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# Ballast Section Design for Bridge Approaches

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## Summary

Transportation Technology Center, Inc. evaluated the performance of a ballast section designed to provide ramped settlement at fixed locations, such as bridge approaches. At bridge approaches, differential settlement can occur between the bridge (founded on a deep pile foundation) and open track (founded on a shallow foundation of ballast over a soil subgrade). The solution presented in this digest may be applicable to locations where the majority of settlement occurs in the ballast layer.

Using a discrete element method (DEM) model of ballast developed by the Association of American Railroads' Affiliated Laboratory at the University of Illinois Urbana-Champaign (UIUC), a bridge approach ballast section was designed, built, and tested at the Facility for Accelerated Service Testing (FAST) High Tonnage Loop. The demonstration test showed that the model is capable of predicting the performance of ballast from characteristics of individual ballast particles, such as size, texture, and shape, and it provides track designers with a powerful tool for ballast section design. The current design methods assume ballast is a continuous layer and apply empirically derived calibration factors.

The four demonstration sections at FAST were built in early 2012 with ballast donated from Union Pacific Railroad. The bridge approach has accumulated 100 MGT of 39-ton axle load traffic operating at 40 mph. The demonstration test produced the following results:

- Using available ballasts, a bridge approach was built, which over time produced a settlement ramp. The ballast nearest the bridge had less settlement than the ballast away from the bridge.
  - Model and/or input data refinement is likely needed, but generally the model predicted the performance trends correctly.
- The test sections had high vertical deformation due to being new construction. Lateral bulging of the section on the high rail side of the curve also contributed to the high rail vertical settlement. This suggests that a review of ballast shoulder design for new and existing track should be conducted.
- Tamping increased the density of newly placed ballast, which was confirmed by weighing ballast sample boxes placed in the track before and after track surfacing.

The test demonstrated the concept of designing a ballast section to provide a more uniform transition from open track to track on a structure, such as a bridge. The DEM model can be used to design track transitions or to predict the performance of different ballasts.



**INTRODUCTION**

Track transitions can often cause track surface or alignment defects. The fundamental problem resides in the differences in the track structures at the transition. Bridge approaches are a good example. Bridges are founded on a deep foundation, such as driven piles. The track on the approach is on a shallow foundation of soil embankment or native soil. The two track structures can have different performance and permanent deformation characteristics. The approach track is likely to have higher settlement rates. This can result in a “bump at the end of the bridge” (i.e., a discontinuity in track surface where the approach settles more than the track on the bridge).

In other cases, such as ballast deck bridges, the ballast layer is less confined on the approaches than on the bridge. In these cases, the ballast also may spread laterally, causing more rapid settlement than on the bridge.

Differential settlement at bridge approaches can result in track surface defects, which can affect train operation adversely. The surface defects are maintained with track tamping to correct surface and alignment. It is the abrupt difference between the bridge and the approach settlement (i.e., the differential settlement) that must be addressed.

**BALLAST SECTION DESIGN**

To mitigate the effects of the bump at the end of the bridge, a settlement ramp was proposed. One of the concrete, ballast deck bridges at the FAST High Tonnage Loop (HTL) was selected for this demonstration project. The demonstration involved changing ballast section performance so that differential settlement at the bridge would be reduced. By ramping settlement to match the ballasted deck bridge, the bump was made into a ramp to reduce required maintenance and improve safety and ride quality.

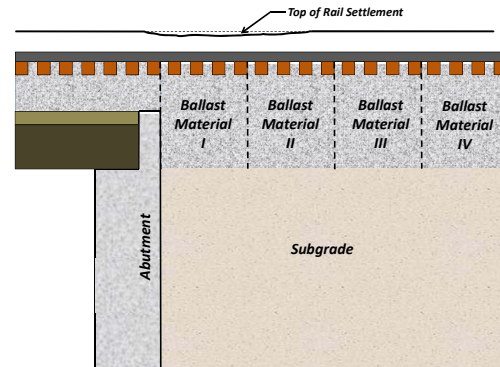
Recent work by the University of Illinois Urbana-Champaign (UIUC), under the Association of American Railroads’ (AAR) Affiliated Laboratory Strategic Research Initiatives, has developed the capability to design ballast sections to meet performance characteristics.<sup>1,2</sup> A DEM model developed for railroad ballast was used to design a bridge approach track. The process involved determining characteristics of proposed ballast materials (including particle sizes, shapes, surface textures, and angularities), then modeling them under railway loading.

