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Engineering Structures 29 (2007) 3210–3226
ENGINEERING STRUCTURES
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Effect of approach span condition on vehicle-induced dynamic response of slab-on-girder road bridges

C.S. Cai[a,*], X.M. Shi[a], M. Araujo[a], S.R. Chen[b]

[a] *Department of Civil and Environmental Engineering, Louisiana State University, United States*
[b] *Department of Civil and Environmental Engineering, Colorado State University, United States*

Received 23 June 2007; received in revised form 10 September 2007; accepted 7 October 2007
Available online 8 November 2007

Abstract

The present study investigates the effect of approach span conditions on a bridge's dynamic response induced by moving vehicles. After developing a 3D bridge–vehicle interaction model for numerical prediction, a dynamic test on a full scale slab-on-girder bridge is conducted with dump trucks to validate the developed numerical methodology. A wooden plank is used to simulate the large faulting between the bridge deck and the approach slab. With consideration of the road surface profile and approach span condition, the predicted dynamic response of the bridge is compared to the experimental results, and they show a satisfactory agreement. The numerical model is also applied to investigate the effect of the approach span condition on the dynamic behavior of the bridge induced by the AASHTO HS20 truck. A parametric study is eventually conducted by changing the road surface condition and the faulting value. The faulting condition of the approach span is found to cause significant dynamic responses for the slab-on-girder bridges and to have a considerable effect on the distribution of impact factors along the transverse and longitudinal directions. Furthermore, impact factors obtained from the numerical analyses are compared with those values specified in the AASHTO codes.

Keywords: Bridge–vehicle interaction; Dynamic impact factor; Load distribution; Approach span

1. Introduction

Vehicle-induced dynamic response of bridges is one of the primary problems concerning bridge engineers. Moving vehicles usually produce larger bridge responses than static vehicles do. Bridge vibrations have become one of the causes of deterioration and reduction in long-term serviceability of bridges, although major bridge failures are not usually caused directly by moving vehicles. The effect of moving vehicles on the dynamic response of bridges is of primary importance in the design of these structures.

As they play an important role in highway transportation systems, slab-on-girder bridges raised great interest in studying bridge–vehicle interactions. Extensive researches have been conducted to determine the dynamic behavior for this type of bridges (e.g., [10,15,21]). Previous investigations indicated that the dynamic characteristics of bridges and vehicles, and the road surface condition of approach roadway and bridge deck are important factors for bridge dynamic performance induced by moving vehicles [12]. Among these factors, the vehicle initial condition is an important one that affects the dynamic responses of both the bridge and vehicles [17]. The vehicle initial condition is caused not only by the roughness of the roadway, but also by uneven approach span conditions upon entrance to the bridge. The uneven approach conditions are usually caused by the differential settlement of embankment soil and abutments and/or bridge approach deformation.

A bridge approach slab is usually constructed to connect the bridge deck with the roadway. It is intended to provide a smooth transition between the bridge deck and the roadway pavement. However, differential settlement often occurs between the bridge abutment and the embankment soil either because the soil underlying the approach slab consolidates or because the embankment soil materials are compressible and the bridge is relatively rigid. When the soil settlement occurs, the approach slabs of bridges lose their contact and support from the soil, and the slabs will bend and deform in a concave manner [5].

* Corresponding address: Louisiana State University, Department of Civil and Environmental Engineering, 3418H CEBA, 70803 Baton Rouge, LA United States. Tel.: +1 225 578 8898; fax: +1 225 578 8652.
E-mail address: Cscai@lsu.edu (C.S. Cai).

0141-0296/$ - see front matter
doi:10.1016/j.engstruct.2007.10.004

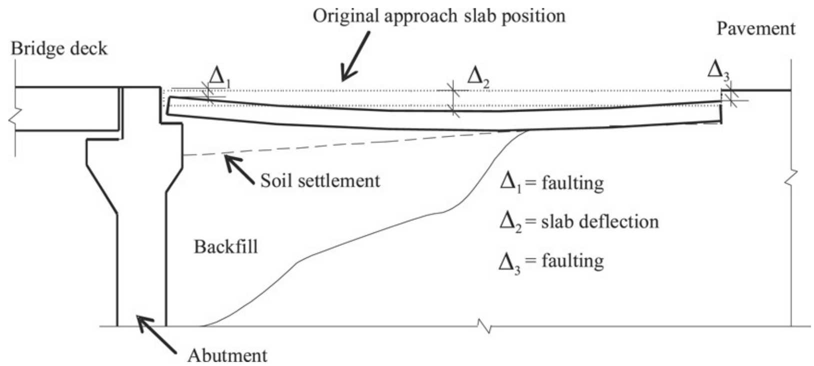

Fig. 1. Illustration of approach span deformation.

