been able to correlate loaded track settlement and track roughness with track degradation.

3.2 UNLOADED PROFILE

The unloaded profile measurement was accomplished by reading top of tie elevations on five selected ties in the geometry subsection. The elevations are read immediately outboard of the high and low rail using a Philadelphia rod. By placing the rod on tacks installed on the measurement ties, the elevation, at each measurement cycle, was always read on the same location of the tie, thus, enabling the comparison of unloaded track settlement between each measurement cycle.

3.3 BALLAST DENSITY

Ballast density measurements are taken by the use of a nuclear density gage (Figure 5). The gage measures subsurface density by the use of a probe attached to an adjustable length cable.

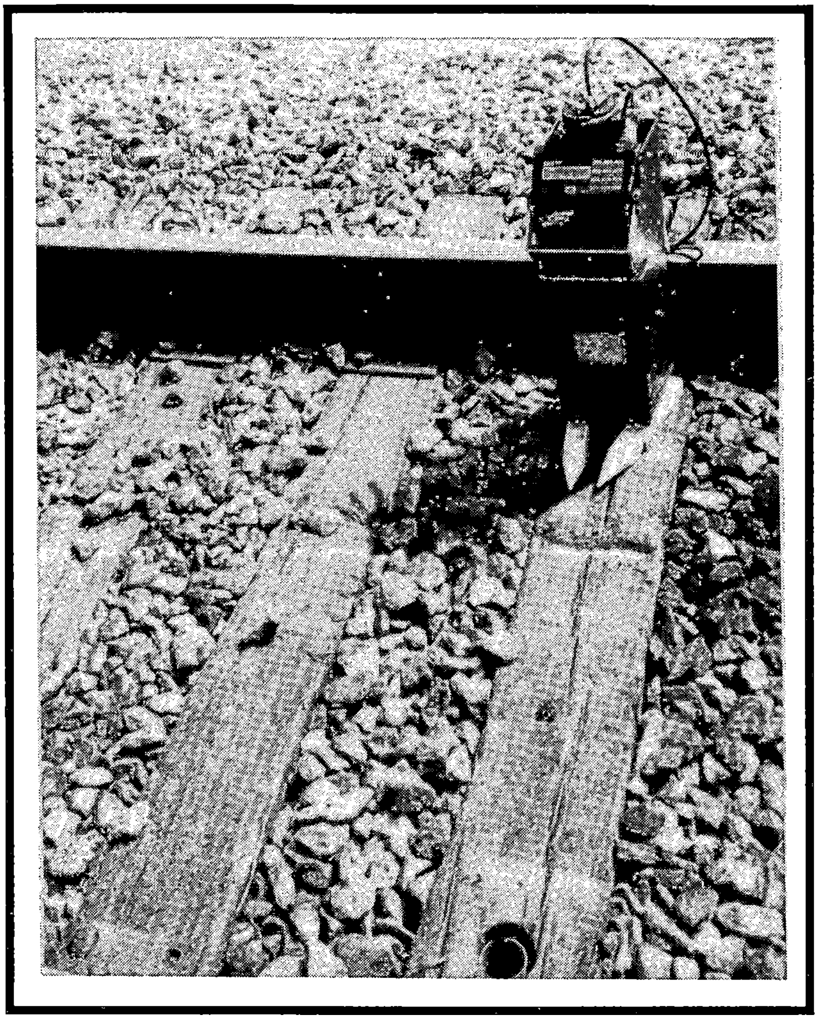

Figure 5. Nuclear Density Gage

The measurement locations are directly inboard of the inside and outside rail of five selected ties in the geometry subsection. The probe is lowered to the ballast/subgrade interface and five measurements are recorded at each pipe location for each measurement cycle.

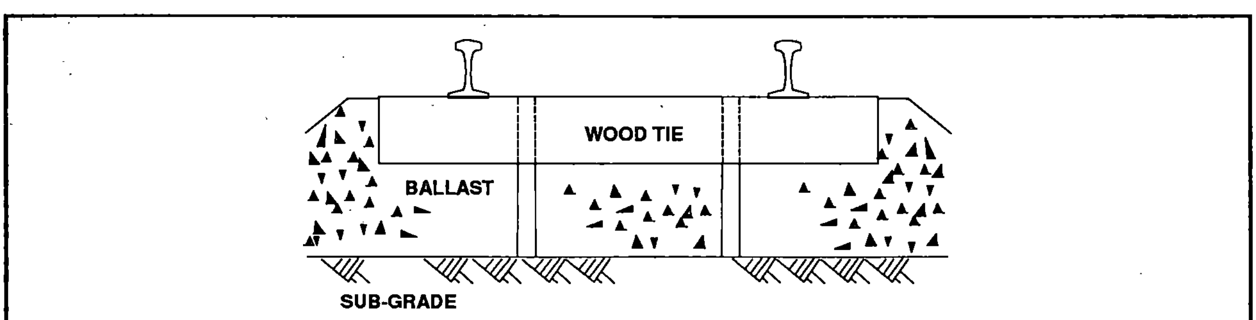

Figure 6. Typical Density Pipe Setup

The probe is lowered to the same depth at each measurement to ensure that the density is always taken at the same depth for comparison at different measurement cycles. Figure 6 shows a typical installation of pipes used to measure ballast density.

3.4 VERTICAL TRACK MODULUS

The vertical track modulus measurement was accomplished using the 605 car, a modified locomotive frame that applies single point loading on both rails to simulate single axle loading. Figure 7 shows the 605 car applying vertical loading to the rail.

The load was applied to both rails, from 0 to 39 kips, to simulate single axle loading. Track modulus is calculated by using the measured vertical track deflection under the applied loads, the moment of inertia of the rail, and the modulus of elasticity of the rail. The track deflection value used in the calculation is the difference between the deflection measured under a light load (10 kips) and the deflection measured under a heavy load (39 kips).

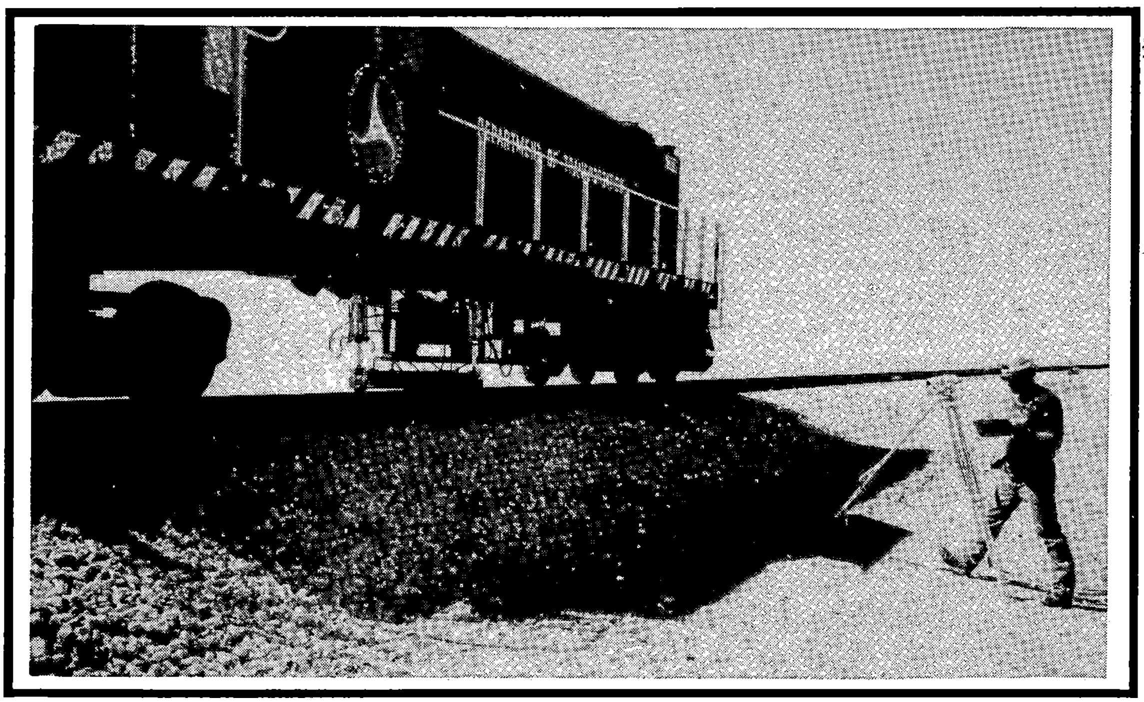

Figure 7. 605 Car -- Track Loading Vehicle

3.5 GEOMETRY CAR

Track geometry retention was monitored with data collected using the EM80, a track geometry measurement car, which measured track profile, cross level, and alinement of the four test zones.

3.6 INSTRUMENTED WHEEL SETS

Dynamic vertical and lateral load data was collected with the 38-inch instrumented wheel sets. Instrumented wheel set data for the entire HTL was collected at predetermined MGT cycles.

3.7 BALLAST DEGRADATION

Ballast degradation was evaluated by comparing gradation curves of the ballast samples removed from track at predetermined MGT intervals. The ballast samples were removed only from the sampling subsection and were retrieved from directly under the rail seat on both the inside and outside rail, at predetermined tie locations, for each measurement cycle. At the 160 MGT measurement cycle, ballast samples were also retrieved from the tamping area to determine if ballast fines were more concentrated in this area.

Ballast gradation was determined by the sieve analysis; ASTM C136. Total sample weight and weight of the sample retained on the consecutive sieves was used to calculate percentage of material passing these sieves. The sieves used in the gradation analysis were 3", 2 1/2", 2", 1 1/2", 1" 3/4", 1/2", 3/8", 1/4", #4, #40, #200, and pan. The percentage passing each sieve was plotted versus the sieve size to depict the change in the gradation curve with accumulated traffic at the predetermined measurement cycles.

3.8 BALLAST BIN DEGRADATION

Ballast bins shown in Figure 8 were used to measure ballast degradation due to dynamic loading. The bins isolated the ballast from foreign material thereby reducing the source of fines to the dynamic action of the train. Ten ballast bins each were installed in the transition zones of the granite and dolomite ballasts. The ballast bins were constructed using sheet metal and geotextile material. The sides of the bins were made of sheet metal, while a geotextile material was used for the bottom to allow for moisture drainage while retaining the ballast fines, a sheet metal covered was used to prevent contamination from wind blown material.

The ballast bins were installed under each predetermined tie and filled with a known grain size distribution determined from the initial ballast gradation analysis. The ballast material that was placed in the test bins in both the granite and dolomite sections was removed at the predetermined MGT cycles and a final gradation analysis was performed after the bins were removed from the track.

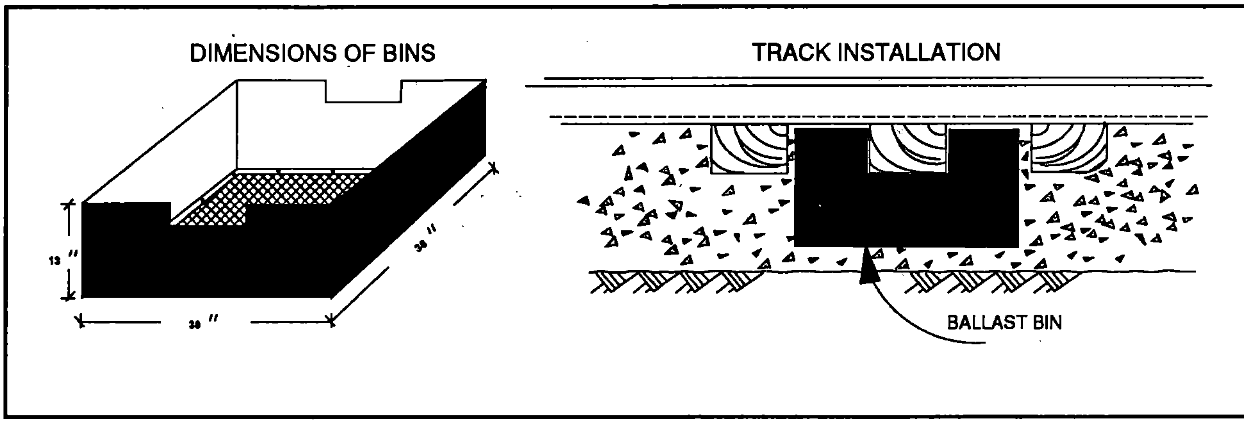

Figure 8. Typical Ballast Bin Installation

4.0 RESULTS

Geometry retention measurements varied with each type of ballast, while particle degradation from samples retrieved under selected ties showed no substantial amount of degradation with increase in accumulated tonnage shown in Figures 33 through 36. Particle degradation data collected in the granite and dolomite zones, using the ballast bins and cyclic tamping, did show a definite difference in ballast degradation between the two ballasts. The following graphs will depict the results of each of the measurements taking in the four test ballasts.

4.1 LOADED PROFILE

During the first 3 MGT of traffic, a large initial settlement occurred for all four ballast materials. However for the dolomite and limestone ballast, which were surfaced during the first 160 MGT, another large settlement also occurred immediately after out-of-face surfacing. The granite and traprock ballasts were not surfaced. Figures 9 through 11 show the results from the two ballast sections which have not required an out-of-face surfacing during the first 160 MGT of traffic.

Figures 9 and 10 show the loaded track profile for the granite test zone. The largest settlement, for both the high and low rail, occurred during the first 100 MGT of traffic. Settlement during the last 60 MGT of traffic was minimal for both rails.

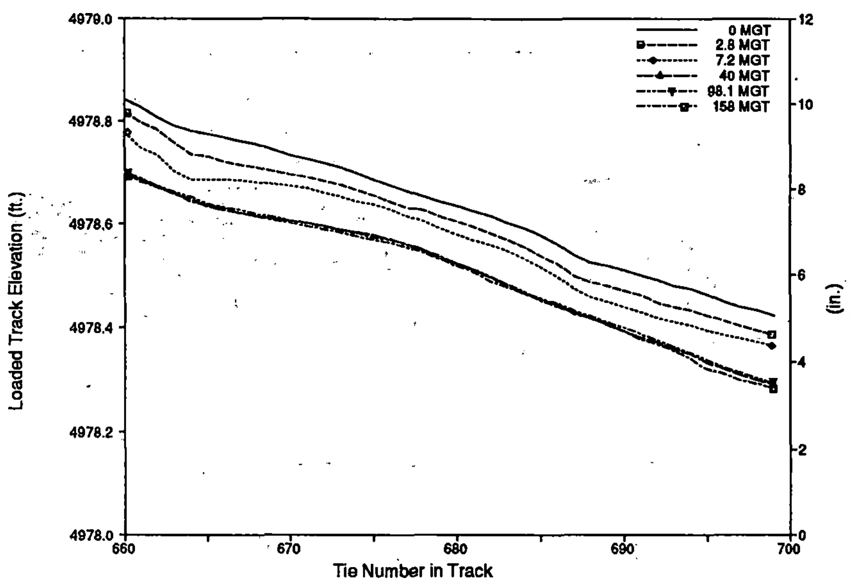

Figure 9. Granite Loaded Track Profile -- High Rail

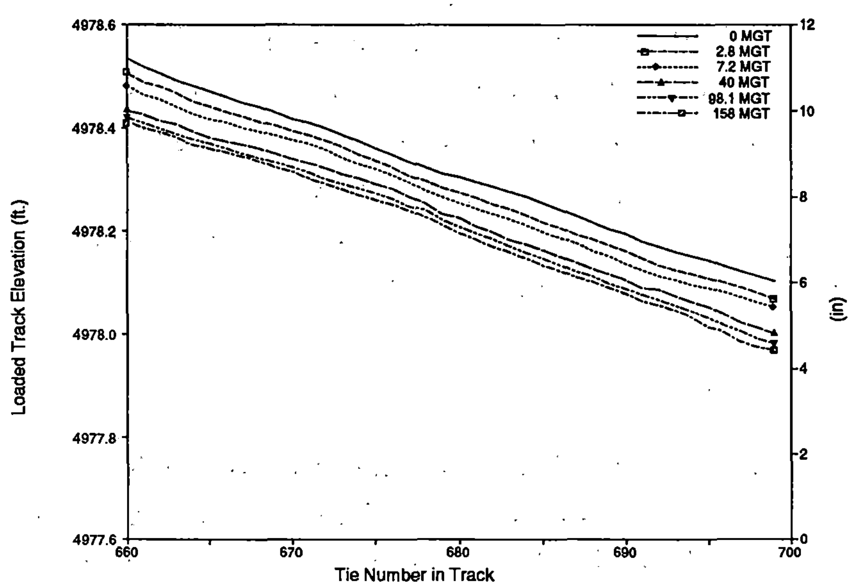

Figure 10. Granite Loaded Track Profile -- Low Rail

Figures 11 and 12 show the loaded track profile for the traprock test zone. The largest settlement also occurred during the first 100 MGT of traffic. Settlement after 100 MGT of traffic was limited.

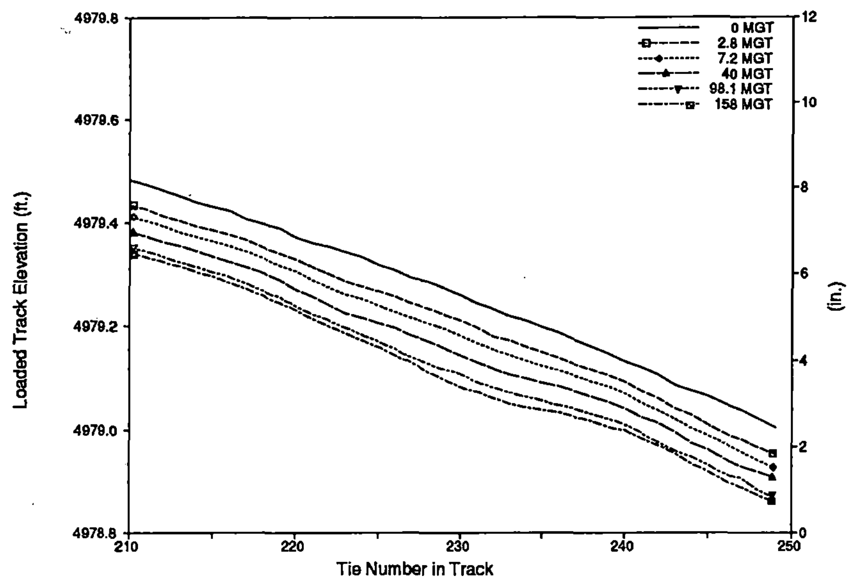

Figure 11. Traprock Loaded Track Profile -- High Rail

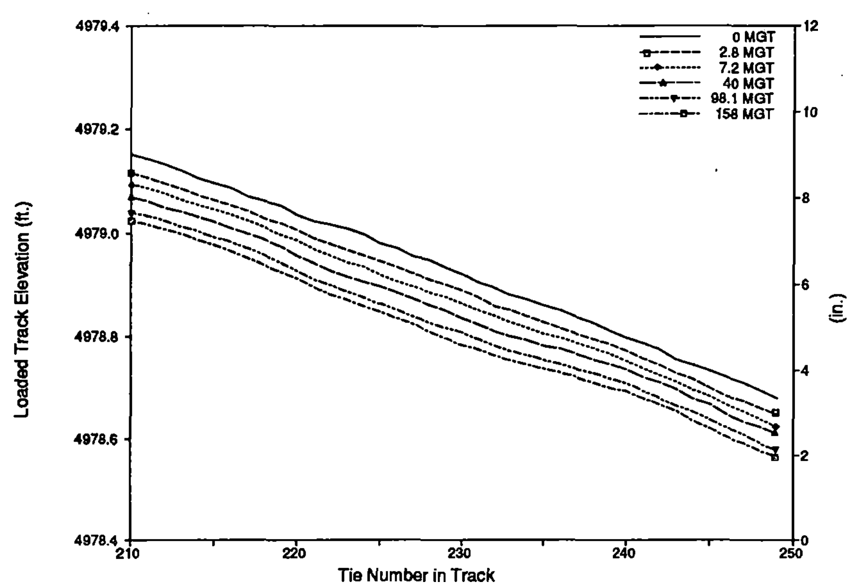

Figure 12. Traprock Loaded Track Profile -- Low Rail

Figures 13 through 20 show the loaded track profile of the dolomite and limestone ballast sections from the start of the test up to the out-of-face surfacing operations (40 MGT for dolomite and 70 MGT for limestone).

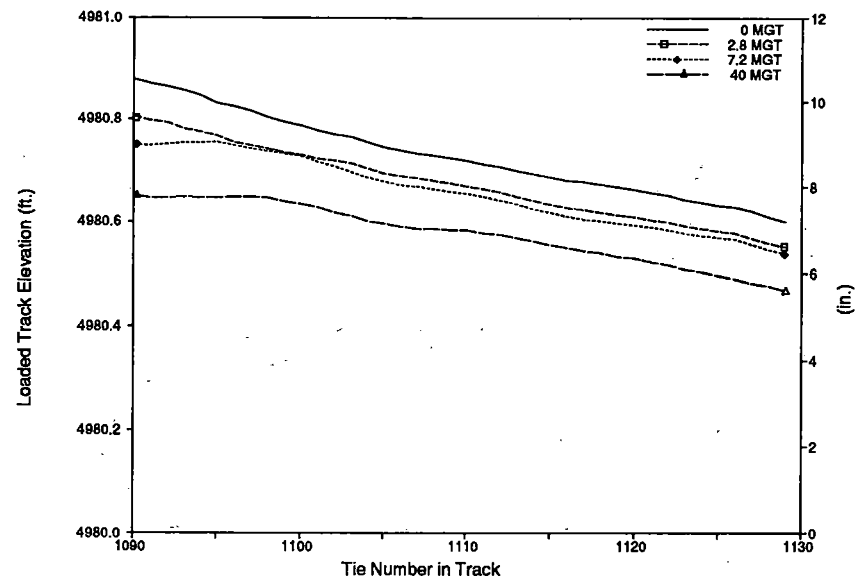

Figure 13. Dolomite Loaded Track Profile -- High Rail

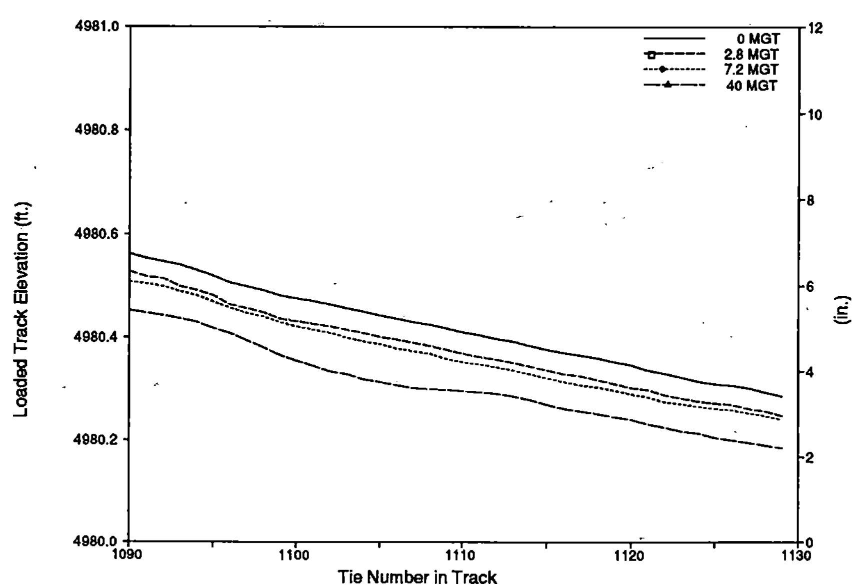

Figure 14. Dolomite Loaded Track Profile -- Low Rail

Figures 13 and 14 show the loaded track profile of the dolomite ballast during the first 40 MGT of traffic. Figures 15 and 16 show the loaded track profile of the dolomite ballast after the out-of-face surfacing operation that was performed after 40 MGT of traffic. The loaded settlement in dolomite ballast shows a much larger settlement between 7.5 and 40 MGT than that evident on the granite and traprock ballasts, especially on the high rail.

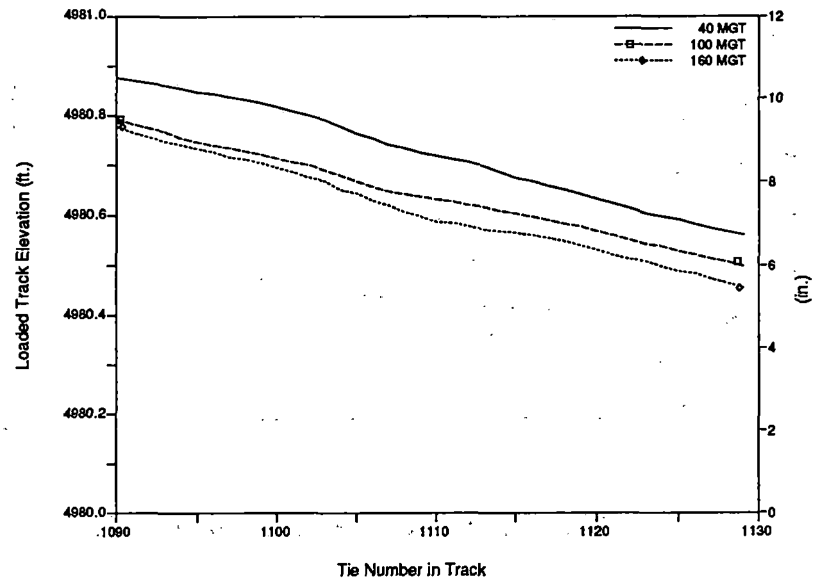

Figure 15. Dolomite Loaded Track Profile -- High Rail Post Out-of-Face Surfacing

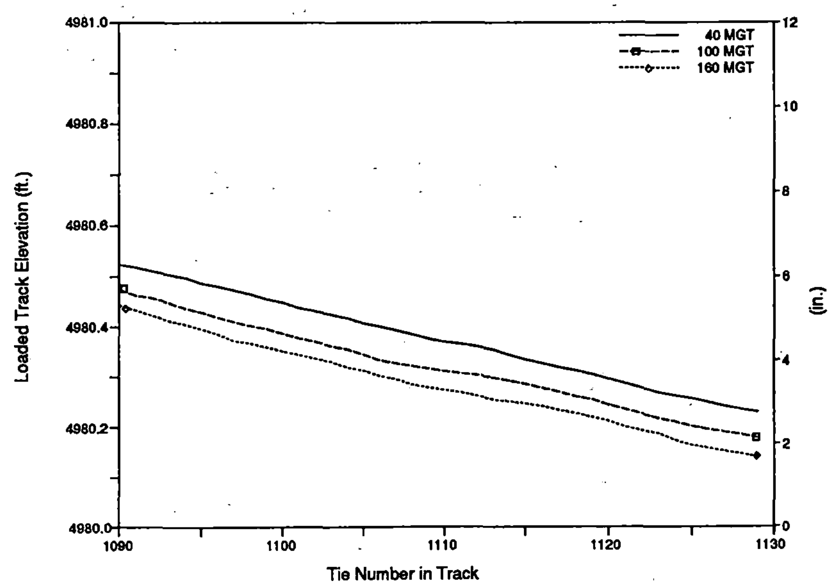

Figure 16. Dolomite Loaded Track Profile -- Low Rail Post Out-of-Face Surfacing

Figures 17 and 18 show the loaded profile of the limestone ballast section during the first 70 MGT of traffic, while Figures 19 and 20 show the loaded profile of the section after the out-of-face surfacing was performed after 70 MGT of traffic.

