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Effects of Short HAL Cars on Subgrade – Part 2

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Summary

Transportation Technology Center, Inc. (TTCI) is investigating the effects of heavy axle load (HAL) traffic on infrastructure, specifically as related to minimum length interchange cars. The use of short cars with high density commodities has doubled in the last five years. Of particular importance and focus are subgrade/embankments and bridges that might have different effects due to cars of minimum interchange length (about 42 feet) as compared to the common 53-foot gondola car. This *Technology Digest* is a continuation of previous efforts on the Effects of Short HAL Cars on Subgrade.¹ It focuses on analytical investigations of soil pressure in subgrade, stability of high embankments, and retaining walls.

The results of the study indicate the following conclusions:

- The pressure distribution “bulbs” under long cars do not overlap, while they do exhibit a slight overlap under short cars. This closer proximity of pressure bulbs and overlap could be a contributing factor in the residual stresses observed under short cars during the test at FAST in 2015.¹
- Retaining walls under 42-foot cars are seen to develop pressures up to 26 percent higher than those under 53-foot cars. This difference is exaggerated for shorter walls, and diminishes as wall height increases and gravity load of the backfill material becomes more of the controlling design factor than train loading. For example, the difference due to car length is only 4.0 percent for a 20-foot retaining wall.
- For embankments, slope stability is higher under long cars than under short cars; however, similar to the retaining wall designs, the difference in slope stability between short and long cars decreases as the embankment height increases.

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INTRODUCTION

Transportation Technology Center, Inc. (TTCI) is investigating the effects of heavy axle load (HAL) traffic on infrastructure, specifically as related to minimum length interchange cars. The HAL cars are considered to be those with a gross rail load (GRL) of 286,000 pounds or more. Data from the railroad industry equipment database, UMLER[®], shows a significant increase in the population of HAL cars shorter than 42 feet during the last 5 years. The number of cars in the North American rail network that are shorter than 48 feet increased from 40,000 to more than 85,000. Of these short HAL cars, most are covered hoppers with overall lengths of 41 to 42 feet. The areas of particular importance are those that might be different for cars of minimum interchange length (about 42 feet) compared to the common 53-foot bulk commodity car. These areas of concern include subgrade/embankments and bridges.

PREVIOUS FINDINGS

A test performed by TTCI in 2015 showed that shorter length cars have a small effect on subgrade.¹ The effects on subgrade were evaluated in the low-modulus track section at the Facility for Accelerated Service Testing (FAST), comparing subgrade pressure transducer readings for short and standard length cars. Observations from the tests are as follows:

- Overall, there was no significant difference in magnitude of subgrade stresses measured under train operations with two different car lengths.
- The effect of speed and direction on average maximum peak stresses was minimal.
- Temporary residual stress was observed in the subgrade that was apparent due to train operations of short cars; however, it was not observed under train operation of standard length cars. Although not large in magnitude at the locations measured, this residual stress does indicate some potentially detrimental effect of shorter cars on subgrade response behavior.

SOIL PRESSURE DISTRIBUTION

Shorter cars with the same gross rail load as longer cars produce a higher weight per unit length of track. This load, in turn, is distributed through the track structure and substructure components. The spreading of wheel loads over a larger area at greater depth depends on the stiffness characteristics of each layer of the track structure including the rail, ties, ballast, and subgrade. A previous *Technology Digest* shows an example using the GEOTRACK[™] computer model to illustrate how a wheel load is transmitted from the wheel-rail interface to the rail-

tie interface, to the tie-ballast interface, and to various depths in the ballast and subgrade layers.²

GEOTRACK[™] MODELING

To obtain a better understanding of difference in track substructure stress distribution, short and long cars were modeled using GEOTRACK. GEOTRACK is a 3-dimensional and multilayered elastic model for analyzing track and subgrade structure under vertical, static loadings. Loadings applied to the track are distributed through the ballast and subgrade and can be defined by a series of pressure bulbs within the subgrade. Since there is no dimensional difference between long and short cars' trucks at the car-to-car interface (between subsequent cars), the pressure distribution under each set of trucks is expected to be identical; however, the shorter distance between sets of trucks in short cars will bring the pressure bulbs produced by each set of trucks closer together and create a larger area of overlapping pressures (Figure 1).

