TECHNOLOGY DIGEST
TD-08-019
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TIMELY TECHNOLOGY TRANSFER

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Evaluation of Reinforced Ballast for Foundations in Rail Joints and Special Trackwork

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Summary

Transportation Technology Center, Inc. (TTCI), a wholly owned subsidiary of the Association of American Railroads, investigated the potential of ballast reinforcement as a means of improving the foundations at key special trackwork components, such as insulated joints (IJs). In work conducted at the Facility for Accelerated Service Testing (FAST), at the Transportation Technology Center (TTC), Pueblo, Colorado, ballast reinforcement with a geogrid reduced settlement of insulated joints in heavy axle load track.

Preliminary findings from the tests include:

- Geogrid reinforcement reduced the initial settlement of IJs installed in mainline track at FAST. The settlement reduction, however, was not sufficient to reduce the surfacing maintenance typically required for newly installed joints.
- Performance benefits may be obtained after the IJ has settled in track. Longer term monitoring will be conducted to determine steady state performance and degradation modes.
- Track with fouled ballast settled more than track with clean ballast. The geogrid reinforcement reduced the settlement for the IJ with fouled ballast to the level of the IJ with clean ballast, but with no geogrid.
- The results of the instrumentation monitoring to-date are reasonable and expected. Under 34-ton axle loads, the elastic stiffness values measured are reasonable.

The tests conducted by TTCI at FAST also explored methods of characterizing track foundations using accelerometers buried or placed in the ground. If successful, these methods will allow more comprehensive analysis of problem areas. The tests verified that track substructure properties can be determined from wave transmission analysis using accelerometers embedded in the track substructure. In addition, the accelerometers can be placed in a cased bore hole, making possible the retrieval and reuse of the instrumentation. This less intrusive and lower cost method of track foundation investigation can make geotechnical investigation and analysis of mainline track foundations more feasible.

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INTRODUCTION

TTCI, with funding provided by the Association of American Railroads and Class I railroads, has been working to improve bonded IJ performance, particularly in heavy axle load service. Recently, this work has focused on improving the foundation conditions under IJs. Improving the track substructure at IJ locations has the potential to extend IJ service life by stiffening the ballast layer and reducing the amount of track deflection and settlement of the IJ. Reinforcement of the ballast layer at IJ locations with geosynthetic material such as geogrid has the potential to:

- Increase the overall elastic stiffness of the ballast layer by increasing the horizontal confinement stress
- Reduce lateral spreading, which will result in a reduction in vertical settlement
- Reduce the amount of loosening of the unbound layer by lateral movement
- Reduce vertical stresses transmitted below the reinforced layer

Rail joints are particularly susceptible to foundation problems due to their inherent weakness in vertical bending, as compared to the surrounding rail.[1] The butt joint designs used are mechanically inefficient and can lead to localized running surface deformation, ballast breakdown, and IJ electrical failure. The increased deflections at IJs cause more relative movement of rail versus joint bar and higher epoxy shear stresses. This leads to epoxy debonding and a relatively short service life. For heavy axle load coal service, average IJ service lives of less than 200 million gross tons (MGT) have been experienced.[2]

Most IJ locations in high-traffic revenue service lines have good subgrade conditions; therefore, the testing of a reinforced ballast layer was conducted with reinforcement in the upper ballast with a good subgrade condition, as Figure 1 shows.

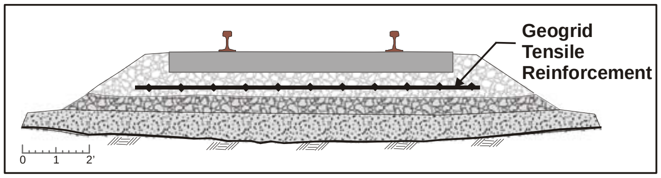

Figure 1. Reinforcement in Upper Part of Substructure

INITIAL RESULTS OF MONITORING

Results from the first 65 MGT of traffic across the site are presented below. Three test zones were installed in Section 35 of the High Tonnage Loop (HTL) at FAST between November 11 and 22, 2006. The purpose for the different zones was to evaluate variations in construction methods and the influence of fouled ballast, a common reason for excessive track settlement. Table 1 summarizes of the conditions for each test zone.

