11-2004

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Publisher's Statement

Original Citation

Siswobusono, P., Chen, S. -., Jones, S., Callahan, D., Grimes, T., and Delatte, N. (2004). "SERVICEABILITY-BASED DYNAMIC LOAD RATING OF A LT20 BRIDGE." Exp Tech, 28(6), 33-36.

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SERVICEABILITY-BASED DYNAMIC LOAD RATING OF A LT20 BRIDGE

County LT20 (Less Than 20 ft) bridges are bridges with span lengths less than 20 feet. Considered minor structures, these bridges are not included in the National Bridge Inventory System (NBIS); hence, they do not usually receive the benefits of federally-mandated bridge evaluations. As a result, these bridges are rated using analytical procedures based on observations made during visual inspections, and are almost never load tested.[3] Ambient excitation has been suggested to nondestructively estimate the remaining load capacity of these bridges for rating purposes.[1,2] To determine the accuracy of the load capacity prediction, a two-lane concrete deck steel girder bridge is studied using measured modal characteristics and static load test results. In particular, the aim of this paper is to confirm the dynamic load test results through static load testing. The ultimate goal of this research effort is to extend the technique to ambient traffic vibration.

DYNAMIC LOAD RATING

The proposed dynamic load rating technique assumes the bridge as a loaded spring (Fig. 1), where the global stiffness of the bridge is analogous to a spring constant, k. When a vehicle passes over the bridge, it exerts a load P, causing the bridge to deflect δ. When linear elastic conditions are assumed, the load P on the bridge is then equal to $\delta * k$. Using serviceability limit deflection, a decrease in global stiffness obviously denotes a decrease in the bridge's overall load capacity.

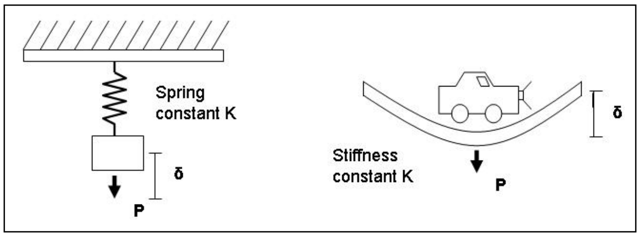

Fig. 1: Single-degree-of-freedom model

Measuring the vibrations under ambient conditions, the bridge's fundamental vibration frequency, f, can be determined as a function of its mass and stiffness:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{1}$$

By measuring the fundamental vibration frequency periodically, the change in frequency, can determine the change in global stiffness. Assuming no significant mass change, the remaining global stiffness of the bridge k', can be determined directly from measured vibration frequency, f':

$$k' = 4\pi^2 m f'^2 \tag{2}$$

The remaining load capacity, P', can be then determined if the deflection is maintained as a constant such as by using the AASHTO (American Association of State Highway and Transportation Officials) deflection limits $\delta_{allowable}$:

$$P' = \delta_{allowable} \cdot k' \tag{3}$$

This new limiting load P' can also be used to determine the amount of load reduction ΔP from the maximum load, P:

$$\Delta P = P - P' \tag{4}$$

Several assumptions are made in this simple model including: 1) the vehicle load is directly applied to top of the bridge (as contrasted to a moving load along the bridge span); 2) the bridge only vibrates in a single mode; 3) the bridge support conditions do not change significantly; and 4) all girders deform by the same amount. These assumptions may limit the application of the method to single span, short bridges with limited vehicle type crossings, considering the effects of vehicle mass, speed and multi-vehicle loads. More critically, by limiting the bridge behavior to a single mode of vibration, modal testing is required to identify the most significant vibration mode. Ideally, the significant mode is also the fundamental mode.

Figure 2 shows the schematic of the proposed algorithm. The baseline frequency values (initial frequency) for the existing structure should be determined first; this determination can be accomplished by conducting a full-scale modal test on the bridge. The captured signal is first transformed into the frequency domain and used to determine the dominant mode. It should be cautioned that significant signal processing might be required to ensure the capture of the dominant mode. By comparing the existing dominant frequency with the undamaged frequency of interest, the frequency shift caused by likely

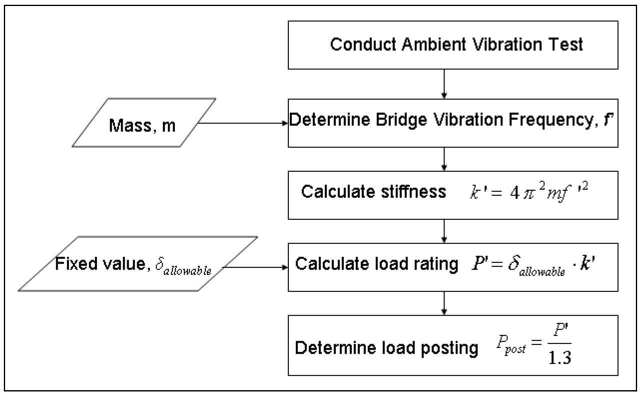

Fig. 2: Flowchart of the bridge dynamic load-rating method

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bridge damage can be obtained. Assuming the bridge did not lose significant weight (<10%), the drop in stiffness can then be determined. The original weight of the bridge can be estimated from the material supplier's data and the original design drawings. The change in stiffness would then be used to determine the remaining capacity of the bridge with a pre-established maximum deflection requirement. This remaining capacity can then be used to re-evaluate the existing load posting.

