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Impact factors for a composite steel bridge using non-linear dynamic simulation

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Abstract

Traditionally, bridges are designed using static loads that are increased by the dynamic load allowance (DLA) factor (or dynamic amplification factor). The DLA factor is a function of span or first flexural natural frequency of the bridge, and indirectly incorporates the dynamic effects of moving vehicles in the design. This article firstly reviews the literature on impact loading of bridge decks. Analytical methods published previously are evaluated and the bridge–vehicle interaction is found to be the most reliable method among them. The article then presents a 3D finite element model to study the bridge–vehicle interaction. Finite elements are developed to simulate the trucks, the road surface and the composite girder bridge itself. Truck parameters include the body, suspension and tires, with variables being the total weight and the speed. The bridge superstructure is treated as a 3D composite steel girder bridge incorporating special end springs that simulate the elastomeric bearings. A parametric study is performed to identify the effect of various parameters on DLA, such as vehicle speed, aspect ratio of steel girders, stiffness of neoprene, type of vehicle, vehicle lane eccentricity and initial bounce of the vehicle due to road surface roughness. The results indicate that the DLA is correlated well with the velocity of the truck, especially at high speed. DLA is vehicle dependent and the dynamic and static live loads can be considered uncorrelated, except when the truck weight is less than 10 percent of the total deck weight, for which a low degree of correlation is observed. The DLA is decreased as the vehicle lane eccentricity (with respect to the deck centerline) is increased, and the same relationship exists with the bridge span length. No distinctive correlation is observed between the DLA and the initial bounce of vehicle at the time of entrance to span.

Keywords: Bridge vehicle interaction; Dynamic load simulation; Dynamic load allowance; Suspension; Impact factor

1. Introduction

Research on the dynamic response of bridges due to moving loads has received considerable attention in recent years. Around the world, passenger and freight traffic have increased significantly in size and number in recent times. Many older bridges are now subjected to heavier traffic flows than designed for, and new bridges are to be designed for higher load levels without excessive deflections or vibration [1]. This has made it increasingly important for engineers to estimate the dynamic effects of vehicle passage on the serviceability of existing bridges accurately and to consider it in the design of new bridges.

In order to check the capacity of existing bridges to handle heavier traffic and for the proper design of new bridges, a bridge engineer requires improved techniques that simulate the bridge–vehicle interaction. This is even more important these days due to the current trend towards longer spans and lighter deck systems, combined with the natural limited damping of these systems. Because of the structural form of composite girder highway bridges, being wide but shallow in depth, this type of bridge is highly susceptible to vertical vibration, which can cause excessive dynamic deflection.

Essentially, the bridge vibration under the effect of traffic movement should be limited in order to satisfy two basic purposes. The first purpose is to control the ratio of dynamic stresses to static stresses. This effect is considered in static design by a dynamic load factor (DLF) or a dynamic load allowance (DLA), and is the focus of this

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study. The second purpose is to control the perceptible vibration. While of no dangerous structural consequence, too much vibration may undermine users' confidence in the structure [2].

The dynamic response of a bridge depends on the dynamic characteristics of the superstructure, especially natural frequency, dynamic properties of the vehicle and its configuration, and the contribution of pavement roughness. In some extreme loading situations, the mass of the vehicle may be significant compared with the mass of the bridge. Neglecting the combined inertia in these cases may lead to substantial errors. Furthermore, vehicle suspension and roadway unevenness are important factors affecting the response of bridges and should be taken into account. Some published studies [1,3,4] suggest that dynamic amplification depends on a wide range of factors including speed, ratio of live load to dead load, tire and suspension stiffness, effect of braking, bounce on suspension, damping of the bridge and vehicle, and bridge configuration, including simple or continuous span, number of spans, straight, skewed, or horizontally curved span.

A number of techniques have been developed for calculating the dynamic effects of wheel load on bridges. However, most have been based on simple, one- or two-dimensional models [1,5,6]. It has been only recently that more comprehensive models are presented [7–10].

