RELATIVE DISPLACEMENT CONTROL FOR HORIZONTALLY CURVED COMPOSITE BRIDGES DURING CONSTRUCTION

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ABSTRACT

Due to the coupling action of vertical bending and torsion, horizontally curved box girders are subject to significant rotations as well as deflections. Installing intermediate external cross-frames between box girders is an effective means to control these displacements. A new parameter, deck unevenness ratio, is utilized in this study to quantify the degree of uneven deck caused by relative deflections and rotations. In order to assess the effects of external cross-frames on the deck unevenness ratio that affect deck slab construction, hypothetical twin-box girder bridges were analyzed using a commercial finite element program.

Keywords: bending, torsion, horizontally curved box girder, external cross-frame.

1. INTRODUCTION

In horizontally curved bridges with sharp curvature, the detrimental differential deflections between box girders occur whether employing multiple deck casting sequences with longitudinal/lateral construction joints or not. Due to the coupling action of vertical bending and torsion, horizontally curved box girders are subject to significant rotations. During construction, the noncomposite steel girder must support the wet concrete and steel weight also known as noncomposite dead loads in addition to other construction loads such as the dead weight of screed, etc. There have been reports of very large differential deflections between box girders, exceeding 120 mm in some cases (Dey 2001). The differential deflection or rotation is defined in this study as those between the exterior box girder (convex side) and the interior box girder (concave side). A large differential deflection and rotation make it difficult to maintain the superelevation specified and to form and key-in the construction joint for the succeeding placements (US Steel Corporation 1978). In the absence of external cross-frames, the magnitude of the differential deflection depends upon the stiffness of the noncomposite individual box girders. Since it is not practical to increase the girder stiffness simply to minimize the differential deflections and rotations, either external cross-frames or temporary shoring are considered. At the external cross-frame location, the entire bridge cross section tends to

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rotate as a unit, and the relative angle of twist between box girders is minimized. The differential deflections between horizontally curved box girders during construction may be controlled by any of the following, either alone or in combination (Kim and Yoo 2006): (1) Increasing noncomposite steel girder stiffness based on the deck pouring sequence; (2) Supporting girders on temporary shoring; (3) Providing temporary or permanent external cross-frames.

Installing temporary shoring or external cross-frames is considered to be a more efficient way of controlling differential deflections than increasing the girder stiffness. Temporary shoring is an effective option in controlling deflections and rotations during construction if the local traffic conditions and terrain permit, although the cost associated with temporary shoring is deceptively expensive. If the construction conditions do not permit temporary shoring, external cross-frames may become the only option.