Table 1. Test Zone Variables

Test Zone	Depth of Reinforcement (inches below bottom of tie)	Ballast Condition	Subgrade Condition
1	No Geogrid	Moderately Clean	Firm
2	4.8	Highly Fouled	Firm
3	5.3	Moderately Clean	Firm

Tensar Earth Technologies, Inc. bi-axial geogrid SSLA30 was used as the reinforcement material. The type and depth of reinforcement, type of tie, type of insulated joint, strength and compressibility of subgrade, and traffic conditions remained the same for each section. The fouling material is typically wind-blown silt and sand, with some ballast breakdown. The subballast is typically a mixture of ballast particles and sand. The subgrade is a medium-dense to dense silty sand.

Figure 2 shows the vertical settlement of the top-of-rail for the inner rail (with IJs) and the outer rail (without IJs) for up to 65 MGT of traffic. Results of the top-of-rail surveys show that there is a greater settlement of the rail at the three reconstructed zones. This is expected since newly constructed track will settle more than existing track due to the newly-constructed substructure layers compacting more under traffic loading.

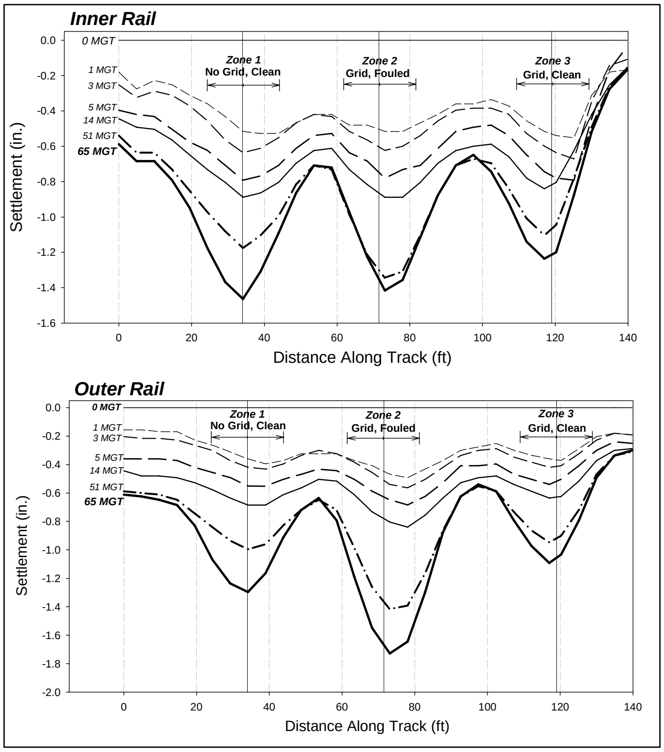

Figure 2. Vertical Settlement of Inner and Outer Rail, Shown Longitudinally

Figure 3 shows the settlement of the top-of-rail at the middle of the three zones as traffic accumulates. Without reinforcement in the fouled ballast section of Zone 2, it would be expected that there would be more settlement of the top-of-rail at the fouled ballast location (Zone 2) than at the clean ballast section. With reinforcement, however, the fouled ballast section settles similar to the clean ballast section. Also, reinforced clean ballast settles less than un-reinforced clean ballast.