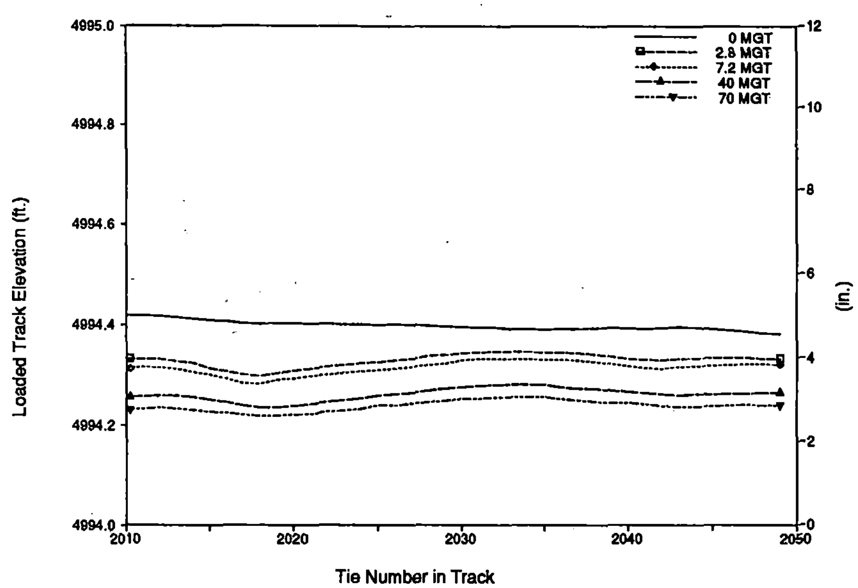

Figure 17. Limestone Loaded Track Profile -- High Rail

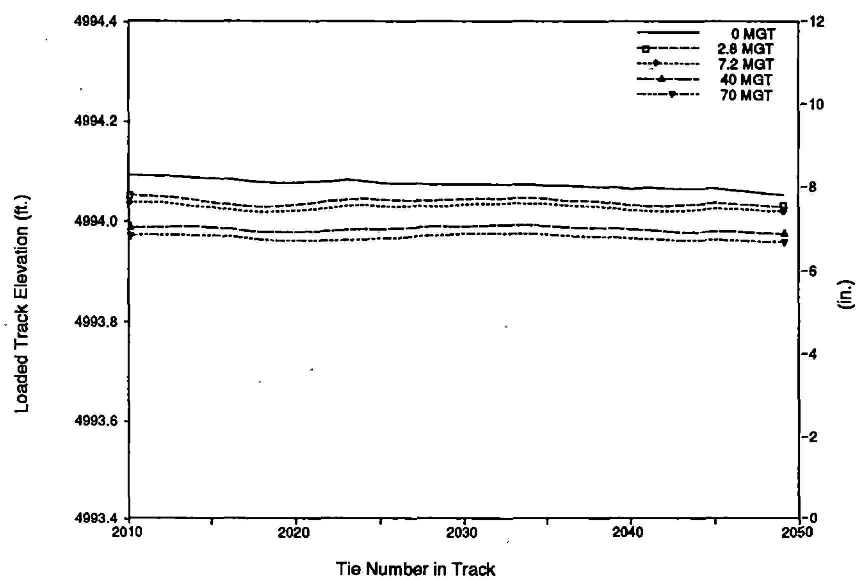

Figure 18. Limestone Loaded Track Profile -- Low Rail

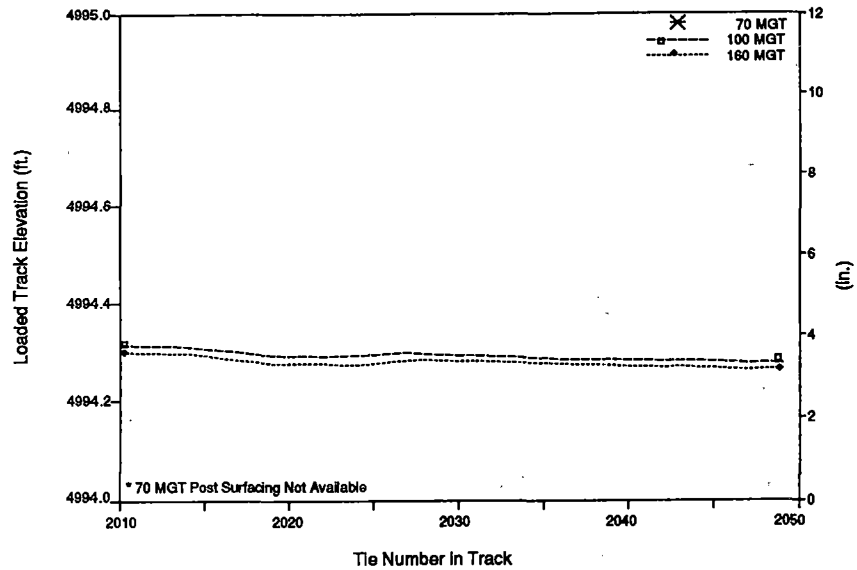

Figure 19. Limestone Loaded Track Profile -- High Rail Post Out-of-Face Surfacing

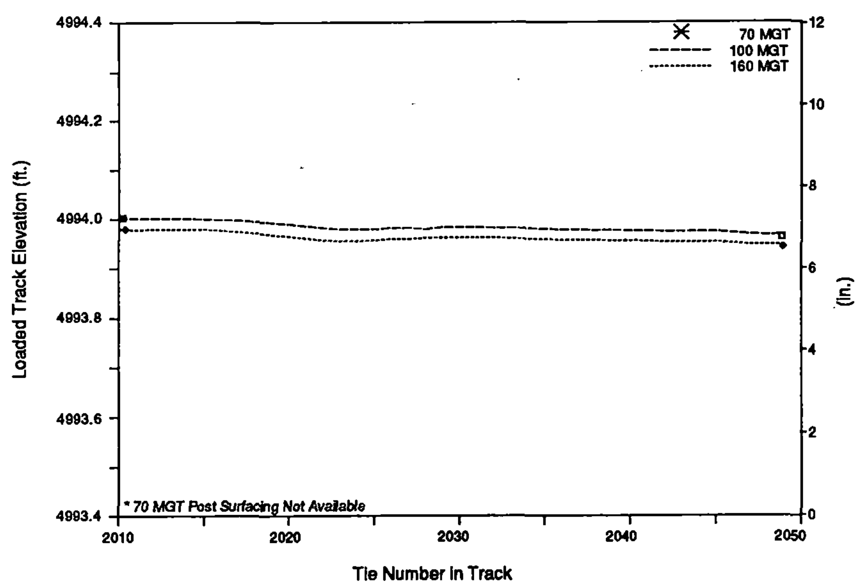

Figure 20. Limestone Loaded Track Profile -- Low Rail Post Out-of-Face Surfacing

To illustrate the total settlement with traffic, the loaded track profile elevation over the entire section was averaged and plotted versus traffic. Figures 21 and 22 show the settlement of the high and low rails. A large amount of average settlement for the granite and traprock ballast is obvious during the first 3 MGT, but stabilizes thereafter. The high rail, in all four ballast materials, has settled faster than the low rail resulting in the loss of superelevation. A greater settlement occurred in the dolomite and limestone, due to this loss of superelevation, re-surfacing was required. After re-surfacing the limestone ballast at 70 MGT, loaded profile measurements were taken, but true elevation was not established; therefore, a post surfacing measurement is not shown.

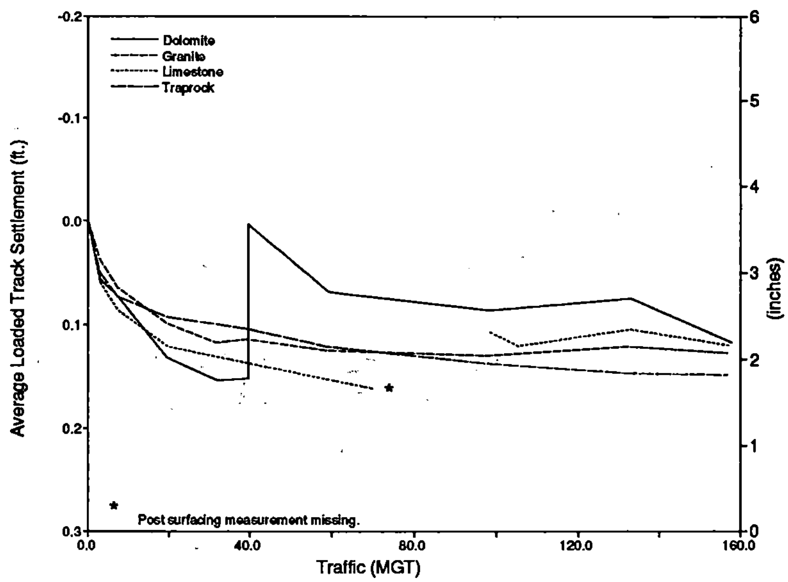

Figure 21. Average Loaded Track Settlement -- High Rail

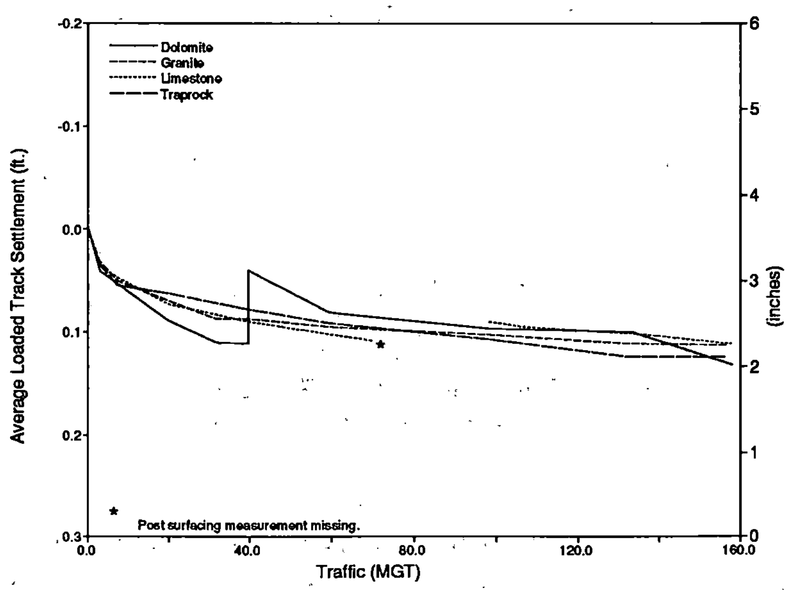

Figure 22. Average Loaded Track Settlement -- Low Rail

4.2 UNLOADED PROFILE

Figures 23 and 24 show the unloaded track settlement, which was calculated using the unloaded top of tie elevations for both the high and low rail. The initial reading was plotted as zero settlement.

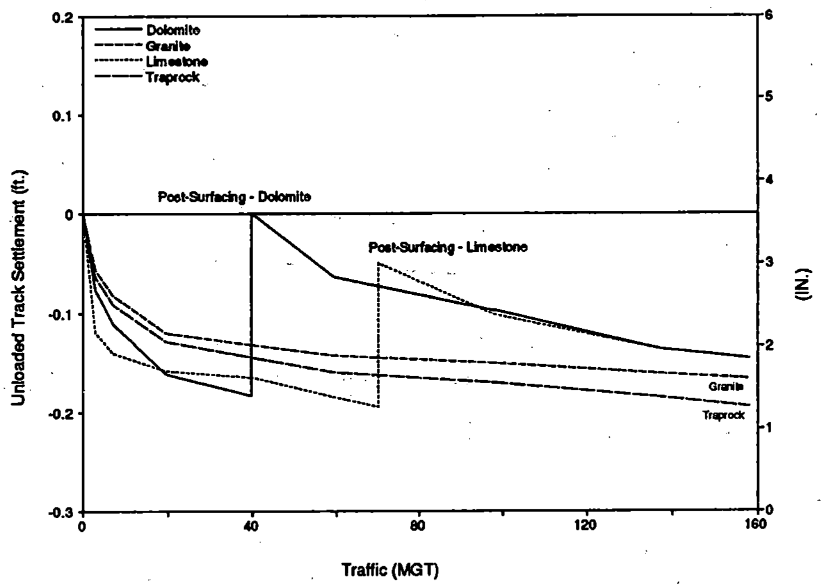

Figure 23. Unloaded Track Settlement -- High Rail

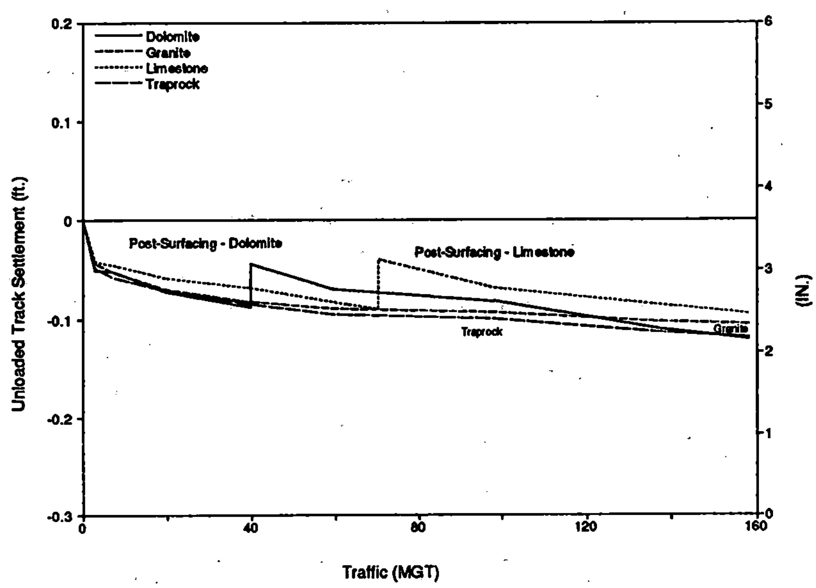

Figure 24. Unloaded Track Settlement -- Low Rail

4.3 BALLAST DENSITY

Ballast density does not show any significant change with accumulated tonnage between the four ballast materials. Each ballast had a different starting density because of its mineral characteristics and gradations, but increased with tonnage proportionately. Figures 25 and 26 depict the ballast density for all four ballast materials.

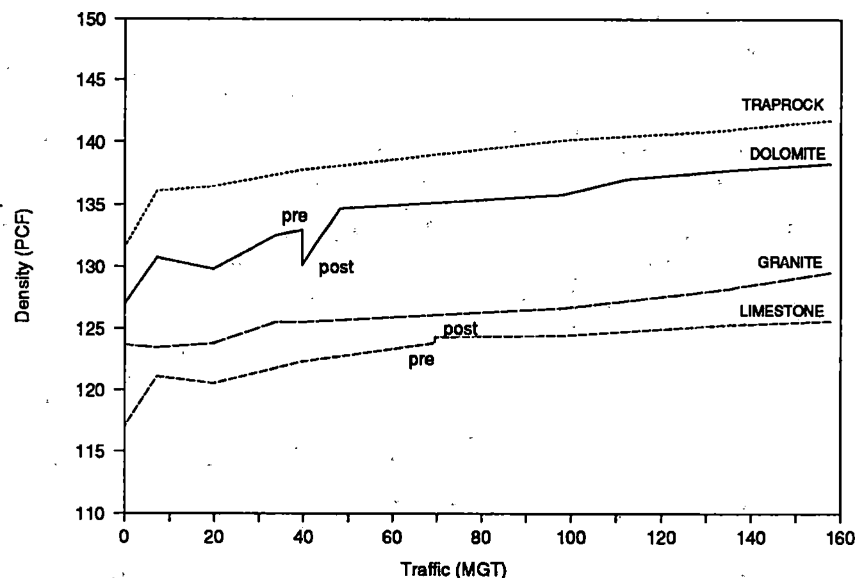

Figure 25. Average Ballast Density -- High Rail

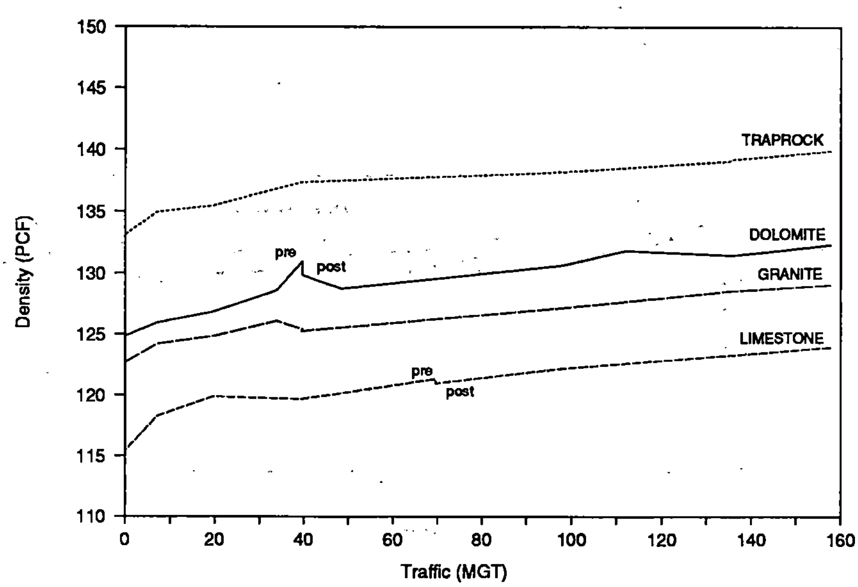

Figure 26. Average Ballast Density -- Low Rail

The surfacing operation decreased the density of the dolomite ballast. The density loss was quickly regained on the high rail but was not completely recovered on the low rail. The surfacing operation had virtually no affect on the density of the limestone ballast. The increase in density, from 0 MGT to 160 MGT, does not vary more than 5 percent within the four types of ballasts.

4.4 VERTICAL TRACK MODULUS

Data from the track modulus measurement reflects no major difference between the ballast materials. The granite appears to retain a higher vertical track modulus than the traprock. Since the dolomite and limestone were both surfaced out-of-face, the comparison of the modulus values must include changes in the modulus after surfacing. Another factor, which could affect the vertical track modulus, is the freezing conditions present during the winter months. Some data points between 100 and 140 MGT were measured during winter months. The results could have been affected by frozen ballast and subgrade conditions.

Figures 27 and 28 show the average track modulus values for the high and low rail from the beginning of the test. The modulus values start at a higher value immediately after the initial test zone surfacing, and stabilize with traffic between 3,000 and 4,000 lbs/in/in. Vertical track modulus results for Section 03, under 33-ton traffic (FAST 1976-1979), show an average vertical track modulus of 3,000 lbs/in/in after 90 MGT of traffic. This modulus value is an average of the five different types of granite tested in Section 03 under 33-ton axle load traffic.

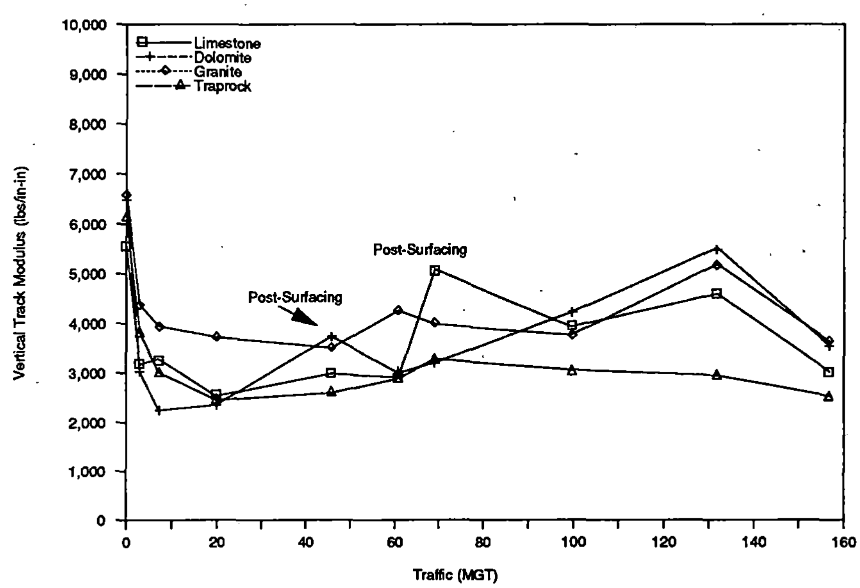

Figure 27. Average Vertical Track Modulus -- High Rail

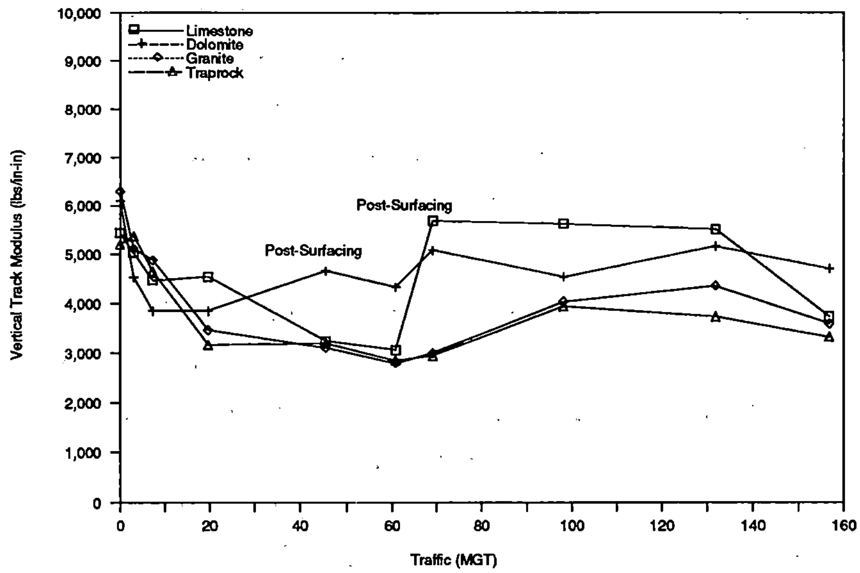

Figure 28. Average Vertical Track Modulus -- Low Rail

4.5 GEOMETRY CAR DATA

The cross level data results shown in Figures 29 and 30 show that the cross level in the dolomite and limestone ballast sections exceeded Federal Railroad Administration (FRA) Class 4 limits, a criterion which is used to perform out-of-face surfacing on the HTL. The settlement on both the high and low rail, for the granite and traprock, has been somewhat equal; therefore, loss of cross level has not exceeded FRA Class 4 Limits.

Data from the loaded profile measurement corresponds to the geometry car data on the loss of cross level, but the loaded profile measurement data appears to show a greater cross level loss. This difference is most likely due to the difference in axle load, with the loaded profile measurement applying a 39-ton axle load, while the geometry car only applies about a 15-ton axle load.

Cross level time history plots of the geometry test zone, using EM-80 geometry car, show a loss of cross level with traffic for all four ballasts. The dolomite and limestone ballasts experienced a loss of cross level beyond the inch and a quarter allowed by FRA Class 4 limits and were surfaced out-of-face. Dolomite was surfaced after 40 MGT while the limestone was surfaced after 70 MGT of traffic. Figure 29 shows the cross level history with traffic for the dolomite ballast, and Figure 30 shows the cross level history for the limestone ballast.

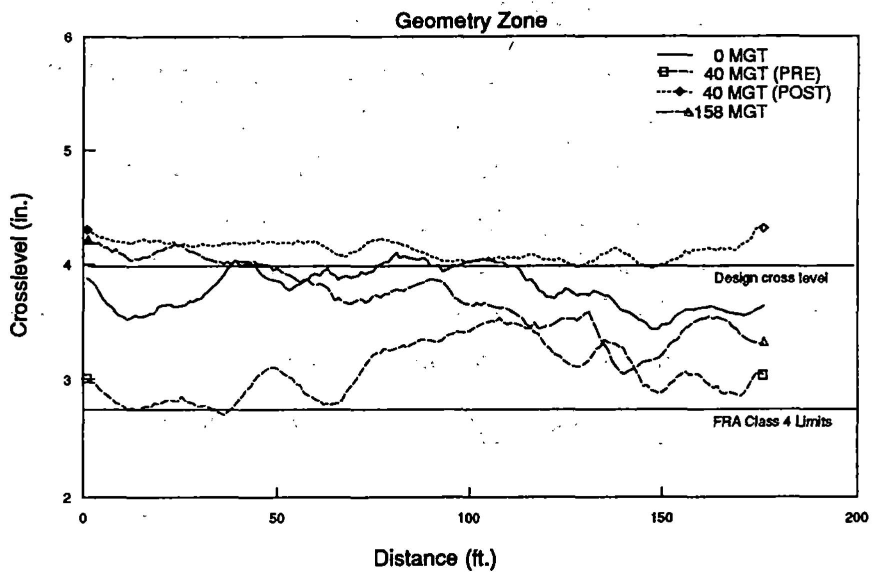

Figure 29. Cross Level Time History -- Dolomite Ballast

After the out-of-face surfacing, the dolomite test zone experienced a much slower loss in cross level during the last 120 MGT of traffic than in the first 40 MGT. At 160 MGT, the ballast did not require maintenance. The loss in geometry was also less severe in the limestone ballast after the out-of-face surfacing.

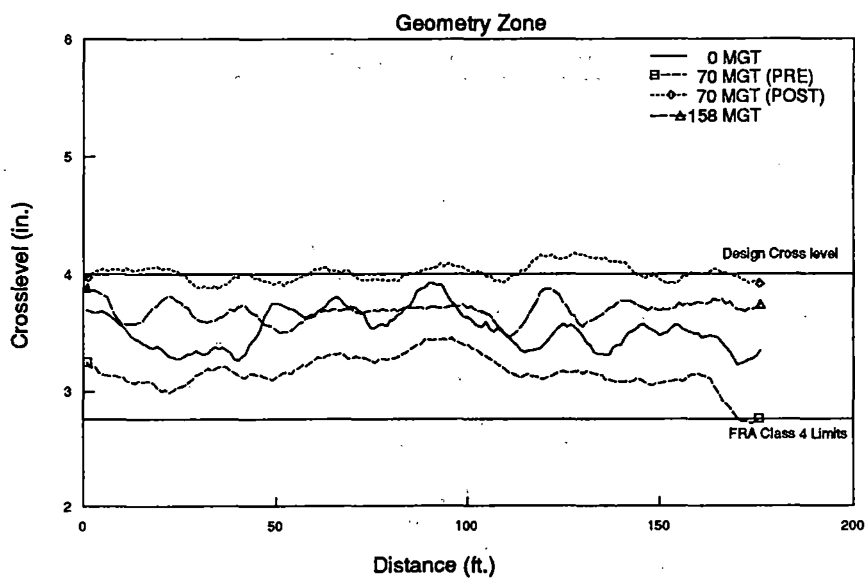

Figure 30. Cross Level Time History -- Limestone Ballast

4.6 INSTRUMENTED WHEEL SET LOAD DATA

The dynamic load data shows that the vertical wheel forces are higher in the ballast sampling zones than in the ballast geometry zones, probably resulting from spot tamping that occurred after the ties had been replaced once ballast samples were taken. This may indicate that spot maintenance performed in this area may have impacted the track geometry retention. This load increase pattern is more evident in the traprock tie sampling zone. Vertical loads time history in the geometry and tie sampling zones is shown in Figures 31 and 32. Vertical wheel loads have increased in the tie sampling zone between 138 and 160 MGT, while in the geometry zone very little change is apparent.

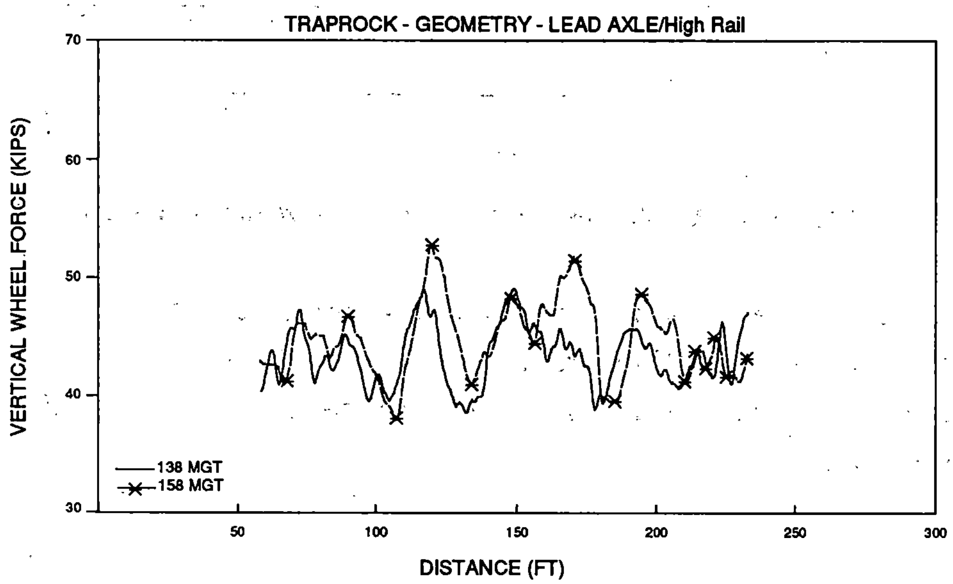

Figure 31. Vertical Wheel Loads -- Geometry Zone

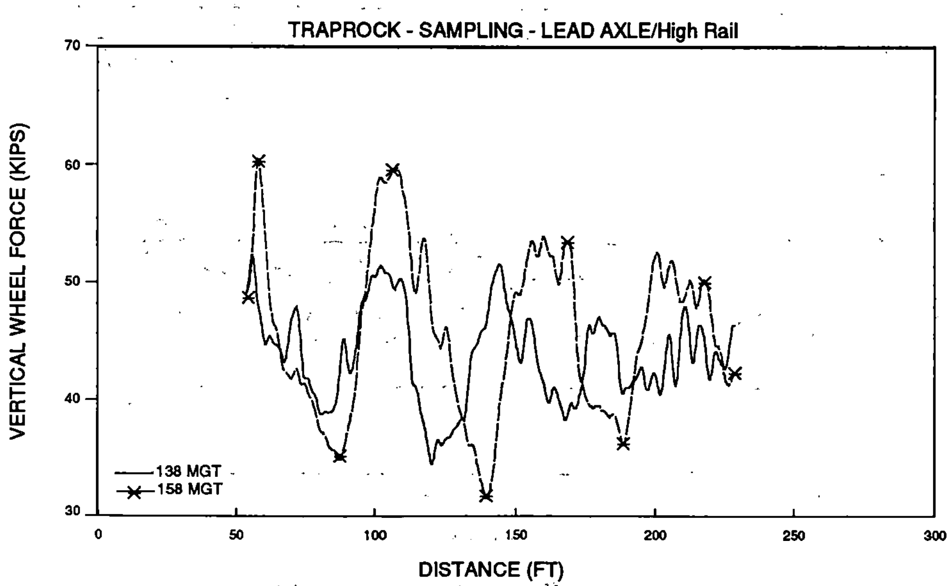

Figure 32. Vertical Wheel Loads -- Sampling Zone

4.7 BALLAST DEGRADATION

Slight degradation occurred in all test ballast materials. Figures 33 and 34 show very little change in grain size distribution during 158 MGT of traffic. In order to ensure a representative sample at 158 MGT of traffic, the ballast shoulder of the tie to be sampled was removed completely, the tie was also removed from track, and the sample was taken directly under the tie area down to the ballast/sub-ballast interface in the tamping zone under the rail seat area.

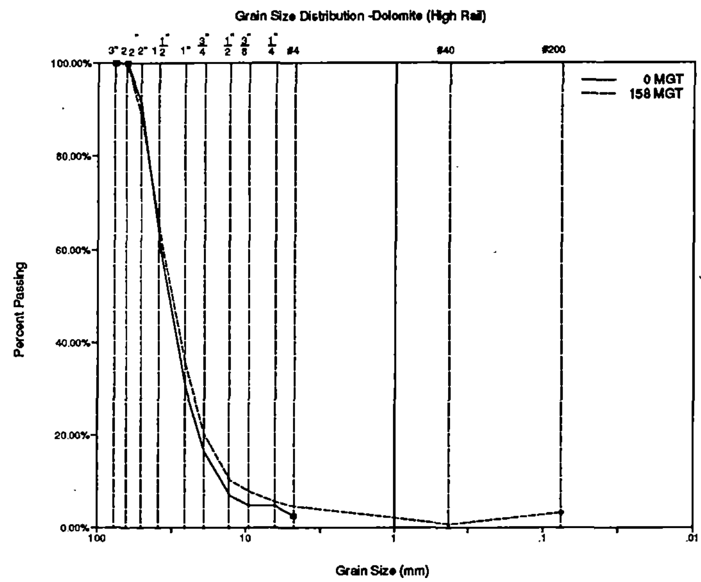

Figure 33. Dolomite Sieve Analysis -- High Rail

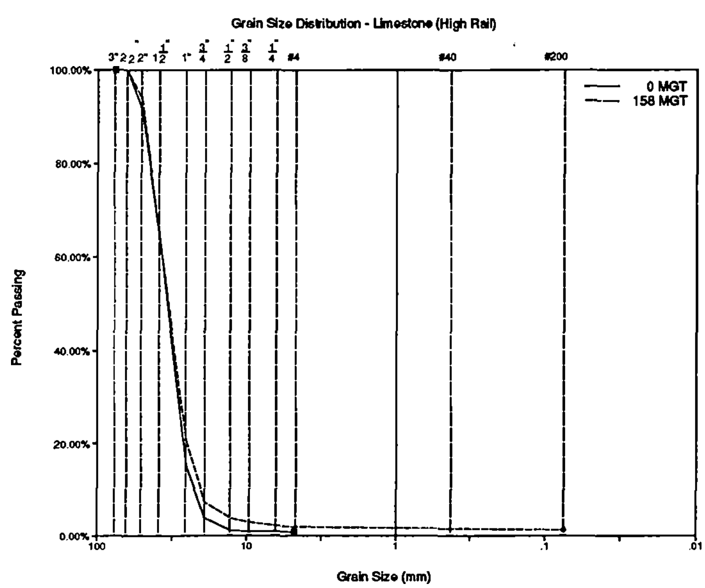

Figure 34. Limestone Sieve Analysis -- High Rail

Ballast degradation in the limestone ballast (Figure 34) appears to be much lower than the other three ballasts. Visual observation, however, shows the ballast becoming rounded and losing its angularity, thus, degrading more than apparent in the grain size distribution plot. Degradation is visually noticeable but not obvious in Figure 34.

