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Evaluation of impact factors for composite concrete–steel cellular straight bridges

X. Zhang [a], K. Sennah [b], J.B. Kennedy [a,*]

[a] *Department of Civil & Environmental Engineering, University of Windsor, Windsor, Ontario, Canada N9B 3P4*
[b] *Department of Civil Engineering, Ryerson University, 350 Victoria St., Toronto, Ontario, Canada M5B 2K3*

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Abstract

This paper presents a method for determining the dynamic impact factors for straight composite concrete deck–steel girder cellular bridges under AASHTO truck loading. The bridges are modeled as three-dimensional structures using commercially available software. The vehicle is idealized as a pair of concentrated forces, with no mass, travelling across the bridge. An extensive parametric study is conducted, in which 120 composite multi-cell bridge prototypes are analyzed. The key parameters considered in this study are: number of cells, number of lanes, span length, number and area of cross-bracing and top-chord systems, and truck(s) speed and truck(s) positioning. Based on the data generated from the parametric study, expressions for dynamic impact factors for moment, reaction, and deflection for such bridges are proposed. The results from this practical-design-oriented study would enable bridge engineers to design new composite cellular bridges more reliably and economically. Furthermore, the results can be used to evaluate the load-carrying capacity of existing composite cellular bridges since even a small increase in strength for live load can make the difference between closing a bridge and leaving it open.

Keywords: Bridges; Cellular Box-girder; Impact factors

1. Introduction

Composite concrete deck–steel cellular straight bridges are widely used in the highway systems throughout the world. In addition to their lighter weight, shallower depth of cross section, and significant longitudinal bending stiffness, composite cellular straight bridges are favored for their considerable torsional stiffness to resist eccentric load when compared to open sections. The cross section renders an efficient transverse load distribution as well as high resistance to torsional vibration caused by moving vehicles, wind, or seismic conditions.

Recent review of available work on the dynamic response of box-girder bridges was presented by Sennah and Kennedy [14]. It was observed that there is lack of information regarding the dynamic response of composite cellular bridges under moving vehicle. The current design practices in North America recommend few analytical methods for the design of straight composite multi-cell box girder bridges to account for the dynamic effect of truck loading. The current design specifications in the United States by the American Association of State Highway and Transportation Officials [1] recommend an impact factor equation as a function of the bridge span only. While, the current design specifications in Canada, the Canadian Highway Bridge Design Code [8], recommend a dynamic load allowance based on the number of truck axles passing over the bridge. The latter recommendation was based on results from the dynamic testing of 27 I-girder bridges in Ontario, Canada [2]. Recently, Sennah and Kennedy [13] presented a simplified design method for straight composite cellular bridges in the form of expressions for moment and shear distributions factors. The objective of this study is to conduct a parametric study to examine the effect of key geometric parameters and loading conditions on straight composite cellular bridges that might influence the impact factors of such bridges. The data

* Corresponding author. Tel.: +1-519-283-4232.
E-mail address: cjk@uwinsor.ca (J.B. Kennedy).

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Nomenclature

A	bridge width;
B	cell width;
c	symbol of cells in designation of bridge type;
C	steel top flange width;
d	depth measured from the center of the bottom flange to the center of the concrete deck slab;
D	total depth of the steel cells;
F	total depth of composite bridge;
G	structural response variable;
G_D	dynamic value of variable G;
G_S	maximum static value of variable G;
I	impact factor;
I_D	deflection impact factor;
I_G	dynamic impact factor for the variable G;
I_M	moment impact factor;
I_R	reaction impact factor;
l	symbol for lanes in designation of bridge type;
L	span of simply supported bridge;
t	time;
t_1	thickness of steel top flange;
t_2	thickness of steel web;
t_3	thickness of steel bottom flange;
t_4	thickness of concrete deck slab;
$\sigma_D(t)$	dynamic normal stress at each increment of time;
σ_s	static normal stress.

generated from the parametric 3D study is used to deduce empirical expressions for impact factors for moments, reactions, and deflections.

2. Description of bridge prototypes

In this study, 120 simply-supported single-span bridges of different configurations were analyzed. The basic cross-sectional details for all the bridges studied are presented in Table 1, using a span-to-depth ratio of 25. The symbols used in the first column in Table 1 represent designations of the bridge types considered: *l* stands for lane; *c* stands for cell; and the number at the end of the designation represents the span length in meters. For example: 2*l*-3*c*-80 denotes a simply-supported bridge of two lanes, three cells and of 80 m span. The cross-sectional symbols used in Table 1 are shown in Fig. 1(a). The number of lanes was taken as 1, 2, 3, and 4. Five different span lengths of 20, 40, 60, 80, and 100 m were included, representing the range for medium span bridges. The number of cells ranged from 1 to 4 in case of one-lane, 1–7 in case of two-lane, 3–9 in case of three-lane, and 4–9 in case of four-lane bridges. When changing the number of cells for the same bridge width, the thickness of the top steel flanges, webs, and bottom flange were altered to maintain the same shear stiffness of the webs and the same overall flexural stiffness of the cross-section. The bridge width was 6.8 m in case of one-lane, 9.3 m in case of two-lane, 13.05 m in case of three-lane, and 16.8 m in case of four-lane bridges. The ranges of the parameters considered in this study were based on an extensive survey of actual designed composite box girder bridges [3]. The moduli of elasticity of concrete and steel were taken as 27 and 200 GPa, respectively. Poisson's ratio was assumed as 0.2 for concrete and 0.3 for steel. Solid-plate diaphragms with access holes were provided at the supports. The material and thickness for the end-diaphragms were taken to be the same as those for the webs.

3. Bridge modeling

The 3D modeling of each bridge prototype was carried out using the finite-element method and the ABAQUS software [4]. Fig. 2 shows a typical finite element mesh used for the bridge static and dynamic analyses. A four-node shell element with six degree of freedom at each node was used to model the concrete deck, steel webs, steel bottom flange, and end-diaphragms. A three-dimensional two-node beam element was adopted to model the steel top flanges, cross-bracings and top-chords. Because of their insignificant flexural and torsional stiffnesses,