TECHNOLOGY DIGEST

Timely Technology Transfer

"TRACK SUBSTRUCTURE ASSESSMENT WITH THE CONE PENETROMETER,"

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Summary

As part of a program to determine the nature of track substructure problems and to recommend the best remedial action, the Association of American Railroads has developed an on-track vehicle which houses a rapid, nondestructive subgrade test apparatus known as a cone penetrometer.

The cone penetrometer test (CPT) vehicle has been used to investigate the cause of excessive maintenance requirements on three member railroads. The data obtained is being used to determine the strength of the subgrade, the adequacy of the granular layer thickness over it, and the extent of weak soil deposits under and along the track. CPT data can be used as a guide to select the most appropriate maintenance remedy.

This is one of the tools that can be used to assess the benefits of adding more ballast, modifying the soil in-place, removing and replacing the subgrade with better material, or adding hot mix asphalt over the weaker layer.

Suggested Distribution:

- ❑ R&T Dept.
- ❑ Maintenance Planning
- ❑ Track Maintenance
- ❑ Maintenance of Way

Association of American Railroads
Research and Test Department
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INTRODUCTION AND CONCLUSIONS

As part of a program to determine the nature of track substructure problems and to recommend the best remedial action, the Association of American Railroads has developed an on-track vehicle which houses a rapid, nondestructive subgrade test apparatus known as a cone penetrometer.

Because the source of track roughness is usually not apparent from the track surface, the engineer needs a fast and reliable diagnostic tool to determine the cause of the roughness and to make the best maintenance choice. The cone penetrometer test (CPT) vehicle provides such a tool, mainly for soft subgrade conditions. With these results, the most appropriate maintenance technique can be selected which addresses the cause, not just the symptoms of track roughness

CONE PENETROMETER TESTING

The source of the problem is not always addressed if tamping is routinely prescribed as a catch-all response to rough track. Repeated tamping (especially in locations where it provides only short term improvements) drives up maintenance costs as tonnage levels increase and track capacity shrinks. A lower life cycle cost is achieved by addressing the underlying cause of the instability, which requires information on the substructure.

With the track-mobile CPT vehicle (Exhibit 1), the railroads now have a means to determine the depth and longitudinal extent of the problem soil, its strength, the adequacy of the granular layer thickness above it, and the effectiveness of alternative corrective actions. Subgrade is evaluated by measuring the pressure or resistance against a cone that is pushed through the track substructure in the zones shown. Soil samples also may be obtained.

CPT data can help determine where the ballast-subballast thickness is under-designed with respect to the subgrade strength, and how much additional thickness may be required to stabilize the track. Exhibit 2 shows an example where the subgrade is weak, yet the track is stable due to adequate stiffness and thickness of the granular layer. This stability is predicted by the Transportation Technology Center's (TTC) granular depth design model which uses the CPT data.

