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# In-Motion Vertical Track Stiffness Measurements with the Track Loading Vehicle

by Steven Chrismer and William Shust


## Summary

Researchers for the Association of American Railroads (AAR), now part of AAR's subsidiary, the Transportation Technology Center, Inc., have configured the Track Loading Vehicle (TLV) to help railroads locate sources of track-support instability and select appropriate maintenance techniques. The TLV measures in-motion vertical rail deflection continuously along the track using light and heavy loads. By identifying areas of weak support, railroads can pinpoint locations where an increased investigative effort — such as cross trenching or probing at depth — should be placed.

Tests performed with the TLV at the Federal Railroad Administration's Transportation Technology Center in the fall of 1997 showed that this method was successful in identifying the location and source of variability in support stiffness in a limited test sample. At one location the data showed that a large deflection was caused by large voids between the ties and ballast, whereas the contribution of the subgrade to the track deflection was relatively small. Tamping is an appropriate maintenance method for such a case. In another location the data showed evidence of the reverse situation where an abnormally large deflection was caused by a zone of very soft subgrade, while the void between ballast and tie was small. For this condition, the locally weak subgrade should be addressed directly by improving drainage, reducing the subgrade stress, increasing the subgrade strength, or other method which is deemed most appropriate based on a more-thorough investigation. Tamping is likely to be ineffective when the primary source of the instability is a weak and deforming subgrade.

Although the initial results seem to indicate that the TLV can provide useful information on substructure support condition and maintenance needs, more work is needed to verify these results under revenue-track conditions. One particularly useful development currently being devised is a system which will provide a one-pass method, rather than the multiple passes currently needed to measure deflection under the three load levels. Testing on AAR member railroads is scheduled to begin in 1998.


**Suggested Distribution:**
- o Maintenance of Way
- o Planning & Analysis
- o Track Maintenance
- o Maintenance Planning


Work performed by TTCI Transportation Technology Center, Inc.

a subsidiary of the Association of American Railroads

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## INTRODUCTION AND CONCLUSIONS

The Association of American Railroads' (AAR) Track Loading Vehicle (TLV) has been modified to provide a continuous, in-motion measurement of track vertical stiffness, and its variability along the track, in order to help railroads locate possible areas of instabilities and select appropriate maintenance techniques. It has been shown that with proper selection of loads and data interpretation, it is possible to determine the severity and cause of variations of support along the track. This information allows the engineer to select a maintenance method or remedy based on the nature of the problem.

## VERTICAL SUPPORT VARIABILITY

Both the track stiffness value and the variation of this stiffness along the track are of interest. A singular value of track stiffness representing an average over a section of track can be used to portray the general support condition, and provide the basis for design of track components. However, the amount of variability of support stiffness along the track indicates the rate at which uneven settlement and excessive roughness can develop. In addition, the data can be used to determine the source of the differential settlement, which in turn can provide a basis for selection of an appropriate maintenance technique.

Changes in vertical support along the track come from two fundamental sources:

- Varying slack or voids between rail and tie, and between tie and ballast
- Changes in stiffness of the substructure layers (primarily the subgrade).

By applying a relatively small seating load to the rail, the resulting seating deflection can indicate the amount of void. With a larger load applied at the same point, the difference between the resulting deflection and that produced by the seating load (this difference being referred to as the "contact" deflection because the slack has been removed) is primarily due to the deflection of the subgrade. These two types of deflection — seating and contact — can provide an indication of the source of the instability (track superstructure, granular layer, or subgrade) and, therefore, help to identify which of these track components should be addressed by maintenance.

For example, if contact deflection is found to be relatively stiff and constant along the track, but the tie-ballast support is not, then tamping may be the best choice, as this provides a more-uniform tie-ballast support. If the opposite is found this may indicate that the likely problem is in the substructure and that a more in-depth look at this is warranted to determine the appropriate maintenance (i.e., removing excess water which has access to the subgrade, reducing the stresses imposed on the substructure and/or increasing the substructure strength and stiffness).