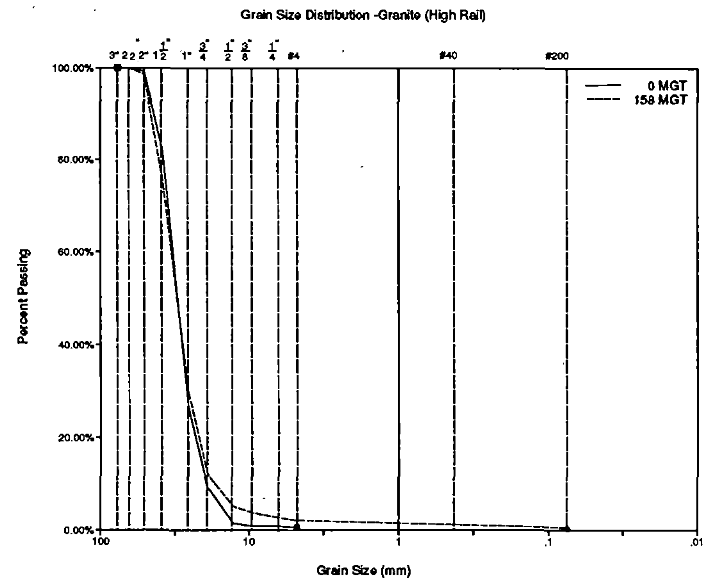

Figure 35. Granite Sieve Analysis -- High Rail

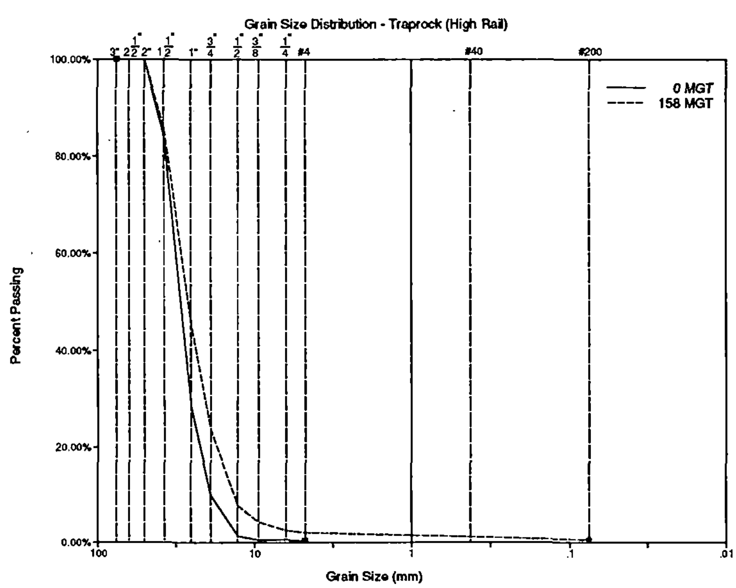

Figure 36. Traprock Sieve Analysis -- High Rail

A direct ballast degradation comparison between 33-ton and 39-ton axle load traffic cannot be made due to the differences in ballast types, traffic accumulation, and construction techniques. Figures 37-40 are grain size distribution data plots of four granite ballasts used in Section 03 under the 33-ton axle traffic.

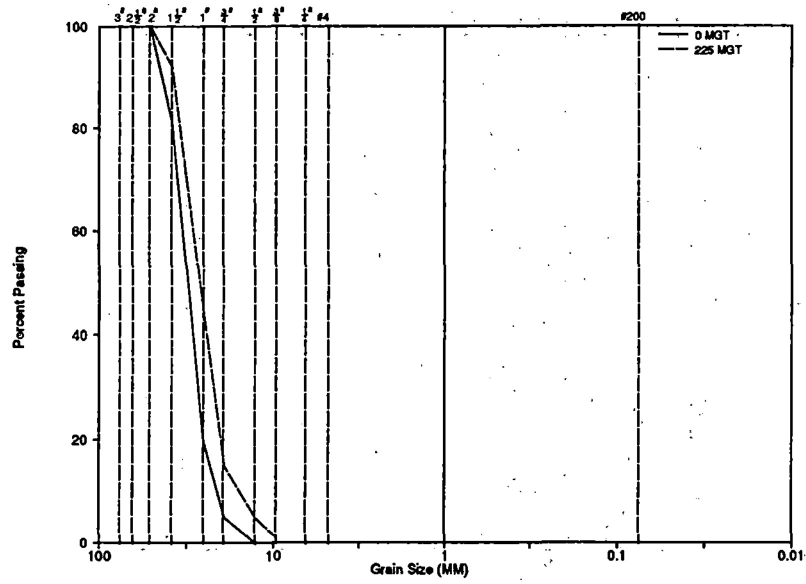

Figure 37. Granite I Sieve Analysis

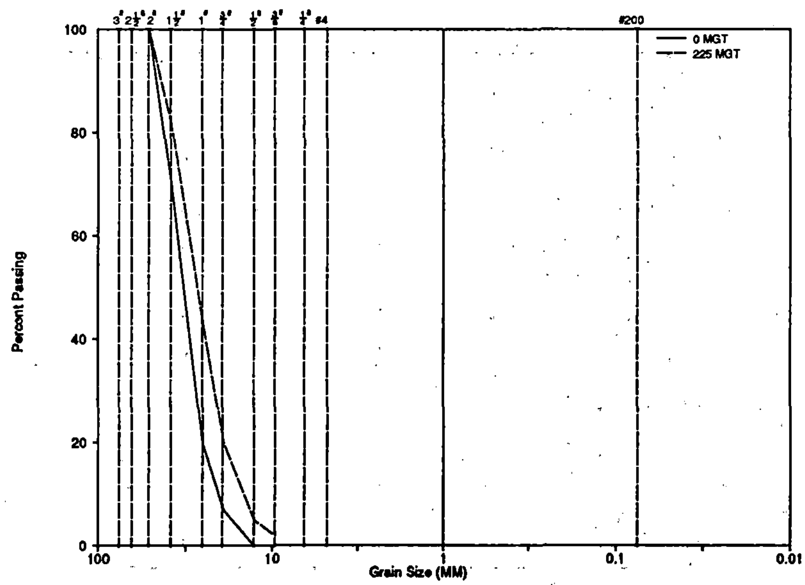

Figure 38. Granite II Sieve Analysis

The change in grain size distribution is from 0 MGT to 225 MGT, under 33-ton traffic. The plots are provided as information on ballast degradation, under 33-ton axle load traffic. Direct comparisons cannot be made due to the differences already discussed and because the 225 MGT of HAL traffic has not yet been accumulated.

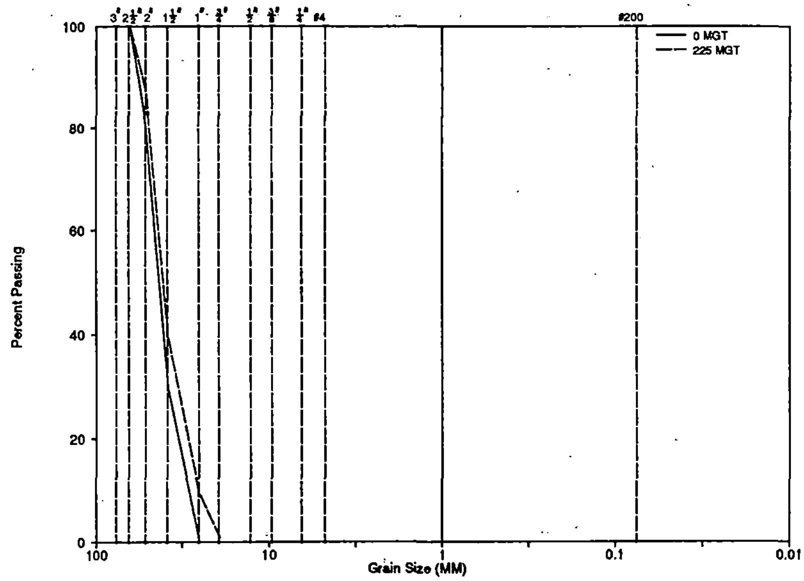

Figure 39. Granite III Sieve Analysis

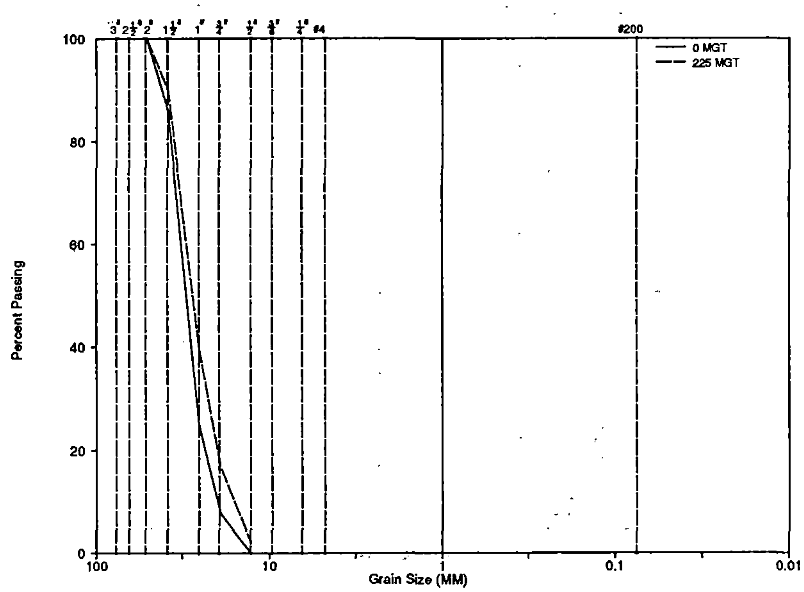

Figure 40. Granite IV Sieve Analysis

4.8 BALLAST BIN DEGRADATION

The ballast bins that were placed in the dolomite test zone remained in track only up to 40 MGT of traffic. Before removal, the bins were requiring daily tamping due to constant loss of track geometry in this area. Thus far, the bins in the granite area haven't experienced major problems with geometry loss, and the two bins that remain in track will be kept for another 100 MGT of traffic.

Figures 41 and 42 show the sieve analysis results from the ballast bins in the granite test zone. Figure 41 shows the sieve analysis results of the control bin that was tamped only at the start of the test (0 MGT) to allow for track settlement. The control bin data does not seem to show any measurable degradation after 160 MGT of HAL traffic, whereas the degradation due to the cyclic tamping is evident in the tamping bin, Figure 42.

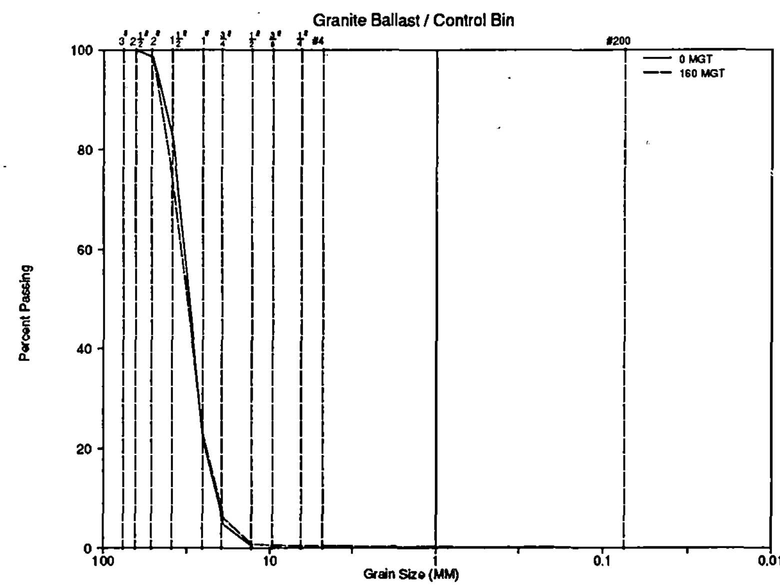

Figure 41. Granite Control Bin Sieve Analysis

The sieve analysis data in Figure 42 shows an increase in ballast degradation in the tamping bin due to the four tamping cycles performed (0, 7.2, 40, and 160 MGT). Since the ballast in the bin was isolated, it is certain that the ballast degradation was generated by the dynamic train action and the tamping tools.

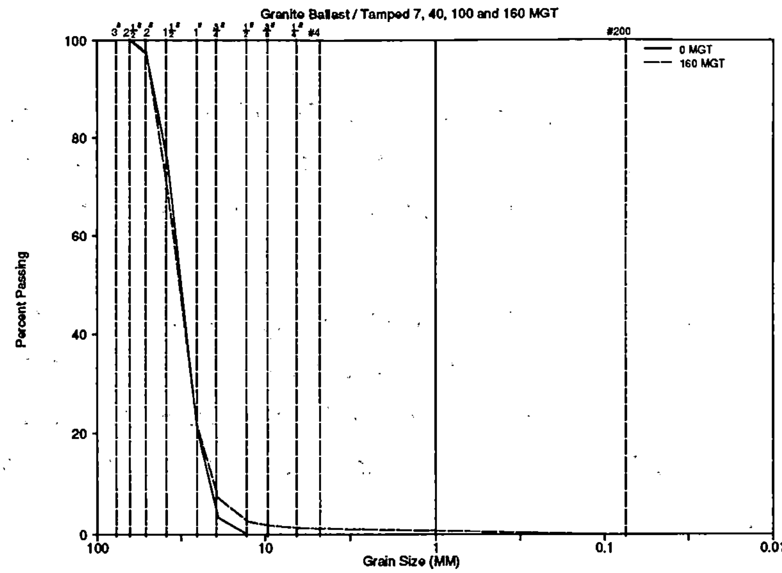

Figure 42. Granite Tamped Bin Sieve Analysis

The sieve analysis results for the dolomite ballast also show little or no breakdown in the control bin and an increase in ballast fines in the tamped bins. The dolomite ballast in these bins was only exposed to 40 MGT of traffic due to problems with track retention in the area. The measurable ballast breakdown in the dolomite bins also appears to be related to tamping as was the case with the granite bins, however, the breakdown is more evident after 40 MGT in the dolomite ballast than in the granite ballast where the ballast was exposed to an additional tamping cycle, and the exposure to traffic was 160 MGT.

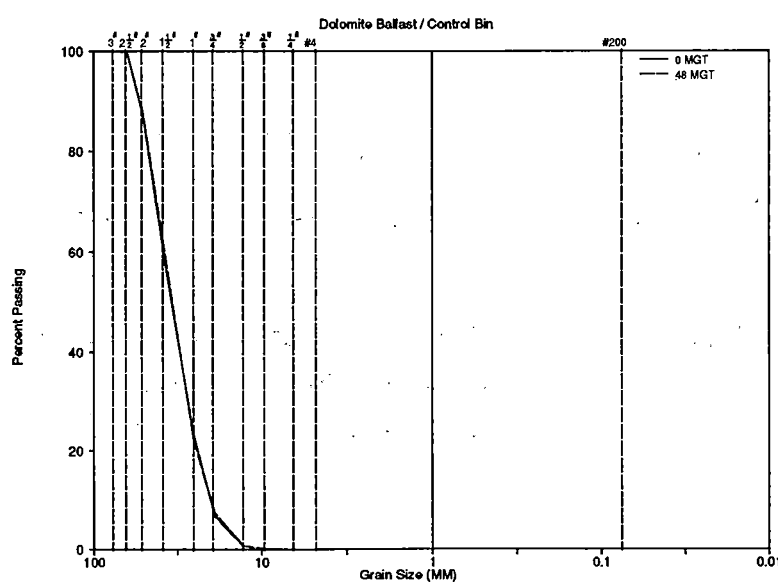

Figure 43. Dolomite Control Bin Sieve Analysis

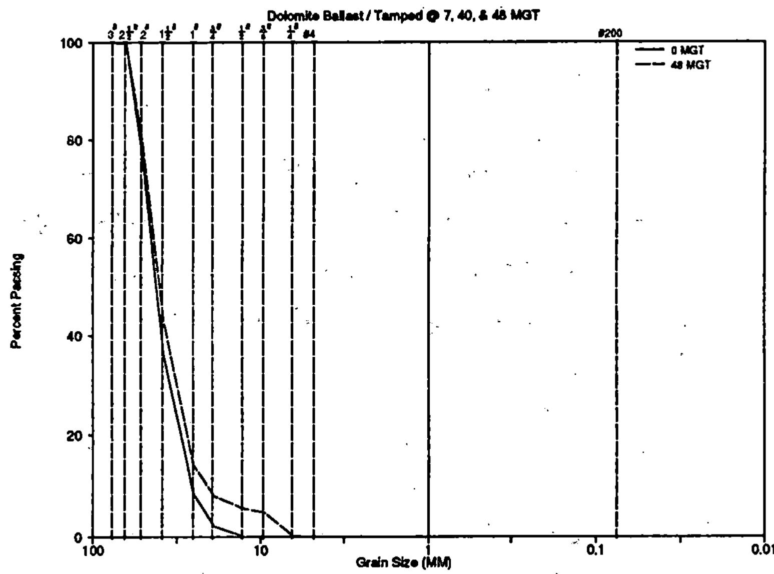

Figure 44. Dolomite Tamped Bin Sieve Analysis

5.0 CONCLUSIONS

Results of these studies indicate that all four ballast materials have been able to withstand the heavy axle load environment during the first 160 MGT of traffic. A direct comparison between 33- and 39-ton axle load traffic cannot be made due to differences in ballast types and accumulated tonnage, however it appears that degradation of the granite material is more dependent on accumulated tonnage than on increased axle load.

One apparent drawback of lower quality ballast, dolomite and limestone, discovered during this experiment was that they required an out-of-face surfacing before reaching 100 MGT of traffic. The dolomite ballast also required frequent spot maintenance in areas where rail joints were present.

Data results from the granite ballast bins show that ballast degradation was evident due to tamping of the ballast.

PART II - SUBGRADE EXPERIMENT

1.0 OBJECTIVE

The Subgrade Experiment was conducted from August 1988 to September 1989 at the Facility for Accelerated Service Testing (FAST), Transportation Test Center, Pueblo, Colorado, to determine how the increase in axle load from 33-ton to 39-ton axle load was distributed to the subgrade structure. If the increase in subgrade stresses was found to be significant, was the measured increase proportional to the applied load.

2.0 TEST LAYOUT

A tangent section of track on the High Tonnage Loop (HTL) was used for the test zone (Figure 1). Constructed in 1975, the section consisted of a fill area that was compacted to a minimum of 95 percent as determined by the standard proctor test (ASTM D698 or AASHO T99). The ballast used in testing was the typical slag ballast found throughout the HTL and the ballast depth was approximately 18 inches below bottom of tie.

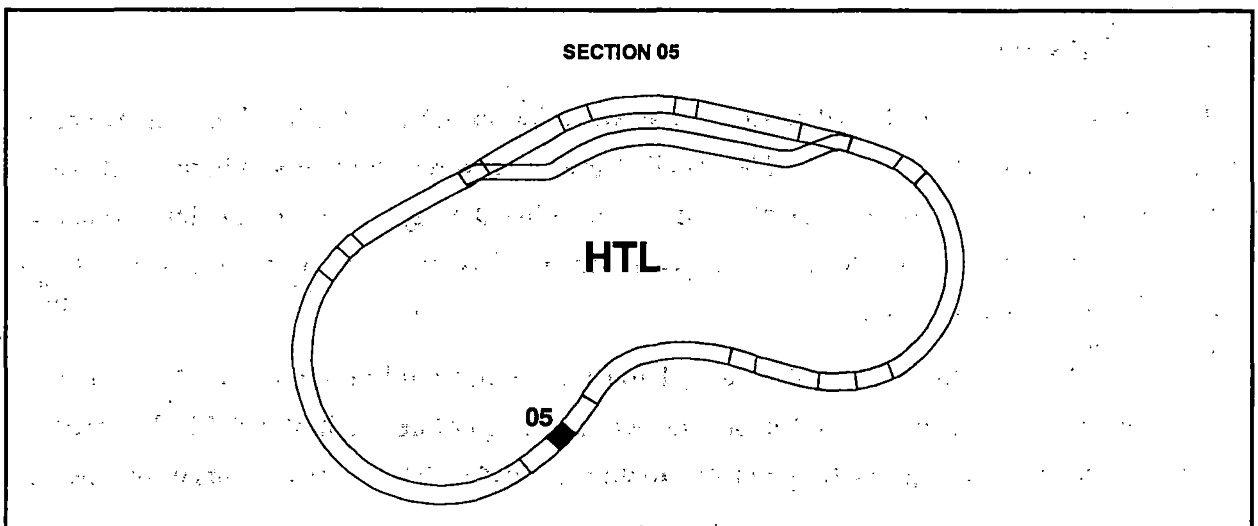

Figure 1. Subgrade Test Location

3.0 INSTRUMENTATION

The test zone was 20 ties long. Five ties were instrumented with pressure cells or extensometers (described in detail below). Three of the ties were instrumented with pressure cells, and two ties were instrumented with extensometers. Instrumented tie plates were installed on the inside and outside rail of one of the ties that had been instrumented with pressure cells. Two battered welds were also installed; one on the outside rail and one on the inside rail. Figure 2 shows the track layout of the instrumentation.

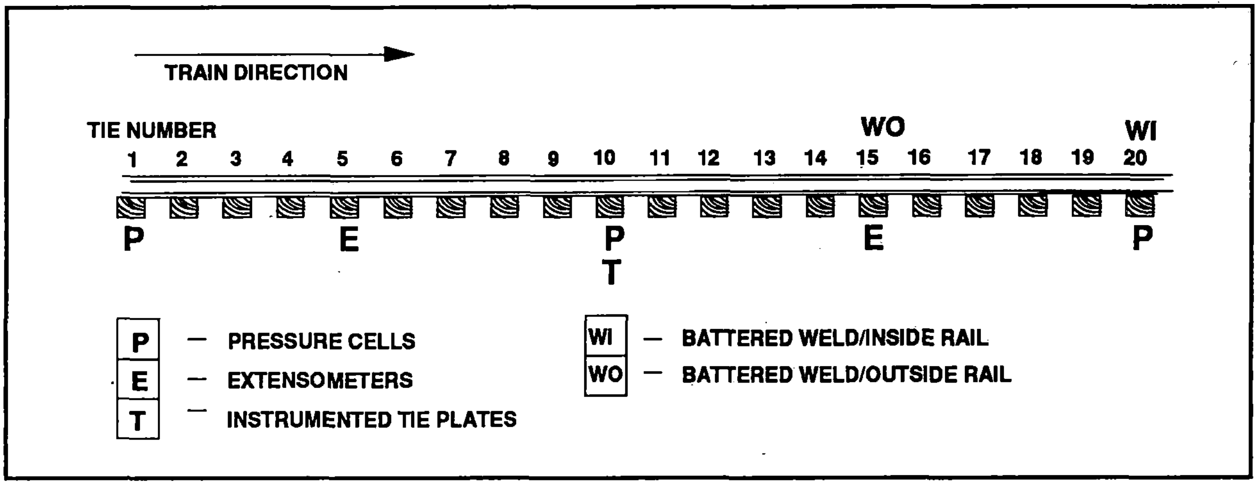

Figure 2. Layout of Instrumentation at Test Zone

To instrument the test section, a 40-foot panel of track and existing ballast were removed. Locations of rails and ties were clearly referenced before removal to ensure that the instrumentation would be placed directly under the ties and rail seat area. The pressure cells were installed at the ballast/subgrade interface. The extensometers were also installed at the ballast/subgrade interface with a rod that went about 10 feet into the subgrade. Figure 3 shows a typical extensometer installation.

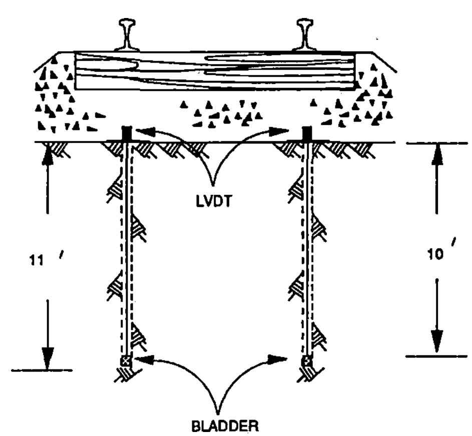

Figure 3. Typical Extensometer Track Installation

The extensometer consisted of a linear variable displacement transformer (LVDT), an expandable bladder, and a 10-foot rod. Holes were bored 11 feet below the ballast/subgrade interface at each installation location. The bladder and rod were installed in the bored hole. Figure 4 shows the bladder, rod, and LVDT used in the installation.

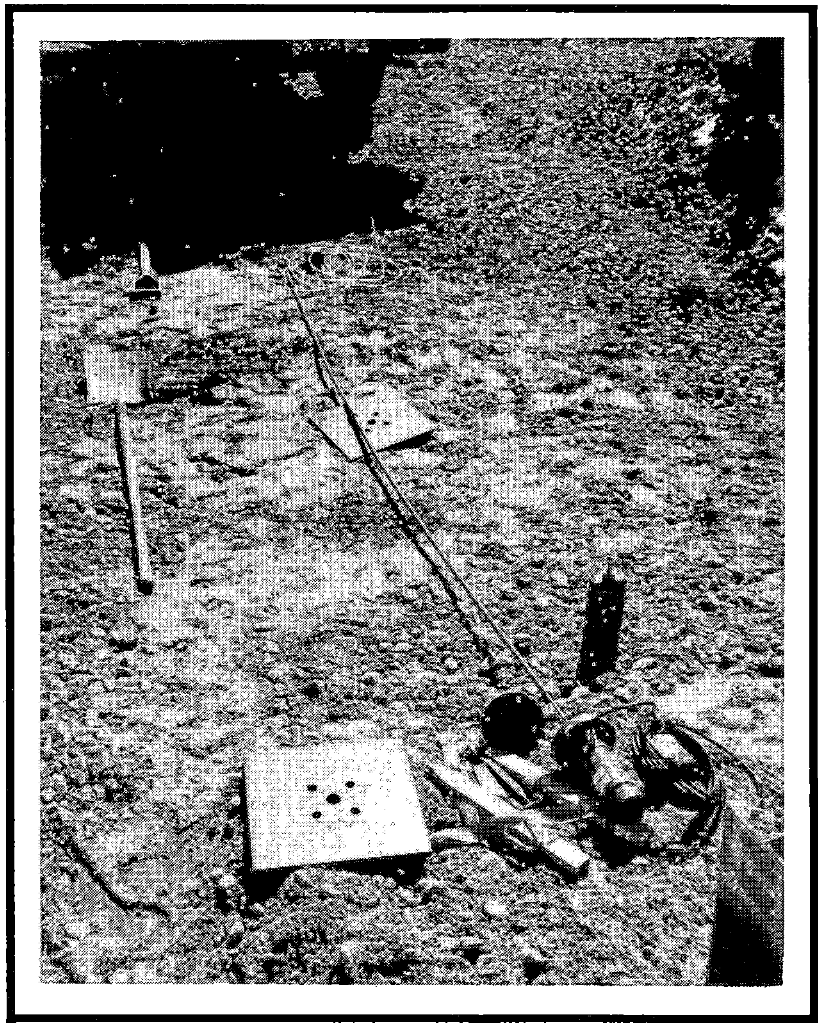

Figure 4. Extensometer Instrumentation

The bladder was used for anchoring the rod at the bottom of the hole. The LVDT (vertical transducer) was placed on top of the subgrade surface and attached to the rod to measure vertical displacement of the subgrade in the 10-foot vertical zone (from bladder to LVDT). The extensometers were installed directly below the rail seat on the inside and outside rail of the loop on the two selected ties. The extensometers were used to measure the deflection of the subgrade under dynamic loading.

Pressure cells were installed at the ballast/subgrade interface. A shallow trench, 3 inches deep, was excavated and filled with sand at each pressure cell installation to provide a more level surface than the natural subgrade. The trenches were filled with 2 inches of sand and compacted to provide a level surface. Figure 5 shows a typical pressure cell installation.

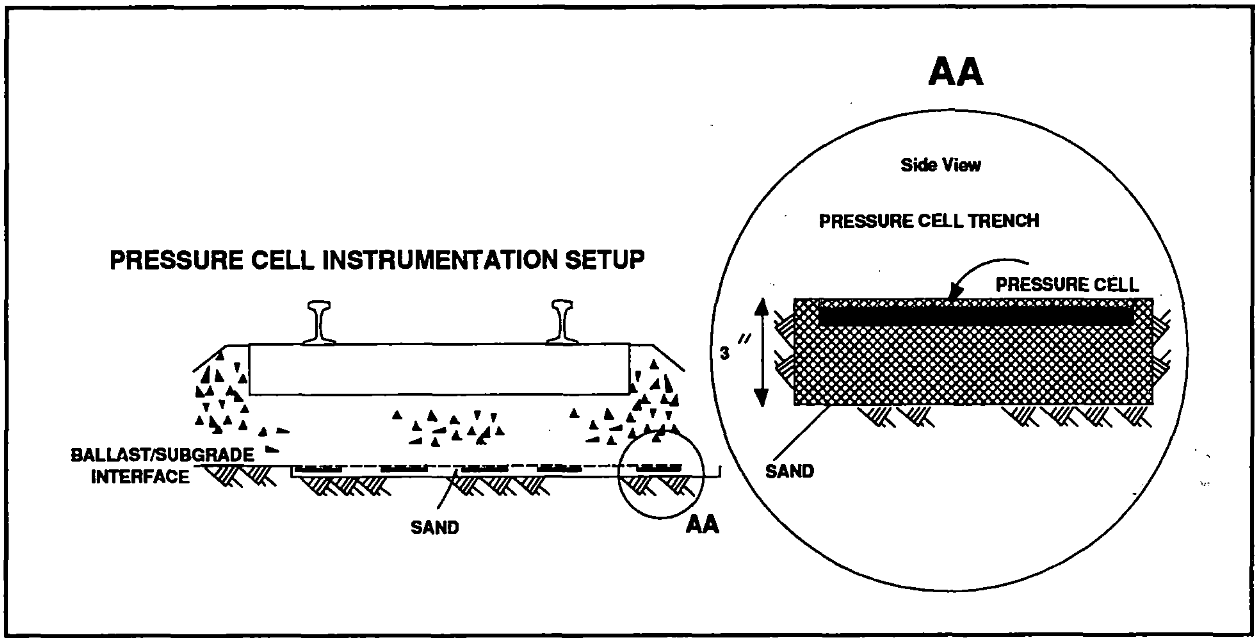

Figure 5. Typical Pressure Cell Track Installation

Once the pressure cells were installed on the sand surface, another half-inch of sand was used to cover the pressure cells and to completely fill the trench. This sand provided a thin buffer zone between the ballast and the pressure cells thereby reducing the risk of damage to the pressure cells from direct contact with the ballast. Figure 6 shows an actual pressure cell installation.