This paper presents a numerical model to study bridge–vehicle interaction. 3D finite element models are developed for trucks, road surface (roughness) and composite girder bridges. Truck parameters include the body (mass), suspensions and tires, and its variables include the total weight and speed. The bridge superstructure is treated as a 3D composite steel girder bridge with simply supported span incorporating its elastomeric bearing at each pier. Bridge properties include the mass, flexural stiffness, span length and elastomeric bearing characteristics. The pavement roughness is determined by surface conditions of the approach and the bridge. Deformations are assumed to remain within the elastic range and DLA + 1 is defined as the maximum dynamic deflection divided by the maximum static deflection at mid-span.

A parametric study is performed to identify the effects of various parameters on the dynamic load and consequently on the DLA of the composite girder bridge, such as vehicle speed, effect of the aspect ratio (ratio of height to length) of a steel girder of a composite deck, stiffness of neoprene, type of vehicle, effect of the vehicle lane eccentricity with respect to deck centerline and initial bounce of the vehicle due to road surface roughness. For each case, the DLA is presented in graphs as a function of the aforementioned variables.

2. Definition of dynamic load allowance and related code values

The dynamic effects of a moving vehicle are important in the design and evaluation of the performance of bridges. Traditionally, the total dynamic load, which is considered as an equivalent static load, is considered as a static vehicle weight amplified by the *impact factor*. The term *impact factor* represents an increase in the traffic load resulting from the interaction of the moving vehicle and the bridge structure. In other words, it describes the static equivalent of the dynamic vibration effects [11]. Recently, the term DLA has superseded the term impact factor as it better expresses the dynamic effects of wheel loads on a bridge, mainly because of the fact that the dynamic load is a complex interaction between a moving vehicle and the superstructure instead of a dynamic effect due solely to the impact action of a wheel. Due to the way DLA is defined, it is sometimes called the *amplification factor* (DLA + 1), which is equivalent to the impact factor.

The effect of the DLA is greatest in those portions of the bridge superstructure that are in closest contact with the deck. In addition to superstructure components, the effects of DLA should be considered in loads transferred from superstructure to substructure, such as the portion of piers above the ground line of concrete, or the steel piles supporting the superstructure, as specified in AASHTO [12].

In general, the amplification factor DLA + 1, which represents the ratio between the effects of moving traffic and those of stationary traffic, can be defined as the ratio of the total dynamic response to the maximum static response. According to O'Connor [13], DLA obtained based on deflection measurements gives higher values than that obtained from stress tracing. Some studies [7–10] have found a good agreement between the DLAs calculated based on deflection and those calculated based on strain. In the current study, the dynamic load effects on the bridge are measured in terms of the maximum static and dynamic deflection (D_{sta}, D_{dyn}) at mid-span [4,5]. The DLA is then defined as the quotient of the additional dynamic deflection and live loads' static deflection as

$$\mathrm{DLA} = \frac{D_{\mathrm{dyn}} - D_{\mathrm{sta}}}{D_{\mathrm{sta}}} \quad \text{or} \quad \mathrm{DLA} + 1 = \frac{D_{\mathrm{dyn}}}{D_{\mathrm{sta}}}. \tag{1}$$

Many codes, including AASHTO [12], specify the DLA as a function of span only. However, some codes such as the 1983 Ontario Highway Bridge Design Code (OHBD) [14] or Australia's National Road Authority, AUSTROADS [11], define the DLA as a function of the first flexural frequency of the bridge. In some codes such as the Euro code for Highway Bridges, dynamic amplification is included in the specified design loads [15].

To consider the dynamic, vibration and impact effects of vehicle load, 1992 AASHTO [12] suggests the following DLA for calculating the static equivalent of the dynamic force:

$$\mathrm{DLA} = \frac{50}{L(\mathrm{ft}) + 125} = \frac{15.24}{L(\mathrm{m}) + 38.1} \leqslant 30\%, \tag{2}$$

where L is the portion of the span that is loaded to produce the maximum stress in the member and can be regarded as