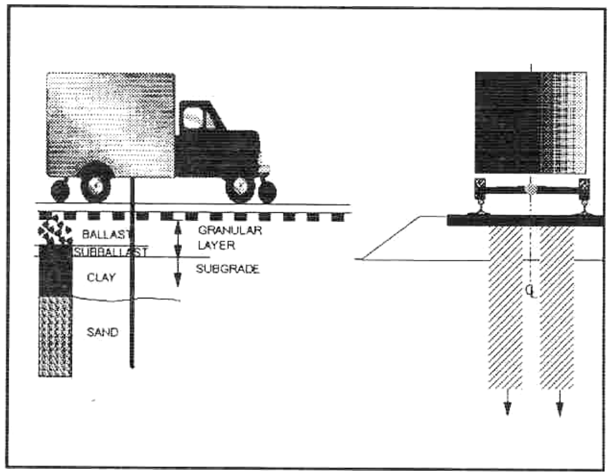

Exhibit 1. CPT Vehicle

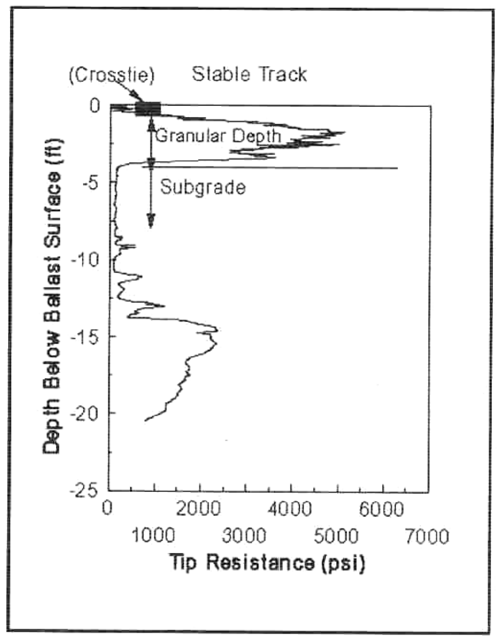

Exhibit 2. Typcial CPT Data showing Weak Subgrade

Exhibit 3 shows an unstable track condition resulting from a soft subgrade combined with a thin granular cover. Outwardly the track in this vicinity appeared to have a thick, clean ballast layer. But the CPT was able to detect the underlying weakness due to a clayey subgrade infiltrating the ballast and residing just a few inches below the tie bottom.

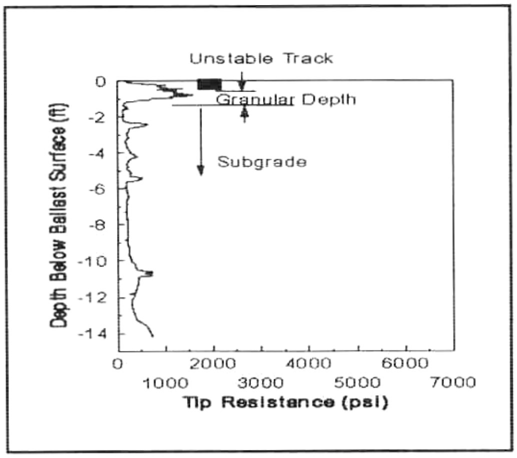

Exhibit 3. Unstable Track Condition

Increased Wheel Loads

Subgrade that may have been historically stable under current loading may suddenly become a maintenance problem under heavier axle loads. The CPT can be used to locate such potential problem areas where the very common soft subgrade failure modes of progressive shear and excessive plastic deformation may occur. Progressive shear is shown in Exhibit 4a where the soil is squeezed out under the ties. The resulting subgrade profile often has the largest depression just under the tie ends where the shearing stresses are usually the largest. For this subgrade failure mode, the subgrade strength just under the granular layer is of primary concern.

Whereas progressive shear is concentrated in the upper few feet of subgrade, excessive plastic deformation (Exhibit 4b) can result from soil strain over a considerable depth. Analyses have shown that significant elastic and permanent subgrade strain can develop over as much as 25 feet. To assess the potential of this failure mode, the CPT is designed to penetrate to this depth.

Predicting Track Modulus

Another use of CPT data is to predict track stiffness or modulus. The modulus of the subgrade largely controls that of the track. Research by Ebersohn and Selig has shown that tip resistance often correlates well with subgrade modulus.[1] With an estimate of subgrade modulus from this correlation, models such as GEOTRACK can be used to estimate the track deflection and modulus.