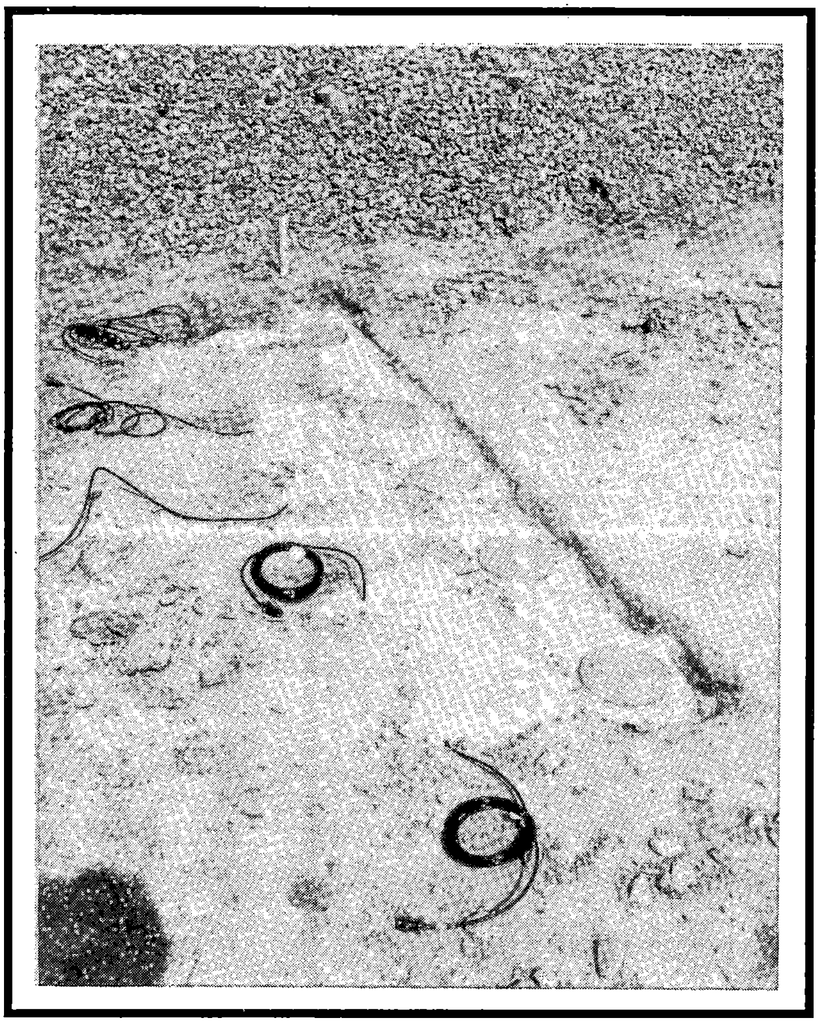

Figure 6. Pressure Cell Installation

Once instrumentation was completed, the track was restored to the original top of rail elevation. In preparation for testing, the test zone was tamped by manual means to avoid any damage by the torsion beam tamper to the buried instrumentation and cabling. A consist was prepared which included fourteen 33-ton and fourteen 39-ton axle load cars.

4.0 TEST IMPLEMENTATION

Before testing, vertical rail deflections were measured using the TTC 605 car, which provides single point loading on both rails simulating a static axle load over a selected tie. The vertical deflections were used to derive track stiffness values on the five instrumented ties. Initially there was a large variation in track stiffness within the test zone. This variation is most likely attributed to the use of manual tamping, which does not provide the consistency of the torsion beam tamper. Once initial data was collected and analyzed, the entire test zone was tamped using the torsion beam tamper to achieve a more consistent vertical track support.

The train consist was made up of both 33-ton and 39-ton axle load cars to provide a direct comparison of the results between the 33- and 39-ton axle load cars. By testing the 33- and 39-ton axle load car simultaneously, problems like changes in weather, instrumentation drift, data collection set up, and changes in train speed were avoided. Data was collected from a wayside location while this train consist operated over the instrumentation test site. A minimum of 20 train passes of data were collected at each measurement cycle to ensure data repeatability. The measurement cycles were taken at 1.4, 15.3, and 82.7 MGT of HAL traffic.

5.0 RESULTS

5.1 VERTICAL TRACK STIFFNESS

The vertical track stiffness varied from tie to tie, and from inside rail to outside rail. This variation is probably the result of hand tamping after instrumentation installation and track restoration. The variation in track stiffness appears to have an affect on the increase in subgrade stresses with the 39-ton axle load traffic. The vertical track stiffness measured during the three measurement cycles is shown in Figures 7 and 8.

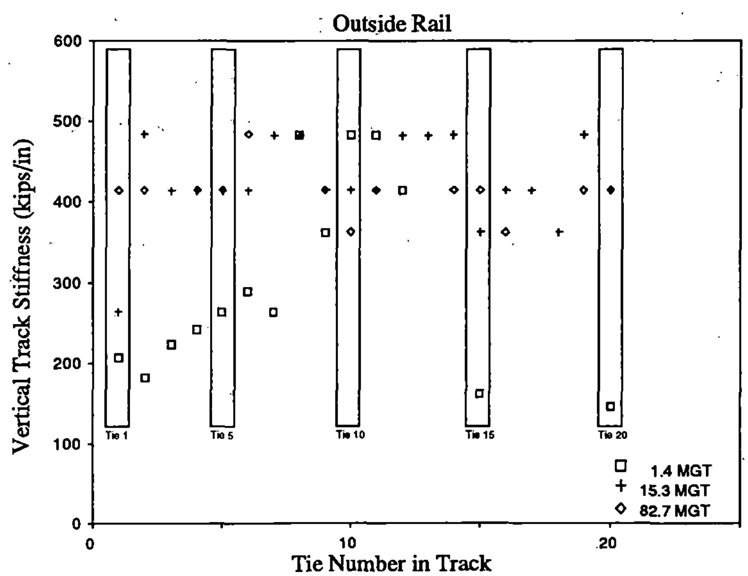

Figure 7. Test Zone Vertical Track Stiffness -- Outside Rail

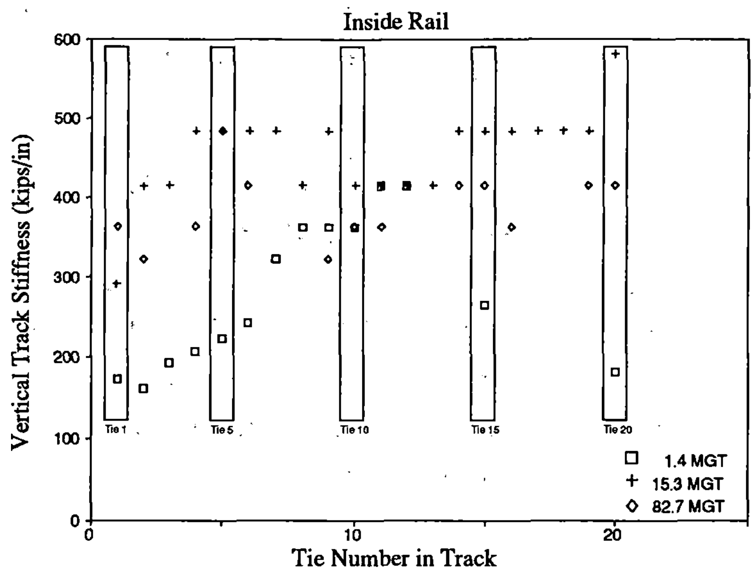

Figure 8. Test Zone Vertical Track Stiffness -- Inside Rail

The variation in track stiffness within the test zone is most noticeable during the first measurement cycle (1.4 MGT). After the wayside data was analyzed and the test zone was again tamped using a torsion beam tamper, a more uniform support condition was achieved throughout the test zone. When wayside data was collected during the second measurement cycle (15.3 MGT), the vertical track stiffness appeared to be more uniform than during the initial measurement at 1.4 MGT; however, frozen ballast conditions existed, limiting the comparison between the measurement data. During the last measurement cycle (82.7 MGT), there was also a more consistent vertical track support condition throughout the test zone than during the initial measurement. Since no frozen ballast conditions existed during this cycle (82.7 MGT) and the initial cycle (1.4 MGT), a comparison of the results can be made without assuming what the effect of the frozen track conditions may have been.

Dynamic data, for subgrade stresses and deflections, was collected using wayside instrumentation. The 20 train passes at each measurement cycle were combined, plotted on frequency distribution plots, and the values reported are at the 10 percent exceedance level (10% of the data results exceed these values).

5.2 SUBGRADE PRESSURES

As shown in Figure 6, five pressure cells were installed directly under each selected tie. Two pressure cells were placed under the rail seat of the inside and outside rail; two were placed in between the rail seats, and one was placed slightly outside from the tie. The top view of this setup is shown in Figure 9.

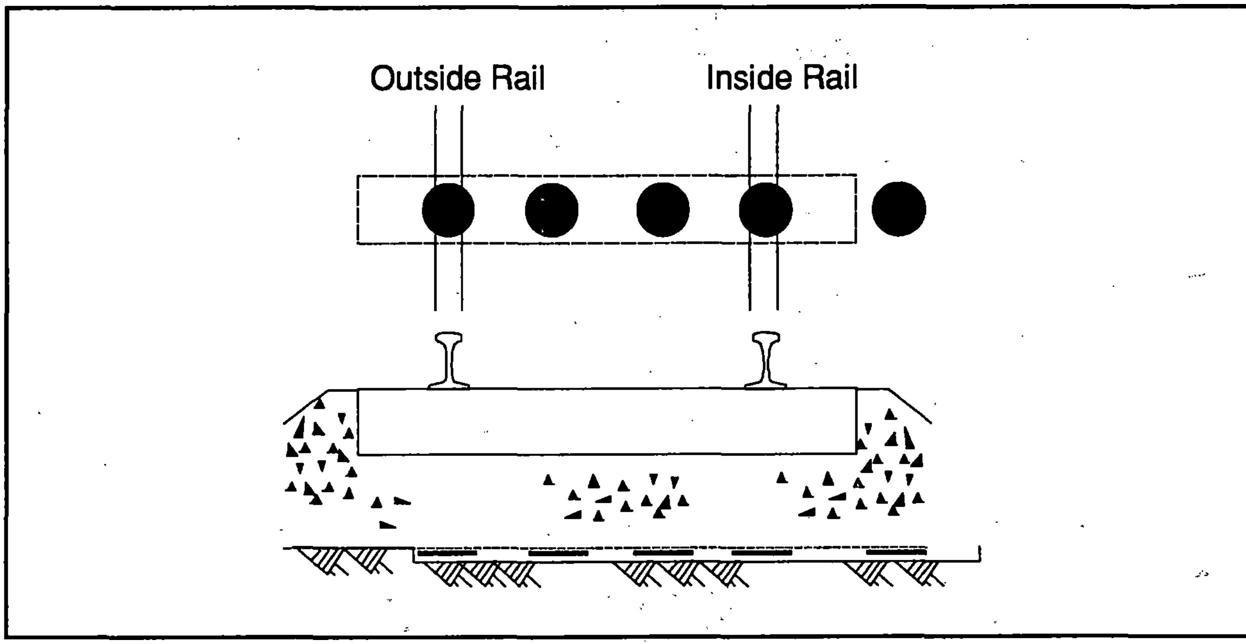

Figure 9. Top View Layout of Pressure Cell Instrumentation

A significant increase, from 33-ton to 39-ton axle load, was evident in all five locations measured across each tie. The largest values recorded were directly under the rail seats, followed by the two locations between the rail seats. The location with the lowest recorded value was the pressure cell, which was slightly offset from the tie. The data collected on the three instrumented ties (1, 10 and 20) showed that the vertical track stiffness influenced the increase in subgrade stresses. Figures 10 and 11 show the subgrade pressures measured directly under the rail seat of tie 20. These values are the highest values measured at the five locations across the tie.

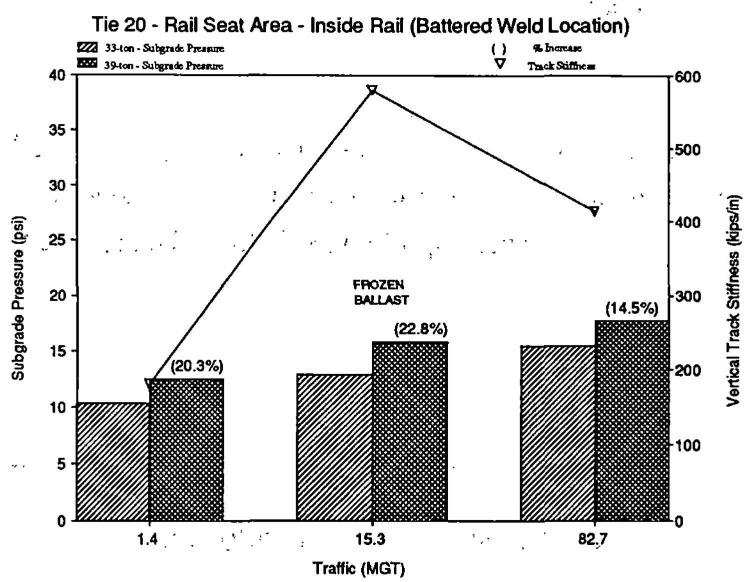

Figure 10. Subgrade Pressure -- 90% of Data at or Below this Level

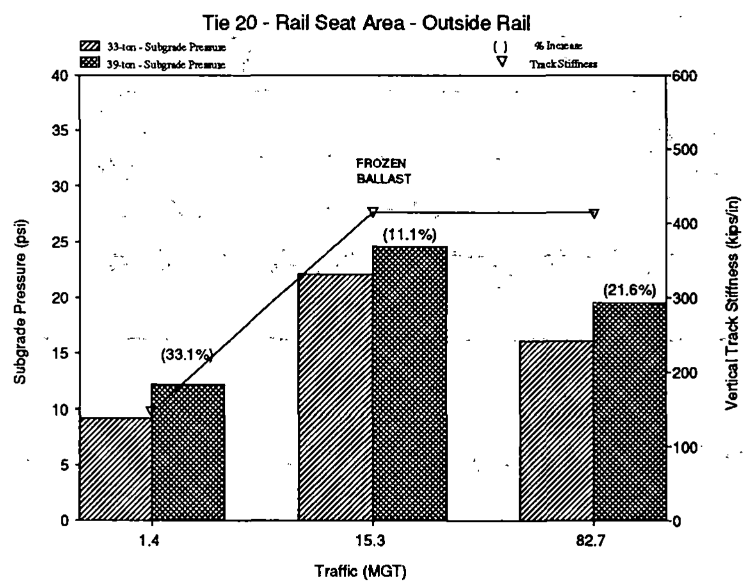

Figure 11. Subgrade Pressure -- 90% of Data at or Below this Level

Figure 12 shows the subgrade pressures measured directly under the tie, about 18 inches inboard from the inside rail. Figure 13 shows the subgrade pressures measured offset from the tie. These values are minimal in comparison to the subgrade pressure values measured in the other four locations under the tie.

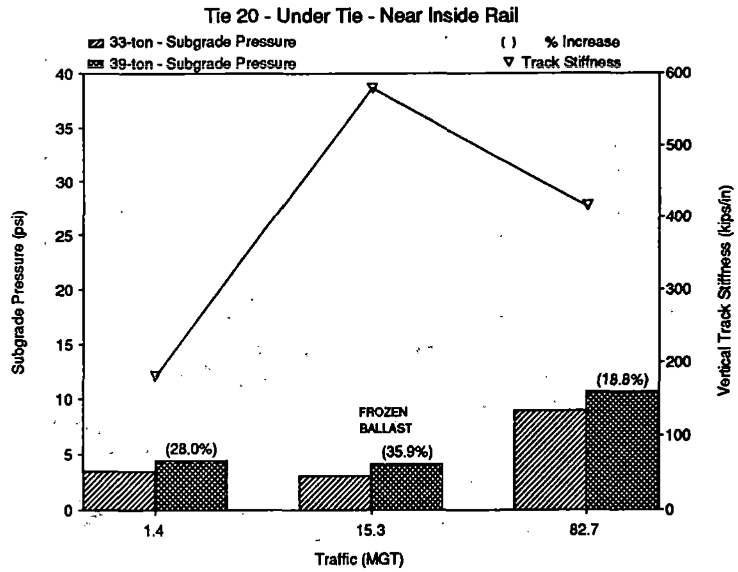

Figure 12. Subgrade Pressure -- 90% of Data at or Below this Level

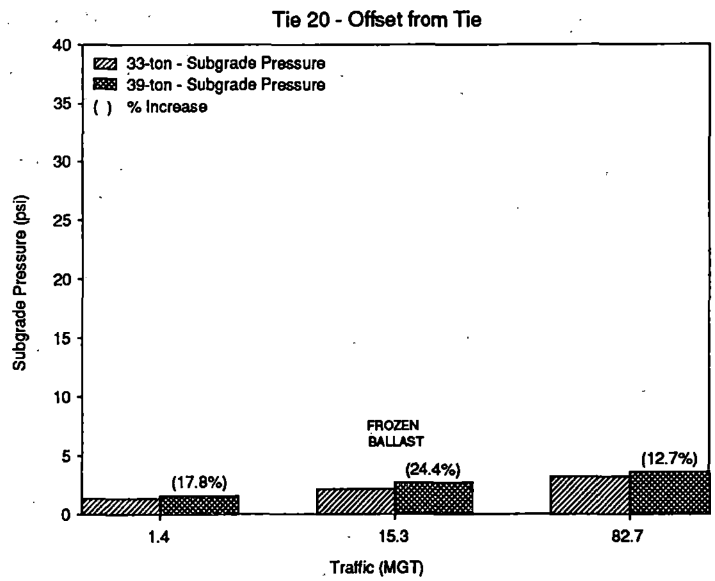

Figure 13. Subgrade Pressure -- 90% of Data at or Below this Level

Figure 14 shows the subgrade pressures measured across tie 20 at 82.7 MGT. The graph shows the distribution of the subgrade pressures across the tie. It clearly demonstrates the largest subgrade pressure values under the rail seat area, and the smallest values measured on the pressure cell, which was installed approximately 10 inches from the end of the tie.

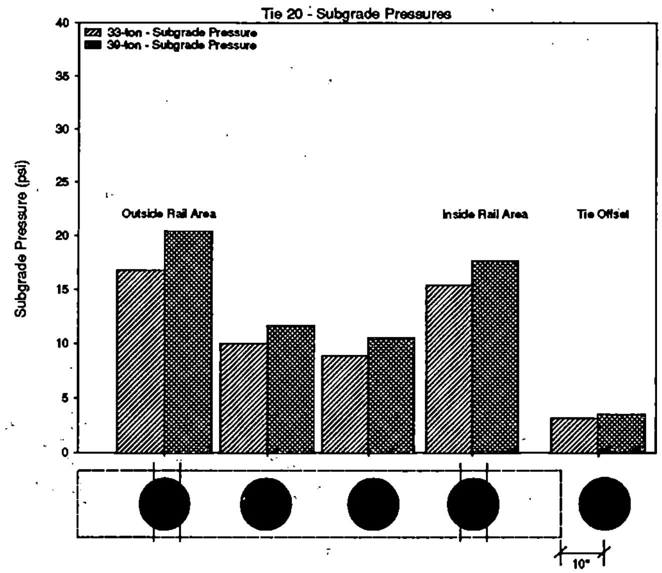

Figure 14. Subgrade Pressure Measured at 82.7 MGT

Figures 15 and 16 show the subgrade pressures and the rail seat loads recorded on tie 10. The rail seat load increase is comparable to the subgrade pressure increase from the 33-ton to the 39-ton axle load at 1.4 MGT. At 15.3 MGT of traffic the rail seat load is much higher than when measured at 1.4 MGT, and the rail seat load increase is less than the increase in subgrade pressure. This is probably due to the frozen ballast condition.

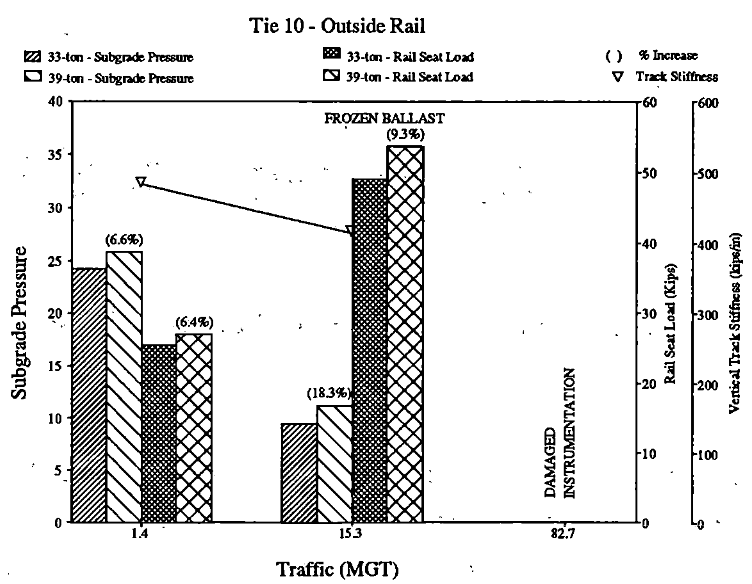

Figure 15. Rail Seat Loads -- 90% of Data at or Below this Level

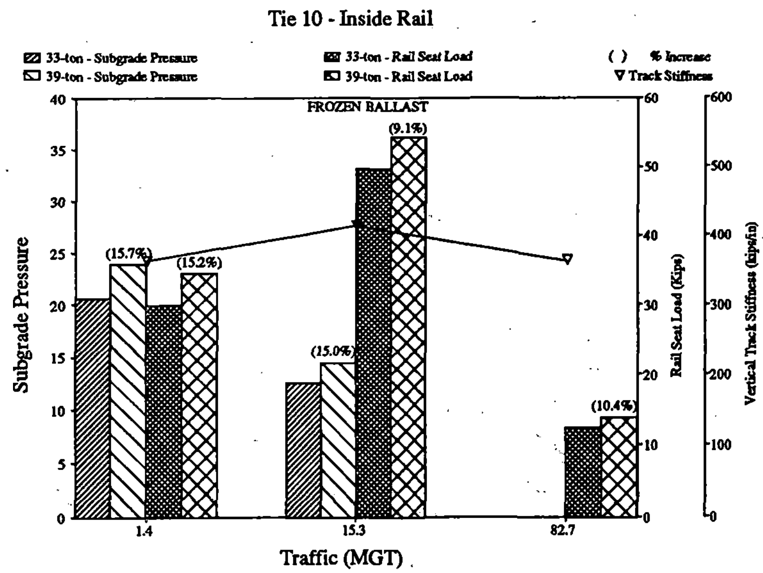

Figure 16. Rail Seat Loads -- 90% of Data at or Below this Level

5.3 SUBGRADE DEFLECTIONS

The subgrade deflections shown in Figure 17 are the deflections measured on tie 15, outside rail, while tie 5, inside rail, deflections are shown in Figure 18. The data for the subgrade deflection also shows a definite increase in deflection due to the 39-ton axle load traffic. The increase tends to vary with location and track stiffness. There is no major change in subgrade deflection with increased tonnage accumulation on tie 5 (no rail anomalies present).

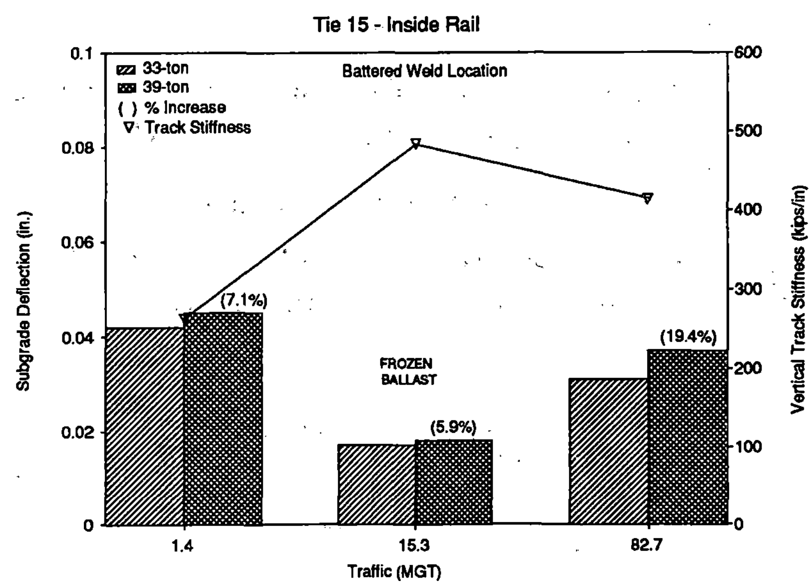

Figure 17. Subgrade Deflections -- 90% of Data at or Below this Level

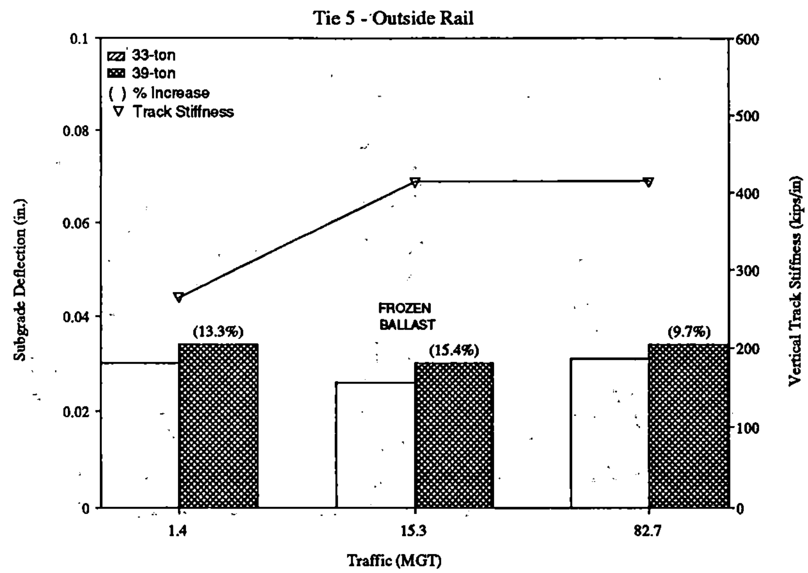

Figure 18. Subgrade Deflections -- 90% of Data at or Below this Level

6.0 CONCLUSIONS

- The overall results of the subgrade test show that the increase in load from 33-ton to 39-ton axle load was evident at the ballast/subgrade interface.
- The increase in subgrade stresses and deflections varied from 10 percent to 30 percent with axle loads of 33-ton and 39 tons (18% increase).
- Defects in the rail running surface may cause an increase in subgrade pressures and deflections and should be researched further.
- Subgrade stresses were influenced by the vertical stiffness of the track. Variation in the vertical track stiffness resulted from hand tamping.
- Increase in axle load from 33-ton to 39-ton did not cause any subgrade failures at FAST; however, the measured increase in stresses could be sufficient to cause significant subgrade related maintenance on some typical North American tracks.

7.0 FUTURE TESTING

- The next phase of the Subgrade Experiment will investigate how subgrade stresses and deflection vary with a typical FAST subgrade structure (4,000 to 5,000 lbs/in/in) versus a lower modulus subgrade structure (1,500 to 2,000 lbs/in/in).

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APPENDIX A

FAST HISTORY, OPERATION AND MAINTENANCE OVERVIEW

by

Richard P. Reiff

INTRODUCTION

To the North American railroad industry, FAST, the Facility for Accelerated Service Testing, means track testing. Since its inception in 1976, well over 1 billion tons of traffic have been operated over a closed loop of track under carefully controlled and monitored conditions. Countless labor-hours have been expended in train operation, track maintenance, measurement, documentation efforts, and data analysis.

This appendix provides readers with an overall background to the FAST program. During the last 4 years, a controlled set of experiments has been conducted to determine the engineering impact to track and mechanical components when subjected to a controlled increase in applied axle loading. Data from these trials is being made available to the industry to provide component performance information as an aid in determining the most safe, reliable, and efficient method of operating a railroad system.

Particular emphasis has been on the effects that heavier axle loads have on track materials and maintenance procedures.

BRIEF HISTORY OF FAST

In September 1975, a report recommending a facility to study wear and fatigue of railroad track and equipment was issued by the Association of American Railroads (AAR) and the Federal Railroad Administration (FRA). The following spring track construction began at the High Speed Ground Test Center, Pueblo, Colorado, (now the Transportation Test Center). The first loop covered 4.78 miles (Figure 1) and utilized some of the existing Train Dynamics Track to reduce construction costs.