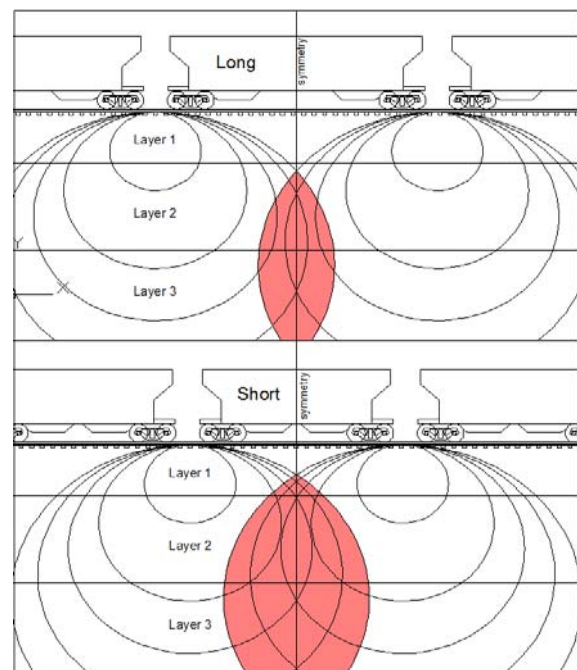


Figure 1. Overlapping Pressure Bulbs between (top) Long Cars and (bottom) Short Cars

These superimposed bulbs indicate larger stresses between short cars in comparison to long cars. Figure 2 illustrates how the GEOTRACK model output lines up with the applied axle loads.

In GEOTRACK models, the pressure distribution produced by the first four axles before the loading is mirrored about a specific car type's symmetry (long or short) and then superimposed. Figure 3 depicts these superimposed loads from each car geometry.

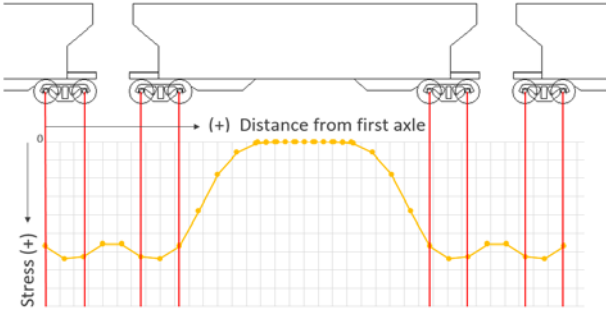


Figure 2. Example of How Car Axle Loads Line Up with GEOTRACK's Stress Distribution Output

The model output values were taken from 2 feet below the bottom of the ties in the track model. The yellow and red lines indicate the superimposed pressure distribution from consecutive long and short cars, respectively. There is no overlap between the two long cars in the model. The short cars exhibit a slight overlap and totals 0.8 psi. The maximum subgrade pressure is 6.7 psi, making the overlapping pressure about 12 percent of the pressure seen directly under the axle loads. This closer proximity of pressure bulbs and overlap seen under short cars could be a contributing factor in the residual stresses observed under short cars during the test at FAST.¹

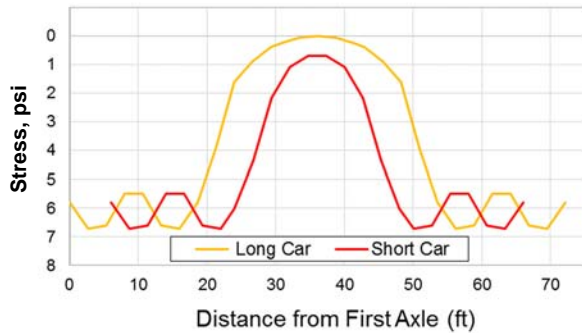


Figure 3. Overlaid Stress Distribution of Short Car and Long Car Loads at 2 feet Below Base of Tie

RETAINING WALLS

The increase in load per unit length can also affect retaining wall performance. Figure 4 presents the pressure distribution due to line load and earth pressure (also called dead load, DL).