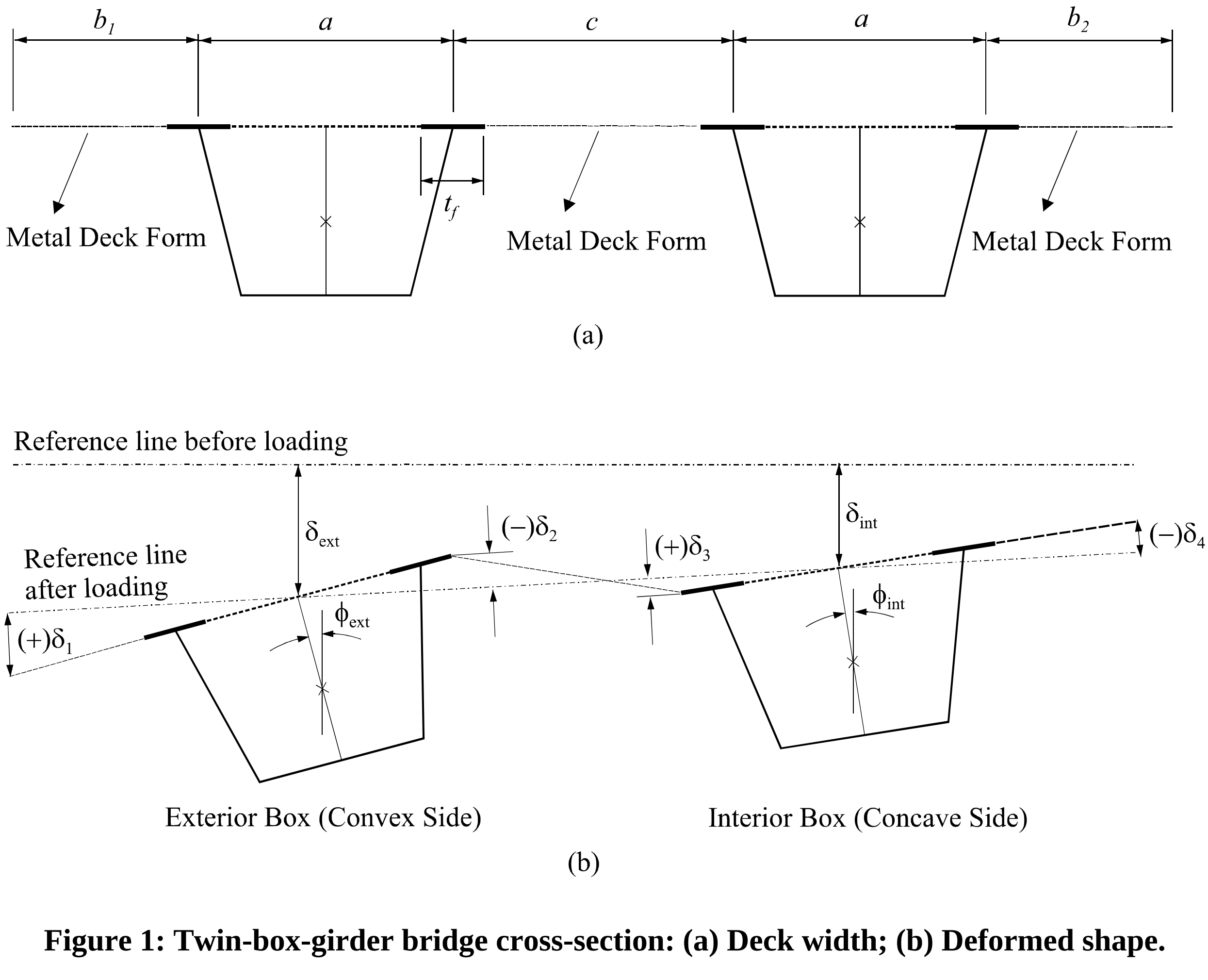


Figure 1: Twin-box-girder bridge cross-section: (a) Deck width; (b) Deformed shape.

2. DECK UNEVENNESS RATIO

In horizontally curved steel box girder bridges, individual box girders undergo deflections and rotations when wet concrete is being poured on the forms for the deck slab. Due to the induced differential deflections and rotations between box girders, the reference line of the deck slab becomes uneven, as shown in Figure 1. Care should be used during deck pouring in order to maintain the minimum required slab thickness, as the thickness can be varied by the uneven reference line along the deck width caused by the uneven deflections. In addition, unless the uneven reference line is controlled to be within the minimum acceptable amount, it will cause unintended additional dead loads on the noncomposite steel section. In this paper, a parameter for the unevenness ratio of the deck reference line, U_R is defined as (Kim and Yoo 2006):

$$U_R = \frac{1}{t_c}\left[Max\left(\delta_1,\delta_2,\delta_3,\delta_4\right) - Min\left(\delta_1,\delta_2,\delta_3,\delta_4\right)\right] \tag{1}$$

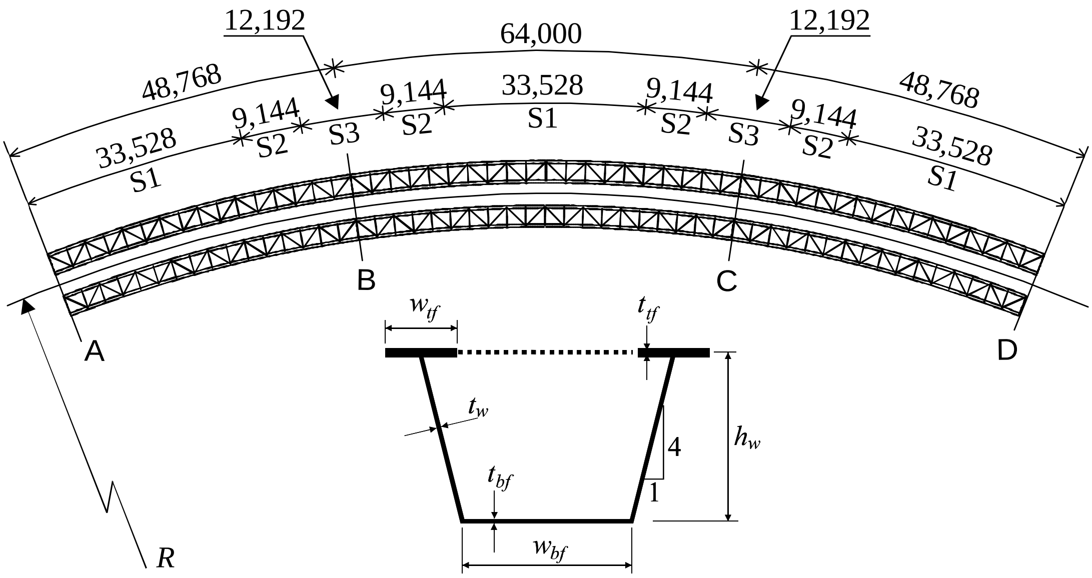
where t_c = design deck thickness; δ_1, δ_2, δ_3, δ_4 = relative deflections from reference line after loading at four reference points, as shown in Figure 1. It is noted that the reference line after loading goes through the midpoints between webs at the top flange level of each box girder. Deflections below and above the reference line after loading have positive and negative values, respectively. The magnitude of the unevenness ratio defined above can be effectively controlled by the use of external cross-frames.