The design team at UIUC used a library of ballast materials obtained from Union Pacific Railroad (UP) source quarries. A number of these ballasts were characterized under another AAR project to evaluate open track performance of ballast materials under heavy axle load traffic.<sup>3</sup> The TTCI project team limited the proposed design to the following requirements:

- Existing ballasts were used: no custom gradations
- Bridge approach was limited to 80 feet of track

With these limitations, the design team developed an approach prototype that used four 20-foot ballast sections. The section starting 80 feet from the bridge was intended to have the highest settlement rate. Moving toward the bridge, each

subsequent section was intended to have lower settlement rates. Additionally, the ballast on the bridge was selected to match the settlement rate of the ballast closest to the bridge. Figure 1 shows the prototype concept.



**Figure 1. Ramped Settlement Bridge Approach Concept**

Table 1 lists the ballast materials, sources, and their properties selected for the demonstration. (Note: Flat and elongated particles (F&E Ratio) are more likely to break in track.) Ballast IV was selected as the baseline ballast. For this demonstration, it was assumed that Ballast IV was used on the line segment for which the bridge approach was designed. Thus, the same ballast was also used on the bridge. In this demonstration scenario, the railway would replace the 60 feet of ballast nearest the bridge with Ballasts I-III that were selected to create a settlement ramp.

**Table 1. Ballasts Selected for FAST Demonstration Test**

Ballast	Aggregate Type	F&E Ratio	Angularity Index (AI)	Surface Texture (ST) Index	Gradation Uniformity
I	Trap Rock	1.9	378	1.1	Cu = 1.72 Cc = 1.03
II	Granite	2.0	426	1.6	Cu = 2.38 Cc = 1.04
III	Granite	2.0	601	3.1	Cu = 1.44 Cc = 1.09
IV	Granite	3.5	590	2.5	Cu = 2.25 Cc = 1.14

\*F&E Ratio = flat and elongated ratio

Using the University of Illinois Aggregate Image Analyzer (UIAIA) imaging based shape indices given in Table 1 for different ballast materials, the DEM simulation platform developed at UIUC was used to conduct numerical simulations of the four ballast test zones for the actual field geometry and train loading characteristics.<sup>2</sup> Previous calibration exercises with the model showed that reasonable predictions of long term performance could be made from relatively few simulation traffic passes.<sup>1,3</sup> Due to the computation requirements of the model, limiting simulation cycles is important for the efficacy of the model as a design tool.

Figure 2 shows the predicted settlement performances of the four different ballast materials for up to 300 car passes. By adequately addressing the ballast aggregate size distributions, particle shape, texture, and angularity as well as initial compacted state of the ballast layer before traffic, the ballast DEM settlement simulations indicated the predicted settlement trends of the four selected ballast materials.

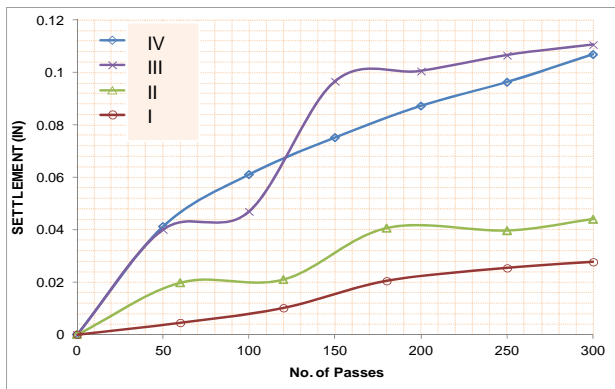


Figure 2. Predicted Settlements with Number of Car Passes using the UIAIA Ballast Model

Engineering judgment was used to alter the order of the ballasts, moving the Ballast IV section further from the bridge. This was done in anticipation that this ballast would have more settlement than predicted, due to the relatively high flat and elongated ratios (Table 1). Flat and elongated particles are more likely to break in track. Currently, the DEM is unable to simulate particle breakage. Thus, it was expected that the model prediction for this section would be conservative.

### PERFORMANCE MEASUREMENTS

The performance of the bridge approach track was measured in the following ways:

- Track settlement
- Track vertical stiffness
- Lateral track strength – as measured by single tie push tests

Track settlement has been relatively high in the test zone due to the replacement of the entire ballast section to a depth of 12 inches below the ties. Figure 3 shows rail elevation versus distance for various tonnages. Comparing the existing ballast to the first replaced section at a distance of 70 feet (i.e., 70 feet from the bridge), one can get a sense of the FAST HTL consolidated track settlement rate versus the newly installed sections.