It should be noted that there are several factors that may impact on the vibration behaviors of a bridge, i.e. temperature effect and change of support conditions, etc. These conditions pose serious limitations to the current proposed method and need further investigations. Support conditions such as excessive settlements of bridge piers may cause frequency shifts either by allowing rotation, imposing moment or resulting in nonlinear behaviors. Temperature effects are known to influence on the transducer and cable behaviors, hence, may limit the potential of permanent sensor installation. However, innovative approaches, such as limiting the time and seasons for bridge monitoring may be imposed to ensure the validity of the test results.

COUNTY BRIDGE NO. 020-59-202Z

The proposed technique was first tested on an existing bridge. The test bridge (Bridge No. 020-59-202Z) is located in southern Shelby County on Shelby County Road 20 (Fig. 3). The bridge has a clear span of 18 ft 3 in. The deck is composed of 5-in. reinforced concrete. Over the existing asphalt pavement is a 16-in.-thick soil aggregate (chert) base and a 1.5-in.-thick bituminous concrete wearing surface. The bridge has standard flex beam guardrails and the girders are steel S12 × 31.8 sections. The bridge was constructed in 1959 with 5 girders spaced at 58 in. on center. The bridge is skewed at a 20° angle perpendicular to the roadway centerline. Figure 4 shows a detailed schematic drawing of the test bridge. Load ratings calculated by the ALDOT Bridge Rating Section using Allowable Stress Design (ASD) method resulted in the posting of maximum allowable traffic loads for different vehicle types on the bridge (Fig. 5). Current load posting for AASHTO H15 truck is about 6 tons. Load capacity based on AASHTO load rating technique shows a 7.231 ton rating for this bridge.