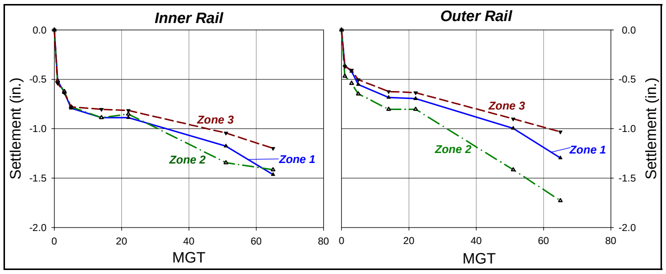

Figure 3. Vertical Settlement of Inner and Outer Rail versus Accumulated MGT of Traffic

FOUNDATION CHARACTERIZATION METHODOLOGY

The FAST IJ foundation test was also used to evaluate two variations of a foundation characterization method. The method uses accelerometers placed in the track to detect and measure waves traveling through the ground from the track surface. A test section was instrumented with an array of piezoelectric accelerometers, as Figures 4 and 5 show.

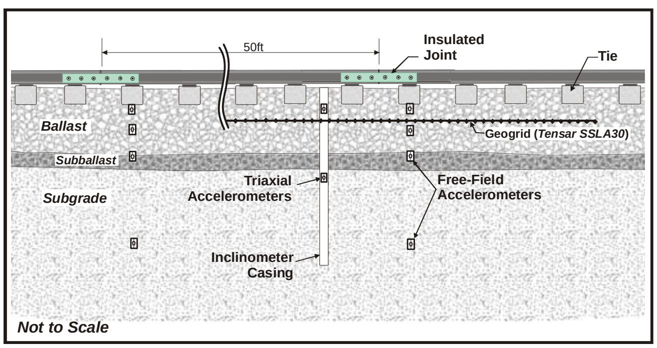

Figure 4. Longitudinal-section of Instrumentation

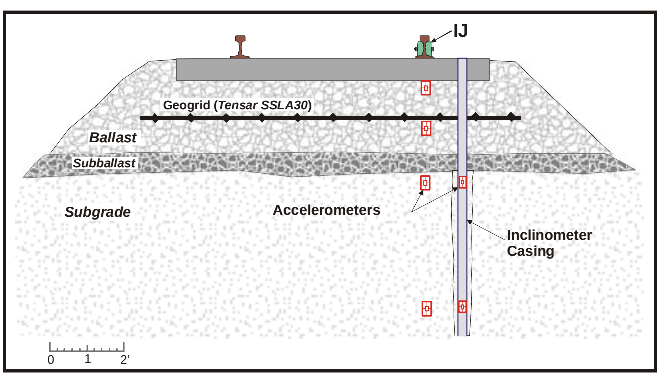

Figure 5. Cross-section of Instrumentation

An impulse hammer was used to induce a transverse shear input through the tie. By determining the time of arrival of the propagating impulse wave at specific locations, the velocity of wave travel can be determined. The stiffness properties of the track foundation are directly related to the wave velocities and can therefore be readily calculated. A comparison was made between using accelerometers buried directly in the substructure soil layers versus accelerometers placed in a cased vertical hole in the foundation, i.e., the downhole accelerometer. The downhole method was less intrusive, and provided for placement of the accelerometer at different depths and reuse of accelerometer in different borehole locations. The free-field accelerometers permanently placed in the ground eliminates any interference that may be caused by the borehole casing, and can also remain in the ground for measurement of long-term effects on material properties.

The accelerometer responses provided a good means for evaluating the elastic modulus of the track bed materials.[3] Figure 6 shows an example of the time histories of one set of accelerometers.