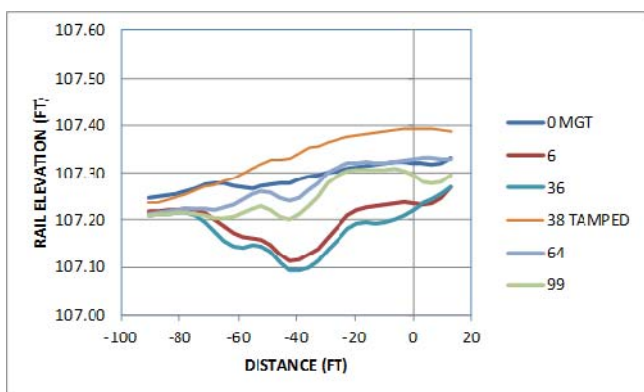


Figure 3. Rail Elevation vs. Distance for 99 MGT of Traffic

Figure 4 shows the average settlement of each section, identified by ballast quarry source, which indicates the same general pattern of settlement from each newly constructed section. There is a high initial settlement, ranging from 1-2 inches depending on ballast material for the first 6 MGT (~38,000 car passes). This is followed by a period of rebound, when the ballast shifts (i.e., particles break) under load. The track loses some superelevation, which appears to cause the low rail to rise. Also, repair of a broken rail in the Ballast III section (red line in Figure 4) likely contributed to the rebound, because the track was surfaced after repair.

A relatively steady rate of settlement follows, in this case from 15 to 36 MGT. The track was surfaced at 36 MGT, making the subsequent settlement rate higher. Since the measurement at 64 MGT, the settlement rates decreased, because the track reached a consolidated steady state. The model predictions generally matched the test section performance. The largest discrepancy was in the Ballast IV section. A possible explanation is that the ballast had fewer flat and elongated particles than the sample used to make the predictions. Since the sample was not within the railroad's specifications, this explanation is plausible.

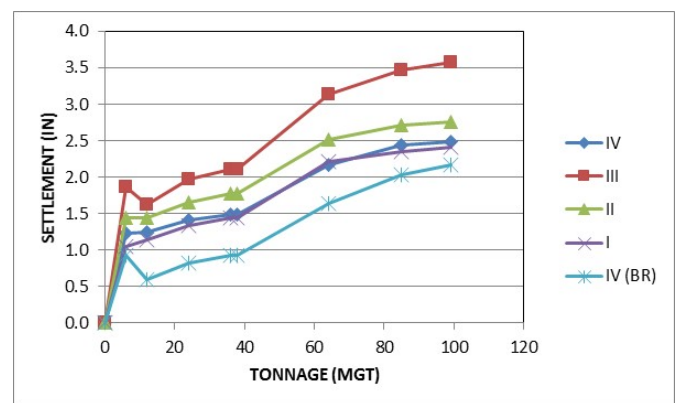


Figure 4. Average Track Settlement by Ballast Section

Ballast IV was used on the bridge (light blue in Figure 4) as well as on the approach (dark blue in Figure 4). The difference in performance between these two sections shows the effects of the bridge foundation on ballast performance. The lack of subgrade and lateral confinement of the ballast in the bridge deck ballast pan caused a reduction in settlement rate. This is the differential settlement that one may see at the end of a ballast deck bridge.

Figure 5 shows an elevation survey taken across the track in the Ballast II section. Note the settlement on the right hand side. This is the high rail of a 5-degree curve with 4 inches of superelevation. The section bulged laterally on the high rail side in response to the high rail elevation change. The other test sections showed similar performance.

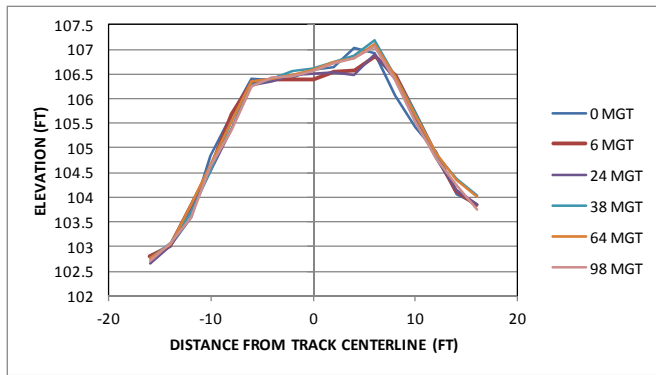


Figure 5. Cross Section Elevation for Ballast II Zone

The stiffness of the track in each test section was measured. It was expected that stiffness would increase from the approach towards the bridge. The as constructed ballast did behave in this manner. Figure 6 shows the track stiffness, as measured at the center of each test section. Subsequent measurements showed a decline in track stiffness from the original value. However, the average track stiffness in general increased after the measurements taken at the initial tonnage of 12 MGT.

