Dynamic response of reinforced concrete bridges due to heavy vehicles

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Abstract

The paper presents results of a comprehensive study of structural responses of reinforced, prestressed concrete bridges loaded with moving, heavy trucks. Two-prong approach was used when carrying this project: computational mechanics and experimental testing. Several complete vehicle-bridge finite element (FE) models were developed for computational dynamics analysis using LS-DYNA computer code. Experimental testing was conducted on a selected bridge. Comparison of results from each method allowed for validation and verification of the FE models developed. Three heavy vehicles and three concrete bridges were considered for this study. The vehicles included a popular tractor-trailer, a moving crane and a heavy truck with stiff suspension. The bridges with AASHTO type II, III, and IV prestressed reinforced concrete girders and concrete decks were chosen. Research output included time histories of accelerations, displacements and strains at selected points of the bridge superstructure. Data obtained allowed for studying a correlation between a vehicle mass, speed, road surface condition and other factors and a resulting dynamic impact factors for the bridges considered.

Keywords: concrete, dynamics, finite element methods, numerical analysis, vibrations

1. Introduction

Smaller, prestressed, reinforced concrete bridges, made of AASHTO girders [1], are very popular in the US. The State of Florida alone maintains an inventory of over 6400 such bridges. Applications of the current LRFD design codes [1] result in lighter structures with reduced safety factors. It requires the designers to assess all loads (especially: dynamic) very carefully.

Dynamic response of the bridges is quantified by the dynamic load allowance (*DLA*) defined in [1] as:

$$DLA = \frac{R_d - R_s}{R_s} \tag{1}$$

where R_d stands for a maximum dynamic response of any quantity (such as displacement or strain) and R_s represents the static response of the same quantity. The major objective of this research was to examine *DLA* for the most popular vehicle-bridge configurations.

Two parallel tracks: experimental and analytical, were designed and implemented as integral parts of this research. Each track resulted in data which was used to calculate *DLA*. Comparison of these results showed a good correlation between experiments and analyses, and was used to verify and validate finite element (FE) models developed.

2. Experimental testing

All experimental tests were carried out on a selected, typical, prestressed, reinforced concrete bridge #500133 on US 90 in north eastern Florida. It is a newer bridge, built in 1999 with three simply supported spans and with six AASHTO type III girders in each span. A selected span of the bridge was instrumented with: (a) two linear variable displacement transformers (LVDT), (b) 38 strain gauges and (c) 14 accelerometers installed at the top of the bridge deck. 35 static and dynamic tests were carried out with the speed ranging from 48 km/h to 80 km/h. Three representative permit vehicles were used for the tests: (a) a Mack CH613 truck tractor with a single drop trailer, (b) a Terex T-340 crane, and (c) a FDOT truck with a very stiff suspension. Data acquisition from experimental testing allowed for calculation of *DLA*. Description of the tests carried out on the bridge #500133, and their results, can be found in [5-7].

3. FE models of dynamic vehicle-bridge systems

The second research track consisted of FE model development and 3-D, numerical analysis using LS-DYNA computer code [4]. 3-D FE models of the bridges have been developed and studied during the past decade. The FE models are becoming more detailed and sophisticated in time along with increased efficiency of the computing software and hardware [2, 4].

In addition to the bridge #500133 (which was used for experimental testing), two other local, prestressed, reinforced concrete bridges were selected for analytical studies of *DLA*. An earlier version of the FE model of the bridge #500133 was described in [3]. The bridge superstructures consisted of AASHTO type II, III and IV prestressed reinforced concrete girders. The FE model of the bridge #500133 was validated and verified in [3] using experimental data. Actual material properties of this bridge were laboratory tested and they were found to be 20-30% higher as compared with the design values. The same material properties were used for the other two bridges.

Table 1 shows basic dimensions of each span of each bridge studied.

