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Investigation of Track Geometry Problems on Norfolk Southern Captina Secondary

David Read and Randy Thompson, TTCI
Jim Hyslip, HyGround Engineering
R. Scott Hailey, Norfolk Southern Railway

Summary

An investigation into the root cause of chronic track geometry problems and high maintenance demand was performed by Transportation Technology Center, Inc. on the Norfolk Southern Captina Secondary as part of the Association of American Railroads Heavy Axle Load Substructure Strategic Research Initiatives Program and the Federal Railroad Administration sponsored Heavy Axle Load Revenue Service Task Order 215.

The results suggest that water trapped in ballast pockets resulting in uneven settlement of a deep ballast layer is the primary cause of the geometry deterioration. Remediation plans for the site are being developed that involve strengthening of the ballast layer with geosynthetics or grout injection and creating a drainage path to remove water trapped in the ballast layer.

Substructure diagnostic tools used in the investigation included ground penetrating radar (GPR) to characterize the track substructure layer conditions, cone penetrometer testing (CPT) to measure the ballast depth and estimate subgrade strength, loaded rail deflection and track modulus measurements from the Track Loading Vehicle (TLV), Norfolk Southern track geometry data, and analysis using GEOTRACK, a computer model that predicts the vertical response of the track, including rail deflections and track modulus values, to applied wheel loads.

The GPR survey was performed as the initial step in the investigation and identified a generally deep ballast layer and two significant ballast pockets at the geometry problem location between mileposts 6+1865 and 6+2465. CPT tests were then performed at 50-foot increments at the same location and the cone tip resistance data was used to estimate the resilient modulus or relative strength of the subgrade. The CPT data indicated the resilient modulus in the top 36 inches of the subgrade was between 2.5 and 4.0 ksi, which is considered to be marginally soft to firm and not highly prone to deformation.

The TLV measured loaded rail deflection and track modulus data of 0.1-0.15 inch and 3,000-4,000 lb/in/in, respectively, were in close agreement with the CPT resilient modulus estimates in term of subgrade strength, also indicating the subgrade was not particularly soft. However, the amplitudes and peak-to-peak variability of the TLV 10,000- and 40,000-pound vertical track profiles were similar to each other implying that much of the total loaded rail deflection was taking place under the 10,000-pound load. This initial deflection under a light load is referred to as the seating deflection and is indicative of the stiffness at the rail-tie and tie-ballast interface and can also be affected by a weak ballast layer. The loaded, or contact, rail deflection that was measured between the 10,000- and 40,000-pound applied load is primarily influenced by the subgrade stiffness.

Although the subgrade strength and performance measurements did not show an abnormally soft subgrade condition, some deformation of the subgrade surface is occurring as evidenced by the deep ballast layer and pockets. The deformation is assumed to be a continuous and incremental process where the top few inches of the subgrade surface becomes softened by water that is trapped in the ballast pocket and is eventually pushed out laterally under load. This process will contribute to the track geometry deterioration but is thought to be too slow to be the primary cause.



INTRODUCTION

The Norfolk Southern (NS) Captina Secondary is a single track line that carries about 15 million gross tons of heavy axle load coal traffic annually. Parts of the line routinely experience track geometry problems that require frequent maintenance and have caused a 10 mph speed restriction to be applied.

Transportation Technology Center, Inc. (TTCI) incorporated a segment of the Captina line as a test site under the Association of American Railroads Heavy Axle Load Substructure Strategic Research Initiatives Program and the Federal Railroad Administration sponsored Heavy Axle Load Revenue Service Task Order 215. The objective of the project was to determine the cause of the chronic geometry problems and recommend a remediation plan.

A number of substructure diagnostic tools were used including GPR, CPT, loaded rail deflection and track modulus measurements from the TLV, track geometry analysis, and GEOTRACK analysis.

INVESTIGATION

A GPR survey was performed between mileposts (MP) 5+00 and 7+00 by HyGround Engineering as the first step in the investigation. GPR uses the reflection of high frequency radar waves to detect changes in subsurface conditions and can be used to assess variations in ballast layer depth, ballast fouling, and moisture content. The survey results were as follows.¹

- A significant depression in the subgrade surface (ballast pockets) from MP 6+1900 to 6+2450 (Figure 1). This was also the location of considerable track geometry deterioration.
- A bulging of the track embankment corresponding to the ballast pocket location that was derived from NS data using Fast Laser Imaging Mapping and Profiling.
- Additional smaller ballast pockets at MP 5+1600, 5+3050 and 5+3600.
- Incipient ballast pockets at MP 5+2900, 5+4800, 6+0100 and 6+3300.

