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FINITE ELEMENT ANALYSIS ON INDUCED STRESSES IN HORIZONTALLY CURVED BOX GIRDER FLANGE

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ABSTRACT

The stress distribution in a horizontally curved box girder flange is quite complicated due to the inherent coupling of vertical bending and torsion plus stresses induced box distortion. Uncontrolled development of the distortional normal stress has a significant detrimental effect on the strength of a box girder. Through studies have been conducted to examine the longitudinal stresses on the bottom flange of a box girder with a horizontally curved geometry, the past studies do not provide sufficiently detailed design speculations to guide a simple determination of cross-frame design parameters. Thus, numerical analysis studies were conducted by using the finite element method to examine the effect of the cross-frames on the induced normal stresses in a tub girder. A typical curved box girder bridge currently constructed in the U.S was simulated and 3-dimensional finite element analyses were performed. Through a series of hypothetical bridge analyses, variation of the induced non-uniform stress along with corresponding diaphragm spacing is numerically examined and an optimum design for the cross-frames is proposed.

Keywords: Box girder, Diaphragm, Distortion, Finite element analysis, Horizontally curved girder.

1. INTRODUCTION

The stress distribution in a horizontally curved box girder flange is quite complicated due to the inherent coupling of vertical bending and torsion plus stresses induced by box distortion. Uncontrolled development of the distortional normal stress has a significant detrimental effect on the strength of a box girder. The distortional normal stresses in a box girder can be controlled by adequate number of internal cross-frames.

Therefore, modern specifications stipulate the maximum allowable distortional normal stresses. Since the distortional stresses can be controlled by placing adequate cross-frames, the design requirements are mainly concerned with the spacing and the stiffness of the internal cross-frames. Although there is no explicit provision in AASHTO LRFD (1996) and AASHTO Guide Specifications (1993) adopted in Article 1.29 that Spacing of internal bracing shall be such that the

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longitudinal distortion stress in the box shall not exceed 10 percent of the longitudinal stress due to vertical bending. If the designer adheres to the above stipulation, the normal stress gradient across the flanges of box girders should be less than 0.1. Hall and Yoo (1998) propose that spacing of intermediate internal bracing shall not exceed 30 feet in all curved box girders.

However, there are no more detailed speculations for design of internal cross frames to control the distortional normal stresses. A detailed examination of stresses induced in a horizontally cured box girder flange is presented in this paper. Analytical studies were conducted by using the finite element method to examine the induced pre-buckling stresses in a tub girder with a horizontally curved geometry, along with the cross-frames.

2. ANYTICAL STUDIES

2.1. Model description

A typical curved box girder bridge currently constructed in the U.S was selected for the analytical study. A one span hypothetical girder with a span length of 150 feet was modeled with simple supports in order to effectively conduct various comparative studies. The modeled box girder has one tub girder with a trapezoidal shaped cross-section as shown in Figure 1 (Choi 2002). The actual vertical girder depth is 72 inches and the slope of the webs is one-on-four.

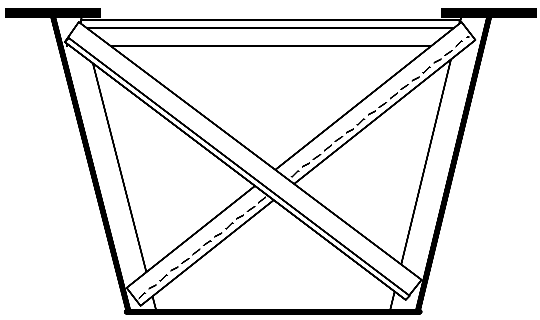


Figure 1: Cross-sections of Curved Box Girder Model

The box girders are internally braced at intermediate locations by X shape cross-frames. The spacing of cross-frames are varied from 150 feet, the same as the entire span length L, to 6 feet, corresponding to L/25 so as to investigate the effect of cross-frame spacing on the distortional stress of the curved box girder. A pair of structural angles is used for the cross-frame member.

2.2. Modeling for finite element analysis

Analyses for this study were performed using a three-dimensional finite element method. The commercial finite element software, MSC/NASTRAN v70.5 (1998), was used for the finite element analysis. Girder webs and flanges were modeled using a 4-node plate-shell element, CQUAD4, because of its simple yet numerically stable performance (Choi and Yoo 2005). Each hypothetical plate panel in this study was modeled by using ten subdivisions between the adjacent longitudinal stiffeners or the webs. The cross-frames of a WT section were modeled by a one-dimensional beam element, CBAR of NASTRAN. Steel weight is introduced into the model by the use of inertial body forces. The superimposed dead loads are applied as a distributed loading.