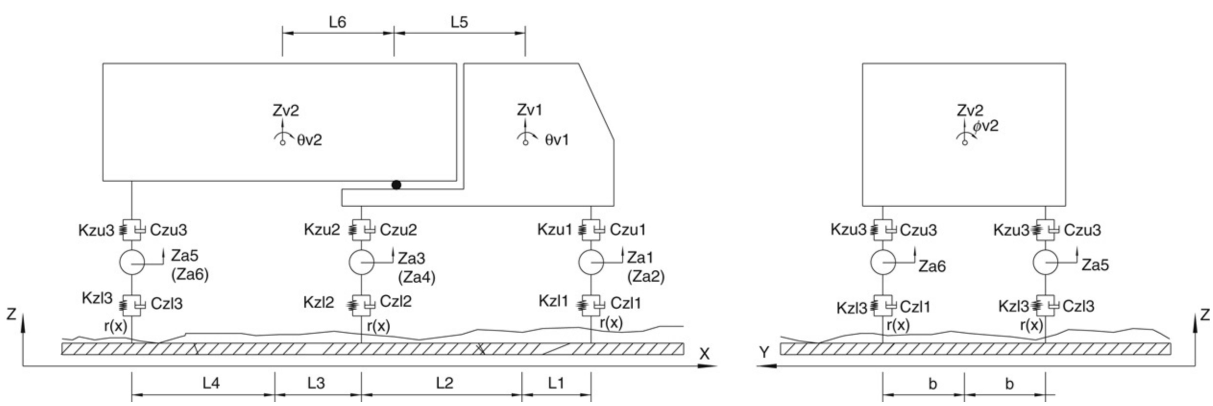

Fig. 2. Vehicle model.

Meanwhile, loads on the slab will also redistribute to the ends of the slab, which may result in faulting (or bump) across the roadway at the ends of the approach slab (Δ_3 in Fig. 1). On the other hand, the expansion joint that connects the approach slab and bridge deck will form a faulting (Δ_1 in Fig. 1) due to the differential settlement of the abutments and/or poor maintenance.

When a "bump" forms at the bridge end, repetitive movements of traffic vehicles can deteriorate the expansion joint in turn. Thus, a rough transition region has developed with time in some bridge approaches. Consequently, the vehicle receives an initial disturbance before it reaches the bridge. This initial excitation of the vehicle causes an extra impact load on the bridge and affects the dynamic responses of both the bridge and the vehicle. The development and cause of bump-related problems have been commonly recognized and identified; however according to current literature review [3,8,9,13,22,18], the effect of bridge approach span conditions on the bridge dynamic performance has seldom been studied.

The objective of this study is to analyze the possible effect of the approach span deformation on the dynamic behavior of slab-on-girder bridges caused by heavy vehicles moving across the bridge. In order to achieve this objective, a bridge–vehicle coupled model, which takes into account the road roughness and approach span conditions, is first developed. Then, the model is adjusted by using experimental results obtained in a full scale field bridge test. Using this validated model, the dynamic behavior of slab-on-girder bridges with different span lengths induced by the AASHTO HS20 truck is investigated. A parametric study is conducted to investigate the influence of approach span conditions on bridge dynamic response. The distribution of impact factors and load distribution factors is also analyzed and compared with values specified in current AASHTO codes.

2. Bridge–vehicle coupled system

The present study has developed a fully computerized program to simulate the interaction of any types of coupled vehicle–bridge systems, with consideration of road roughness and approach span deformations. For computational efficiency generalized modal coordinates are used for bridges and physical coordinates are used for trucks. More details are seen in Henchi et al. [11] and Shi et al. [19].

2.1. Bridge–vehicle numerical model

A heavy vehicle is idealized as a combination of a number of rigid bodies connected by a series of springs and dampers while the bridge is modeled using the conventional finite element method. For demonstration purposes, a three-axle articulated truck consisting of up to 11 independent degrees of freedoms is shown in Fig. 2. The equations of motion for the vehicle and bridge are derived based on the following matrix form:

$$[M_v]\left\{\ddot{d}_v\right\} + [C_v]\left\{\dot{d}_v\right\} + [K_v]\{d_v\} = \{F_v^G\} + \{F_c\} \quad (1)$$

$$[M_b]\left\{\ddot{d}_b\right\} + [C_b]\left\{\dot{d}_b\right\} + [K_b]\{d_b\} = \{F_b\} \quad (2)$$