"HAL Substructure Investigation Using Rapid, Non-Destructive Techniques,"

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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, non-destructive subgrade test apparatus known as a cone penetrometer. Although still in the planning stage, another rapid, non-destructive diagnostic tool being developed is a moving vehicle which continuously measures track deflections under load.

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 asses the potential 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.

Deflection data can determine whether the problem resides in the ballast/subballast (granular layer) or in the subgrade. The running deflection measurements can first be used over long track distances to identify whether the problems are granular or subgrade related. Then, for locations with apparent subgrade problems, the CPT can be called in for a more detailed assessment. The deflection and CPT data are also used to decide when and whether more intrusive techniques (such as cross-trenching) are needed to further identify the problem.

INTRODUCTION AND CONCLUSIONS

As part of a program to determine the nature of track substructure problems and recommend the best remedial action, the AAR has developed an on-track vehicle which houses a rapid, nondestructive subgrade test apparatus known as a cone penetrometer. Work is also progressing on a vehicle designed to determine track maintenance needs by measuring vertical track deflection.

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. While the cone penetrometer test (CPT) vehicle provides such a tool mainly for the subgrade, the track deflection-measuring vehicle will further assist the engineer to distinguish between ballast/subballast, and subgrade failure. With these results, the most appropriate maintenance technique can be selected which not only addresses the symptoms of track roughness, but also the cause.

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. However, 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, which requires information on the substructure, can often be achieved by addressing the underlying cause.

With the track-mobile CPT vehicle (Figure 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 a given solution. Subgrade is evaluated by measuring the pressure or resistance against a cone that is pushed through the track substructure in the zones shown. The vehicle weight, approximately 30,000 pounds, is used as the reaction mass while the cone is advanced using a hydraulic push frame mounted inside the vehicle. The frame can be moved laterally to position the cone between the rails.

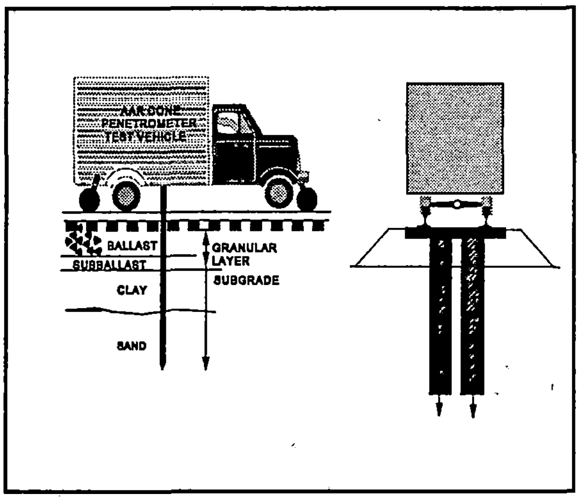


Figure 1. CPT Vehicle and Probing Locations

Figure 2 offers an example of how the CPT results can provide a unique insight into the cause of track instability. Although the track surface was rough, the cause of the instability was not apparent from outward appearance. The ballast surface was clean and seemed to be relatively thick. However, the tip resistance measurements illustrate that the clean ballast layer is very thin with a soft layer just under the ties. Excavations in the track revealed that the clay had pumped up from the subgrade, migrated through the ballast voids, and mixed with the ballast just under the ties.

CPT data can be used to determine the likelihood of the two most prevalent soft subgrade failure modes of progressive shear and excessive plastic deformation. Progressive shear is shown in Figure 3a 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.