TTCI developed a plan to augment the GPR results with subgrade strength and vertical track performance data using CPT and TLV measurement technologies.

Cone Penetrometer Testing

CPT is an established geotechnical technique that measures the force required to push an instrumented cone into the ground. Output data includes the cone tip resistance (q_c), sleeve resistance, friction ratio (tip resistance as a percentage of the sleeve resistance), and depth of cone penetration.

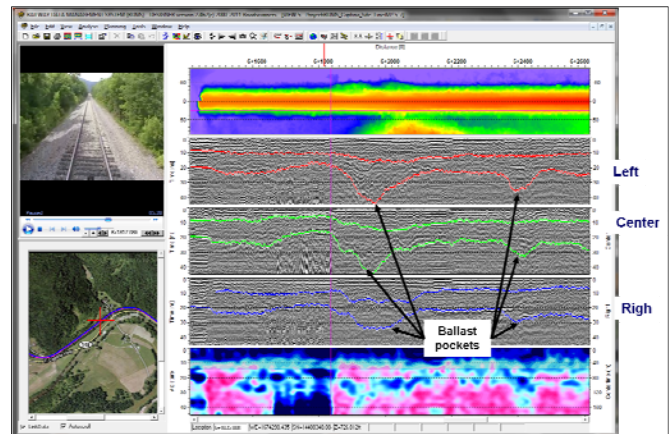


Figure 1. GPR Ballast Depth Data Showing Pockets

Thirteen tests labeled CPT 1-13, were performed at 50-foot increments in the large ballast pocket area beginning at MP 6+1865 (CPT 1) and ending at 6+2465 (CPT 13). Four additional tests (CPT 14 – 17) were performed at MP 6+100, 5+4800, 5+3600, and 5+1600 respectively. Data could not be collected at 6+2315 (CPT 10), 6+100 (CPT 14), and 5+3600 (CPT 16) locations where the cone was unable to penetrate the ballast layer.

The subgrade resilient modulus (E_r), which is the soil modulus of elasticity after a number of load cycles, was calculated from the tip resistance data using a correlation documented by E. Selig² where:

$$E_r = 14q_c.$$

Subgrade E_r less than 2.5 ksi is considered very soft and prone to deformation under heavy axle loads and E_r between 2.5 and 3.5 ksi as being moderately soft to firm and less likely to deform.³

CPT is not a suitable method for measuring the strength of coarse granular material, such as ballast.⁴ However, the cone response in the ballast layer can be used to indicate relative differences between locations (Figure 2).

Because the change in tip resistance is generally well defined at the subgrade interface, it can be used to determine the apparent ballast depth, as Figure 2 shows.

Figure 3 shows the ballast depth and subgrade E_r data from CPT tests 1-9 and 11-13 plotted as functions of distance from MP 6. The CPT ballast depths in Figure 3 are in agreement with the GPR data and show a very deep layer presumably produced by subgrade deformation over time.

The E_r data in Figure 3 was calculated from the average tip resistance in the top 36 inches of the subgrade indicating a moderately soft but not highly soft subgrade condition.

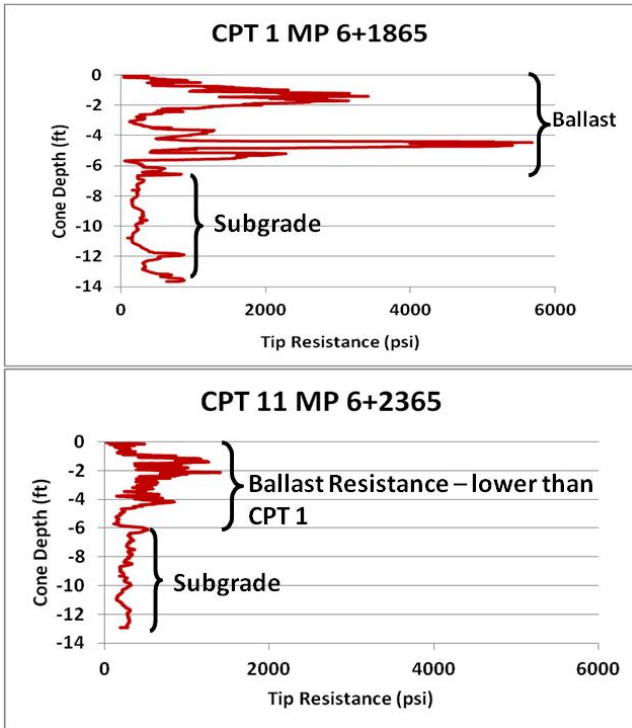


Figure 2. CPT 1 and 11 showing Difference in Ballast Response and Subgrade Layer Interface