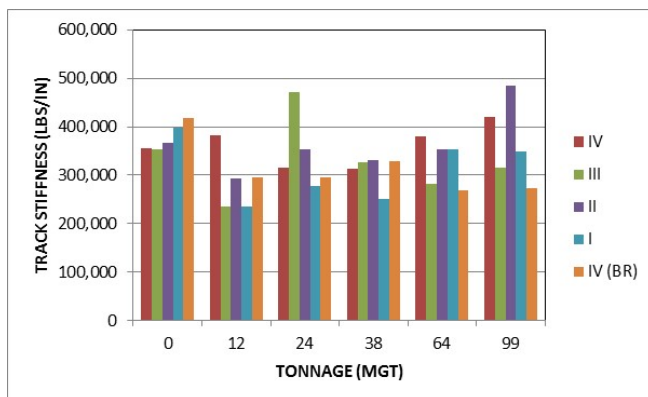


Figure 6. Track Stiffness vs. Tonnage for Each Test Ballast

Lateral track stiffness was also assessed with single tie push tests. This is a measure of the ability of the ballast section to hold track alignment. Initial measurements were taken after construction and before traffic. A second measurement was taken after 112 MGT of traffic. Figure 7 shows the lateral strength for one tie in each test section. A test was not done on the bridge ballast, due to logistical issues. As intended, the ballast closer to the bridge was stronger. With tonnage, the ballast increased in lateral strength. Three of the sections increased about 30 percent in strength. The Ballast IV section increased in strength by 350 percent.

An assessment of the density of the ballast before and after tamping was made using a 12-inch by 12-inch ballast box in each test section. Each box was placed on the subgrade of each section and filled with ballast. Each box was then weighed before and after tamping to determine ballast density. Table 2 lists the results of the measurements. Note that tamping did increase the density of the ballast in these sections by an average of 11 percent.

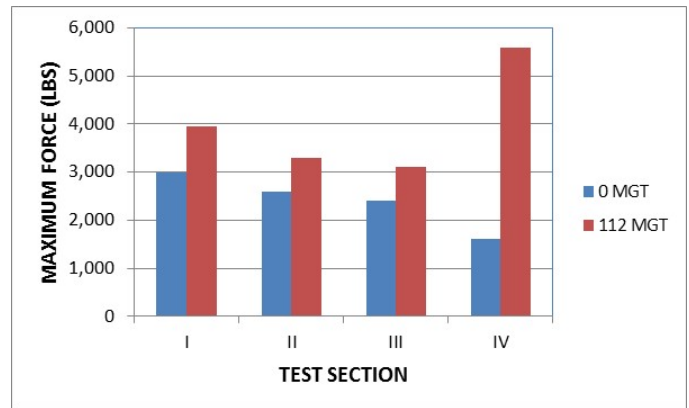


Figure 7. Lateral Strength of Each Test Ballast

Table 2. Ballast Density Before and After Tamping

Ballast	Placed Density (Pcf)	Tamped Density (Pcf)	Increase (%)
IV	53.93	60.65	12
III	47.97	52.05	9
II	47.59	52.80	11
I	47.11	52.75	12

## SUMMARY

The demonstration test produced the following results:

- Using available ballast materials, a bridge approach was built that produced a settlement ramp over time.
- The ballast model based on the DEM was able to predict the effects of ballast properties on settlement and on lateral strength.
- The test sections had high vertical deformation, because it was new construction and because of lateral bulging of the section on the high rail side of the curve.

The demonstration sections were built at the FAST HTL in early 2012 with ballast donated from UP. The bridge approach accumulated 100 MGT of 39-ton axle load traffic operated at 40 mph.

## REFERENCES

1. Davis, D. et al. July 2011. "Evaluation of Factors Affecting Ballast Performance." *Technology Digest* TD-11-019, Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.
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