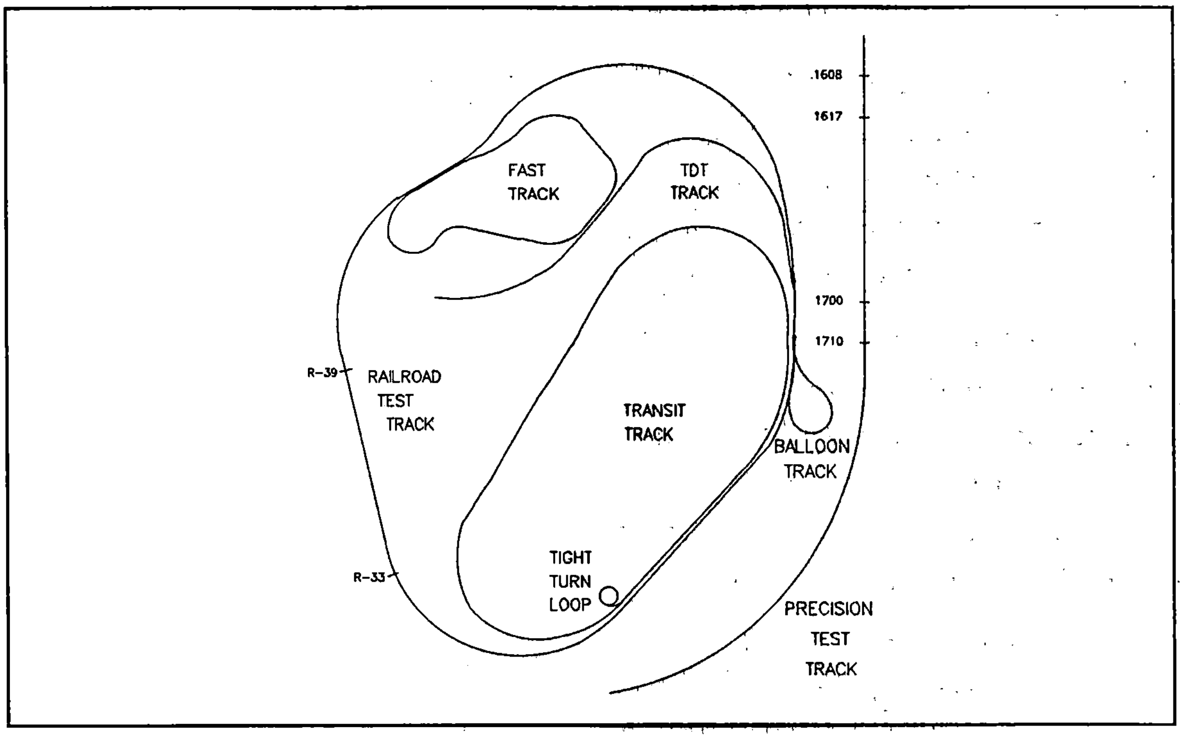


Figure 1. Test Tracks at High Speed Ground Test Center, Pueblo, CO, Showing General Location of FAST

On September 22, 1976, the first FAST train began accumulating tonnage on the dedicated test track. Since that time, a test train in various configurations and under a variety of test conditions has continued to operate.

The original FAST program was sponsored by the FRA, with all operating and measurement costs being the responsibility of the government. The railroad industry contributed significantly to the program by providing technical assistance and equipment, and by transporting materials for construction and maintenance.

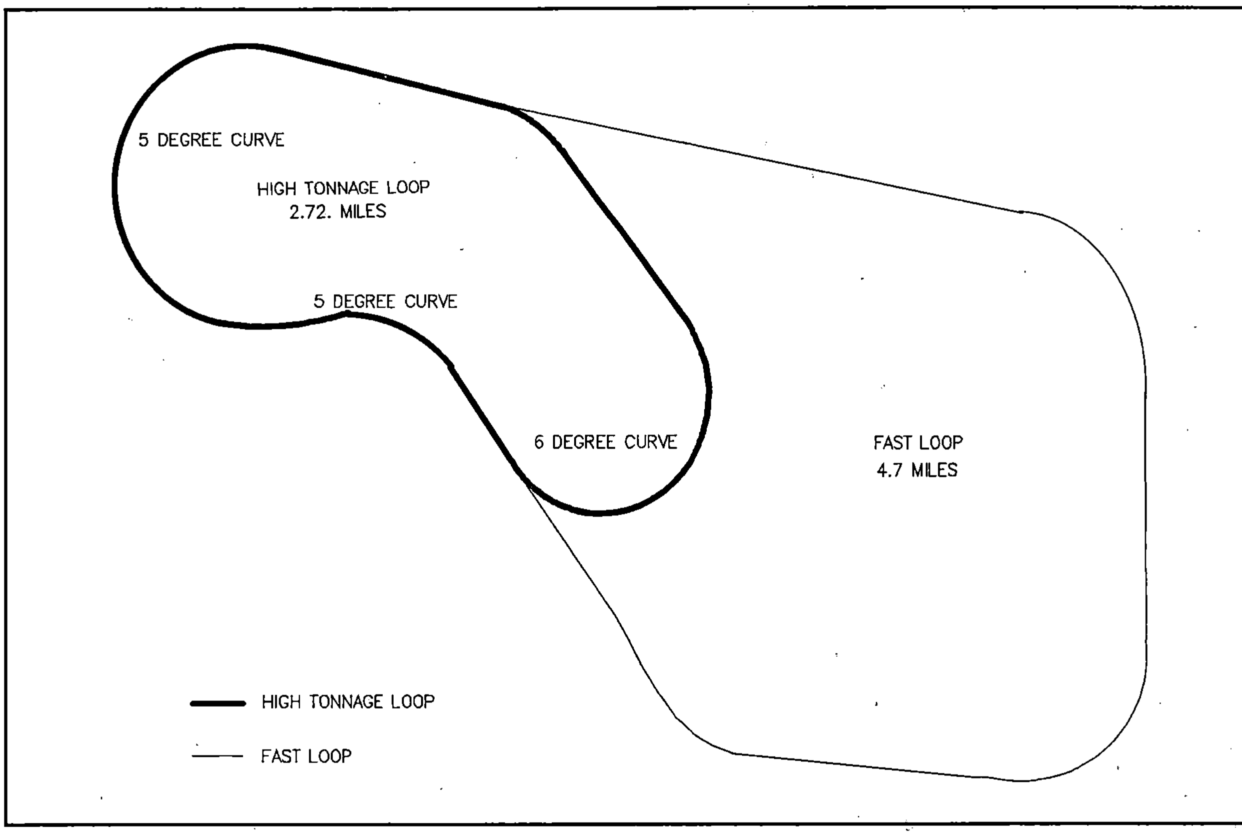


Figure 2. High Tonnage Loop

After 1977, government emphasis at the test center shifted away from high speed transportation to research of conventional transportation modes. The testing center was renamed Transportation Test Center (TTC), and in late 1982, government policy changed the operational procedures making the AAR solely responsible for its operation and maintenance.

FAST also continued to change. The annual FAST program operating budget had steadily decreased over a period of five years and, by 1985, it was apparent that the expense of operating a full train over the 4.78 mile loop was no longer affordable. To permit continued operation of FAST, a cut-off track was proposed, designed, and constructed using AAR funds (Figure 2). The cut-off track, approximately 1.3 miles, effectively reduced the loop from 4.78 miles to 2.7 miles. The new loop, named the High Tonnage Loop (HTL), consisted of one 6-degree curve and three 5-degree curves. All curves in the loop utilized spirals 300 feet long. As with the original loop, the HTL was divided into a number of test sections, which made inventory, maintenance, and measurement activities easier to document.

Completion of the HTL in June 1985, significantly reduced operating costs and allowed continuation of the FAST program using the original 33-ton axle load consist.

Since 1976, FAST has monitored tonnage applied to all test sections. This is accomplished by having every car and locomotive weighed and assigned a control number. This number is used to monitor daily train consist makeup and, when combined with the lap count for each shift, allows an accurate determination of applied tonnage over the loop. Each train operation is monitored in such a fashion, except for occasional work trains used for ballast dumping, rail unloading, or other track maintenance support functions.

Details of HTL Operations
33-ton Axle Load Phase

Along with the HTL came minor changes to the method of train operation. At the start of the HTL operation, a major rail fatigue test was initiated that required different operating characteristics than was used before. Train operation under the previous FAST policy controlled train direction so that both clockwise and counterclockwise operations were balanced. The train operated only counterclockwise on the HTL. The main reason was that lubrication, applied from a wayside lubricator, could be controlled from one location. (A calcium soap base lubricant with 11 percent graphite has been utilized at all wayside lubricators at FAST.) The combination of single directional operation and the use of wayside lubricators created the intended differential in the lubrication -- more near the lubricator, less at distances remote from the lubricator. By installing like or identical rail sections at various locations around the loop, the effect of a different lubrication levels could be assessed.

The shorter length of the HTL, 2.7 miles opposed to the original 4.78 miles, necessitated a major change in the signal system. The original signal system configuration was composed of a basic 3 block, direct current track circuit design. It utilized conventional, off-the-shelf signal components. Signal spacing on the HTL, however, prevented the proper function of this system as the block lengths would be so short, relative to the length of the train, that the locomotives would be continuously operating on a yellow approach. The signal system, which was solely used for broken rail protection and not block control of trains, was redesigned to function only as a broken rail detector.

As a result of the revised system, the outside and inside rail of the loop was fully insulated from each other, and each rail became its own independent signal loop. One master insulated joint was installed at a location on the outside and inside rail. Independent power supplies feed each circuit, with each loop of rail becoming its own continuity check circuit. Due to the short blocks, only a red (stop) or green (proceed) indication is now given. By using switch control boxes and additional insulated joints at turnouts, signals will also display red if a switch is thrown for an incorrect route. This revised signal system has been successful in detecting broken rails, joints, and improperly aligned turnouts.

Another variation initiated with the start of the HTL was to lubricate only the outside rail of the loop. Previous tests were conducted by alternating operating periods of lubricated rail (both rails) and dry rail. Typically 40 MGT of lubricated operation was followed by 10 to 15 MGT of dry rail, with this sequence repeated over a number of cycles. The new rail fatigue test required a long term (150 or more MGT) period of fully lubricated rail, without extended dry operation. Such a long lubricated test period would have prohibited the testing and evaluation of rail in the dry mode.

By only lubricating the outside rail, and leaving the inside rail dry, the one reverse curve (Section 7) on the HTL would have a dry gage face and offer a site for evaluating dry wear characteristics (Figure 3). As the train was turned end-for-end on a scheduled basis (but operated only in the counterclockwise direction), some contamination of the inside rail was observed immediately after train turning, but rapidly disappeared.

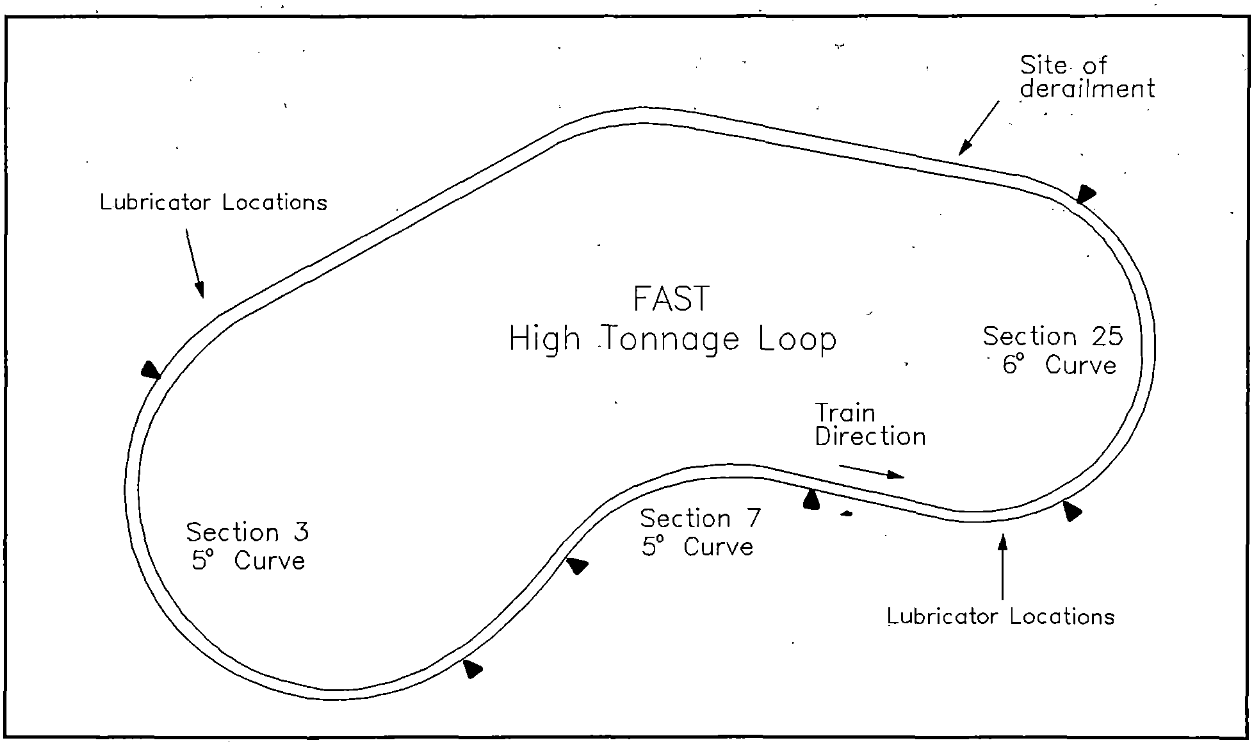


Figure 3. Lubricator Locations on the High Tonnage Loop

In July 1986, a major derailment occurred with the FAST train when the inside rail, after the exiting spiral in Section 25, overturned. Although track in this area was visibly in good condition, subsequent measurements located several pockets of weak gage restraint. A number of tests were conducted to determine the cause of the rail overturning. It was determined that under extreme differentials of high rail to low rail lubrication (high rail over lubricated, low rail extremely dry) a high truck turning moment could be obtained especially with locomotives in traction. It was suggested that this high moment accelerated the fatigue of wood tie fastener support near the derailment area, until rail rollover occurred. Results of this study are reported in AAR report R-712, "Effect of Track Lubrication on Gage Spreading Forces and Deflections," by K. J. Laine and N. G. Wilson, August 1989.

To eliminate, or at least reduce high differences of lubricant effectiveness between high and low rails without severely impacting the rail wear test, a very small amount of lubrication was required on top of both the high and low rails. Since the high (outside) rail of the loop was already lubricated, it was decided to place a small amount of contamination on top of the low (inside) rail of the loop. This was accomplished by installing some modified Fuji roller lubricators on cars kept near the end of the train. These lubricators were configured to lubricate the wheel tread (NOT THE FLANGE) with a very small amount of lubricant.

As an added safety check, gage widening "tell tales" were installed at a number of locations around the FAST/HTL loop (Figure 4). The tell tale is a small spring loaded device that provides an indication of maximum gage widening at that location due to the action from a passing train. The track inspectors at FAST routinely monitor these devices and check to see if excessive gage widening is occurring. This provides a safety check and gives advance notice if impending loss of gage holding ability is occurring.

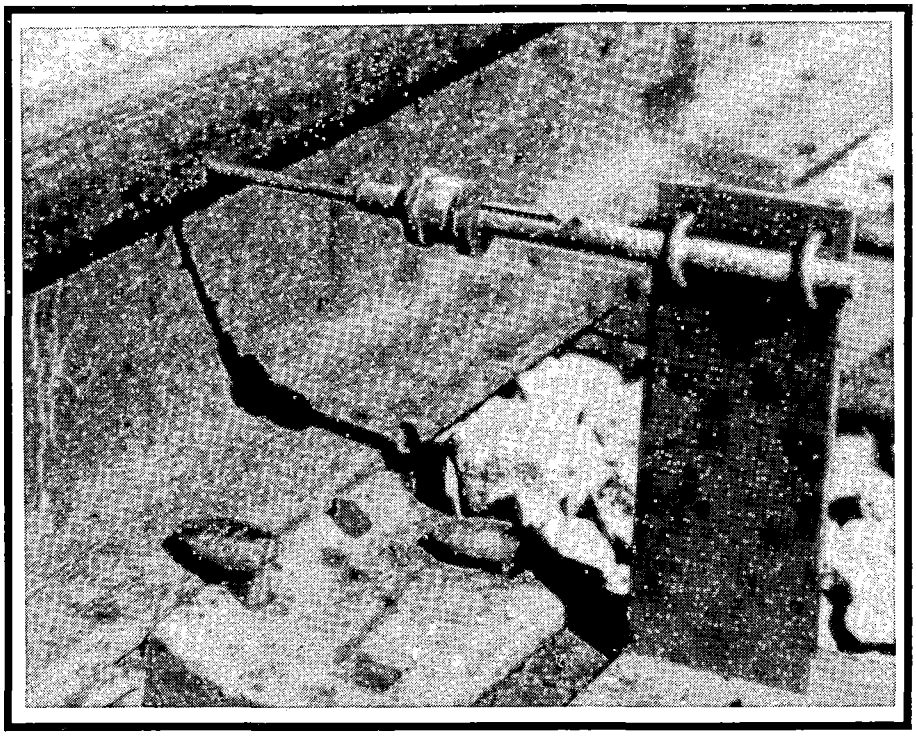


Figure 4. Tell Tale Installed on the HTL

Background and Need for the HAL Test Program

The completion of the 33-ton axle load (100-ton car) phase of the HTL occurred March 28, 1988. A total of 160 MGT was operated in the HTL configuration, while those parts of the HTL that utilized the original FAST loop had a total of 1023 MGT.

Up until this time the FAST consist was made up entirely of 100-ton-capacity cars, which resulted in a weight on rail of 263,000 pounds per car. Occasionally a few 89-foot flatcars, tank cars, and other less than 100-ton capacity cars were operated for special tests. The 100-ton car, as it is commonly referred to, has an axle load of 33 tons. The standard for such equipment includes 36-inch diameter wheels, 6 1/2 by 11-inch wheel bearings and a truck wheel base of 5 feet 6 inches (see Figure 5); this is the maximum weight on rail that is currently accepted for unrestricted interchange of equipment in North America.

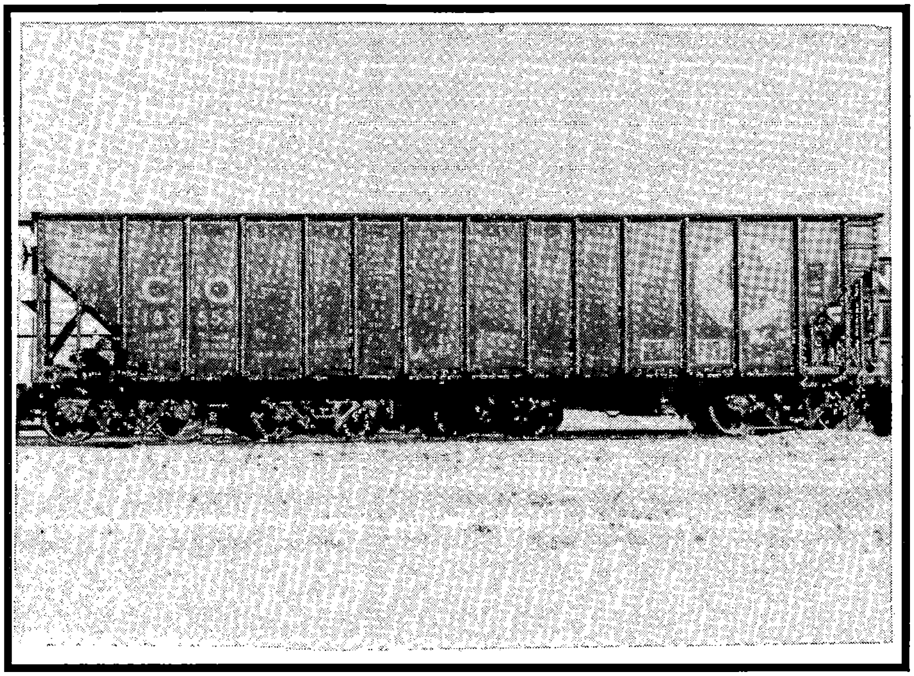


Figure 5. Typical 100-ton Capacity Car

The industry Vehicle Track Systems (VTS) group became involved with HAL testing in 1988. Under VTS direction experiment plans were revised to incorporate current industry concerns. The FAST Steering Committee recommended that the operation of the HTL continue, but that the train weight be increased to a 39-ton axle load. The purpose of the continuation would be to document the effect of heavier cars on existing track structures since some do exist and operate daily in North America. Examples include the Detroit Edison coal train, which consists of 125-ton-capacity equipment. These cars have larger wheels (38" diameter), larger bearings (7" X 12") and a longer truck wheel base (6'), as shown in Figure 6a and 6b. Table 1 summarizes the differences between 100- and 125-ton-capacity cars.

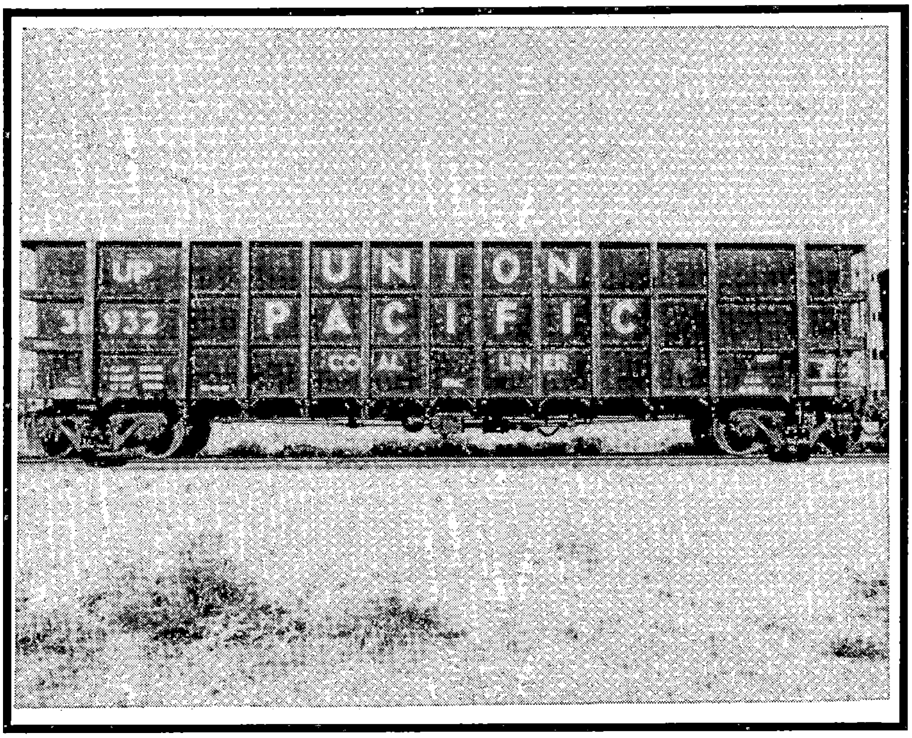


Figure 6a. Typical 125-ton Capacity Open Top Gondola

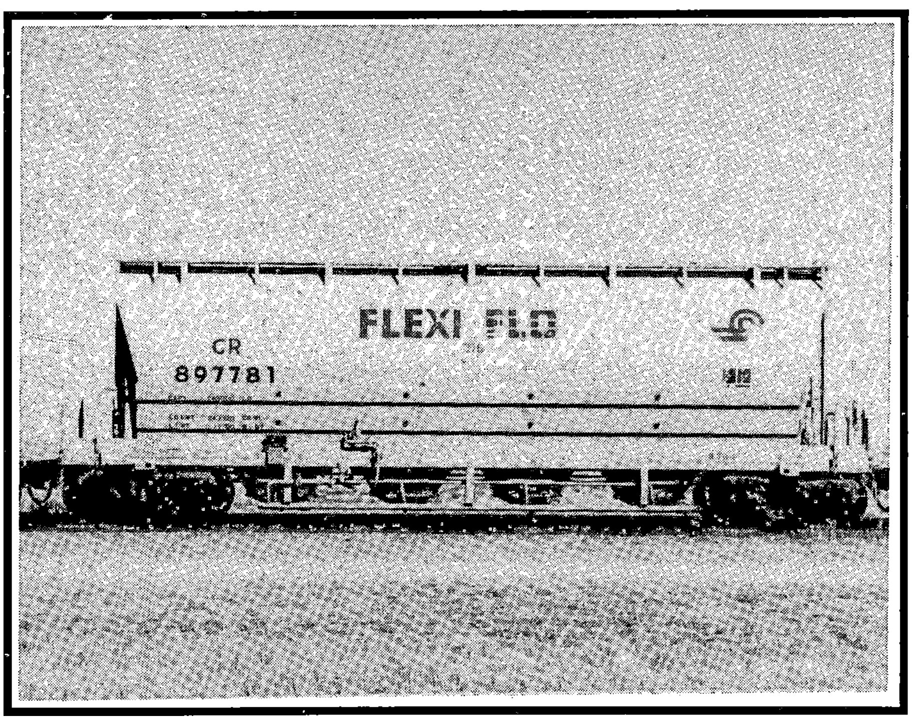


Figure 6b. Typical 125-ton Capacity Covered Hopper Car

Table 1. Differences between 100- and 125-ton Capacity Cars

COMMON NAME	ACTUAL CONFIGURATION
100-ton car	100 tons of lading 31.5 tons of empty car weight 131.5 tons on the rail 263,000 lbs on the rail 33,000 lbs per wheel (33 kips) 36" diameter wheel (33-ton axle load)
125-ton car	124.5 tons of lading 33 tons of empty car weight 157.5 tons on the rail 315,000 lbs on the rail 39,000 lbs per wheel (39 kips) 38" diameter wheel (39-ton axle load

Where heavier axle load cars are already in operation, they are not the sole traffic over a line. For this reason it is impossible to determine the exact damage factor that the heavier car load applies to the track. Maintenance prediction, for lines that may soon see a large amount of these heavier cars, is therefore difficult to determine. Thus, in order to obtain a better understanding about such degradation and wear rates, and fine tune track degradation and performance models, it was decided to operate the HTL using a heavier car.

The Heavy Axle Load (HAL) testing program was initiated in 1988. Up until this point in time, all FAST operations were funded solely by the FRA. For the first time in the history of the FAST program, funding for train operation use and data collection was supplied from both FRA and AAR funds. Guidelines for experimental goals were established as follows:

- Utilizing 125-ton equipment, repeat as near a possible the basic experiments conducted with 100-ton equipment during the final 160 MGT of the HTL.

- The only major variable was to be that of increasing the axle load; thus car type, train speed and configuration, and track layout would remain the same.
- Data would be collected to determine the effect, if any, on increasing the axle load.
- Data would also be collected to assist in validating existing track performance and deterioration models.

HAL TEST SCHEDULE AND PARAMETERS

HAL experiment plans were prepared after reviewing the results of the 160 MGT of 100-ton traffic on the HTL. Minor changes were made where results indicated a change in test procedures was needed, or where direct back-to-back comparisons could not be made. In some cases, where comparative data was simply not available, new test plans were drawn up.

Track rebuilding efforts began in April 1988, and a completed loop was made available for testing in early July. The track loop for the HAL Test was essentially the same as that for the 33-ton axle load (HTL) period, with the exception of adding a "by-pass track" (Figure 7). The loop was divided into test zones, which were identified by numbers.

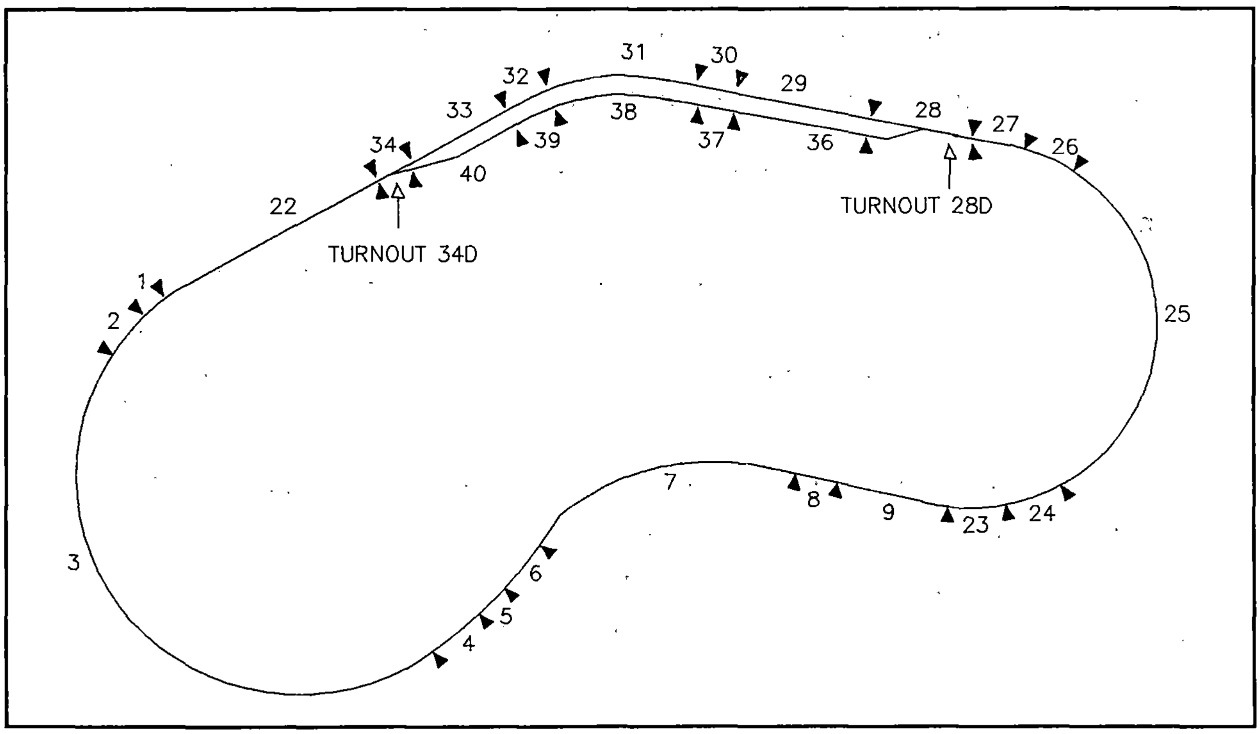


Figure 7. Map of HTL with By-Pass Track Added at Start of HAL Operations

The by-pass track, or siding, provided additional operating configurations and testing opportunities. The primary purpose of the by-pass was to permit operation over turnouts in both the straight-through and diverging route directions. FAST schedules called for 20 percent to 30 percent of the traffic to operate over the by-pass, thus applying tonnage to diverging route turnout components.

An added benefit to this type of operation was that it allowed track experiments that required small but controlled dosages of traffic between measurement and inspection cycles to be conducted. It was possible to operate as little as one train or as much as one full shift (0.01 to 1.35 MGT) during any given shift over the by-pass, thus affording selected track experiments controlled increments of tonnage between inspection periods.

After track rebuilding efforts were completed in August 1988, train operation began immediately. Small increments of MGT accumulation required by the Ballast Test, located on the main loop, resulted in low MGT accumulation rates during the first month. Rapid accumulation of tonnage began in October 1988, with the first 15 MGT of the HAL program operating in a dry, no lubrication mode.