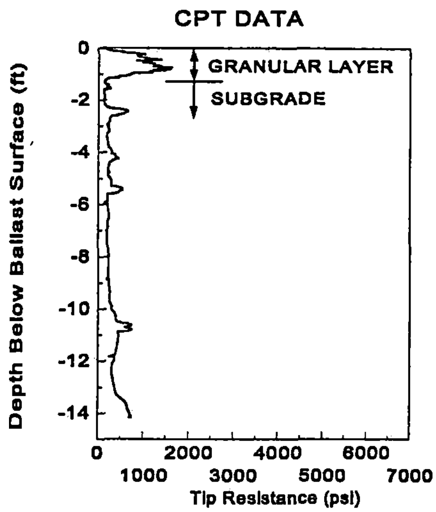
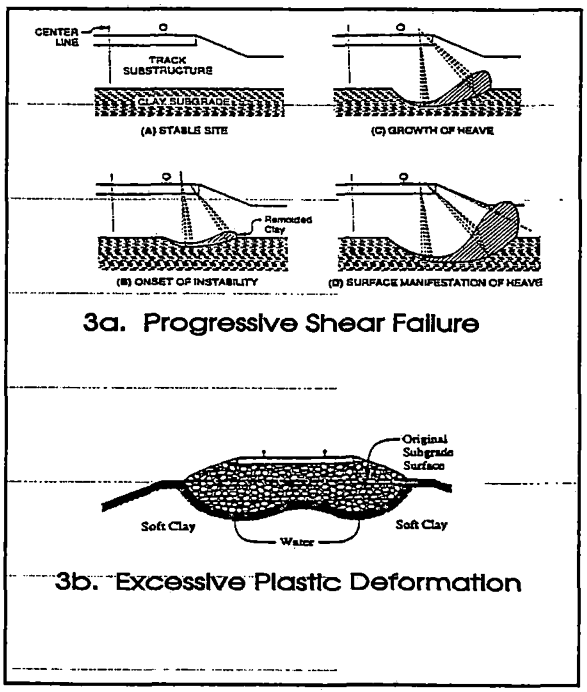


Figure 2. CPT Profile Over Weak Track



3a. Progressive Shear Failure

3b. Excessive Plastic Deformation

Figure 3a and 3b. "Soft" Subgrade Failure Modes

Whereas progressive shear is concentrated in the upper few feet of subgrade, excessive plastic deformation (Figure 3b) can result from soil strain over a considerable depth. Analyses with the GEOTRACK model, a three-dimensional, multi-layer model to predict the elastic response of the track structure, 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 should be able to penetrate to this depth. It is not necessary to determine if the soft subgrade extends beyond this depth or if a harder layer is just beyond, because neither resilient or permanent strain are significantly affected.

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, as shown in Figure 4. This relationship was determined from four investigations with widely varying track super- and substructure conditions. With an estimate of subgrade modulus from this correlation, models such as GEOTRACK can be used to estimate the track deflection and modulus.

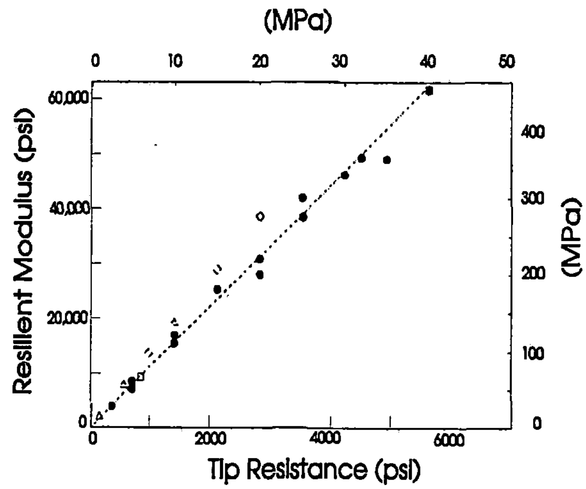


Figure 4. Tip Resistance and Resilient Modulus Relationship

Placing hot mix asphalt (HMA) between the ballast and subgrade is sometimes used to reduce the stresses on the underlying weaker materials. 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 subgrade. The CPT may be used to first determine if such a weaker layer is present and within this distance.

