Revista de la
Universidad Politécnica
de Puerto Rico

Publicado semestralmente por la Universidad Politécnica de Puerto Rico para difundir los hallazgos de la investigación científica que en ella se hace

VOL. 7 JUNIO 1997 NÚM. 1

Bridges under dynamic loads: comparison between finite element analysis and experimental results

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Abstract

AASHO Road Test performed experimental tests on bridges under dynamic and static truck loads. This paper shows a comparison between AASHO's tests and the analytical results of UPR-PAVI2, a computer program developed by the authors. This work is part of a study performed in order to validate the analytical results of UPR-PAVI2. We modeled the bridges using the published data of AASHO Tests and the UPR-PAVI2. The results obtained were very close to the field measurements. We discuss the importance of the different parameters involved in the dynamic bridge behavior. It was concluded that the UPR-PAVI2 computer program may be used for the structural analysis of bridges under dynamic or static truck loads.

Puentes sujetos a cargas dinámicas: comparación entre el análisis de elemento finito y pruebas experimentales

Sinopsis

"AASHO Road Test" desarrolló pruebas experimentales en puentes sujetos a cargas dinámicas y estáticas de camiones. Esta publicación muestra la comparación entre las pruebas de AASHO y los resultados analíticos del programa de computadora UPR-PAVI2. Con los datos publicados por "AASHO Road Test" se modelaron los puentes usando el programa UPR-PAVI2 y se obtuvieron resultados muy parecidos a los medidos en el campo. También se analiza y comenta la importancia de los diferentes parámetros involucrados en el comportamiento dinámico. En conclusión, el programa de computadora UPR-PAVI2 se puede usar para el análisis estructural de puentes sujetos a cargas dinámicas ó estáticas de camiones.

Introduction

Many bridge superstructures in Puerto Rico experience premature structural failures before the end of their projected service life. Such failures have been attributed to a combination of factors such as increases in traffic loads, changes in axle load configuration, effects of temperature gradient and use of inappropriate materials. As bridges are a major infrastructure expense, improving their durability in terms of long-term performance implies significant benefits to Puerto Rico's highway network.

It was found that the amplification factors used to take into account the dynamic nature of the load can be greater than those specified by the Design Codes, especially when there is slab unevenness (Rodriguez et al.,1995; Ganga-Rao,1992).

The current methodologies for bridge design are based on analytical methods using static truck loads and amplification factors. To improve the performance of bridges, new methodologies of structural analysis must be developed to model the real effect of loads more accurately. In Puerto Rico a realistic analysis is necessary because heavy trucks are typical on the highways.

Computer program UPR-PAVI2

The computer program UPR-PAVI2 was developed to model rigid pavements and the superstructure of bridges under temperature gradient, dead load and dynamic or static truck loads (Tito, 1996).

The output obtained from the program includes slab moments in each direction, principal slab moments and slab displacements. The traffic load is represented by trucks with constant velocity and longitudinal wheel path. The program allows variation in the number of trucks and their velocity, longitudinal path, geometry, load configuration, tire and suspension spring stiffness and damping. The pavement roughness is considered as the vertical variations of the surface and can be modeled in the program.

AASHO Road Test performed experimental tests on bridges under dynamic load; a complete report was published with the results (HRB, 1962). This paper shows the comparison between AASHO's tests and the analytical results of the computer program UPR-PAVI2. This work is part of a study performed in order to validate the analytical results of UPR-PAVI2 (Tito, 1996).

Description of facilities for AASHO road test

The AASHO Road Test was conceived and sponsored by the American Association of State Highway Officials as a study of the performance of pavements and bridge structures of defined characteristics under moving loads of known magnitude and frequency (HRB, 1962).

Eighteen slab and beam bridges were subjected to test traffic. The behavior and performance of the bridges under regular test traffic and during the accelerated fatigue tests were reported (HRB, 1962).

The objectives of AASHO's bridge tests were to determine the behavior of certain short-span highway bridges under repeated application of overstress and to determine the dynamic effects of moving vehicles on these bridges.