The initial dry mode was operated for several reasons:

- To obtain early dry wear-rate data for "quick look" purposes
- To break-in rail and wheel profiles to a "worn" shape
- To provide a conformal worn rail/wheel profile on selected test rails for rail fatigue information

The 15 MGT dry mode was completed in January 1989. By design, a large amount of test rail was replaced to allow installation of "lubricated only" rail in support of fatigue testing. At the same time, a large amount of transition rail was replaced due to excessive wear observed during the dry operation.

Fully lubricated operation was initiated in March 1989, and continued until an additional 135 MGT was applied on April 20, 1990. During this period a number of interim measurements, minor rebuilds, and the replacement of a major turnout occurred. A total of 160 MGT of HAL (39-ton) traffic was applied to the loop.

HAL Track Description

A detailed description of the HAL loop, initial experiments and an overview of train operation are contained in Appendix B. Refer to this section for detailed descriptions of track sections, experiments, measurements and other items.

FAST/HAL TRAIN MAKEUP/OPERATION

The HAL train consists almost entirely of 39-ton axle load cars, as detailed above. Train length varied from 60 to over 75 HAL cars, with the addition of up to five standard 33-ton axle load (100-ton capacity) cars for mechanical test purposes. The 33-ton axle load cars were included for wheel wear control measurements and carried known defective bearings in support of mechanical tests.

Under normal conditions, four or five 4-axle locomotives (B-B truck configuration) were used to pull the consist; an example is shown in Figure 8.

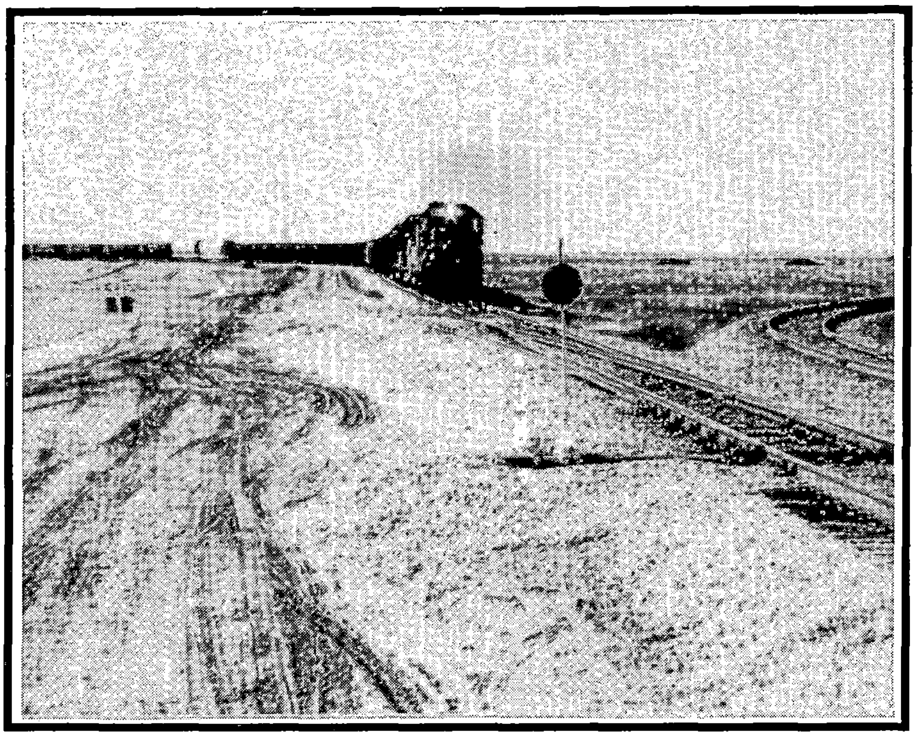


Figure 8. Typical HAL Train in Operation

These usually consisted of EMD GP38 and GP40, and GE U30B locomotives loaned to the FAST program by AAR members. On occasion, due to locomotive maintenance requirements, a rental or TTC locomotive was used to ensure adequate horsepower. Six axle (C-C) locomotives were used in the consist only during special test runs or as a work train. Train speed, after the initial "check-out lap" was held to 40 mph, with an average range of 38 mph to 42 mph. All curves were balanced so that at 40 mph a 2-inch underbalance condition occurred; that is, the high rail was loaded more than the low rail. The 5-degree curves were built with 4 inches of superelevation, while the 6-degree curve was built with 5 inches of superelevation. All elevation was run-out within the length of the 300-foot spirals.

Most train operation during the HAL testing occurred during early morning, third shift hours. Generally train operation was started at or near midnight and continued until 8 to 9 a.m., unless a broken rail or other defect required an earlier stop. The night operation was conducted for two major reasons:

1. Rail Temperature: Due to the short loop and 40 mph operation, the time between last car and locomotive passage for the next lap was about 2 1/4 minutes. The rail did not have sufficient time to cool, and daytime rail temperatures of over 160 degrees Fahrenheit had been recorded. This led to some track instabilities, buckles, and other problems. Night operation, without the added heat load of the sun, eliminated most track instability problems.

2. Track Time for Maintenance Crews: As will be discussed later in this document and in the track maintenance section, spot and "housekeeping" maintenance requirements soared during the HAL Test as compared to the conventional axle load period. The night operation allowed daily access to the track in support of maintenance functions.

During a typical eight hour shift, 100 to 120 laps could be accumulated; however, due to a significant problem with broken welds, many lap counts ranged between 65 to 90, and on occasion even less. This translates to about 0.6 to 1.35 MGT per eight hour shift, depending on train length. Train mileage, for a 65 to 120 lap shift, would range from 175 to 325 miles.

All cars were inspected every third shift of full operation, or within a 500 to 700 mile interval. Locomotive maintenance followed standard railroad daily, and 30- and 90-day inspection cycles.

Details of HAL Train Operation, Lubrication Application and Control:

As stated previously, train direction was primarily counterclockwise, with the following exception:

After every 3 MGT of operation (+ /- 1 MGT), the wayside lubricators were turned off and the power run around the loop to the rear of the train. Then up to 30 laps (no more than 0.35 MGT) were operated in a reverse (clockwise) direction with no lubrication added to the track. The clockwise dry-down operation served two purposes:

1. It removed excess lubricant from top of the rail to aid in ultrasonic inspections

2. It provided beach marks (growth rings) which are used to monitor and track the initiation and growth of internal rail defects, especially shells and transverse defects

After completion of the ultrasonic rail inspection, generally every 3 MGT, the train was turned end-for-end, and reset for a counterclockwise operation. Upon restarting train operation, the wayside lubricators were reconnected and full lubrication was usually obtained within 15 to 20 laps. The main lubricator providing the basic lubrication was located in Section 24 (a spiral) just before the beginning of the 6-degree curve.

During periods of cold weather, a backup lubricator, located in Section 1 about halfway around the loop from the main lubricator, was used to establish and occasionally maintain required levels of lubrication (Figure 3).

Lubrication levels around the loop were recorded using TTC's Lubricant Level Gage (often dubbed the goop gage). This device (Figure 9) is used by the track inspector to monitor the visible level of lubricant on the gage face of the rail. Although this device will in no way determine lubrication effectiveness, since the same lubricant was used at all times during both the 33- and 39-ton axle load tests, the values recorded can be used to determine amounts of lubricant present.

The normal maximum lubricant level desired, as measured by the goop gage, is a +10. The rail at the beginning of the 6-degree curve, nearest the lubricator, had significantly more lubrication, averaging +20 to +30.

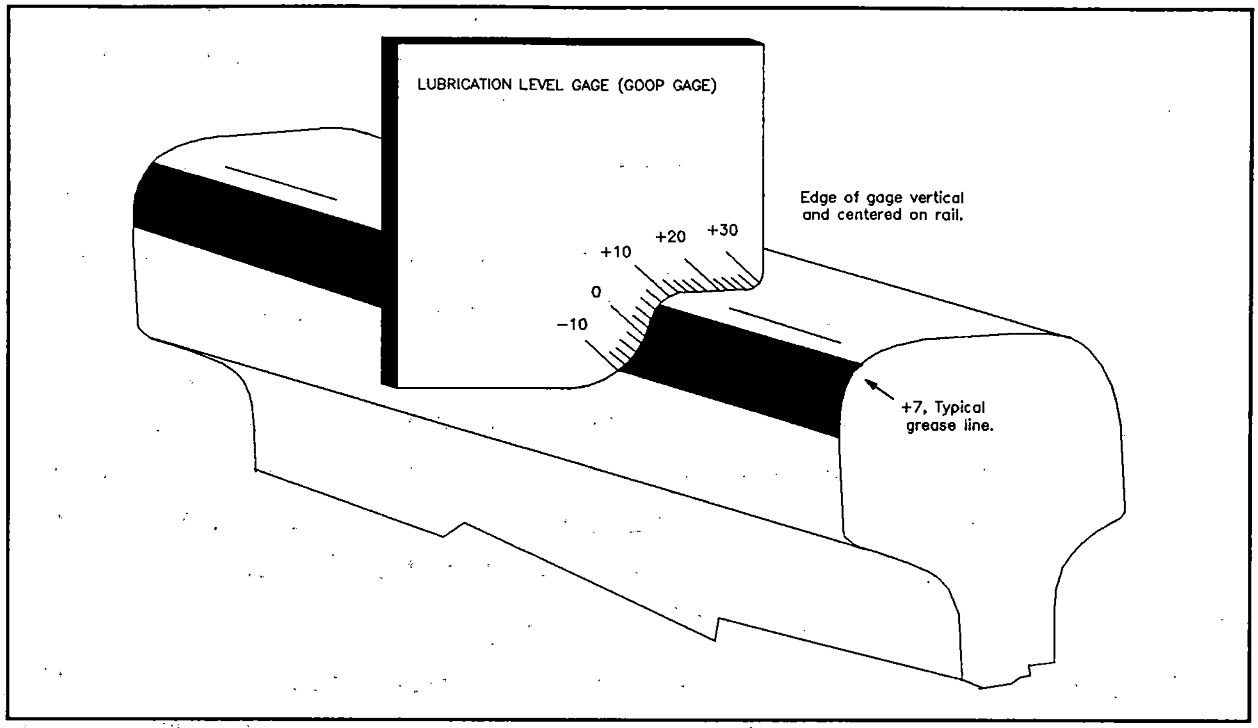


Figure 9. TTC's Lubricant Level Gage (Goop Gage)

Track Inspection Policy

The FAST/HTL loop is inspected continuously during operations and after every 2 MGT of operation during daytime periods.

During train operating periods for the HAL Test, which generally occurred at night, one track worker was utilized to inspect and adjust the lubricators. The duty of the second track worker was to constantly rove and look for any damage to the track, change in support conditions, broken components or loose bolts. By using road vehicles equipped with extra lights, this inspection was carried on continuously throughout the shift.

Additional information on track conditions was received from the onboard train crew. Due to the short nature of the loop, the crew soon learns the "feel" of the track and becomes aware of any changes. By use of radio contact, the ground inspector can readily be directed to a suspect area and ensure that an adequate track is being operated over.

The night crew had access to hand tools and some track machinery, which allowed them some repair capability. In some cases, such as a field weld failure, a two-worker crew was insufficient to pull rail gaps together, and operation of the train was suspended; however, most of the time minor repairs could be made and the train operation continued. Such repairs were made only in areas where experiment plans allowed, not where support data or measurements were needed.

The nighttime track inspectors monitored the entire loop, and, through inspection logs, documented areas that required immediate remedial repair, as well as areas of concern. Thus, items such as heavily corrugated rail, which might be causing undo ballast damage under train action, were noted for detailed daytime inspection.

The daytime track inspectors would make a detailed inspection, on foot, of the entire loop every 3 MGT, in conjunction with the ultrasonic inspection cycle. They would note all items requiring repair in the following categories: (1) fix immediately, and (2) schedule for repair.

Items such as missing fasteners, clips, and bolts would be in the "fix immediately" category. Other long-term planning items like tie replacement needs and grinding requirements would be in the "schedule for repair" category.

The track supervisor would advise the experiment monitor of repairs needed in test section areas, especially if such repairs might have damaged or altered measurement sites. When required, pre- and post-maintenance measurements were obtained in order to quantify the effect of the activity.

Track was generally allowed to degrade until it neared the FRA Class 4 limits. Such standards were monitored by the EM80 track geometry car (Figure 10) along with the above outlined visual/manual track inspection. In some locations, where no test was designated, the track inspectors and foremen were free to maintain track before Class 4 limits were met, depending on other work loads.

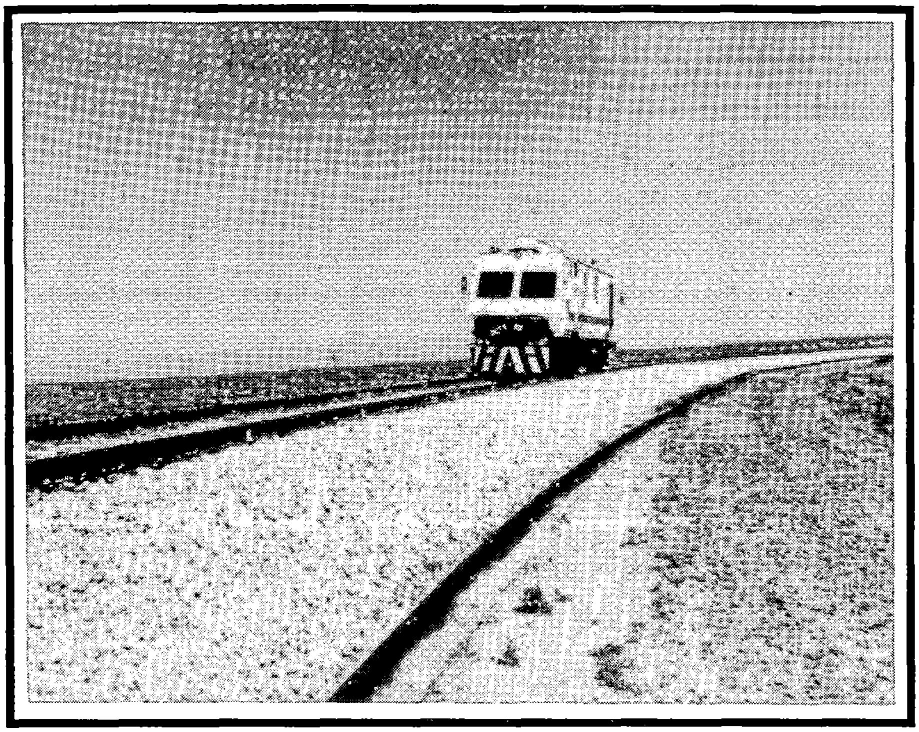


Figure 10. EM80 Track Geometry Car

Track geometry car inspections are scheduled after ever 5 MGT of operation to allow general monitoring of changes to gage, surface, line, and cross level. Extra inspections with the EM80 car are scheduled before and after specific maintenance functions, such as surfacing and lining, when such activities are over specific test zones.

An important item to note is that the track was not allowed to degrade below a level designated safe. Proper maintenance was always completed so that the track could sustain at least 1.3 MGT of additional traffic. Because of this, FAST may be defined as being "over maintained," a policy enacted and followed since 1976. On a revenue railroad, a turnout frog, for example, may be recorded as requiring grinding. Typically a 40 to 50 MGT per year line may operate 10 to 20 train moves during a 24-hour period between maintenance windows. Deferring maintenance in this example by one, two, or even three days generally will not cause an unsafe condition or undo damage to the item.

However at FAST, unless special conditions exist, one must plan for "worst case and best efficiency" train operations. Thus up to 135 laps (or train passes) of a fully loaded train, 12,500-ton, could be operated before the next maintenance window. With this in mind, with the frog grinding example described above, repairs would have been initiated for metal removal in advance to ensure that damage to the frog from excessive lip formation did not occur.

For this reason, all track degradation limits must be sufficiently high to allow for the anticipated extra degradation that a 1.3 MGT loading would apply at a given location. To permit this safety factor, certain items were prematurely maintained to ensure that a safe track structure would be available for an entire operating shift. Any comparison with other periods at FAST can be made with similar track maintenance limits in mind. The only change during the HAL Test was that, in some cases, the HAL train caused higher degradation rates at joints and other anomalies. This higher rate required extra caution when determining how far defects should be allowed to degrade before applying corrective maintenance efforts.

Interim Rebuilding/New Tests

During the course of the 160 MGT HAL operation, a number of minor changes to the original test configuration were made. As test components wore out or sufficient data was obtained on original items, new materials were placed in track.

A guideline for placement of most track components in the original HAL Test was that the item was already to be in general use by the railroad industry. As stated in the original HAL goals, the purpose for the initial HAL Test was to determine the effect of the HAL train on track and train components. While new and experimental components were not always restricted, the budget for HAL dictated that the first priority was to evaluate the effect of heavier axle loads on conventional track materials and structures.

Major test components that were added to the original configuration included:

- Replacement of the original AREA standard design #20 turnout with a state of the art heavy duty turnout with the same overall AREA geometry
- Addition of post tensioned concrete ties
- Addition of concrete ties designed for tangent track
- Addition of Azobe hardwood ties
- Installation of a Frog Casting Quality Test zone

The follow-on test program, in the form of at least a 100 MGT extension, will place more emphasis on new and improved materials that are designed to better withstand the effects of the HAL train environment.

General Observations after 160 MGT of Traffic

Experiments were conducted under the same conditions and constraints. These include the following major considerations:

1. All traffic was made up of loaded cars and locomotives. No empty or light cars were operated for any extended period of time.

2. All trains were operated at 40 mph except for the first and last daily train pass, and when a slow order (10 to 15 laps at 25 mph) pass was needed for testing purposes. All curves were elevated for the same 2-inch superelevation cant deficiency condition.

3. Ninety percent of the traffic was in one direction (counterclockwise); 10 percent went clockwise. This was accomplished in 300 lap/30 lap increments.

4. All operation was conducted with the outside rail fully lubricated and the inside rail slightly contaminated at all times. Every 3 MGT, dry-downs were conducted; however, some trace of gage face lubrication remained at all times, even after the dry-down.

5. Under normal operating conditions, train brakes were not used. Occasionally, when the signal system detected a broken rail, a standard 10 psi to 15 psi brake pipe reduction was made to stop operation. Other than that, air brakes were rarely used to control train speed.

6. Most equipment contained conventional design mechanical components, with three-piece trucks.

7. The TTC is located in the high plains of Colorado where natural moisture is relatively low -- approximately 11.5 inches per year. Subgrade support conditions are almost ideal for track construction; firm, sandy, and

well-drained soil. The winter season generally sees little in the nature of freeze/thaw cycles. Winter snows usually evaporate in one to three days, with relatively little moisture seeping into the ground.

Comparisons between 160 MGT of 33-ton and 39-ton experiments were made with the same gross tonnage applied. For comparison purposes, all track related data is tied into this net applied load. As the axle loads were different for the two periods, a different number of cyclic loadings occurred to obtain the same applied tonnage. The 39-ton axle load period had approximately 16 percent fewer loading cycles for the same 160 MGT period as the 33-ton axle load test configuration (Table 2).

Table 2. Differences in Cyclic Loading for 33- and 39-ton Axle Load Periods with the Same Net 160 MGT on the Track

33-TON AXLE LOAD TEST	39-TON AXLE LOAD TEST
15,850 Trains	13,370 Trains
4,820,000 Rail Loading Cycles	4,065,000 Rail Loading Cycles
114 Million Tons of Lading Hauled	120 Million Tons of Lading Hauled

Note: Track loading for equivalent 160 MGT application of track load using 4 locomotives, 72 car average train. Heavier car required approximately 16% fewer trains to apply same loading onto the track, and hauled approximately 5% more net tonnage.

Major Items Showing Significant Impact during the HAL Period

Quality control of maintenance activities became even more important at FAST during the HAL period. The higher axle load caused even minor deviations and anomalies to degrade at a rate faster than before, thus workmanship during repair cycles was critical.

Track maintenance items could not be deferred to the extent permissible under the lighter load. Even small anomalies would often grow rapidly, when left to be repaired by the next shift.

All track work required careful blending and transition into adjacent areas. Sudden transitions must be avoided to prevent introducing bounce modes in vehicles, which could initiate additional degradation at other locations. Uniform support conditions, with little or no change in resulting track geometry, afforded the lowest track maintenance effort.

The surface condition of the rail became even more critical. Joint batter, welds and mechanical joints, (Figure 11), and rail corrugations (Figure 12) occurred more often and grew more rapidly under the HAL program. Metal flow at rail ends and frogs required significantly more maintenance effort than before.

Field weld failures (Figure 13) played an important part in the efficiency of operation during the HAL Test. Frequent failures, which were not observed during the 33-ton phase, resulted in a significant impact to train operations. The need for improved quality control during the welding process as well as improved welding techniques and materials to withstand the heavier axle loads was noted. The standard mix content of most field welds often lead to excessive batter, especially when used on 300 Brinell hardness (Bhn) and heat treated rails of standard chemistry.

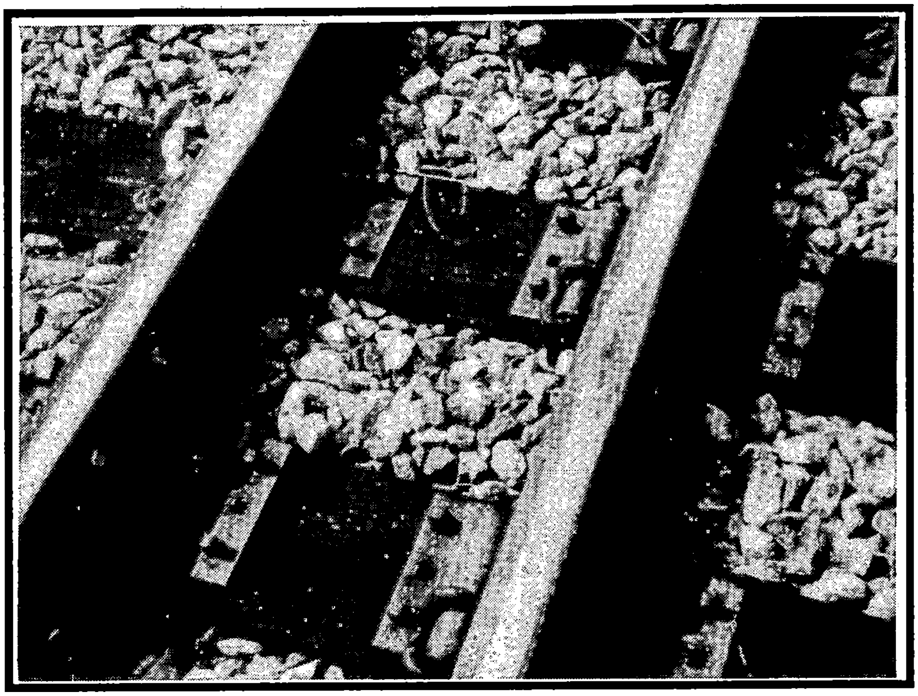


Figure 11. Typical Welded Rail Joint Batter

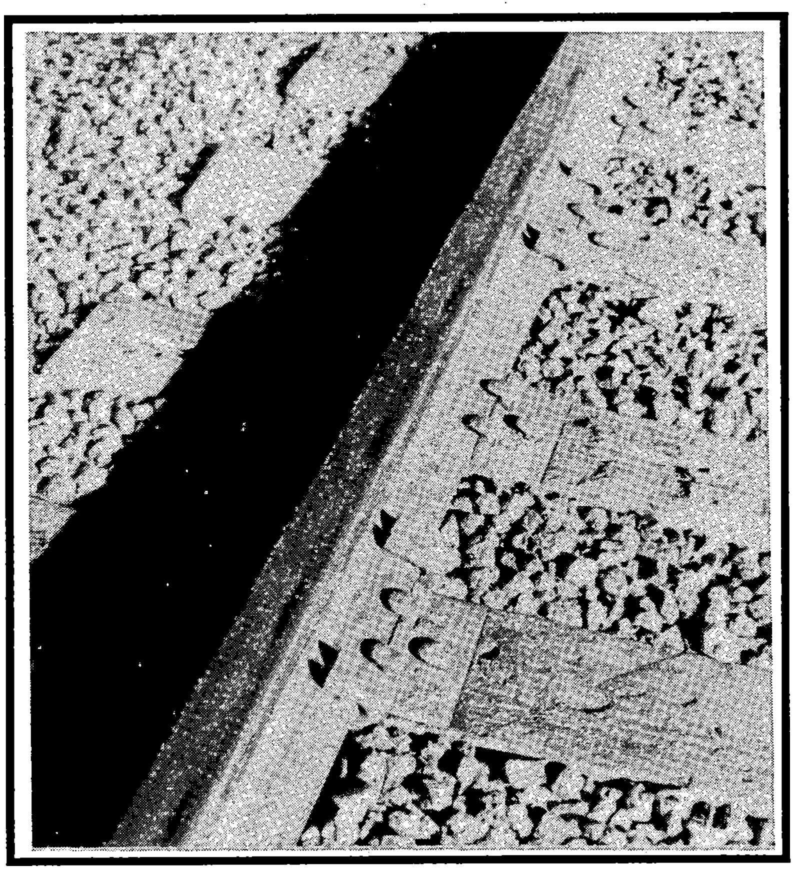


Figure 12. Typical Corrugations

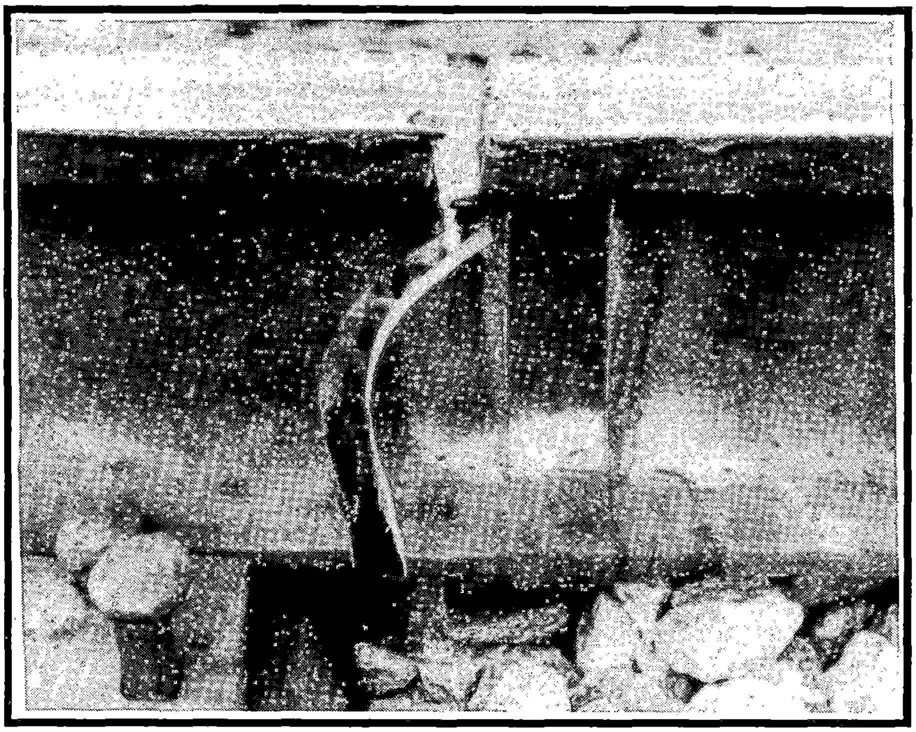


Figure 13. Typical Broken Field Weld

Under the HAL train operation, turnouts were second to field weld failures in the area of increased track maintenance. As with conventional field weld material, standard rail and frog components exhibited the shortest life and highest amount of maintenance and repair (Figure 14). Overall, turnouts required a significant increase in spot maintenance, grinding, and buildup requirements.

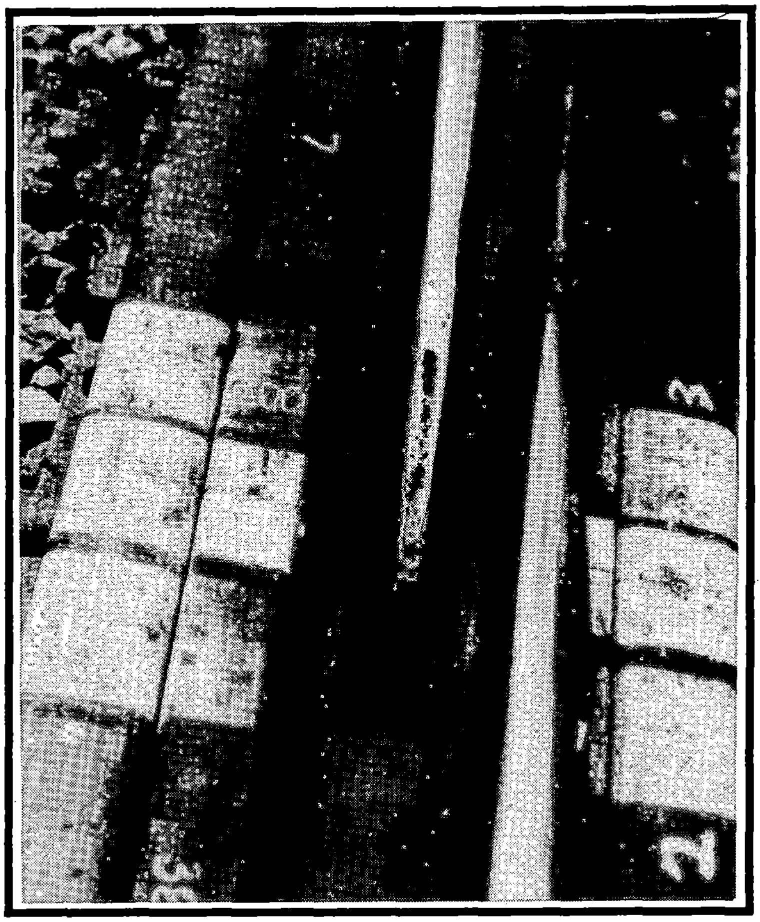


Figure 14. Typical Worn Frog Components

The overall track maintenance effort increased, with the following areas showing the highest demand.

1. Out of face grinding for corrugation control

2. Increased welding requirements

3. Immediate attention required for spot surfacing needs

4. Increased failure rate of field welds

In general, corrugations on tangent track, especially where standard rail was in place, became very common during the HAL Test. The increase in dynamic loads, due to vibrations, often required additional spot maintenance in these areas.

The heavier car emphasized problems using the lighter axle load geometry car. Low spots and pumping track areas, observed under traffic by the track inspectors, would not always show up as full depth defects on track geometry car inspection reports. The use of heavier geometry cars or heavier axle loads on geometry measuring equipment may eliminate this anomaly.