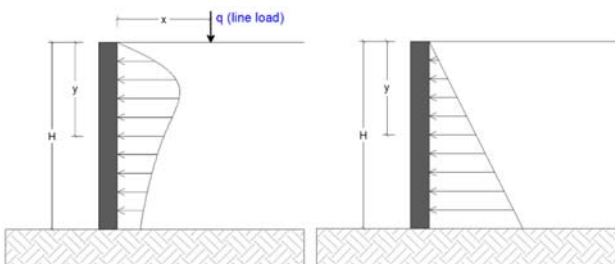


Figure 4. Pressure Distribution Due to Line Load and Earth Pressure

For the purpose of this study, four heights of retaining wall were used: 5 feet, 10 feet, 15 feet, and 20 feet. The distance between applied line load and the retaining wall was assumed to be 4 feet and was kept the same for all heights of the retaining walls. The soil considered in the study was clay with a weight of 120 pcf, 28 percent moisture content, and a 15-degree friction angle. Based on the material properties, additional parameters were calculated such as the at rest and active lateral earth pressure coefficients: $k_0 = 0.61$ and $k_A = 0.59$. Figure 5 shows examples of pressure distributions due to various loads (line and earth loads) for a 10-foot tall wall.

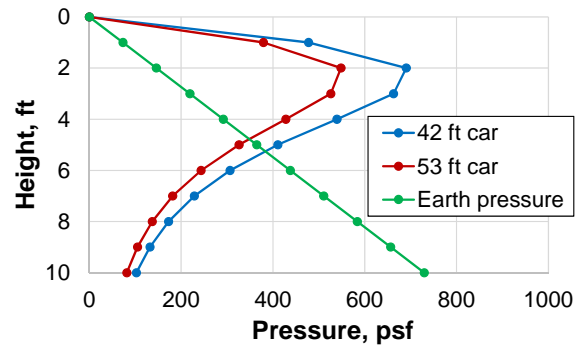


Figure 5. Pressure Distribution for Various Loads

Overall, pressure due to a 42-foot car is 26 percent higher when compared to a 53-foot car. This is consistent for all heights of retaining wall (Figure 6). However, the proportion between pressure due to train load and the earth pressure varies for different heights of the retaining wall (Figure 7).

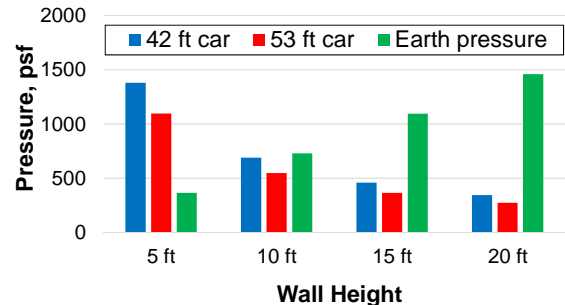


Figure 6. Pressure Comparison for Various Loads

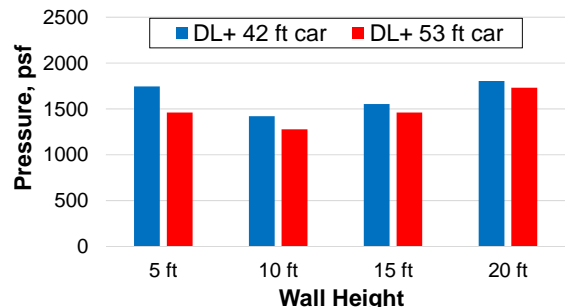


Figure 7. Design Pressure Comparison

In analysis, both loads should be combined (DL + train load). When comparing the total load, the effect of short cars becomes less visible on taller walls. It is about 19 percent for the short wall, but only 4.0 percent for the 20-foot wall.