Fig. 3: Shelby county bridge no. 020-59-202Z

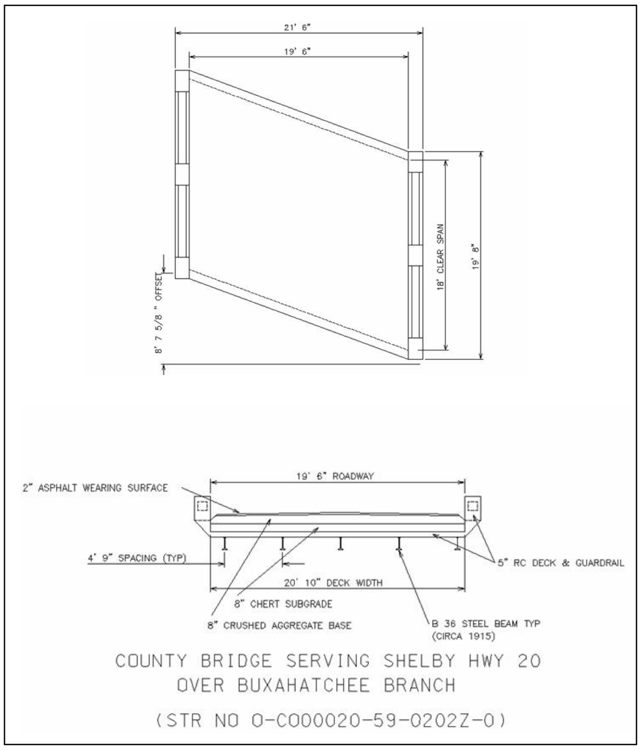

Fig. 4: Schematic details of test bridge

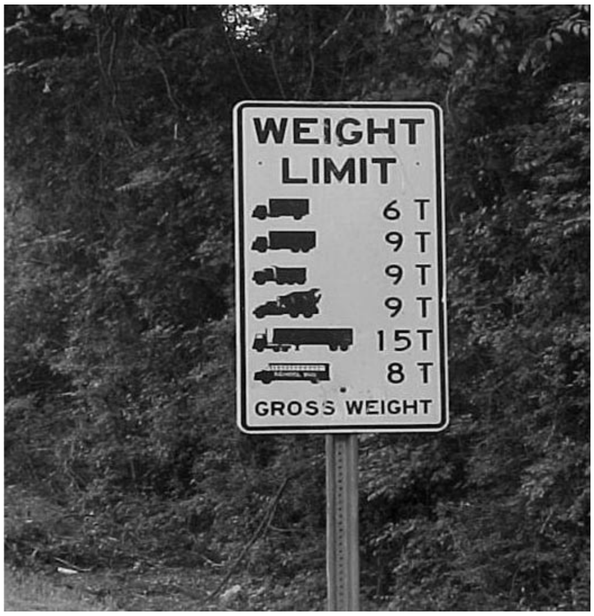

Fig. 5: Current posted load limits for bridge no. 020-59-202Z

DYNAMIC LOAD TEST

Full-scale modal testing was conducted on the bridge using impact excitation and single accelerometer measurements. Impact excitation was done using an instrumented 20-lb sledgehammer. The vibration responses were detected using a single seismic piezoelectric accelerometer (PCB Piezotronics) with a magnetic base placed at the center of the outermost girder. The signals were collected using a 12-channel

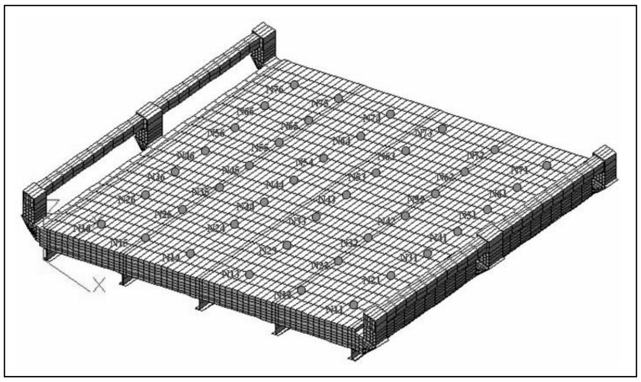

Fig. 6: **Impact grid for modal testing**

data acquisition system (DAQ) (Wavebook/513 IOtech, 12-bit MHz Data Acquisition System). A 4-channel ICP Sensor Signal Conditioner (PCB) was used to enhance the signals. A grid of 42 nodes was laid out on the bridge (Fig. 6), which was struck individually with the sledgehammer. Each node, depicted as node N_{xy} at point (x,y), was excited five times using a sampling frequency between 500 to 1000 Hz. The frequency of the first bending mode of the bridge was determined to be 18 Hz.

Ambient traffic excitation testing was then conducted[1] to study the effects of different vehicles traveling on the bridge, which include varied vehicle axle spacing, weights and speeds. By monitoring the excitation of the bridge during regular traffic, the mean measured fundamental mode frequency was found to be 18.1 Hz. The measured vibration frequency was then used to back-calculate the load capacity using the process outlined in the flowchart of Fig. 2. Using the AASHTO serviceability deflection limit, δ_{limit}, of span/800 (0.0256 in), would result in a load capacity of 27,586 lb (12.498 ton). This load capacity is significantly greater than the current posted load limit of 6 ton.

STATIC LOAD TESTS

Static load testing was conducted in order to validate the dynamic load test results. For the selected bridge, 9 dial gages were set up below the outermost and middle girders to measure deflection. Each dial gage was clamped to an aluminum rod of a specific height, which was secured to a concrete base. A 2-axle truck with an axle spacing of 12 feet and an empty gross weight of 15000 lb (6700 lb on front axle and 8400 lb on back axle) was used to load the bridge. The truck was loaded with aggregate up to the target gross weight on the back axle specified in Table 1. The truck was placed with the back wheels at the center of the bridge for each incremented weight. Figure 7 shows the position of the truck and dial gauge locations.