Many areas of the HTL were not totally rebuilt before starting the HAL train operation. In such areas, for example, where wood ties remained in place from the previous test period, more rapid tie degradation and higher replacement requirements than during a similar period with the lighter axle load were noted. Track inspectors had a more difficult time determining remaining tie life during the HAL train period, as the wood tie's ability to hold gage appeared to decline more rapidly, and with less visual indication. Hidden defects in the ties tended to degrade more rapidly, and with less visual warning, necessitating the replacement of more ties during cyclic renewals to ensure a safe operation.

The above observations are based on areas where back-to-back comparisons between 33- and 39-ton axle load data is available. A number of other test results from the 39-ton axle load phase include: localized cracking of selected concrete ties, early replacement of a standard turnout, and failure of one wood tie fastening system. Results from these tests cannot be compared to equivalent results under 33-ton axle loads at FAST simply because they were not under controlled tests during the HTL comparison phase.

These and other results were presented at the Workshop on Heavy Axle Loads, Pueblo, Colorado, October 16-17, 1990.

OVERALL TRACK MAINTENANCE IMPACT

Under the conditions of the FAST loop, the percentage of daily "spot" or "housekeeping" track maintenance effort increased significantly when compared to the axle load increase. Labor hours increased over 60 percent compared to an axle load increase of 20 percent.

The increase in spot maintenance requirements was determined by collecting records of all daily track maintenance activities recorded by field personnel. Each "routine" maintenance requirement, that is, an activity not associated with special requests due to experiment objectives, was assigned a standard labor hour rate. For example, each time a low joint required tamping a standard rate of 0.5 labor hours was applied while to repair a broken weld a standard rate of 16 labor hours per occurrence was applied. Also excluded were major component changeout efforts, such as major rail replacements due to wear, new test component installations, and other "capital improvement" work.

By eliminating the special request maintenance items, such as replacement of a weld due to laboratory analysis requirements, only those maintenance activities directly associated with track degradation were monitored. The use of standard labor hour rates for each activity also eliminated many of the inherent "unique" situations found at FAST. At FAST many maintenance activities require special care due to adjacent instrumentation, the need for pre- and post-measurements, and position of special test materials. Use of the standard labor hour rates permits the total maintenance demand to be normalized for comparison purposes.

The test loop was subjected to a number of changes during the course of the 33- and 39-ton axle load experiments. Both experiments, however, started out with track in approximately the same condition and with similar materials. As tonnage was applied, track materials were changed and new test materials installed, thus making direct comparisons more difficult as the programs progressed. Due to these changes comparisons after the initial 85 MGT are unreliable.

Figure 15 indicates the cumulative labor hours of effort for the following basic track maintenance categories: joint maintenance, rail maintenance, surface and lining operations, turnout maintenance, and miscellaneous. A total effort in labor hours is also shown. These values represent the total number of standardized labor hours for each maintenance category required to keep the track in the same general condition for the initial 85 MGT of each test train period.

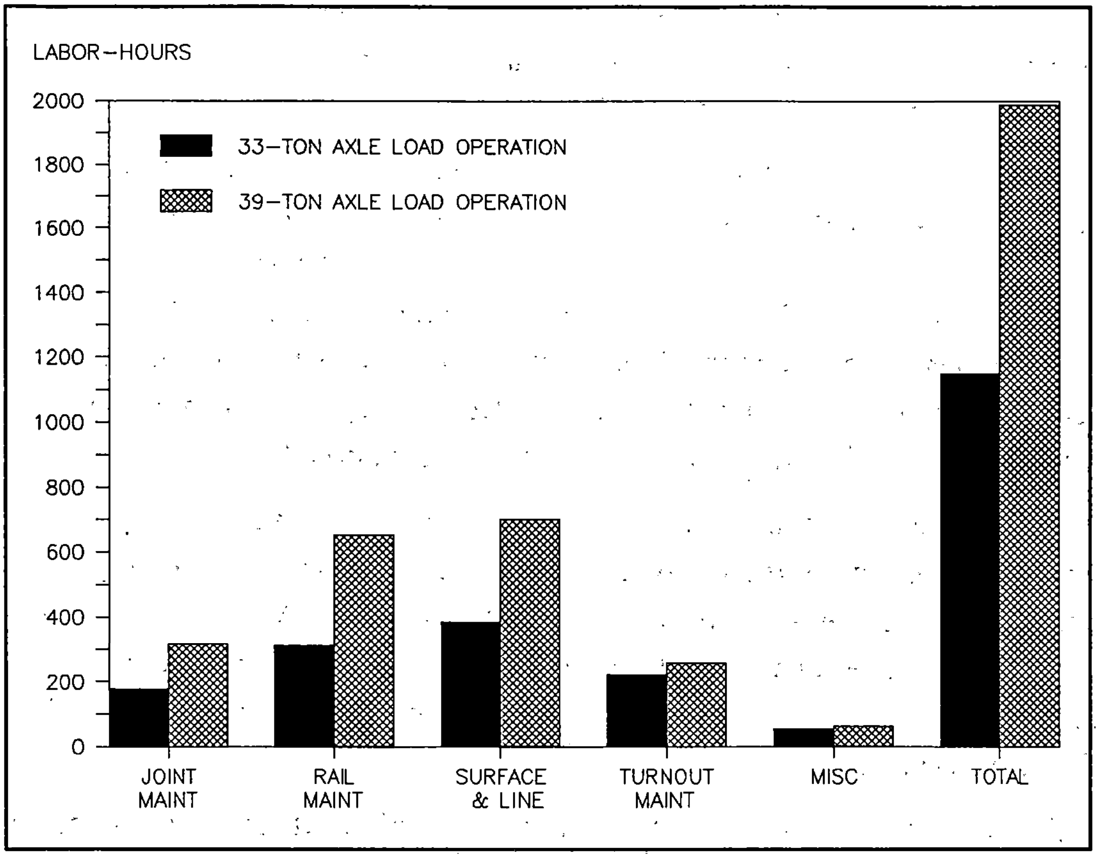


Figure 15. Breakdown of Track Maintenance Effort

Figure 16 shows the cumulative labor hour maintenance data by MGT for each test train period. For reference, the total labor hours for the 3-ton axle load test are shown beyond the 85 MGT base comparison period. Data beyond the initial 85 MGT baseline is shown for the 39-ton axle load test period. Labor hour maintenance totals continued at about the same rate per MGT as tonnage was accumulated to 100 MGT.

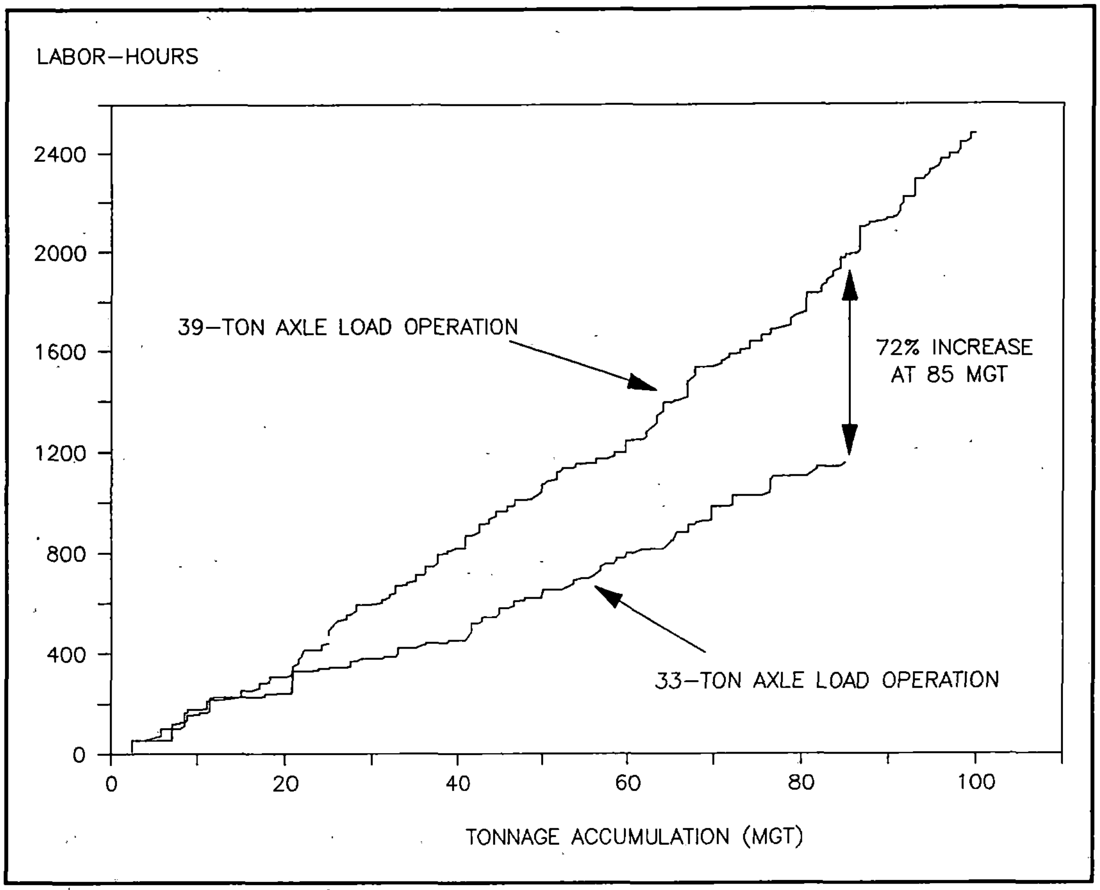


Figure 16. Track Maintenance Effort as a Function of Tonnage

The difference in cumulative labor hours after 85 MGT between 33- and 39-ton axle load test periods indicates a 72 percent increase due to the heavier axle load. Caution must be used in interpreting this data, as a significant error band in the total figures does exist. These labor hours represent spot maintenance demand, and as such is often dependent on the discretion of the field track supervisor. The data does not represent long-term replacement demand, such as out of face tie renewal, ballast work, or other capital investment related activities. The spot maintenance efforts represent comparison of activities needed to keep similar track at the same general geometry level during two periods of axle loads.

The long-term effects of rail wear, ballast work, wood and concrete tie life, fastener life and other capital intensive efforts have not been fully developed, but as the information and data trends indicate, the effect is not nearly as dramatic as the 72-percent increase in spot maintenance demand.

Results at FAST indicate that conventional track structure, as utilized by the majority of North American railroads, can survive 39-ton axle loads with some basic strategies which include:

- An increase in the attention to track maintenance detail and quality of work is required.
- Improved uniformity of work in blending repairs into the adjacent existing track structure will reduce non-uniform and impact loads.
- Areas of high impact forces, such as at frogs and within turnouts, require premium materials to withstand repeated loads
- Where premium materials are not used, such as in existing track that is to be subjected to a high percentage of increased axle loads, faster capital replacement will occur

Areas of Track Requiring Improvement

A number of basic areas of improvement have been identified for future evaluations. These are areas that could withstand the increased axle loads but required a disproportionately higher level of maintenance, based on FAST experience.

In areas where continuously welded rail (CWR) is utilized, which is the case in the majority of heavy mainline in North America, two major areas of improvement were identified:

1. The performance of field and shop welds declined significantly under the HAL train. In all cases weld batter must be reduced to lower the degradation of ballast and ultimately surface and lining demands. In the case of thermite type field welds the failure rate as well as batter rate was observed to be unacceptably high.
2. Where field welds are not practical or possible, such as at insulated joints or emergency plug repair sites, joint maintenance becomes critical. Emergency bolted plugs require immediate replacement with field welds when possible.

In areas where jointed rail is in place, early replacement with CWR is very desirable. Where complete replacement of jointed rail is not possible, or where programmed upgrades to an existing secondary line require operation over jointed track for a period of time, the FAST experience suggests the following:

- Eliminate jointed rail on curves. The few areas on FAST where jointed rail existed on curves resulted in significant track geometry degradation and high maintenance.
- In areas where jointed rail exists, repair of bent rail ends and loose fitting or worn bars must be completed immediately. Ballast memory was a higher problem under the HAL train than in previous FAST operations.
- Repeated tamping of joints, especially with certain ballasts that tended to become rounded with degradation, is ineffective. Repair of the rail surface problem (bent rail ends or joint bars) was required before a joint maintenance problem could be reduced.

Rail quality has improved over the last decade to where standard rail of 300 Bhn is usual for most installations, and premium rail of 340 Bhn and higher is found on most curves. Comparisons using 248 Bhn rail as a base are not directly applicable as many railroads have already eliminated this older rail on curves. There are cases, however, where older rail is still present on tangents of main lines and careful inspection may be needed before operating a significant amount of HAL type traffic. In the category of running surface materials, the following areas of improvement are suggested:

- Field inspections suggest that rail that corrugates easily should be eliminated or it will require increased out-of-face grinding maintenance. Corrugations on tangent track became common on the FAST loop in areas where older rail (less than 300 Bhn) was utilized. Even where 300 Bhn rail was used in tangents, corrugations were noted; especially, in turnouts. The requirement for premium rail in tangents needs to be investigated as a potential means of reducing grinding requirements.

- In turnouts, top quality materials are desirable. On FAST, the use of non-premium materials will lead to early failure along with high maintenance and repair costs. Rapid degradation was noticed where non-heat treated rails were used in components such as frog wing rails.
- Improved turnout geometry and component strength should be investigated to reduce spot maintenance requirements.
- Once started, the surface degradation leads to a rapid degradation of other components or adjacent areas, requiring spot maintenance activities to be scheduled on a frequent basis.

The items summarized above deal mainly with the ability of materials and components to withstand the heavier load.

General Maintenance Policies of Railroads in the Daily and Cyclic Inspection, and the Maintenance Duties of Track Personnel

Results of the FAST/HAL investigation point to the following areas where improvements to these duties would be beneficial where a large number of HAL type traffic is to be operated:

- Lower tolerance for deferred maintenance was noted. Small anomalies tend to degrade much faster under the HAL environment, thus reducing the allowable time between locating and repairing such defects.
- Improved methods of locating these minor defects will probably be needed, especially with automated track geometry systems. The need to identify small surface related defects, such as engine burns, low joints and other housekeeping requirements is increased.
- For long-term maintenance planning, wood tie integrity measurements are needed.
- Finally, once the above items are located, better tools for spot maintenance repairs may be needed. Spot work such as welding, grinding, and tamping of rail surface will take on even more importance with HAL traffic.

The major thrust of the HAL program to date has been to document the effect on track component wear and track maintenance requirements with increased axle load. Track, of course, does not degrade significantly by itself. The vehicles that operate over the rails are the major cause of this deterioration. The present FAST consist was selected for a number of reasons; however, the major factor was that the mechanical design of car bodies and trucks were very similar to that used for the previous test periods. Thus, the only main variable would be the axle load, allowing back-to-back comparisons between previous FAST tests with the least number of input variables.

Review of the results to date indicates that some areas in the mechanical equipment side need additional investigation, along with long-term research and development. With the existing train, which is made up of equipment designed and built in the late 1960s, allowable defects in components, especially the wheels, must be investigated under direction of the Vehicle Track Systems Committee. These include:

- Size of allowable wheel flats
- Limits of out of round wheels
- Limits of allowable surface defects, such as spalls and shells

These items may lead directly to increases in dynamic loads into the track structure, especially at the rail and tie level. Limiting the allowable size of such defects could result in a significant increase in the life span of the rail, tie and fastener. The extent to which these loads are transferred to various components in the track structure is not fully documented; however, additional investigations are planned.

Alternative car and suspension designs also need to be investigated. By reducing the impact and dynamic loads into the track structure, life of track components could be increased. Areas in mechanical design that need to be investigated include:

- Evaluate the effect of reducing unsprung mass. With a larger wheel diameter (and subsequent heavier wheel mass) the HAL car is already at a disadvantage, when compared to the conventional car. Additional design work in the suspension area may help reduce this effect.

- Premium trucks, which not only improve curving performance but reduce vertical dynamic forces, have been and should be evaluated.

- The effect of axle spacing, articulated cars and other designs should be investigated. The existing HAL train applies vertical loads at specified truck and car axle spacings, which are different than that of "double stack" and other alternate car designs.

Summary of Limitations

The future investigations, for both track and mechanical components, are based on the results from the existing FAST loop configuration, train operating policies, track maintenance standards and equipment designs. The results must be reviewed with some specific limitations in mind. These were stated in detail during the introduction section, and apply to all FAST test results to date. Limitations of the current test suggest changes that may be included in future test programs. These include:

- Variable speeds, with resulting different overbalance and underbalance conditions on curves should be investigated.
- Since the HAL program has been conducted with equipment manufactured in the 1960s, new mechanical equipment technology, including suspension, truck design, and wheel spacing, will be evaluated.
- Traffic mix of FAST is all loaded traffic, with no light cars or empties. The percentage of HAL traffic on some revenue lines may not be a high percentage of the overall tonnage.
- FAST produces a relatively mild environment for in-train forces. The effects of heavy braking (air and dynamic), and results from train forces from slack run in, grades and speed changes have not been addressed. Such forces will play a role not only in mechanical component fatigue life, but in forces that must be absorbed by the track structure as well.
- The dry climate at FAST, coupled with the stiff subgrade, may have reduced some of the track degradation effects of the HAL train. Future investigations will include a "low modulus support" track segment that is intended to evaluate the effects that HAL has on track geometry retention.

FUTURE

The results of the 33- and 39-ton axle load experiment have been presented in this document. The ongoing extension, which is utilizing the same train configuration and operating modes, started in late 1990.

This extension is being operated primarily to address some of the specific areas of track components that indicated immediate improvement was needed. Two major areas in this category include turnouts and field welds. Other test areas, such as fatigue of rail, grinding and ballast life, did not exhibit a full life cycle during the initial 160 MGT, and additional operations will be required to complete experiment objectives. Finally, the performance of some components, although adequate, could still be improved. The installation of a full matrix of tests to evaluate new and improved fastening systems, ties, rail and other track components will allow the evaluation of such items to continue.

Future FAST/HAL investigations will need to incorporate advanced technology in mechanical equipment designs. The program goals will be to monitor the effects of such equipment on existing as well as other improved track components. This will allow the engineering staff to determine the effect that such designs will have, if any, on overall operating and maintenance costs of a Heavy Axle Load system.

APPENDIX B

1990 HEAVY HAUL WORKSHOP AND FAST/HAL PROGRAM DESCRIPTION OF EXPERIMENTS

DESCRIPTION OF EXPERIMENTS

Below is a summary of the experiments that have been implemented to meet the objective of the HAL Program.

Rail Performance Experiment

The Rail Performance Experiment is one of the major tests currently being performed at FAST. The objective of this experiment is to determine the effects of 39-ton axle loads on rail wear, rail defect occurrence and growth, corrugation occurrence, metal flow, and weld batter.

This test is concentrated on the high rail of the three main curves of the HTL. The lubrication of the outside rail dictates that fatigue tests occur in Sections 25 and 3. Rail wear testing is performed in Section 7 due to the dryness of the high rail.

Rails of varying cleanliness, chemistry, hardness, and profiles were installed to see how they affect the test parameters. Cleanliness pertains to the volume and type of inclusions in the steel; chemistry refers to the chemical make-up of the steel. The hardness of the rails varies from 269 Brinell (old standard practice) to 370 Brinell (in-line head hardened practice), and rail profile generally pertains to the crown radius of the rail head, *i.e.*, how round or how flat the rail head is.

Though most of the rail was new at the beginning of the test, some had previous exposure to traffic. This includes conditioned rails with 150 MGT of 33-ton axle load exposure and "dry break-in" rails with 15 MGT of nonlubricated 39-ton axle load exposure. Also, some of the new rail installed was the same type that was tested during the 100-ton car test. The 100-ton and the 125-ton test results on this particular rail can and will be compared with each other.

A special rail grinding/conditioned rail experiment is being performed in Section 25. This test consists of four test zones: (1) rail with 15 MGT of dry 39-ton axle load exposure, (2) rail with a profile ground to match a worn profile, (3) asymmetrically ground rail, and (4) rolled rail. This test will be used to determine whether rail fatigue life can be improved by conditioning the rail with dry exposure, grinding the profile for "artificial wear," or grinding an asymmetrical rail profile pattern to alter the wheel/rail contact geometry.

Tie and Fastener Experiment

The objective of the Tie and Fastener Experiment is to determine behavior and performance of concrete and wood ties, along with various types of rail fasteners in a heavy axle environment. The experiment includes three separate areas of investigation: (1) wood tie and fastener performance, (2) gage restraint ability, and (3) concrete tie and fastener performance.

Test zones are established in the 5- and 6-degree curves of the HTL. Measurements include track geometry, fastener stiffness, tie plate cutting, visual inspections of concrete ties, and dynamic rail loads and deflections.

The data will be analyzed to determine the behavior of the tie/fastener systems as a function of traffic accumulation (MGT) and compared to performance under the 100-ton consist.

The experiment also addresses the ability of wood ties with cut spike fasteners to maintain gage.

Measurements of dynamic lateral wheel force and lateral rail deflection will be taken at various locations on the HTL at various increments of MGT accumulation to characterize the dynamic performance of the various systems. The dynamic vertical and lateral wheel loading of the test zones will also be characterized on a regular basis.

Turnouts and Frogs

Early in the 100-ton test, turnouts were evaluated for component performance. A similar experiment is being conducted during the HAL phase with two #20 turnouts.

The experiment will measure the load environment, geometry degradation, vehicle response, and stiffness of the turnouts at specific levels of tonnage accumulation.

The by-pass track will permit operation on both sides of the turnouts, with a minimum of 20 percent of the traffic on the diverging side of the turnout. Since the traffic on the HTL is primarily unidirectional, one turnout is exposed to predominantly facing point movements and the other to trailing point traffic. Load data is collected through the turnouts using an instrumented wheel set and rail mounted strain-gage circuits. Dynamic lateral, vertical, and longitudinal rail deflections are taken at the point and heel of switch, and at the point of frog and guard rail area. Vertical and lateral track stiffness measurements are taken at selected points throughout the turnout.

A test of newer design turnouts using moveable point frogs and concrete ties may be also be implemented.

As part of the turnout and frog test, a "frog farm" was recently installed in the tangent track of Section 22. The five isolated frogs (frogs not in turnouts) consist of three railbound manganese and two European designed frogs. The objective of this test is to compare the performance characteristics of the frogs. Criteria include insert wear rates and maintenance time demanded. The inserts were radiographed prior to installation to determine inclusion and void content. These results will be used in performance evaluations.

Track Irregularity

The Track Irregularity Experiment is designed to determine track geometry degradation at rail profile irregularities such as battered welds and joints.

The affect of vehicle dynamics, specifically roll and bounce motions, on track degradation will be observed. The key parameters being measured are applied wheel loading as measured with an instrumented wheel set and rail mounted strain gage circuits, and track geometry. Supporting data includes longitudinal rail profile and vertical track stiffness.

Ballast Resistance Characterization

The Ballast Resistance Characterization Test will define the rate at which track lateral resistance as provided by the ballast section is restored with traffic, after disruption of the ballast section by maintenance.

Ballast Test

A comprehensive ballast experiment compares performance of granite, limestone, traprock, and dolomite ballasts, with results obtained during the 100-ton phase. A test zone of each ballast type is established on a 5-degree curve, and varies in length from 570 to 900 feet.

Each test zone contains approximately 8 inches of sub-base material between the subgrade and the ballast section, and a below tie ballast-depth of 12-15 inches at the low rail. Track geometry, loaded track profile, track settlement, sieve analysis, ballast density, and vertical track modulus are measured in each zone.

Ballast degradation, track strength, and track geometry are the parameters used to evaluate ballast performance as a function of MGT accumulation.

Subgrade Test

The potential for subgrade failure is one of the more troubling issues in evaluating track performance under heavy axle loads.

Available analytical models have not been validated for axle loads of 39-tons. One hypothesis predicts linear increases in subgrade pressures and deformations while another postulates a non-linear increase resulting in additional maintenance requirements. The potential for complete subgrade failure also exists.

To provide validation data, pressure cells and extensometers, which measure subgrade deflection, have been installed at two sites on the HTL. Test site is located on tangent track with slag ballast. The site is on a fill area with a below tie ballast depth of 18 inches.

Unlike the other HAL experiments, the 100-ton comparison is not based on early FAST data, but on subgrade pressures and deflections acquired during the final months of the 100-ton operation. This was done to obtain as closely as possible the same soil moisture and compaction levels between programs.

Mechanical Components Performance

During the initial stages of the HAL Program, a wheel wear evaluation will be conducted as a part of the Mechanical Component Performance Experiment. The objective is to determine the wear rate and fatigue behavior of the 38-inch, class C wheels expected to be used in revenue service with heavy axle loads. A few class C, 36-inch wheels with 33-ton axle loads will be inserted into the HAL consist for comparative purposes.

The test consist will include three HAL cars equipped with standard three-piece trucks, and three 100-ton cars equipped with standard three-piece trucks.

TRAIN OPERATION

A fleet of high side gondolas and covered hopper cars has been obtained and loaded to a gross vehicle weight on the rail of 315,000 pounds. To replicate the center of gravity typical of these cars in revenue service, the gondolas are loaded with a lightweight aggregate material with a density similar to coal and the covered hoppers filled with sand to simulate concrete.

Normally, the consist includes 65 to 85 HAL cars plus the three 100-ton cars of the Mechanical Components Test. Four or five 4-axle locomotives are used to power the train at a steady 40 mph, resulting in an overbalance condition of approximately 2 inches on the curves.

The train operates an average of three days per week, with two days set aside for track maintenance, and car inspection and repair. A typical day of train operation produces 1 MGT of tonnage on the track and 270 miles on the cars. Every 5 MGT, track geometry data is collected for experimental and maintenance purposes. An ultrasonic rail flaw inspection vehicle is operated at 3 MGT intervals.

The train operates in a counterclockwise direction on the loop, except for 30 laps every 3 MGT when the train is reversed. The reversal of direction alters the shape of rail defect growth rings, permitting accurate tracking of defect growth rates. Car orientation is reversed periodically to equalize wheel wear.

SUMMARY AND DESCRIPTION OF MEASUREMENTS

Measurements required by each experiment are conducted periodically, usually triggered by a specified accumulation of tonnage. The various measurements taken at FAST are as follows:

Rail Head Profile

The Yoshida rail head profilometer is used to record a 1:1 copy of the rail head profile.

Rail Hardness

Two measurement devices are used to measure Brinell and surface hardness at several points at the top of the rail head.

Tie Plate Cutting

The height of the tie plate relative to top of the tie is measured with a self indexing fixture.

Track Inspection

A walking inspection of all test zones is made every 1 MGT to 3 MGT.

Lateral/Vertical Rail Force

Dynamic vertical and lateral wheel loads are measured with strain gage circuits mounted on the web and base of the rail.

Dynamic Rail Deflection

Displacement transducers measure rail head and base lateral displacement relative to the tie.

Track Geometry

Track geometry is measured with an EM80 track geometry car.

Vertical Track Stiffness

A known vertical load is applied to the rail and the resultant vertical rail deflection measured.

Spike Pullout Resistance

A load cell is used to measure the force needed to pull the spike from the tie.

Single Tie Push Test

A load cell is used to measure the force needed to displace individual ties laterally through the ballast section.

Ballast Sieve Analysis

Gradation analysis of ballast per the ASTM C136 modified procedure.

Ballast Flakiness Indices

Classification of ballast particles having a thickness dimension less than 60 percent of nominal particle size.

Ballast Elongation Indices

Classification of ballast particles whose length is greater than 180 percent of nominal particle size.

CIGGT Shape Factor Test

Ballast particles retained on a specific sieve are measured for smallest width and longest dimension. Shape factor is the ratio of the sum of the longest dimension to the sum of the shortest width.

Ballast Density

A nuclear density probe is inserted into a steel pipe which has been installed through the tie and ballast to 3 inches above the subgrade/ballast interface to measure the ballast density.

Loaded Track Profile

The top of rail elevation is measured under the wheel of a fully loaded car.

Level Net

Top of tie elevation is taken immediately outboard of both rails. Tacks are used to ensure subsequent measurements are taken at the same location.

Subgrade Classification

Laboratory tests are performed in accordance with the ASTM D2487 standard to classify soil for engineering purposes.

Moisture Content

Laboratory tests are performed in accordance with the ASTM D2216 standard to determine the soil moisture content.

Liquid and Plastic Limit

The ASTM standards D423 and D424 are used to determine the liquid and plastic limits of the soil.

Instrumented Tie Plate

The rail seat load on wood ties is measured with instrumented tie plates which have been calibrated in track.

Dynamic Soil Measurements

The dynamic response of pressure cells and extensometers installed in the subgrade under the ties is monitored.

Static Soil Measurements

The measurement is accomplished by loading the track incrementally to a maximum of 50,000 pounds at each tie where subgrade pressure transducers have been installed.

Continuous Wheel Load Measurement

Instrumented wheel sets are utilized to measure vertical and lateral wheel loads, and axle torque.

Gage Widening

Static lateral and vertical loads are applied to both rails simultaneously producing a 0.5 L/V ratio, and the total lateral displacement of the rails are measured relative to the tie.

Longitudinal Rail Profile

A profilometer traces the rail head profile in the longitudinal direction for a length of 36 inches.

Goop Gage

A template is used to measure lubrication position on the gage side of the rail head.

Rail Flaw Monitoring

The rail is inspected for internal defects using ultrasonic equipment.

Rail Corrugation

Running surface degradation of rails and welds are monitored using the longitudinal rail profilometer.

Dynamic Corrugation

Strain gage circuits are mounted on the web of the rail to measure the load at the corrugation valley and the peak.

CN Profilometer and Snap Gage

A CN profilometer is used to collect wheel profile data and a TTC snap gage measures wheel area loss.

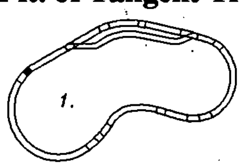
Metallurgical Evaluation

Selected rails and wheels exhibiting internal and/or surface defects are submitted to macroscopic inspection, metallography, hardness profiles, scanning electron microscopy and x-ray analysis.

DESCRIPTION OF HTL TRACK SECTIONS

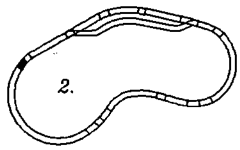
The typical HTL track structure consists of continuous welded rail fastened to wood ties with cut spikes and fully box anchored at every second tie. Included in specific test zones are concrete ties, jointed rail, and elastic type rail fasteners. A description of each section follows:

Section 1
171 ft. of Tangent Track



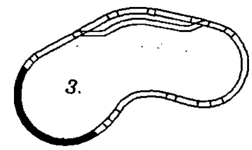
Transition zone/available for testing.
Location of hot bearing detector.