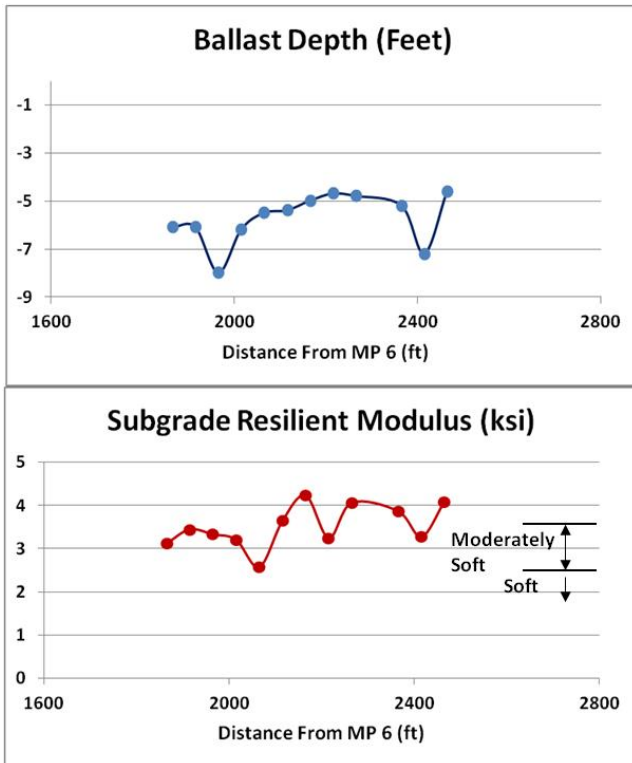


Figure 3. Ballast Depth and Subgrade Resilient Modulus Data from CPT Tests

TRACK LOADING VEHICLE AND GEOTRACK

Two in-motion TLV tests were performed between MP 4 and 7 — the first with an applied vertical force of 10,000 pounds, followed by a 40,000 pound test. The TLV consist did not include an empty tank car that is used to provide the unloaded rail baseline. Therefore, the vertical rail deflection was based on the 30,000-pound force differential between the two tests, and the track modulus (supporting force per unit length of rail per unit deflection) was calculated from the 30,000-pound deflection data.

Figure 4 shows the loaded deflection and track modulus data for the left rail between MP 6+1600 and 2800, along with CPT test locations 1-13. Figure 4 also shows the rail deflection and track modulus data predicted by GEOTRACK analysis that was based on the CPT subgrade E_r and ballast depth parameters, and 30,000-pound wheel load. The GEOTRACK and TLV data are in reasonable agreement, supporting the CPT based subgrade strength data.