## TLV VERTICAL TRACK STRENGTH MEASUREMENT SYSTEM

Exhibit 1 shows the basic configuration of the TLV. The loads may be applied to the track by varying the axle load of the middle bogie and making three passes to obtain the "zero load" reference rail position, the seating deflection, and the maximum load deflection. Alternatively, to allow the data to be obtained in one pass, an improved system is being developed using lasers to simultaneously measure the vertical deflections of the rail under the seating load of the bogie and under maximum load provided by one of the truck wheels.

The load-deflection curve can be represented as a bi-linear plot as in Exhibit 1 with the seating stiffness or modulus obtained from the lower part of

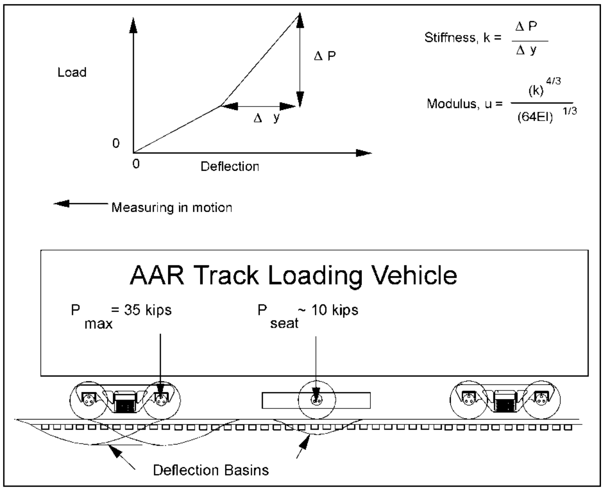


**Exhibit 1. Basic Configuration of Track Loading Vehicle**

the curve, and the contact stiffness or modulus taken from the upper portion. Typically, track modulus is associated with this upper portion as shown, with the effect of the track voids or slack removed.

The predicted basin deflections shown indicate that the basin from one wheel of the truck should not significantly affect the measured deflection under the center of the adjacent wheel for the soft track conditions assumed. Therefore it appears that there should be minimal error in assuming that the 35-kip load acts as an isolated wheel load as required for the stiffness and modulus equations in Exhibit 1.

## TESTING AT FAST

Though most of the subgrade under the test track at the Facility for Accelerated Service Testing (FAST) is relatively stiff, the 600-foot low-track-modulus (LTM) test section with a 5-foot-thick clay layer was used to test the capability of the TLV vertical-deflection measurement system under soft track conditions. This was accomplished using rail-contacting Linear Variable Differential Transformers (LVDTs). Different vertical loads were applied with the test bogie, and the TLV vertical actuators were used to measure the deflection. Although the installation of a laser system should provide more efficient measurements, these preliminary measurements were useful to show the capabilities and limitations of the TLV to measure vertical track deflections.

Three runs were performed at each vertical wheel-load level of 1, 15, and 35 kips to provide a check on the system repeatability. Exhibit 2 shows the "seating-load" and "full-load" deflections obtained over this track section. The contact deflection is obtained by subtracting the full-load deflection from the seating-load deflection.

Further testing with different load levels will help determine the optimal seating load. This seating load must be large enough to remove the slack, yet not be too close to the full load so that a significant amount of subgrade compression results from the seating- to full-load increment (contact deflection). A too-small contact deflection may not be sufficiently sensitive to changes in subgrade stiffness. Also, because the track stiffness calculated from the contact deflection can be very sensitive to the selected lower and upper load values, the chosen seating and full loads will be held constant for all future TLV tests.

## RESULTS AND ANALYSIS

The full deflection data in the soft-subgrade section (Exhibit 2) shows a considerable degree of support variation but, by itself, does not indicate its source. A review of the seating and contact deflection data shows that variations in subgrade stiffness dominate at some locations, while at others the voids between tie bottom and ballast produce most of the support variation. Selig and Ebersohn[1] have shown how seating and contact deflection indicate either support deficiencies from the ballast/tie interface, or from the subgrade, respectively.