Section 2
300 ft. Spiral



Transition zone/available for testing.

Section 3
3740 ft. of Track on a 5 Degree Curve



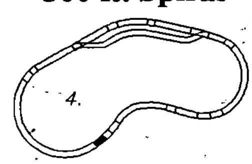
Location of Ballast, Rail Performance and Tie and Fastener Experiments.

Rail performance measurements include gage point wear, head height loss, metal flow, rail head profile, rail hardness, welded rail end batter, LRP, goop gage, rail flaw monitoring, wheel force data, track geometry, and corrugation.

Tie measurements include track geometry, rail fastener stiffness, rail loads, dynamic rail deflection, tie plate cutting, and static track gage.

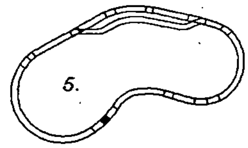
Ballast measurements include ballast sampling, particle indices, ballast gradations, loaded profiles, level net, ballast density, track geometry, and vertical track modulus.

Section 4
300 ft. Spiral



Transition zone/available for testing.

Section 5
224 ft. of Tangent Track



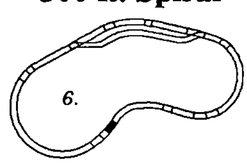
Location of Subgrade Experiment and Frog Casting Performance Test.

Measurements include static and dynamic subgrade pressure and deflection.

The subgrade material will be classified in the laboratory and tested for moisture content, liquid and plastic limits.

Location of hot bearing and acoustic bearing detector.

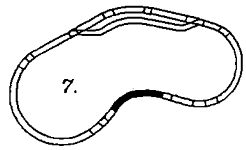
Section 6
300 ft. Spiral



Location of Ballast Resistance Characterization Test.

Measurements include lateral ballast resistance as measured with the single tie push test.

Section 7
1002 ft. of Track on a 5 Degree Curve

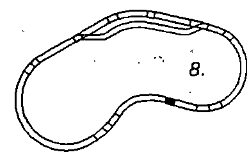


Location of Tie and Fastener and Rail Performance Experiments.

Tie measurements include tie plate cutting, fastener stiffness, rail loads, dynamic rail deflections, track geometry, and static track gage.

Rail wear measurements include gage point wear, head height loss, metal flow, rail head profile, rail hardness, welded rail end batter, LRP, and rail flaw monitoring.

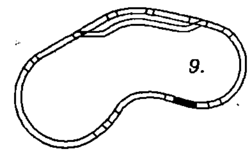
Section 8
300 ft. Spiral



Location of Ballast Resistance Characterization Experiment.

Measurements include lateral ballast resistance as measured with the single tie push test.

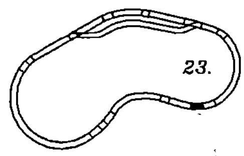
Section 9
313 ft. of Tangent Track



Road crossing and #10 turnout.

Proprietary test of uncased 12 inch and 36 inch pipes buried under railroad track.

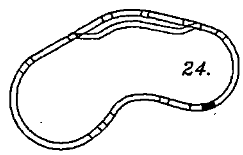
Section 23
164 ft. of Track on a 1 Degree-45 Minute Curve
and
201 ft. of Tangent Track



Frog Casting Performance Test.

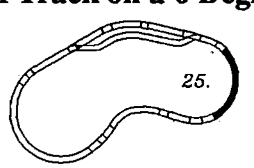
Wayside rail lubricator.

Section 24
300 Ft. Spiral



Transition zone/available for testing.

Section 25
2692 ft. of Track on a 6 Degree Curve

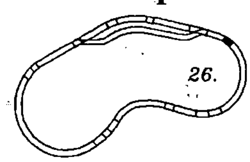


Location of Rail Performance, Ballast Resistance Characterization and Tie and Fastener Experiments.

Tie measurements include tie plate cutting, fastener stiffness, rail loads, dynamic rail deflections, track geometry, and static track gage.

Rail performance measurements include gage point wear, head height loss, metal flow, rail head profile, rail hardness, welded rail end batter, LRP, rail flaw monitoring, goop gage, track geometry, wheel force data and corrugation.

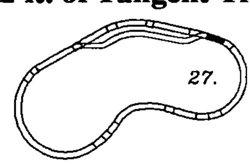
Section 26
300 ft. Spiral



Location of Tie and Fastener Experiment.

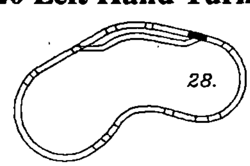
Measurements include static gage widening.

Section 27
332 ft. of Tangent Track



Location of Frog Casting Performance test.

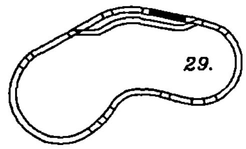
Section 28
#20 Left Hand Turnout



Location of Turnout Experiment.

Measurements include rail/wheel loads, dynamic rail deflections, lateral and vertical rail stiffness and track geometry.

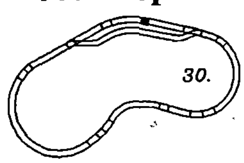
Section 29
987 ft. of Tangent Track



Location of Track Irregularity Experiment

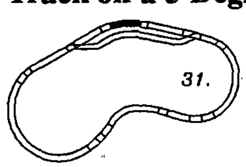
Measurements include rail/wheel loads, dynamic rail deflections, vertical track stiffness and track geometry.

Section 30
300 ft. Spiral



Transition zone/available for testing.

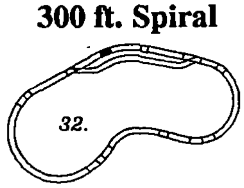
Section 31
511 ft. of Track on a 5 Degree Curve



Location of Tie and Fastener Test.

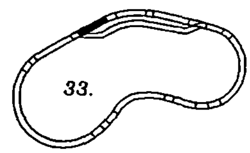
Measurements include tie plate cutting and track geometry.

Section 32
300 ft. Spiral



Transition zone/available for testing.

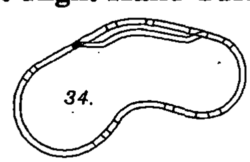
Section 33
517 ft. of Tangent Track



Location of Ballast Resistance Characterization Experiment and Frog Casting Performance Test.

Measurements include lateral ballast resistance as measured with the single tie push test.

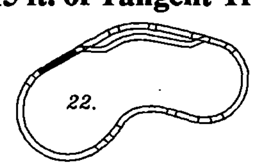
Section 34
#20 Right Hand Turnout



Location of Turnout Experiment.

Measurements include rail/wheel loads, dynamic rail deflections, lateral and vertical rail stiffness, and track geometry.

Section 22
715 ft. of Tangent Track

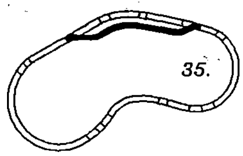


Location of Ballast Resistance Characterization Experiments and Frog Farm Test.

Measurements include lateral ballast resistance as measured with the single tie push test.

Frog Farm Test measurements include Brinell hardness and cross section profiles of the frogs.

Sections 28B - 34B
By-pass Track
1187 ft. of tangent track, 2 - 300 foot spirals, and 511 ft. of track on a 5 degree curve



Location of the Ballast Resistance Characterization Experiment.

Measurements include lateral ballast resistance as measured with the single tie push test.

DATA COLLECTION AND REPORTING

The various data are collected on magnetic tape/disk or recorded manually on a data form, then transferred to a data base on TTC's mainframe computer. All the dynamic data collected under the train is saved in digital format; the digitizing frequency being 1000-1500 samples per second. The tracings from the different profilometers are also digitized as XY coordinates to permit computer generated profile shapes and the computation of area loss. The track geometry data is digitized at one sample per foot of track.

Interim reports describing progress of the various experiments will be issued, along with a final report. These reports will be published by the FAST program and information as to their availability can be obtained through the FRA program office -- (202) 366-0464.

During the time the experiments are active, the TTC staff is planning to host several "open house" seminars so that interested parties can visit TTC and receive an up-to-date assessment of experiment progress, including a walking tour of the HTL. The seminar schedules will be published in the various railroad trade journals. If more information is required, interested parties should contact the FAST Program Manager at (719) 584-0581.

SAFETY CONSIDERATIONS

High volume, high mileage train operation can be very informative, but must be conducted safely. To ensure safety of personnel and equipment, visual inspections of the consist and car components are performed on a regular basis. All safety procedures comply with the AAR and FRA safety standards as appropriate.

The safety oriented measurements are as follows:

Wheels

Every car and locomotive wheel is measured for flange thickness, flatness and height, and rim thickness. Visual inspections are made to detect cracked or broken flanges; thermal cracks in flange, tread or plate; built-up, grooved, shelled or slid-flat treads; cracked, broken, burnt, shattered or spread rims; overheated wheels; cracked or broken plates or hubs.

Axle Journal Roller Bearings

The journal roller bearings are checked for grease loss, and loose or missing cap screws.

Roller Bearing Adapters

During regular shop maintenance, safety checks are made for adapter crown wear, pedestal roof wear above the adapter, thrust shoulder wear, and machined relief wear.

Trucks

Friction castings, side frames, and bolsters are checked for deterioration.

Air and Hand Brake

Train crews check for cracked or bent pipes, fittings and valves; defective or loose hoses; broken shoe keys; piston travel and inoperative air brakes; inoperative hand brakes; and worn brake beams, levers, guides, or bends.

Miscellaneous Components

Minimum standards examinations of running boards, brake steps, sill steps, handholds, ladders, center sill, body bolsters and structural welds are conducted.

Center Plates

During regular maintenance periods, crews check for vertical wall wear on both body and truck plates, horizontal surface wear and vertical linear weld cracks on the truck center plate. In addition to the regular maintenance intervals, inspections are required for body center plate cracks and weld connection cracks.

Side Bearings

Inspections are conducted for required side bearing clearances, cracks in the truck side bearing cages, wear in the body side bearing wear-plates and loose or bent body side bearing bolts.

Brake Shoes

Inspections are made prior to operation for cracks, breaks or excessively worn shoes.

Coupler and Carrier Wear Plates

Coupler shank plates and carriers are checked for cracks.

Couplers

During regularly scheduled maintenance, head and knuckles, shank length, butt thickness, knuckle wear, and draft key wear are checked to ensure the components meet minimum standards. Coupler body and shank are checked for cracks, bends, and breaks.

General

A hot bearing/hot wheel detector unit is utilized to monitor the train during each pass around the loop. The locomotives are also equipped with radio communication to advise the crew if a shutdown is necessary.

A broken rail detector system utilizing a modified track circuit system is in constant operation to detect broken or separated rails. This system is also detects improperly lined switches.

APPENDIX C

PETROGRAPHIC ANALYSIS
HAND SPECIMEN AND MODAL ANALYSIS OF THE FOUR TEST BALLASTS

By

Vincent DelloRusso, Geologist
Dept. of Civil Engineering, UMass

GRANITE (Gneiss)

Hand Specimen Description

The sample is composed of medium grade metamorphic rocks which can be separated into three types. The dominant material (Type 1) is a fine-grained biotite-quartz-feldspar gneiss. The rock is medium to dark gray, moderately foliated, with a moderate to high percentage of biotite mica (10-20%), which gives the rock its dark color. Milky quartz veins of varying thickness are common throughout the particles, parallel to foliation, but are generally subordinate to the gneiss. There is no inter-granular porosity, and only a small amount of macroscopic fractures are observed. There are some platy particles present as a result of the rock's foliation, and fewer elongate particles. Particles are generally angular to sub-angular with only slight rounding of corners evident.

The second material (Type 2) of pure quartz and quartz-feldspar veins derived from Type 1 material. These particles are biotite, and poorly developed foliation. Particles are angular and block with a rare platy or elongate particles.

The third material type (Type 3) is light to medium gray, very fine-grained, poorly foliated feldspathic quartzite or possibly aplite with <2% biotite. This material has a distinctly higher percentage of quartz and little mica in comparison with Type 1 material. This material is angular and block with a rare platy particle.

Modal Analysis of Ballast Sample

Compo-sition	Equant	%	Platy	%	Elong.	%	Tl	% of Tl
Type 1	6127 g	87.3	684 g	9.7	211 g	3.0	7022 g	68.5
Type 2	1283 g	92.8	78 g	5.6	22 g	1.6	1383 g	13.5
Type 3	1645 g	89.1	202 g	10.9	-	-	1847 g	18
Totals:	9055 g	88.3	964 g	9.4	233 g	2.3	10252 g	

TRAPROCK (Gabbro)

Hand Specimen Description

This sample is dominated by a medium-grained black and white speckled, pyroxene-plagioclase gabbro (composition similar to basalt, but coarser grained; Type 1). This igneous rock has no porosity and has a generally equigranular, massive texture with an average grain size of 1 mm. There is a small amount of geologically-related, finer-grained diabase (basalt; Type 2), which is compositionally the same as the gabbro (ave. grain size <0.5 mm). Both of these materials are generally angular and blocky with few or no platy particles.

Three additional particle types occur in small amounts, and are unrelated to Type 1 material. Type 3 material is medium gray, massive micritic limestone and buff to white cryptocrystalline dolomite. These carbonate particles are generally angular and blocky with little or no visible porosity. Type 4 material is dark green and black, massive non-vesicular, and vesicular, aphanitic to glassy blast furnace slag. Type 5 material is composed of well rounded cobbles of variable composition derived from a stream or glacial deposit.

Modal Analysis of Ballast Sample

Composition	Equant	%	Platy	%	Elong.	%	Tl	% of Tl
Type 1	7637 g	92.9	394 g	4.8	191 g	2.3	8222 g	79.8
Type 2	541 g	94.3	33 g	5.7	-	-	574 g	5.6
Type 3	741 g	95.6	34 g	4.4	-	-	775 g	7.5
Type 4	331 g	100	-	-	-	-	331 g	3.2
Type 5	370 g	91.1	-	-	36 g	8.9	406 g	3.9
Totals:	9620 g	93.3	461 g	4.5	227 g	2.2	10308 g	

DOLOMITE

Hand Specimen Description

This sample is composed of cryptocrystalline, massive, nonporous, siliceous dolomite (Type 1). The dolomite is generally very clean and variably colored pink, gray, red, and pure white, with a small amount of gray quartzite as thin lenses in the dolomite. The rock may be of low metamorphic grade. A small amount of dark green, well foliated quartz-chlorite schist, and dark green to black massive basalt is also present in the ballast sample (Type 2). In general, ballast particles are angular with minor rounding of edges and corners.

Modal Analysis of Ballast Sample

Composition	Equant	%	Platy	%	Elong.	%	TI	% of TI
Type 1	9586 g	96.7	258 g	2.6	68 g	0.7	9912 g	97.9
Type 2	177 g	83.1	-	-	36 g	16.9	213 g	2.1
Totals:	9763 g	96.4	258 g	2.6	104 g	1.0	10125 g	

LIMESTONE (Dolomite)

Hand Specimen Description

The sample is almost entirely composed of white to light gray, well indurated, fossiliferous, non-slightly argillaceous, microcrystalline dolomite with fine vuggy porosity common (7-10%). The dolomite has a relative Moh's hardness of 4.0. Particles are generally sub-angular with some sub-rounded chalky particles present. Particle corners are extensively rounded, edges are slightly rounded. Surfaces are slightly rough due to rock pores. Particles are generally equant and rarely (<1%) platy or elongate. A small amount of dark, glassy, vesicular and dense slag is present. A few particles of biotite-quartz-feldspar gneiss, and rare diorite particles are also observed.

Sample composition (3/4" - 1 1/2")

Rock Type	Weight	% of Sample
Dolomite	13,334 g	98.3
Slag	44 g	0.3
Gneiss	116 g	0.9
Diorite	74 g	0.5
Total	13568 g	

APPENDIX D

MILL ABRASION TESTS ON TEST BALLASTS

Submitted by: Prof. E. T. Selig
University of Massachusetts
Amherst, MA

Tests done by: R. R. Devulapally

Mill Abrasion Test Results

Ballast Type	MA(%)	B(%)	P(%)
GRANITE	4.4	5.2	84.1
	4.4	5.3	82.5
	4.7	6.3	75.2
AVERAGE:	4.5	5.6	80.6
DOLOMITE	8.5	9.1	93.8
	8.9	10.2	87.2
	8.4	9.1	92.8
AVERAGE:	8.6	9.4	91.2
TRAPROCK	4.6	4.7	96.8
	4.3	4.4	96.0
	4.5	4.6	97.7
AVERAGE:	4.4	4.6	96.8
LIMESTONE	8.8	9.0	98.4
	8.3	8.4	98.0
	8.8	9.0	97.4
AVERAGE:	8.6	8.8	97.9

Abrasion Number = Los Angeles Abrasion Loss in % + 5 x Mill Abrasion Loss in %[1]

Ballast Type	Abrasion Number
Granite	18.5 x 5(4.5) = 416.2
Traprock	10.2 x 5(4.4) = 224.4
Dolomite	34.1 x 5(8.6) = 1466.3
Limestone	29.7 x 5(8.6) = 1277.1

1 A. W. Clifton, M. J. Klassen, and B. R. Watters. "Ballast Production and Testing," Presented to: Session on Performance of Aggregate in Railroads, Transportation Research Board, Washington, D.C., 1987.

APPENDIX E

FAST ELONGATION INDEX TEST
FAST FLAKINESS INDEX TEST RESULTS

performed by AAR personnel

SHAPE FACTOR TEST (CIGGT)

performed by
S. E. Woolwine Jr.
W. W. Boxley Co.

FAST Elongation Index Test

FAST Flakiness Index Test Results

Shape Factor Test (CIGGT)

Ballast Type	**FAST Elongation Index**	**FAST Flakiness Index**	**Shape Factor Test (CIGGT)**
Dolomite	49.52 42.66	13.58 16.79	2.14 2.04
AVERAGE:	46.09	15.18	2.09
Granite	47.92 41.68	25.77 23.48	2.39 2.29
AVERAGE:	44.80	24.62	2.34
Limestone	26.38 27.43	13.69 8.56	1.99 1.98
AVERAGE:	26.90	11.12	1.98
Traprock	50.83 41.64	27.14 30.59	2.46 2.47
AVERAGE:	46.23	28.86	2.46

APPENDIX F

Initial Ballast Sieve Analysis
and
AREA Recommended Methods of Ballast Testing

By

Lincoln DeVore Inc.
Geotechnical Consultants

Sample: DOLOMITE

Sieve Analysis, ASTM C-136 - minus No: 200, ASTM C-117

Modal Analysis of Ballast Sample

Sieve Size	% Finer
2 1/2"	100.0
2	84.8
1 1/2"	67.4
1	33.9
3/4	17.3
1/2	9.0
3/8	6.3
No: 4	3.9
200	1.2

Soundness of aggregate by use of magnesium sulfate,
ASTM C-88, 5 cycles
% Loss - 0.23

Soundness of aggregate by use of sodium sulfate,
ASTM C-88, 5 cycles
% Loss - 0.26

Los Angeles abrasion, ASTM C-535, grading 2
% Loss after 1000 revolutions - 34.1

Clay lumps and friable particles, ASTM C-142
% Loss - 3.37

Scratch hardness of coarse aggregate, ASTM C-235
% soft particles - No loss

Unit weight of aggregate, ASTM C-29
Wt./cu. ft. - lbs. - 104.8

Sample: GRANITE

Sieve Analysis, ASTM C-136 - minus No: 200, ASTM C-117

Modal Analysis of Ballast Sample

Sieve Size	% Finer
2 1/2"	100.0
2	97.6
1 1/2"	84.5
1	37.9
3/4	16.1
1/2	8.0
3/8	5.4
No: 4	3.2
200	0.8

Soundness of aggregate by use of magnesium sulfate,
ASTM C-88, 5 cycles
% Loss - 0.24

Soundness of aggregate by use of sodium sulfate,
ASTM C-88, 5 cycles
% Loss - 0.20

Los Angeles abrasion, ASTM C-535, grading 2
% Loss after 1000 revolutions - 18.5

Clay lumps and friable particles, ASTM C-142
% Loss - 0.8

Scratch hardness of coarse aggregate, ASTM C-235
% soft particles - 20.7*

Unit weight of aggregate, ASTM C-29
Wt./cu. ft. - lbs. - 101.8

* Loss due to soft mica

Sample: LIMESTONE

Sieve Analysis, ASTM C-136 - minus No: 200, ASTM C-117

Modal Analysis of Ballast Sample

Sieve Size	% Finer
2 1/2"	100.0
2	89.5
1 1/2"	50.3
1	6.4
3/4	1.0
1/2	0.9
3/8	0.9
No: 4	0.9
200	0.5

Soundness of aggregate by use of magnesium sulfate,
ASTM C-88, 5 cycles
% Loss - 0.24

Soundness of aggregate by use of sodium sulfate,
ASTM C-88, 5 cycles
% Loss - 0.23

Los Angeles abrasion, ASTM C-535, grading 2
% Loss after 1000 revolutions - 29.7

Clay lumps and friable particles, ASTM C-142
% Loss - 0.29

Scratch hardness of coarse aggregate, ASTM C-235
% soft particles - No loss

Unit weight of aggregate, ASTM C-29
Wt./cu. ft. - lbs. - 93.8

Sample: TRAPROCK

Sieve Analysis, ASTM C-136 - minus No: 200, ASTM C-117

Modal Analysis of Ballast Sample

Sieve Size	% Finer
2 1/2"	100.0
2	99.0
1 1/2"	68.9
1	10.9
3/4	2.4
1/2	0.2
3/8	0.2
No: 4	0.2
200	0.1

Soundness of aggregate by use of magnesium sulfate,
ASTM C-88, 5 cycles
% Loss - 0.56

Soundness of aggregate by use of sodium sulfate,
ASTM C-88, 5 cycles
% Loss - 0.13

Los Angeles abrasion, ASTM C-535, grading 2
% Loss after 1000 revolutions - 10.2

Clay lumps and friable particles, ASTM C-142
% Loss - 0.14

Scratch hardness of coarse aggregate, ASTM C-235
% soft particles - No loss

Unit weight of aggregate, ASTM C-29
Wt./cu. ft. - lbs. - 106.9

APPENDIX G

Ballast Specifications

from
Second Ballast Experiment

under 33-ton axle load traffic

Test Name: **GRANITE I:**

Geological Description: Micaceous-Quartzo-Feldspathic Gneiss

Installation: Section 03, Wood Ties

Index Tests:

Soundness of aggregate by use of sodium sulfate,
ASTM C-88
% Loss - 0.05

Los Angeles abrasion, ASTM C-131
% Loss - 23.1

Flakiness Index, Initial, BS 812
35

Elongation Index, Initial, BS 812
29

CIGGT Shape Factor
2.44

Petrographic Description:

Microcrystalline to fine-grained xenoblastic micaceous-quartzo-feldspathic gneiss showing a crystalloblastic texture with fair to good foliation. The more distinct foliation is present in those thin sections showing increased percentages of mica. K-feldspar and quartz are the main constituents with the remaining mineralogy consisting of plagioclase (oligoclase), biotite, muscovite, and accessory zircon, apatite and magnetite. Alteration products include chlorite and hematite in minor amounts when present.

Test Name: **GRANITE II:**

Geological Description: Granite to Quartz Monzonite

Installation: Section 03, Wood Ties

Index Tests:

Soundness of aggregate by use of sodium sulfate,
ASTM C-88

% Loss - 0.20

Los Angeles abrasion, ASTM C-131

% Loss - 16.7

Flakiness Index, Initial, BS 812

24

Elongation Index, Initial, BS 812

27

CIGGT Shape Factor

2.12

Petrographic Description: This is a trimodal rock consisting of:

a) Granite to Quartz Syenite to Quartz Monzonite: holocrysatalline, inequigranular, porphyritic fine to medium grained, hypidiomorphic-granular, porphyritic granite, porphyritic quartz syenite, porphyritic quartz monzonite.

b) Granite: holocrystalline, inequigranular, porphyritic, fine to medium grained hypidiomorphic-granular, porphyritic granite.

c) Basalt: holocrystalline, equigranular, fine-grained hypidiomorphic-granular basalt.

Test Name: **GRANITE III:**

Geological Description: Alkali-Feldspar Granite to Alkali-Feldspar Syenite, Trimodal

Installation: Section 03, Wood Ties

Index Tests:

Soundness of aggregate by use of sodium sulfate,
ASTM C-88
% Loss - 0.13

Los Angeles abrasion, ASTM C-131
% Loss - 24.7

Flakiness Index, Initial, BS 812
17

Elongation Index, Initial, BS 812
29

CIGGT Shape Factor
2.11

Petrographic Description: This is a trimodal rock consisting of:

a) Alkali-Feldsapr Granite to Alkali-feldspar Quartz Syenite to Alkali-Feldspar Syenite: holocrystalline, inequigranular, porphyritic fine to coarse grained hypidiomorphic-granular, porphyritic alkali-feldspar granite, porphyritic alkali-feldspar quart syenite and porphyritic alkali-feldspar syenite.

b) Alkali-Feldspar Granite to Alkali-feldspar Quartz Syenite: holocrystalline, inequigranular, porphyritic fine to medium grained hypidiomorphic-granular porphyritic alkali-feldspar granite and porphyritic alkali-feldspar quartz syenite.

c) Alkali-Feldspar Granite: holocrystalline, equigranular, fine-grained hypidiomorphic-granular alkali-feldspar granite.

Test Name: **GRANITE IV:**

Geological Description: Hornblende-Biotite Syenite

Installation: Section 03, Wood Ties

Index Tests:

Soundness of aggregate by use of sodium sulfate,
ASTM C-88
% Loss - -

Los Angeles abrasion, ASTM C-131
% Loss - 21.5

Flakiness Index, Initial, BS 812
24

Elongation Index, Initial, BS 812
17

CIGGT Shape Factor
2.06

Petrographic Description:

Holocrystalline, inequigranular, porphyritic fine to medium grained hypidiomorphic-granular, porphyrite hornblende-biotite syenite.

Test Name: **GRANITE V:**

Geological Description: Quartzite

Installation: Section 03, Wood Ties

Index Tests:

Soundness of aggregate by use of sodium sulfate, ASTM C-88

% Loss - 0.10

Los Angeles abrasion, ASTM C-131

% Loss - 19.9

Flakiness Index, Initial, BS 812

24

Elongation Index, Initial, BS 812

28

CIGGT Shape Factor

2.09

Petrographic Description:

Fine to coarse grained quartzite exhibiting typical hornfels texture of interlocking sutured grains of quartz with interstitial muscovite and chlorite. Accessory minerals include rutile, zircon, and opaques (pyrite and hematite).

Transportation Test Center

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OAVP/RAA/91-150

ff WRP

VTS Executive Committee
Research Committee

I am pleased to enclose a copy of AAR R-788 entitled "FAST/HAL Ballast and Subgrade Experiments." This report summarizes the results obtained during the first phase of the Heavy Axle Load program on the Heavy Tonnage Loop at the Facility for Accelerated Service Testing, Transportation Test Center, Pueblo, Colorado.

The results contained in this report include the performance of four ballast materials, relative to their ability to withstand the loads associated with the heavier, 39-ton, axle load environment. The report also incorporates the results of the effect of the 39-ton axle traffic on the FAST subgrade structure.

Sincerely,

Roy A. Allen
Assistant Vice President

Enclosure

cc: FAST Steering Committee
AREA Committee 1
AAR Ballast/Subgrade Working Group

ASSOCIATION OF AMERICAN RAILROADS | RESEARCH AND TEST DEPARTMENT | REPORT BRIEF

FAST/HAL BALLAST AND SUBGRADE EXPERIMENTS

R-788

August 1991

The increase in axle load from 33-ton to 39-ton may have a dramatic influence on the track and support structure in the railroad environment. Two experiments, the Ballast and the Subgrade, were conducted at the Association of American Railroads, Transportation Test Center, Pueblo, Colorado, to investigate the influence of the increase in axle loads during the first 160 MGT of the Heavy Axle Load (HAL) program. Two of the ballasts tested (dolomite and limestone) have required an out-of-face surfacing. The axle load increase was also measurable at the ballast/subgrade interface. While the increase in axle load did not cause any subgrade failures at the Facility for Accelerated Service Testing, the measured increase in stresses could be sufficient to cause significant subgrade related maintenance on some typical North American tracks.

Ballast degradation and track geometry retention measurements were used to monitor the ability of the ballast materials (granite, traprock, limestone, and dolomite) to withstand the HAL environment. During the first 160 MGT of traffic, all four ballast materials were able to withstand the 39-ton axle load traffic; however, the dolomite and limestone required an out-of-face surfacing due to loss of cross level. Even though all four ballasts completed the test, the dolomite material required more spot tamping where rail anomalies were present. A direct comparison of the ballasts presently in test under 39-ton axle load traffic with the previous 33-ton axle load ballast test results cannot be made due to differences in the ballast properties and accumulated tonnage.

The Subgrade Experiment was conducted to determine how the increase in axle load from 33-ton to 39-ton axle was distributed to the subgrade structure. Also if a significant increase in subgrade stresses was present between the 33-ton and 39-ton axle load, was the increase proportional to the applied load? For this experiment, a section of tangent track was instrumented to measure the vertical load generated at the rail seat, and subgrade stresses and strains generated at the ballast/subgrade interface. Measurements were taken at three predetermined MGT cycles. The train consist used for data collection was an equal number of 33-ton and 39-ton cars. Testing of the 33-ton and 39-ton axle loads simultaneously allowed a direct comparison of data without the influence of weather, instrumentation drift, operating conditions, or train speed. Pressure cells, extensometers, and instrumented tie plates were used to collect the data on the selected tangent section of the Heavy Tonnage Loop.

Copies of the AAR Report: "FAST/HAL Ballast and Subgrade Experiments," are available from the Document Distribution Center, Chicago Technical Center, 3140 South Federal Street, Chicago, Illinois 60616. The AAR report number is R-788; the price is $10.00 for member railroads and $100.00 for nonmembers. Illinois residents please add 8% sales tax. The cost includes surface mail postage if mailed within North America. There will be a surcharge for any overseas mail. Checks should be made payable to the Association of American Railroads. This report was issued in August, 1991. A report list is available upon request.

FAST/HAL Ballast and Subgrade Experiments, 1991
Association of American Railroads, M Carmen Trevizo

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U.S. Department
of Transportation
**Federal Railroad
Administration**