Bridge description

The data provided by HRB Special Report 61 (HRB 1962) were used to model the bridges. Three steel beam bridges were modeled using the computer program UPR-PAVI2. Figure 1 shows the structural detail and the finite element model used to analyze the bridges called 2A and 3B.

The bridges constructed in the AASHO Road Test were two simple span bridges sharing the same substructure. This substructure consisted of two abutments and one pier supported on spread footings located on a hard-clay soil. The superstructure consisted of girders, a concrete slab and transversal diaphragm. Steel bearings supported the girders. Fixed bearings were placed on the center piers and expansion rockers on the end abutments.

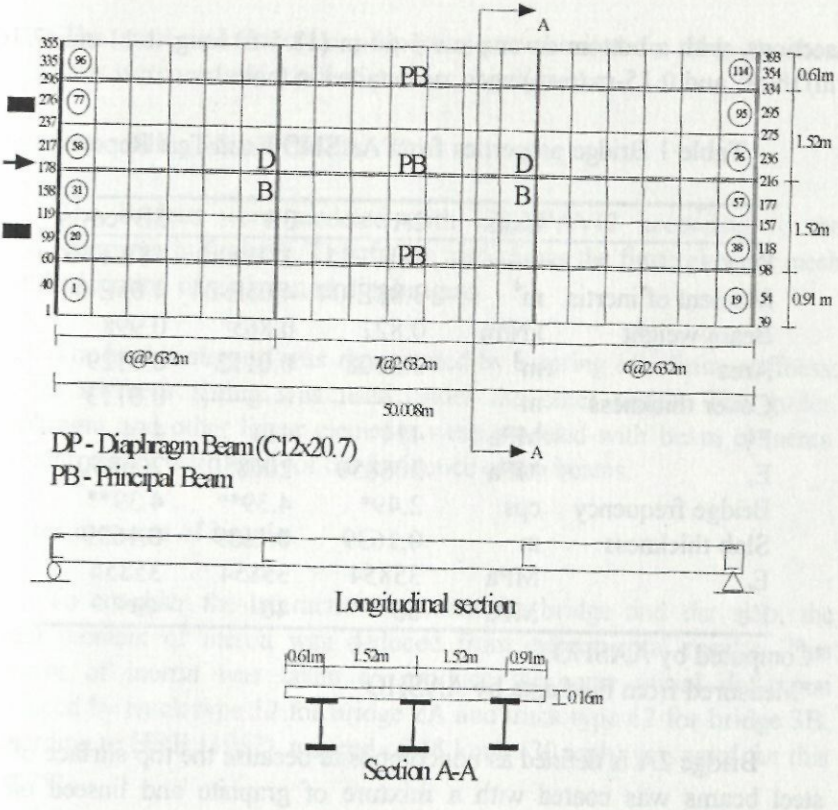

Figure 1. Structural detail and finite element model of bridges 2A and 3B used by AASHO Road Test.

Each bridge superstructure consisted of three identical steel girders. These girders were simply supported on a 15.24-m (50-ft) span and carried a reinforced concrete slab 0.163-m (6.5-in) thick and 4.57-m (15-ft) wide. The slab was separated from the adjacent bridges and the backwall of the abutment by 2.5-cm (1-in) of clear space and was provided with a 0.30x0.30-m timber curb bolted to the outside edge.

The steel sections were rolled wide-flange beams. Bridge 2A had 18WF50 sections without cover plate and the bridge 3B had 18WF60 sections, with a bottom cover plate 5.64-m (18.5-ft) long, 1.11-cm (7/16-in) thick, and 0.15-m (6-in) wide, as detailed in table 1.

Table 1 Bridge properties from AASHO Road Test Report

	Units	2A	3B	3B+cover
Size	----------	18WF55	18WF60	18WF60
Moment of inertia	m^4	3.88E-04	4.05E-04	4.05E-04
Beam weight	kN/m	0.822	0.865	0.998
Area	m^2	0.0108	0.0112	0.0129
Cover thickness	m	----------	----------	0.0113
Fy	MPa	414	414	414
E_s	MPa	206850	206850	206850
Bridge frequency	cps	2.49*	4.39**	4.39**
Slab thickness	m	0.1639	0.1639	0.1639
E_c	MPa	35854	35854	35854
f'c	MPa	35	40	40

*Computed by AASHO

**Measured from field data by AASHO

Bridge 2A is defined as noncomposite because the top surface of the steel beams was coated with a mixture of graphite and linseed oil to inhibit formation of bond.

