

Measurement of Bridge Response Using AAR's Track Loading Vehicle (TLV)

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TD92-009

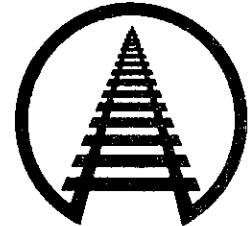
Summary

This digest presents the results and conclusions from a series of bridge tests conducted using the AAR's Track Loading Vehicle (TLV). The results indicate that the TLV can be used as a bridge testing machine in the study of stresses in bridge members under heavy axle loads. An experimental load distribution diagram (influence line) for any selected bridge member can be obtained by using the TLV load configuration, leading to an assessment of the actual load distribution among various members.

In general, the test findings suggest that a significant difference can exist between the theoretically calculated stresses and those measured during the test - actual measured stresses are often lower. It is believed that this discrepancy is due largely to the semi-rigidity of the actual truss connections. Analytical techniques treat these as freely rotating members when stresses are calculated. This allows freer redistribution of the applied loads through the structure in the analysis than exist in reality.

The test results also show that structural mode shapes, natural frequencies and damping can be measured by using the TLV. This provides more accurate prediction of dynamic responses of bridge structures than previously available. Furthermore, the TLV's capability to provide controlled excitation of a bridge can be used to support structural inspections to detect damage by vibration monitoring.

The TLV bridge tests were conducted in June 1991 on the Big Creek Through Truss Bridge on the Norfolk Southern Railway in Tennessee. The primary objective of these tests was to determine the utility of the TLV as a bridge testing machine under heavy axle loads. The bridge structure had already been instrumented for the measurement of load and stresses in critical members under revenue traffic. Using the TLV, response of the bridge to statically applied loads was measured at various panel points on the bridge. The dynamic characteristics of the bridge were investigated by exciting the structure at frequencies up to 15 Hertz.



Association of American Railroads
Research and Test Department



INTRODUCTION AND CONCLUSIONS

The dynamics of railroad bridges excited by the action of moving trains has been of great interest since the turn of the century. Although there are no known cases of catastrophic bridge failure due to traffic induced vibrations, there have been numerous examples of detected fatigue damage to bridge components due to cyclic loading induced by the passage of vehicles. Recent developments in structural analysis techniques make it possible for bridge engineers to calculate this dynamic behavior. There have, however, been relatively few correlations between these analyses and full-scale measurements. Response to moving traffic has been measured for different types of bridges, but there are only a few cases of theoretical studies of the natural frequency and damping behavior of railway bridges.

A bridge structure is subjected to a series of vertical and lateral load pulses as each axle of a train passes. Excitation frequencies resulting from these pulses depend on the wheel base and truck spacing and increase with speed from zero to about 20 Hertz at 60 mph. Moreover, higher frequency dynamic response can be excited by discrete track irregularities and by wheel tread surface anomalies. This type of cyclic loading can excite a bridge resonance when the driving frequency coincides with one of the bridge's natural frequencies, producing larger displacements and loads than produced under static loads.

To further enhance the understanding of dynamic response of bridge structures, a research program was initiated in 1991 under the joint auspices of the Association of American Railroads (AAR) and the National Science Foundation (NSF). The TLV participation in this program was jointly funded by the Federal Railroad Administration and the AAR.

The Big Creek Bridge, already instrumented in conjunction with AAR's Bridge Research Program

was used to demonstrate the bridge testing capabilities of the TLV under controlled loads. As emphasis was on the use of the TLV as a bridge loading device, rather than a comprehensive bridge analysis, only axial response of the bridge members was investigated in this study.

The following conclusions were made from the results of full-scale bridge testing using the TLV:

- The TLV provides a controlled method of testing of railroad bridges to determine overloading and identification of defective members.
- The use of the TLV provides a means to synthesize the effect of various loads on a bridge and to determine the load distribution among bridge components.
- Vibration testing of a bridge by using the TLV proved to be a very powerful capability to identify the natural frequencies leading to the estimation of mechanical properties of the bridge structure. Values of damping measured by the TLV can be used for calculation of structural response of bridges to transient and cyclic forces induced by the passage of vehicles.
- The TLV, or a similar device capable of applying dynamic loads, can be used in bridge inspections to locate damaged members and structural deterioration.
- The TLV is capable of conducting a wider range of static and dynamic tests on short span bridges which could be straddled by the TLV trucks and loaded solely by the centrally located load bogie.

TLV BRIDGE TESTS

Exhibit 1 shows a photo of the TLV and the bridge structure used during the testing. The load distribution among various members of the truss structure, shown in Exhibit 2, illustrates the differences between the test (shown in parentheses) and the theoretical results obtained by using analysis data. It should be noted that



these results are load position specific, and that they greatly depend on the degree of isolation of axial strains from other influences such as bending.

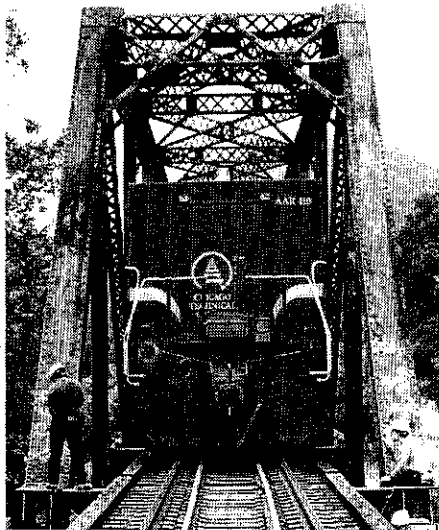


Exhibit 1. TLV and the Through Truss Bridge.