ANALYSIS OF HIGH EMBANKMENTS

Short and long cars were also studied for their effects on stability of high embankments. For this study, high embankments were considered with a 1V:3H (vertical to horizontal) rise. Similar to the retaining wall analysis, 5-, 10-, 15-, and 20-foot high embankments were considered. For this analysis, Bishop’s Method was used to determine stability of high embankments.⁴ A slope stability modeling program was used to expedite critical slip surface identification: Geostudio® 2012 SLOPE/W. Table 1 shows the input parameters used in the analysis.

Table 1. Input Parameters used in Analysis

Embankment Properties	- Slope ratio 3H:1V - Heights (V): 5ft, 10ft, 15ft, 20ft
Mohr-Coulomb Material Properties	- Homogeneous - Unit weight of 120 pcf - Cohesion of 450 psf - Internal friction angle of 15°
Slip Surface Analysis	- Bishop Method - 100 slices - 1,000 iterations

Since slope stability analysis is 2-dimensional and deals with plane strain, line loads going longitudinally along the length of the track (into the paper), have to be reduced to loads that can be put into the same analytical plane as the model. Average line loads were applied for short cars (6.8 kip/ft), long cars (5.4 kip/ft), and consecutive trucks (15.0 kip/ft). Each loading was applied in one of three different ways: (1) a single-point load representing the line-axle loading, (2) two-point loads representing the line-wheel loads, and (3) the total line load being distributed into a 9-foot tie (Figure 8).

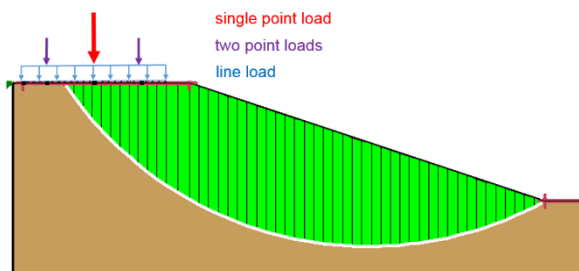


Figure 8. Geostudio® Model – White line represents the critical failure mode for the embankment

Each one of these loading configurations was applied to the load per unit length for short cars, long cars, and consecutive trucks. The results between the three approaches vary slightly. It was decided the two-point loading scenario was the most representative output from the results.

Figure 9 shows that the controlling value is determined by the adjacent trucks in the model. This result makes sense, as the highest load concentration along the train would be at the adjacent trucks between cars. The loading density is the same whether the train is composed of long cars or short cars. The only significant difference in car geometry between long and short cars is the distance between trucks on the same car; the distance between trucks of consecutive cars remains the same. Figure 9 shows how the results of slope stability for the two-point loading case fluctuates with changing embankment height. As embankment height decreases, the factor of slope stability generally rises. For the two-point loading case, embankment height exhibits a higher stability under long cars than under short cars, the difference of which increases as the embankment height decreases. Adjacent trucks still lead to the cases with the lowest slope stability.

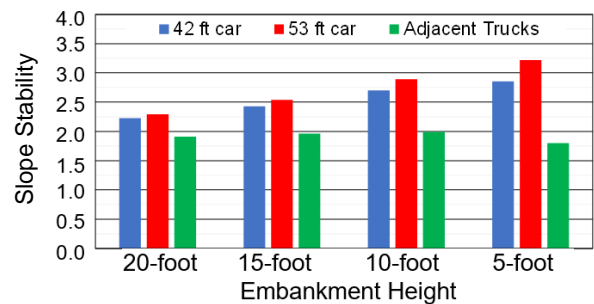


Figure 9. Slope Stability Comparison

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