Table 1. Overall dimensions of one span of each bridge

Bridge #	AASHTO girder type	Number of spans	Span length [m]	Span width [m]
540074	II	2	12.1	11.6
500133	III	3	21.0	13.1
590056	IV	3	29.1	12.6

An FE model of one span of each bridge was developed in detail. Each model included such elements as: AASHTO girders, concrete deck, diaphragms, bridge barriers, elastomeric bearing pads, and a bridge approach. Most of the parts of the bridge superstructures were modeled with linearly elastic 8-node brick elements with concrete properties as tested. Bridge reinforcement was explicitly modeled using 1-D truss elements with nodes shared with the nodes of the adjacent concrete elements, as shown in Fig. 1. A complete, typical FE model of the bridge span consisted of 145,604 finite elements.

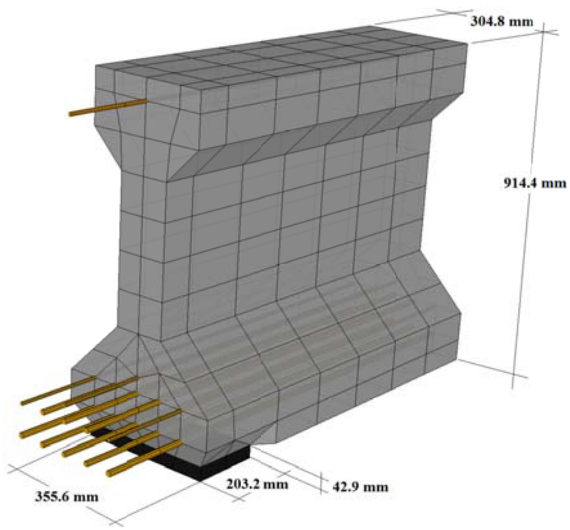

Figure 1: An end part of the FE model of the AASHTO type II girder

Three FE models of permit vehicles were developed. The models were simpler and smaller as compared with the FE models of the bridges. The largest of all was the tractor-trailer model with 26,194 finite elements. Mostly shell elements were used for all vehicle models. While rigid body elements were used to correctly represent the vehicle mass and axle loads, great attention was paid to model 3-D rotating wheels with pneumatic tires, and suspension with springs and shock absorbers. All vehicle models were thoroughly verified and validated by driving the vehicles over speed bumps with lower velocities, with the speed ranging from 8 km/h to 32 km/h.

4. Numerical dynamic analysis of *DLA*

Dynamic load allowance factors were calculated for all bridges depending on vehicle types and their velocities. *DLA*s were determined based on maximum displacements and strains using data from experimental testing and from computational analysis. Strain based *DLA* factors came out to be more reliable, closer to experimental data, and to values recommended by AASHTO. Several features were identified as triggering significant *DLA*. They included: surface imperfections (as abutment joints and bridge approach depression), loosely attached cargo producing so called hammering effect, and characteristics of the vehicle suspension. Figure 2 shows one of the examples: the bridge #500133 loaded by the moving Terex crane at different speeds.

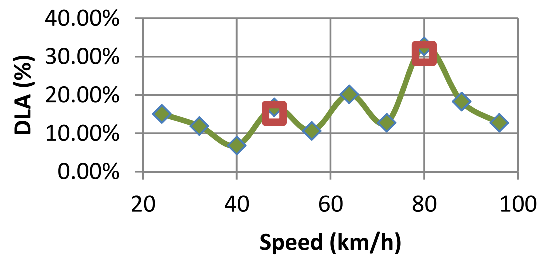

Figure 2: *DLA* vs. speed based on maximum strain on the bottom of girder #4, for the Terex crane in the center of the westbound lane

Two points selected from the calculated results, shown in Fig. 2 as larger, red squares, were validated earlier by two field tests of the selected vehicle-bridge system.

It can be clearly seen that the *DLA* is not a monotonically increasing function. In fact, driving for instance the Terex crane with 40 km/h on that bridge produces a lower *DLA* as compared with that at 25 km/h speed. The overall response of the vehicle-bridge system, and the related *DLA*, depends on superposition of two dynamic events: (1) the forced vibrations of the vehicle system and its cargo, and (2) the free vibrations of the bridge.

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