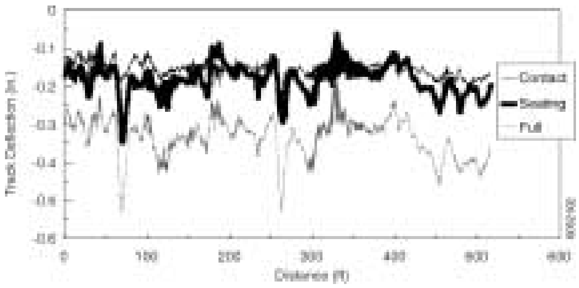


**Exhibit 2. Seating-Load and Full-Load Deflections Obtained in Low-Test-Modulus Section at FAST**

One track area in which excessive deflection is thought to be due to a void is at the 70-foot location. This is indicated by the large dip in seating deflection but nominal value for contact deflection. This is the area where the subgrade changes abruptly to clay from the native silty sand. A visual inspection of the track at this location revealed large rail-to-tie, and tie-to-ballast gaps (hanging ties) in the immediate vicinity. Furthermore, instrumented cone penetrometer test (CPT) probes used to measure the subgrade stiffness/strength in this location verified that the subgrade is not excessively soft in this location. Therefore, tamping appears to be an appropriate maintenance choice at this spot.

On the other hand, the subgrade is a major contributor to the track deflection at the 260-foot location. The CPT measurement indicates that the subgrade is locally very soft compared to the adjacent soil. Therefore tamping will probably be less effective here.

Tests were also performed at FAST on track over the natural, relatively stiff, sandy subgrade. Exhibit 3 shows the varying contact deflection over this section and the average track modulus over the respective tie sections. Although, as mentioned, the contact deflection is primarily dependent on subgrade stiffness, tie compressibility can also affect the measure. The effect of tie-material stiffness is shown by the greatest moduli in the concrete-tie section, the lowest in the soft composite-tie (compressed wood chips and glue) section, and intermediate modulus values in the wood-tie section.

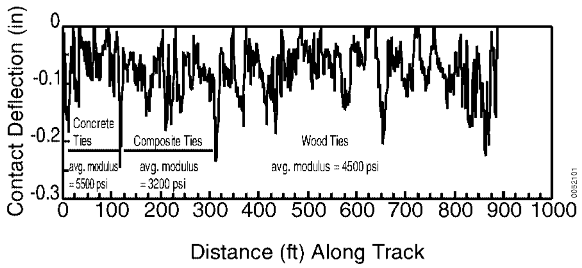


**Exhibit 3. Contact Deflection over Natural, Stiff, Sandy Subgrade and Respective Tie Sections**

These preliminary tests and resulting data are encouraging because it is shown that the weak spots can be easily identified and, with proper interpretation of the data, the underlying cause is also identifiable. With a better system provided by the laser instrumentation, the increased reliability and accuracy should allow easier location and classification of track substructure problems.

## FUTURE WORK

As the TLV deflection measurement system is further developed, it may be possible to extend the testing to include the collection, interpretation, and analysis of basin-deflection data. The basin-deflection shape can provide information on the layering and contribution of soil layers at considerable depth. Selig and Ebersohn[1] have shown that the presence of a relatively stiff subgrade layer at a depth of 20 feet under the top of subgrade can be detected by its effect on the basin shape. The basin deflection may provide a more-accurate picture of the support condition than does the deflection measured only under the wheel as obtained with the current TLV configuration.

Also, track-deflection measurements are planned for other track features such as the stiffness transition at bridge abutments, road crossings, and special track work. This work can provide information on the amount of change in track stiffness at these locations and determine the effectiveness of various means applied to produce a smoother transition.

## TESTING ON REVENUE TRACK

In 1998 revenue test sites will be investigated with TLV vertical-stiffness measurements. A preliminary investigation of the track section on the railroad sites will provide information on track geometry, identification of track superstructure features and their location, and follow-up investigations with the CPT, and perhaps cross trenching, where appropriate.

## REFERENCE

1. W. Ebersohn, and E. Selig, AAR Report # LA-009, “Evaluation of Substructure Using Field Tests,” December, 1996.

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