It should be noted that limitations are imposed on the testing due to the TLV truck centers (47 feet) being shorter than the total length (156 feet) of the bridge. As a result, the bridge structure sees loading from both the TLV load bogie and from other axles of the TLV and other vehicles resting on the bridge. In order to account for this influence, tests were run with and without the bogie applied loads. Subsequent subtraction of the corresponding bridge loads eliminated the effect of the other vehicles in the consist.

Exhibit 3 shows a comparison between the predicted and measured values of the distribution of maximum axial loads in various bridge members. Influence lines were derived for each bridge member for a special loading case involving a bogie load of 33,000 pounds and corresponding unloading on the TLV trucks. As seen in this exhibit, the actual load carried by the bridge components appears to be somewhat less than that predicted by theoretical methods.

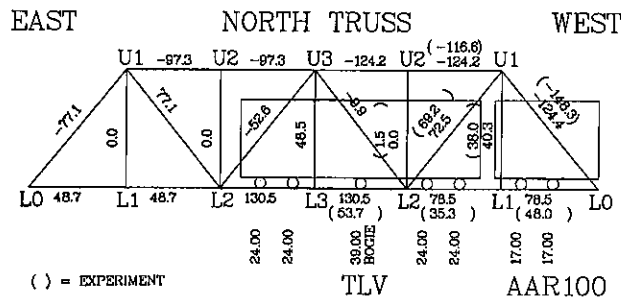


Exhibit 2. Comparison between Measured and Predicted Static Axial Load.

It is apparent from this exhibit that the axial loads in the top chord, hangers, diagonals, and in the end post are quite close between test and the theory. In the bottom chord, however, the test results are substantially lower than those given by theory. It appears that such a difference could occur due partly to the framing action of the floor system and to semi-rigid connections.

The TLV provides the capability for testing a bridge structure under controlled dynamic loads at various frequencies using full scale components in a manner not previously possible. This capability was demonstrated in a series of forced vibration tests to determine the mode shape and fundamental frequencies of the bridge structure.

The dynamic characteristics were investigated by exciting the bridge at different frequencies so that time histories of strains in various components could be determined. Sinusoidally varying loads of 15 +/- 5 kips were applied at mid point of center span at discrete frequencies from 0.5 to 15 Hz in 0.5 Hz increments to capture the resonant peaks corresponding to natural frequencies of the structure. The frequency versus peak amplitude of axial hanger load (Exhibit 4) clearly illustrates the resonant peaks near 3, 7, and 13 Hz. When the frequency of excitation coincides with one of the natural frequencies of the system, including the TLV, resonance accompanied by large



amplitude vibrations occurs.

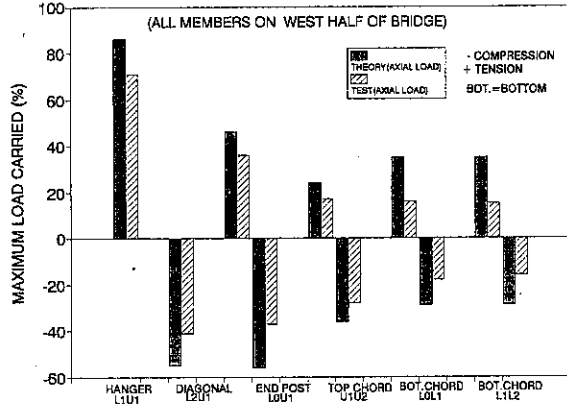


Exhibit 3. Axial Load Distribution Among Bridge Members due to TLV Loading Only.

Natural frequencies and percentage critical damping values for the first three bending modes of the bridge structure are shown in Exhibit 5. This table also shows the dependence of amplitude of vibration on the frequency mode and the location of the bridge component. The dynamic load factors were computed as a ratio of maximum dynamic to static vibration amplitude at each frequency.

Although the structural and frictional damping in truss joints and bearings limits the vibration amplitudes during resonance, the failure of major bridge structures under resonance is a low probability but the consequences of such a failure could be catastrophic. Thus, the knowledge of natural frequencies and damping values of bridge structures is of major importance to bridge designers and analysts.

Note: Contact Semih F. Kalay at (312) 808-5842 with questions or comments about this document.

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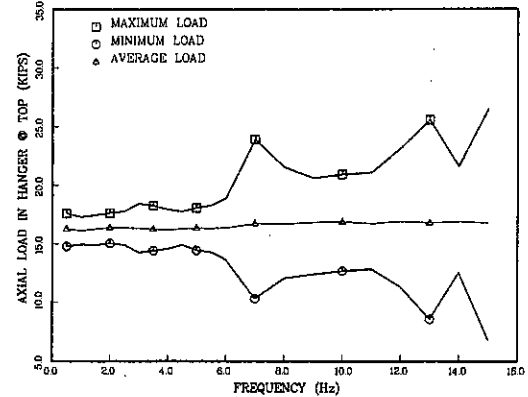


Exhibit 4. Maximum Vibration Amplitude vs. Frequency.

Furthermore, measurement of mode shapes and natural frequencies can be used to estimate the mass and stiffness properties of bridge structures. This information can be compared to expected mass and stiffness values based on design drawings. Deterioration of a structure would manifest itself as discrepancies between measured and design values guiding the inspection of the structure

MODE NUMBER	FREQ. Hz	DAMPING RATIO		DYNAMIC LOAD FACTOR	
		HANGER	TOP CHORD	HANGER	TOP CHORD
1ST BENDING	3.0	0.0649	0.0137	1.129	1.126
2ND BENDING	7.0	0.0208	0.0081	1.432	1.217
3RD BENDING	13.0	0.0172	0.0364	1.523	1.045

Exhibit 5. Measured Bridge Frequency and Damping Values.