Bridge 3B is defined as composite bridge because the interaction between the slab and the steel beams was obtained with mechanical shear connectors. The connectors were steel channels. The slab of this bridge was built flushed with the top surface of the beams.

In all bridges, along the transverse edges over the supports the slabs were thickened and they were in contact with the top surface of the end diaphragms. The slab reinforcement consisted of two layers of longitudinal and transverse deformed bars placed at top and bottom of the slab.

The steel and concrete properties are detailed in table 1; these properties were measured before performing the tests.

Bridge modeling with UPR-PAVI2

The bridges were modeled with UPR-PAVI2 according to the geometry given in figure 1. This figure also shows the finite element mesh and the location of girders and diaphragms.

The bridge support was represented by a spring of infinite stiffness; a zero stiffness spring was used under the other nodes. The girder, diaphragm and other linear elements were modeled with beam elements. The slab nodes were used for the incidence of the beams.

Girder moment of inertia

To consider the interaction between the bridge and the slab, the girder moment of inertia was deduced from experimental results. This moment of inertia was taken to produce the same initial deflection produced by truck type 52 for bridge 2A and truck type 62 for bridge 3B. According to HRB (1962), a speed of 48 km/h (30 mph) was used for this purpose.

Vehicles

Figure 2 shows the schematics of the vehicles used by the tests. The transversal distribution of the wheels was assumed, considering similar trucks, because this data are not defined in the report. Table 2 shows the stiffness properties of the trucks.

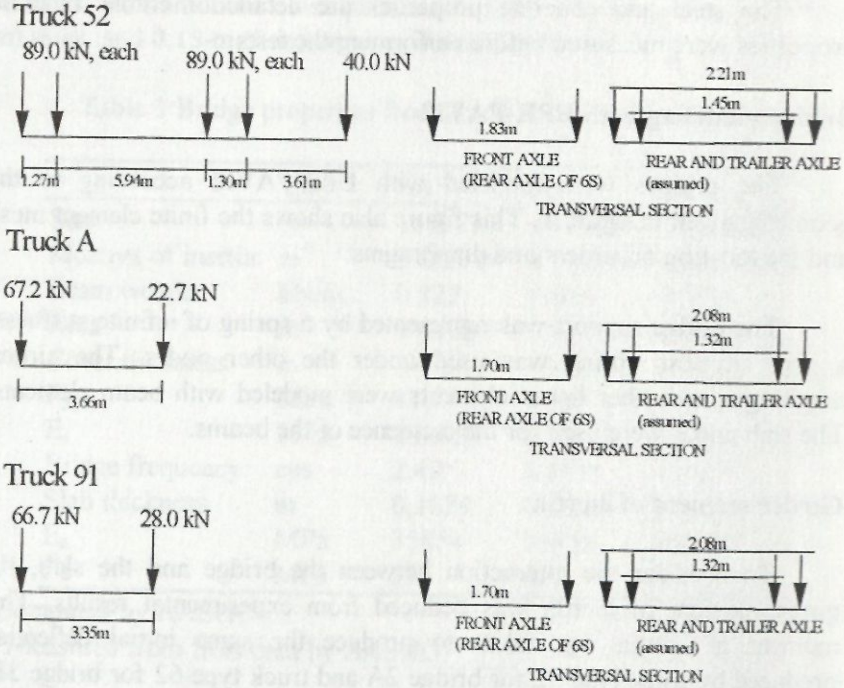

Figure 2. Trucks used in bridge research by AASHO

Table 2. Truck suspension used by AASHO

Truck	Kt per tire (kN/m)	Kv per tire (kN/m)
52	1225	1678
A Front	773	315
Back	1050	337
91 Front	905	350
Back	919	700

note : 1kN = 0.2248 kip
1kN/m = 0.06854 kip/ft

Natural frequency

In the case of bridge 2A, no experimental measure of the natural frequency was reported. A computed value was given. The basic assumption was that the bridges responded as simple supported beams. The value obtained was 2.49 cps (Tn = 0.402 sec). The model used by UPR-PAVI2 computed this value as 2.79 cps (Tn = 0.359 sec).