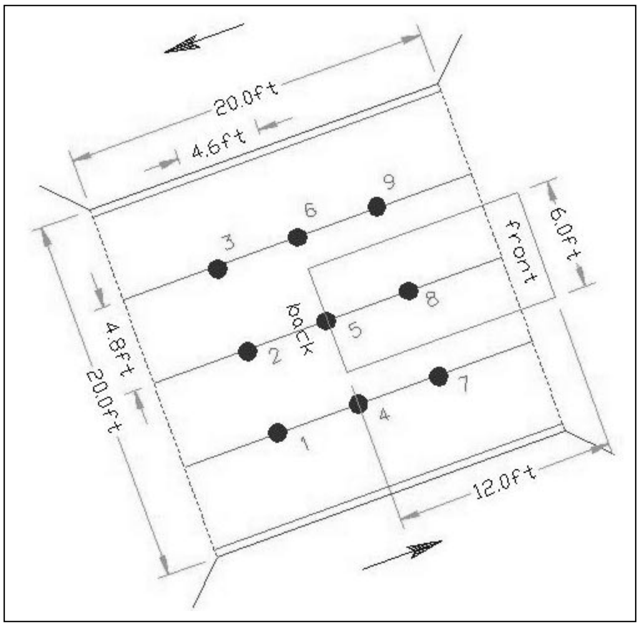

Fig. 7: **Static load test setup with position of truck load**

Deflection measurements of the bridge were calculated based on the dial gage readings taken for each loading. Since the proposed method assumed vehicles to be passing at the center of the bridge, average girder deflection recorded was used for comparison. Deflections are calculated based on stiffness computed from equations (2) and (3) using measured bending frequencies from the impact test and traffic excitation test, are tabulated in Table 1. Also shown in Table 1 are actual measured deflections from static load tests. Analyses show the deflection measured from the load test to be 30% different from the deflection determined from the traffic excitation test. From Fig. 8 it also shows that a linear relationship was depicted between the deflection and load up to 7 tons.

DISCUSSION

The target of this research is to provide highway engineers with a more rapid and accurate assessment tool for deter-

Table 1—Deflection measured from impact test, traffic excitation, and static load test

	DEFLECTION (in.)		
GROSS TRUCK WEIGHT ON BACK AXLE (lb)	CALCULATED FROM IMPACT EXCITATION TESTS	CALCULATED FROM TRAFFIC EXCITATION TESTS	MEASURED FROM STATIC LOAD TESTS
10,050	0.007	0.008	0.006
12,050	0.008	0.010	0.007
14,100	0.010	0.012	0.010

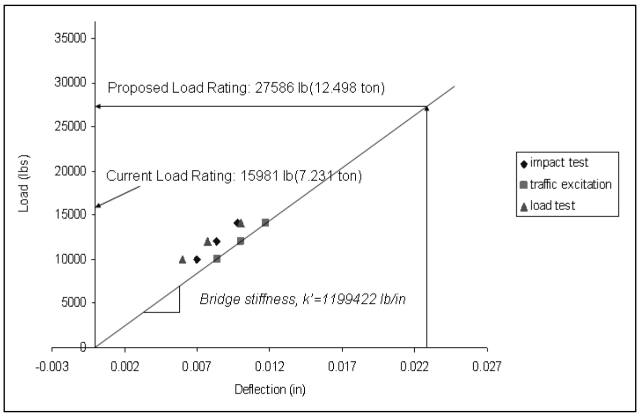

Fig. 8: Comparison of deflection measurements

mining load capacity of highway bridges. With a more accurate load rating, the management of the state's highway bridges can be improved. The proposed use of ambient vibration is hoped to minimize interruption to ongoing traffic and improves the safety of the bridge inspectors and the public.

The results of the current research show the potential of the proposed testing methodology, which is validated by the dynamic and static load tests on an actual bridge. For all practical purposes, the estimated deflections from the three tests (static load test, impact test and ambient traffic test) all fall in the same orders of magnitude with a statistical variation within 30%.

Although all bridges vibrate in multiple modes during ambient excitation, it is evident that this technique works best when the dominant mode is the first bending mode. To ensure only measurement of bending vibrations, the strategic placement of sensors is critical. The best result occurs when the vehicle is driving across the center of the bridge because no torsion modes are excited, which may not always happen.

Limitations of this proposed approach may include having *a priori* knowledge of the bridge's original condition and the change of condition in the course of bridge repair, such as the addition of future wearing surfaces, and the unreported changes of bridge condition done by contractors. If possible, traffic information (vehicle type, speed, direction of travel, and lane position) should be recorded. An automated measurement system such as a remote-sensing system is currently under investigation and development.

CONCLUSION

Dynamic testing was conducted on a selected short-span bridge to study the bridge's behavior and to determine the natural vibration frequencies of the bridge. Included in the dynamic testing were ambient traffic excitation and full-scale modal testing. By using a deflection limit, it is possible to establish the remaining load capacity of the bridge, which is valuable information for bridge engineers.

Based on the deflection measured from the static load test, the stiffness calculated from the proposed method seems to be a reasonable estimate of the actual bridge stiffness of 1,199,422 lb/in (Figure 7). The findings indicated that the method is a viable technique as a supplement for existing evaluation of those LT20 bridges by suggesting a service load capacity based on the measurement of global stiffness and allowable service deflection limits.

ACKNOWLEDGMENTS

This paper is based on research funded by the University Transportation Center for Alabama (project No. 01221) and the Alabama Department of Transportation (ALDOT No.525784). The writer would like to acknowledge Dr. Sreeneevas Alampalli, Dr. Mostafiz Chowdhury, C.K. Ong, Lei Zheng, Prithwish Biswas and Trey Gauntt, for their invaluable contribution to the project. The authors also appreciate the support from Mr. Fred Conway and Mr. George Connor from Alabama Department of Transportation for their support of the project.

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