MAKING THE RIGHT TRACK MAINTENANCE CHOICE

Distinguishing Between Ballast and Subgrade Failure

Track deflection under load is a good indicator of substructure support and how it changes along the track. Figures 5a and 5b shows the deflections from both a small seating load used to close the voids between the tie bottom and the ballast, and a larger "total" load. The difference between these two deflections is called the contact deflection because the tie is assumed to be in full contact with the ballast. This contact deflection is primarily the elastic deflection of the substructure layers, and therefore indicates the support stiffness and its variance along the track.

In Figures 5a and 5b, the track, which, in both examples, is rough and in need of maintenance, shows considerable variation in support conditions. What is not immediately clear is the extent to which the problem is in the ballast or the subgrade. As a later investigation would show, the maintenance problems at these two sites are from two distinct failure conditions (in the ballast and in the subgrade respectively) and require very different maintenance remedies. However, this could have been determined by reviewing the deflection data in the manner shown below.

The track failure in Figure 5a is caused by a heavily fouled ballast. As the plots suggest, changing deflections are due mainly to variations in voids under the tie with the tie seating loads (variations in tie-ballast support) and not from the contact deflection. Data indicates that the contact load deflection, which is primarily indicative of subgrade conditions, was fairly firm and only gradually varying at this site.

On the other hand, because the track in Figure 5b had relatively large variations in contact load deflections, subgrade strength variation is the foremost problem to be addressed. Variations in seating and total load deflections resulted primarily from non-uniform subgrade support, and were not due to the ballast. This was confirmed by excavations which showed that the subgrade was failing at different rates at various locations due to strength variability.

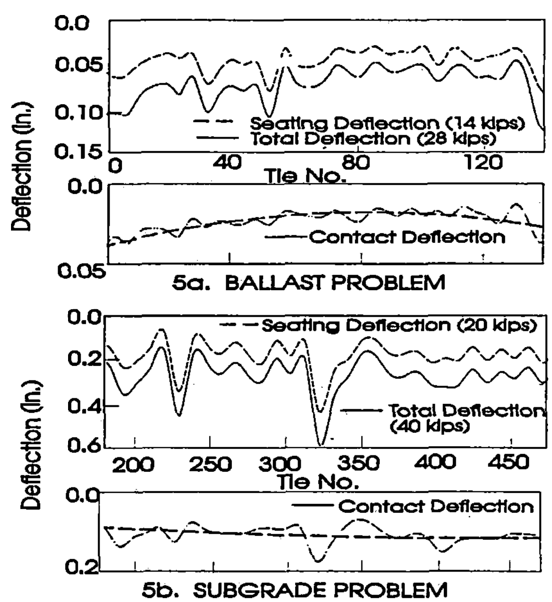


Figure 5. Determining Maintenance Needs From Track Deflection Data

To Tamp, or Not to Tamp

Raising the track and tamping more ballast under the ties is often used 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 Li and Selig were used to obtain the relationship shown in Figure 6.

To define the relationship and obtain the curves shown, the granular design model was used to determine the ballast depth required for varying subgrade strength values. Certain combinations of ballast depth and subgrade strength gave the same amount of predicted subgrade strain. This equivalent strain is interpreted as equivalent tamping cycles and provides the contour lines shown in Figure 6.

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.

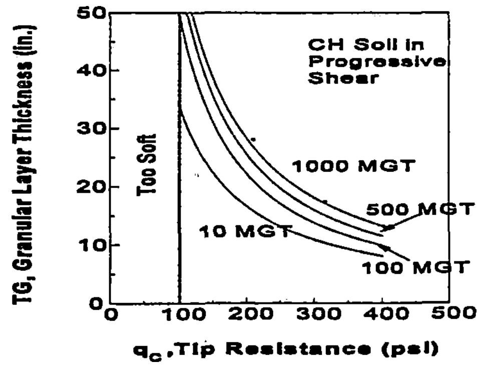


Figure 6. CPT Data Used to Predict Maintenance Frequency