From Table 1, the natural frequency measured in the field for bridge 3B was 4.39 cps (Tn=0.221 sec); while using UPR-PAVI2 this value is 4.42 cps. These values are very close. The closeness is an indicator that the slab and beam are well modeled by the program.

Bridge damping

The damping was measured in the field with two methods. The first method uses the free vibration of the bridge produced by the truck. This method gave a damping of $\xi = 0.03$ (3% of critical damping) for a bridge similar to 2A, and $\xi = 0.008$ for the bridge 3B, as reported by AASHO. The high damping of bridge 2A may have been caused by the relative displacement between slab and beams.

The other method computed the damping from oscillator tests. This oscillator applied loads greater than those produced by free vibration. In this case the bridge was probably cracked, and it mobilized frictional forces in the bearing that increased the damping. These damping values are 0.06 for bridge 2A and 0.035 for bridge 3B.

To model the bridges the damping values obtained from the oscillator or greater values were used, because these measures are more representative of the problem.

Approach to bridges

The approaches to the bridges are not smooth. According to the bridge profiles, a model of an unevenness of 0.25 cm is used to represent the approach.

Comparison of tests with bridge 2A

Figure 3 shows a comparison between the history of the measured dynamic stress and that computed by UPR-PAVI2 for bridge 2A. These curves represent the response of strain gages located at midspan. The measured ratio of the strain versus maximum strains for dynamic and static cases is plotted and compared with the analytical results of UPR-PAVI2. This ratio is not the amplification factor.

Figure 3 also shows the influence of truck damping in the dynamic bridge behavior. In this case the curves computed using UPR-PAVI2 are inside a range of 10% of error compared with the experimental measurements.

The well defined experimental data, such as dimensions and other characteristics of the truck and bridge, produced agreement of the results in shape and magnitude.

Comparison of tests with bridge 3B

Figure 4 shows the history of the moment amplification factor at midspan of the center beam of bridge 3B. In this case, the abscissa shows the relative location of the rear axle. Dump truck type 91 with a speed of 64 km/h (40 mph) was used in the test. HRB (1962) does not detail the transversal distribution of the wheels; this distribution was assumed according to the available data. Agreement was obtained with the experimental curve, considering that some parameters were not well defined.

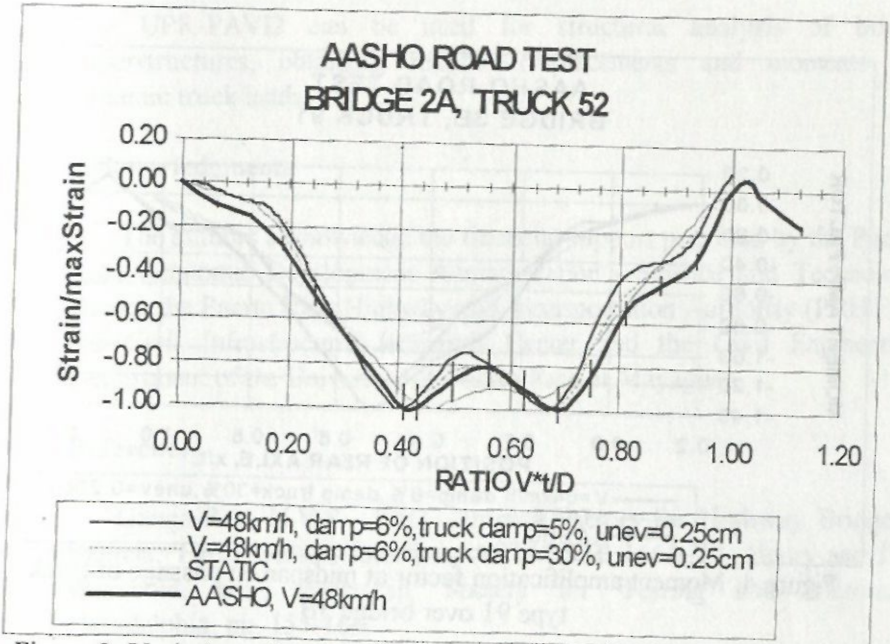

Figure 3. Variation of bottom strain at midspan on passage of truck type 52 over bridge 2A