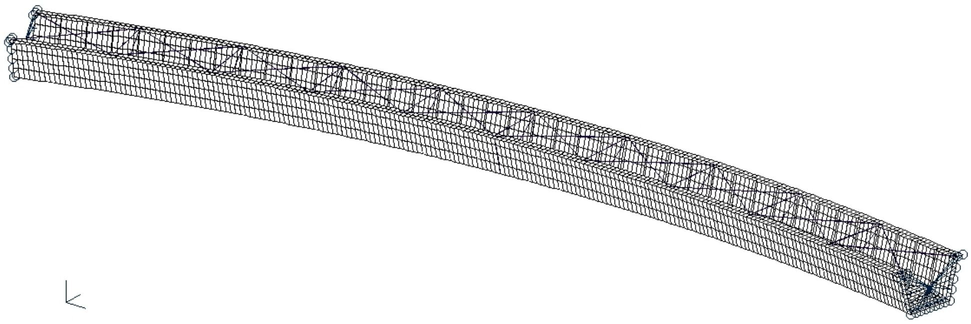
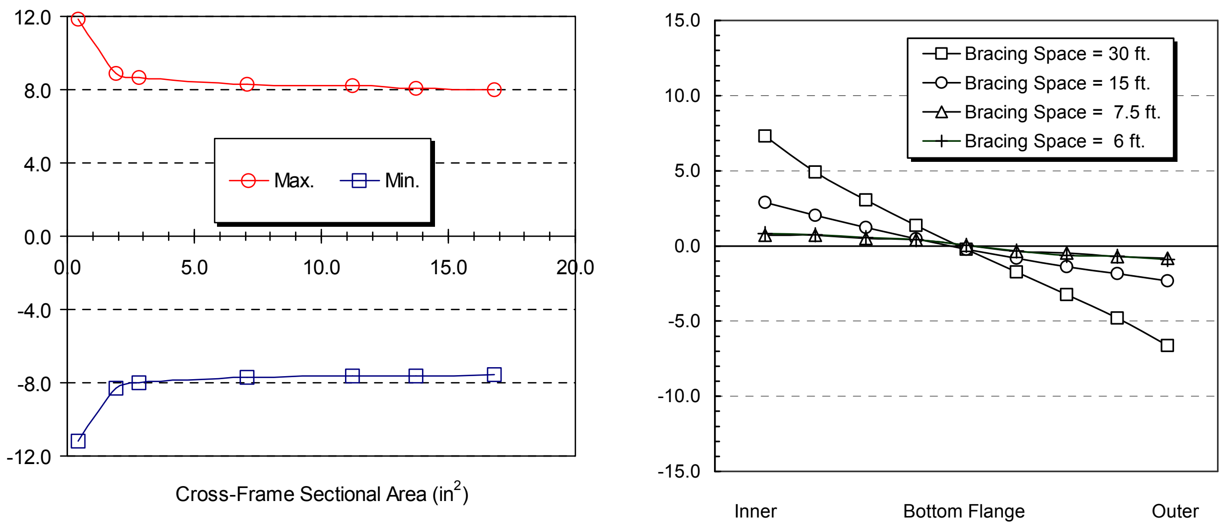


Figure 2: Finite Element Model Description

3. ANALYSIS RESUTLS

3.1. Effect of Sectional Stiffness of Cross-Frames on Distortional Stress

There is no detailed design specification for the determination of the internal cross-frame size. Therefore, a parametric study was conducted to examine which size of structural member would be appropriate for the internal cross-frame. The parametric study revealed that the cross-sectional area of internal cross-frames affect the distortional stresses of a closed composite girder section. The variation of the distortional stress ratio is presented, along with the stiffness of the cross-frame in Figure 3(a).



(a) along with Cross-Frame Sectional Area (b) along with Bracing Space

Figure 2: Non-Uniform Normal Stress Distribution in the Bottom Flange

After a certain point, there is no more variation in the ratio as the area continues to increase. Therefore, an optimum size for the cross-frame can be determined at this point. For this model bridge, the structural tee section, WT 7X24, was selected for the cross-frame member after a few trials.

3.2. Effect of Spacing of Cross-Frames on Distortional Stress

It is evident from Figure 3(b) that the distortional stress is linearly distributed across the cross-section of the bottom flange of horizontally curved box girders and the maximum value is greatly influenced by the spacing of cross-frames. The maximum distortional stress is inversely proportional to the spacing of the cross-frames. When the cross-frame spacing was reduced from 30 feet to 15 feet, the maximum ratio of the distortional stress to vertical bending stress ratio reduced from 10% to 4.8%. When the cross-frame spacing was reduced by half again, i.e., from 15 feet to 7.5 feet, the maximum stress ratio reduced only from 4.8% to 3.5%. There is no substantial decrease in the stress ratio corresponding to further reduction in the cross-frame spacing.

4. CLUDING REMARKS

The stress distribution in a horizontally curved box girder flange induced by distortional behavior is numerically examined. Effects of sectional stiffness and spacing of cross-frames on the distortional normal stresses were investigated for a typical curved box girder bridge. Consequently, an optimum size and spacing for the cross-frame was determined for the model bridge.

ACKNOWLEDGMENTS

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