3. NUMERICAL EXAMPLE

The investigation was then extended to three-span continuous composite box girder bridges. The three-span bridges examined had total lengths of 161.5 m, made up of spans of 48.75 m, 64.0 m, and 48.75 m, with three different centerline radii of curvature of 45.7 m and 30.5 m. Each bridge had a total of 52 bracing panels (16+20+16). Mesh refinements and the finite element modeling of the bridge cross sections were kept the same as those used for the simple-span bridges analyzed. Each box girder consisted of three different cross sections. The thicknesses of the top and bottom flange were varied while keeping all other dimensions unchanged. The dimensions of the hypothetical bridges and three different cross sections are given in Figure 2. Three-dimensional full model analyses were carried out on each. Detailed description for finite element modeling is given by Kim and Yoo (2006).

Except for very short span bridges, it is highly unlikely that the entire three-span continuous girder bridge deck would be cast at once. Article 2.5.1, AASHTO Guide Specifications (2003) stipulate that concrete casts be included in the approved construction plan, but there is no universally accepted deck concrete pouring sequence. There are two generally agreed upon issues: (1) when the pour volume becomes large, a deck pouring sequence is suggested, where the volume limitation varies from 125 m^3 to 230 m^3, and (2) when a deck pouring sequence is considered, the objective is to minimize the tensile stresses induced in the previously cast concrete slab. Article 13.3, AASHTO Guide Specifications (2003) limits the factored tensile stress during deck pouring to be no more than 0.9 times the modulus of rupture.

In order to investigate the interactions among the external cross-frames, unevenness ratios, and the schemes of deck pouring sequence in the case of a continuous girder bridge, a number of hypothetical horizontally curved bridges were analyzed. The noncomposite dead load analysis procedure may consist of four steps in order to reflect the staged construction: (Stage I) Noncomposite dead load analysis of the wet concrete poured on steel girders; (Stage II) Noncomposite dead load analysis of the wet concrete poured in Stage I, with a modified girder stiffness reflecting the partial composite properties; and (Stage III) Noncomposite dead load analysis of the wet concrete poured in Stage (II), once again with a modified girder stiffness reflecting the partial composite properties.

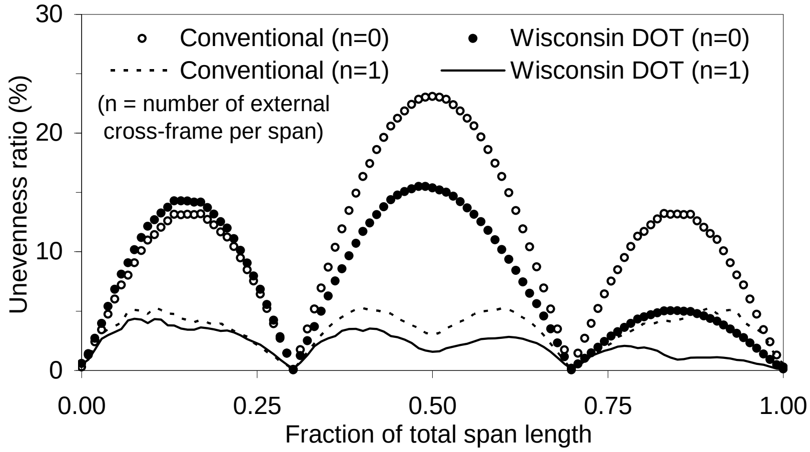


Section	w_{tf}	t_{tf}	w_{bf}	t_{bf}	h_w	t_w
S1	406.4	31.8	2057.4	19.1	1981.2	14.2
S2	406.4	44.5	2057.4	31.8	1981.2	14.2
S3	406.4	82.6	2057.4	44.5	1981.2	14.2