The influence of the stiffness of the truck spring was also studied by AASHO Road Test. This is important in understanding the differences with the experimental results because alterations in the truck characteristics affect the history of the response. For example, HRB (1962) reported an increase from 1.03 to 1.35 in the amplification factor of the bridge 3B using truck 91 with a velocity of 48 km/h (30 mph) when the spring was blocked (infinite spring). The shape of history curves was also affected.

Conclusion

The agreement between the experimental and analytical results may be considered excellent for the case of bridges 2A and 3B, where the parameters are well defined in the HRB report.

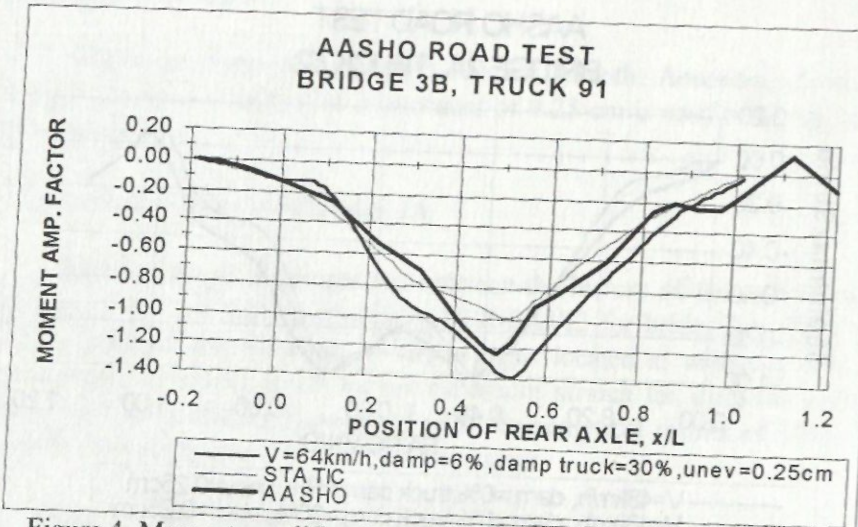

Figure 4. Moment amplification factor at midspan on passage of truck type 91 over bridge 3B

In all analyzed bridges the difference in the curve shape with respect to the experimental results may be due to any variation of the transversal or longitudinal distribution of wheels: changes of slab or truck damping; initial vibration of the truck different from that supposed by UPR-PAVI2; longitudinal and transversal profile of the bridge or other small variations in the idealization of slab or truck.

UPR-PAVI2 can model the profile of the bridge, but there were not enough data to do it. The profile is an important factor, which can modify the results obtained. A constant unevenness was assumed for the analysis.

Because alterations of the truck characteristics are influential factors in the resultant history obtained, it is important to obtain all the parameters in the field tests. In the HRB (1962) report, the transversal configuration of the trucks and their damping were not completely defined.

UPR-PAVI2 can be used for structural analysis of bridge superstructures, obtaining reliable displacements and moments for dynamic truck loads.

Acknowledgments

The authors acknowledge the financial support provided by the Puerto Rico Economic Development Administration - Science and Technology Board, the Puerto Rico Highway and Transportation Authority (PRHTA), the Civil Infrastructure Research Center and the Civil Engineering Department of the University of Puerto Rico at Mayagüez.

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Notation

cpc : Cycles per second

Ec : Concrete elasticity modulus

Fy : Steel yield stress

f'c : Concrete compressive stress

Tn : Natural period (sec)

ξ : Damping ratio