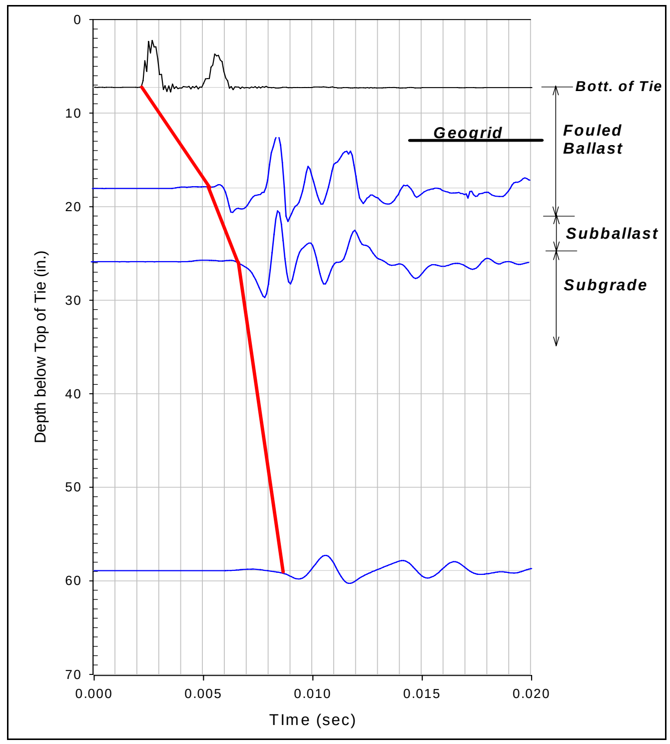

Figure 6. Free-field Accelerometer Time Histories from IJ Testing at FAST

The time histories proved to be an effective means of evaluating the material properties. Table 2 shows a sample of the interpretation of the data. The elastic stiffness (E values) of the materials are fairly reasonable. Initial results also show good agreement between the accelerometers buried directly in the ground (free-field accelerometers) and the accelerometers placed in the borehole casing (downhole accelerometer). The triaxial accelerometer is intended on being a portable device that can be inserted and removed for use at multiple sites.

Table 2. Assumed and Calculated Values Resulting in Elastic Moduli for Substructure Layers

Soil	Mass Density (lbm/ft^3)	Poisson's Ratio	Wave Velocity V_s (ft/sec)	Elastic Modulus E (psi)
Clean Ballast	3.26	0.20	444	3,500
Fouled Ballast (FF*)	3.42	0.30	290	1,500
Fouled Ballast (DH**)	3.42	0.30	313	1,700
Subballast	3.57	030	513	4,600
Subgrade	3.73	0.35	1,310	30,200

* FF = Free Field **DH = Down Hole

As more data is obtained, these numbers will be refined. In particular, finding the true shear wave arrival times will be a critical aspect of deriving accurate E values.

APPLICATION OF METHODOLOGY TO TRACK MAINTENANCE

Characterization and diagnosis of track foundation problems is a major need for heavy haul railroads. This diagnostic tool may allow railroads to pinpoint changes in the foundation, provide for more comprehensive analysis of problems areas, and thereby make maintenance more effective.

The specific application of the seismic wave analysis presented in this *Technology Digest* is for the purpose of assisting in the evaluation of track substructure conditions. Placement of an array of accelerometers enables the measurement of the shear wave velocity to determine if any changes have occurred in the track substructure. Softening of the geotechnical material would be reflected in a decrease in modulus. Changes in damping characteristics may also indicate important changes that might result in increased deformations. These changes can occur from various factors such as ballast fouling and cyclic degradation of the substructure layers. The accelerometer-based instrumentation is being used in revenue service at a bridge-approach transition study at Norfolk Southern's eastern Mega Site in West Virginia.

Another intended application is to observe the response of the accelerometers to train input loads. In particular, a geometry car can be driven over the instrument array. By using the acceleration measurements of the geometry car as an input and the different accelerometers as outputs, transfer functions can be calculated using Fourier analysis of the input signal and output response. Transfer functions indicate characteristics of how an input load can relate to the susceptibility of the reinforced ballast layer to settlement.

ACKNOWLEDGMENTS

The authors would like to acknowledge the following organizations: the Association of American Railroads for the financial and personnel support and access to FAST; Tensar Earth Technologies, Inc. for providing financial support and geogrid material; and Terrill Track Consultants. Without their assistance, the research presented in this paper would not have been possible.

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