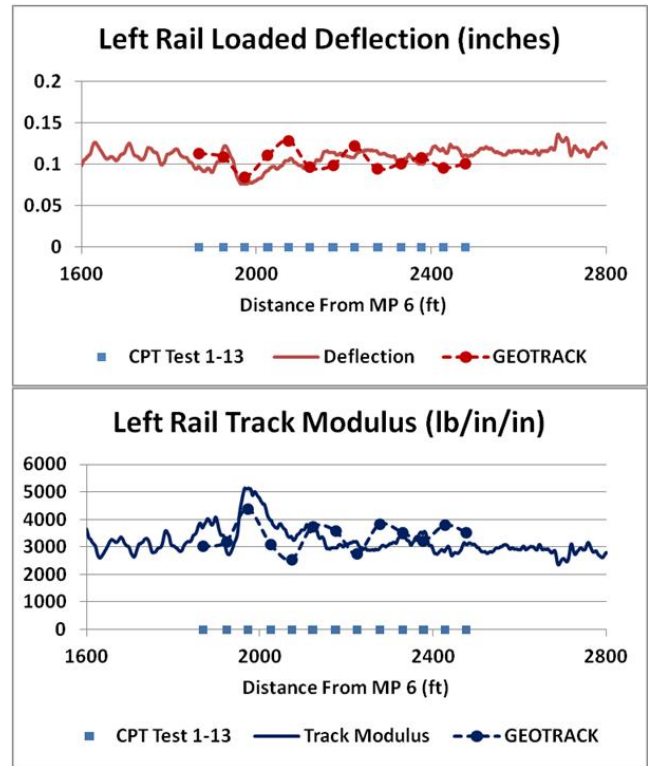


Figure 4. Loaded Rail Deflection and Track Modulus Data

Figure 5 shows the TLV 10,000 and 40,000-pound loaded left rail profiles and the loaded rail deflection. The two profiles are very similar in terms of peak-to-peak variability, or roughness. However, the same trend is not seen in the loaded deflection data. In fact, the loaded deflection has the least variability between MP 6+2300 and 2500 where the most profile roughness occurs. In addition, the profile roughness measured by the NS track geometry car about a month before the test is almost identical to the TLV data.

The dissimilarity between the profile roughness and loaded deflection data, plus the relatively low amplitude of the deflection data in general, suggests much of the total deflection may be taking place under the 10,000-pound load. This initial deflection under a light load is referred to as the seating deflection and is caused primarily by slack at the tie-ballast interface but can also be produced by a weak or unstable ballast layer.⁵

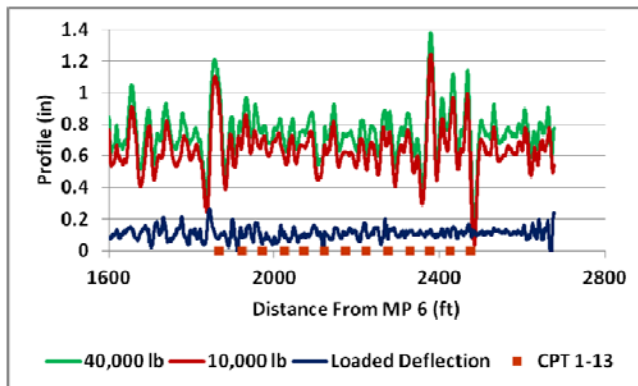


Figure 5. Left Rail Loaded Profiles and Deflection

INVESTIGATION SUMMARY

Test data taken between MP 6+1865-2465 is summarized as follows:

- Ballast depths of 4 to 8 feet confirmed substantial subgrade deformation over time. However, the E_r data in Figure 3 and the TLV/GEOTRACK loaded rail deflection and track modulus data in Figure 4 all indicate the subgrade is not excessively soft or weak. The deformation likely occurs as gradual lateral plastic flow caused by softening of the subgrade surface by water that is trapped in the ballast pocket.
- The TLV and NS track geometry vehicle both measured significant track roughness between MP 6+2300 and 2500. However, the profile roughness was not accompanied by similar changes in the subgrade strength, track modulus, or loaded rail deflection data.
- Although not measured directly, a possibility of high seating deflections is deduced from the similarities between the 10,000 and 40,000-pound loaded profiles and relative small loaded rail deflections. Large seating deflections are caused by the slack between the rail and ties or ties and ballast and from reduced ballast strength. Reduced ballast strength is a cause of track geometry deterioration.

REMEDIATION

Following drainage of the water currently trapped in the ballast pockets and creation of a permanent drainage path, TTCI and NS are considering methods to stabilize the ballast layer and mitigate the effects (rough geometry) of uneven ballast settlement at the site, including ballast reinforcement and ballast layer modification using chemical grout. Both techniques are amenable to high-production application and minimal disruption to traffic.

Ballast reinforcement that uses geogrid-type geosynthetic materials placed relatively high in the ballast layer (just below the tamping zone) has been shown to improve ballast performance and reduce uneven settlement.⁶ Horizontal reinforcement in the ballast layer increases the elastic stiffness, reduces lateral spreading, reduces the amount of particle loosening, and reduces the vertical stress below the reinforced layer.

In-situ grouting of ballast using low-viscosity, quick setting chemical is also being examined to provide stable, bound ballast layer. Grouting techniques are available that use small equipment and small diameter grout probes, so work can be performed through the cribs, in small work-widows, without removing the track panel.

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