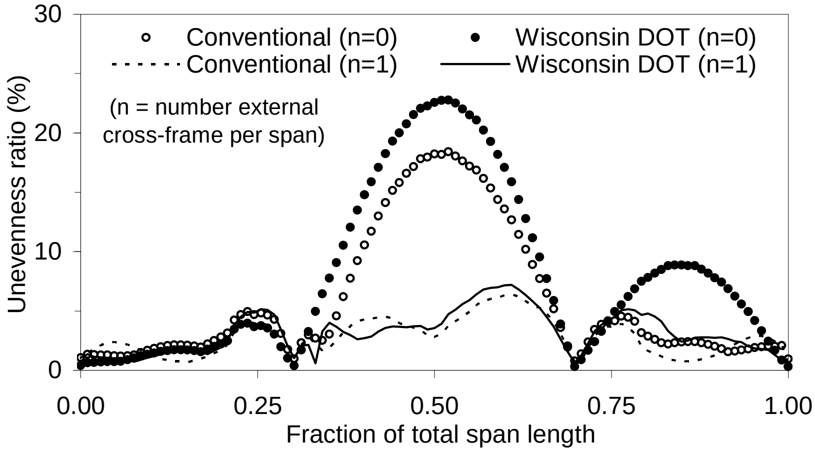
(Unit: mm)

Figure 2: Planar dimensions of a three-span continuous twin-girder and dimensions of three different cross sections.

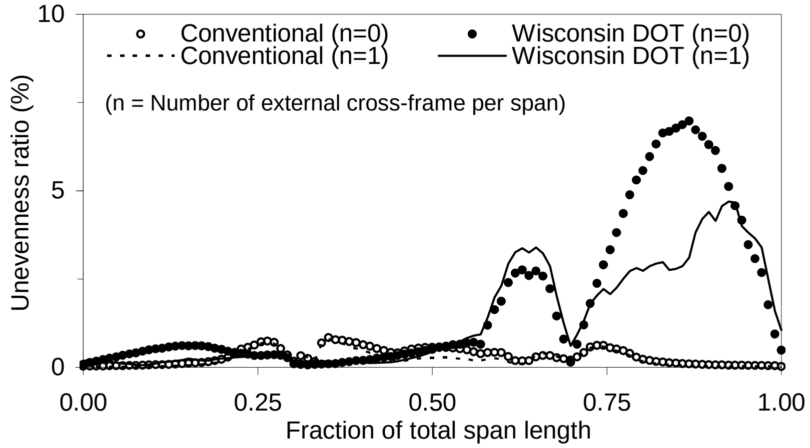
The Wisconsin DOT pouring sequence (State of North Carolina 2005) and the conventional deck pouring sequence (US Steel Corporation 1978; AISI 1996) have been examined for comparison. The unevenness ratios of an example three-span bridge with R=30.5 m during staged deck castings using the conventional and Wisconsin DOT pouring sequences are given Figures 3. After the first stage was completed, relatively large amounts of unevenness ratios were induced due to the dead loads of the poured deck concrete in every span by both Wisconsin DOT and conventional pouring sequences as shown in Figure 3(a). It has been found that the effects of the external cross-frames are evident in controlling the unevenness ratios. Once the second pour was complete, the unevenness ratios decreased significantly in both end-spans. At the final stage, when all the concrete has been poured (Figure 3c), the unevenness ratios have decreased considerably along the span length, except for relatively small amounts in the right-end-span for the Wisconsin DOT pouring sequence.



(a) After the first stage completed



(b) After the second stage completed



(c) After the final stage completed

Figure 3: Comparison of unevenness ratio during staged deck pouring sequence.

4. CONCLUDING REMARKS

Relative deflections and rotations caused by the deck concrete pouring were investigated for horizontally curved twin-box girder bridges with and without intermediate external K-frames. For three-span continuous bridges, two different deck pouring sequences were considered. A new parameter, the deck unevenness ratio, used to quantify uneven deck reference line in the transverse direction induced by relative deflections and rotations due to deck pouring. The additional external cross-frames did not significantly improve the unevenness ratio beyond that with only one. The unevenness ratios and forces in the external cross-frame members were not greatly affected by the stiffness of the external cross-frame members beyond a certain limiting threshold value. With regard to the unevenness ratio, the Wisconsin DOT pouring sequence appeared to offer no clear advantage over the conventional pouring sequence.

5. ACKNOWLEDGMENTS

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