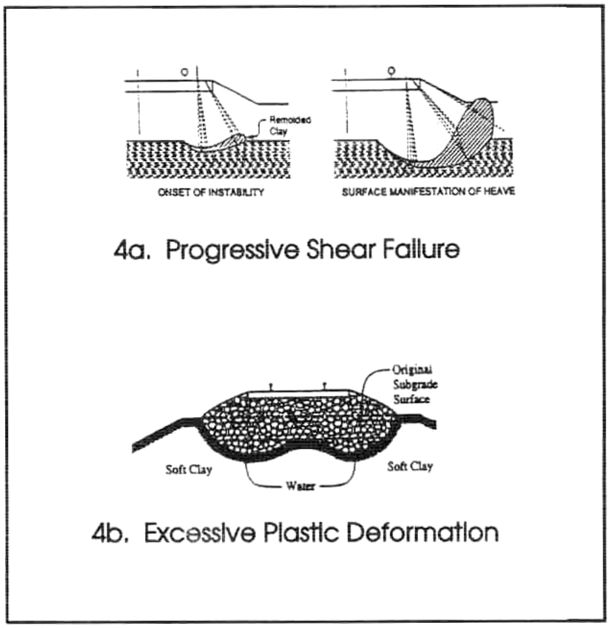

Exhibit 4a-4b. Progressive Shear and Excessive Plastic Deformation

MAKING THE RIGHT TRACK MAINTENANCE CHOICE

Before Attempting Costly Remedies

The CPT has a number of potential applications; for example, placing hot mix asphalt (HMA) between the ballast and subballast is sometimes used to reduce the stresses on the underlying weaker subgrade. However, research has shown HMA to be of little benefit in reducing stresses if the weaker layer is more than about 3 feet under the asphalt. The CPT may be used first to determine if such a weaker layer is present and within this distance.

Injection or mixing of materials into the subgrade is also sometimes used to improve soil properties. A preliminary investigation should be made to determine if the subgrade material is of the type that would benefit from such an effort. The CPT could perform this function with its soil sampling ability.

Removal and replacement of a very weak subgrade is sometimes attempted. Before such work is performed, the CPT could be used to map out the thickness and longitudinal extent of the weak soil deposit.

To Tamp, or Not to Tamp

Raising the track and tamping more ballast under the ties is often attempted as a means to increase the depth of ballast between the tie and the weaker underlying layer. However, it is not clear how much the tamping cycle will be improved by the added ballast and reduced stresses on the subgrade. In an attempt to quantify this improvement, CPT data and a granular depth design model by Dingqing Li (AAR) and Professor Ernest Selig (University of Massachusetts) were used to obtain the relationship shown in Exhibit 5.

Using the CPT data of tip resistance (q_C) and granular layer thickness (T_G), the tonnage at which the track is estimated to exceed FRA Class 4 roughness is shown. For a certain increase in T_G, the resulting reduction in subgrade stress and deformation provides an increase in tamping cycle duration. The contribution of ballast and subballast settlement to track deformation and roughness have also been accounted for in Exhibit 5.

As more field data is collected from CPT work, this relationship will be refined and modified. For now, however, it is offered as a method to determine the potential benefit of tamping, or to show that another maintenance technique may be more economical than continued tamping.

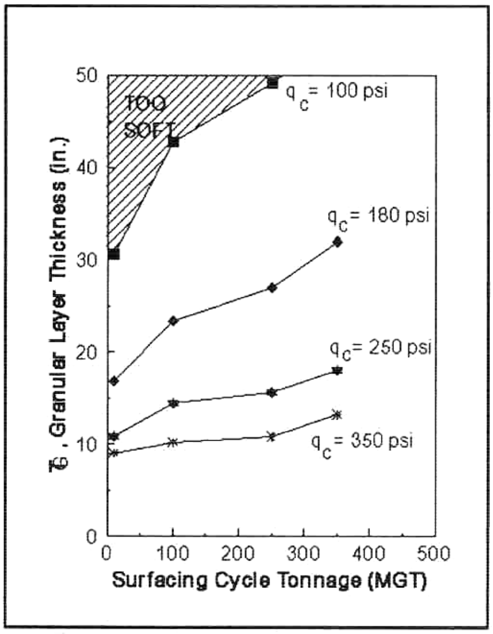

Exhibit 5. CPT Data used to Predict Tamping Frequency

Part of a Substructure Investigation

The CPT is most powerful when it is combined with other techniques to determine the cause of the track instability. A full investigation involves reviewing track geometry records, track super- and substructure inspection, and sampling and evaluating substructure layers. With the findings, the most cost effective remedy can be selected based on life cycle costing.

Reference

1. Ebersöhn, Willem, Ernest T. Selig. "Evaluation of Substructure Using Field Test." Geotechnical Report No. AAR95-429F, Dept. of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA June 1995 unpublished.

Note: Contact Steven Chrismer at (719) 584-0590 with questions or comments about this document.

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