곡선박스거더교의 뒤틀림효과에 대한 연구
A Study of the Distortional Effect on Curved Box Girder Bridge

뉴웬반반* • 한택희** • 김성남*** • 강영종****
Nguyen, Van Ban • Han, Taek Hee • Kim, Sung Nam • Kang, Young Jong

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ABSTRACT

Although just developed in recent years, curved box girder has widely used in modern highway system due to their load resistance capacity as well as aesthetic considerations. According to recent literature reviews on curved box girder designs, distortional load was not considered as much as it deserves to be. In practice, the effect of distortional force is very small in straight bridge systems but yet unknown how it is in curved bridge systems. For the reason, this paper will show up an extensive parametric study on distortional behavior of curved box girder with trapezoidal section. Based on Dabrowski formulas, using finite element method, various bridges were investigated. In this study, following parameters will be included: span length, curvature radius, section height, section width, and internal section angle (web slope). From the obtained results, some initial geometric parameters are proposed for curved box girder bridges.

Keywords: *Curved Box Girder, Distortional, Transverse Bending, Parametric Study, Trapezoidal Section.*

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1. Introduction

With the development of transportation system, numerous bridges were built; a bridge structure has developed not only the number of constructions but also the technology. Many constructions of elevated roadway, interchange··· require that bridge must be located on curves. With advantage itself, curved box girder was developed as an optimal solution for such the problems. Curved box girder bridges has widely been used in modern bridge structure due to their high response capacity of flexural, torsional as well as aesthetic considerations. Curved bridge could be reinforced or prestressed concrete structures, steel structures, or composite steel - concrete structures; the cross section could be rectangular or trapezoidal. Examining constructed bridge structures, composite steel concrete box girders are commonly used. Curved composite box girders have a number of unique qualities that make them be the best choice such as their structural efficiency, aesthetically appearance, high capacity to resist large torsional force,···. Although box girder has a number of advantages and many box girder bridges was constructed, but so far structural behavior of box girder bridges remains uncertain.

General theories on distortional behavior can be found in textbooks by Dabrowski 1968 or Nakai and

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[*] Ph.D. candidate, Dept. of Civil and Environmental Engineering, Korea Univ., E-mail: nvban2050@korea.ar.kr
[**] Ph.D. Dept. of Civil and Environmental Engineering, Korea Univ., E-mail: taekie@mail.korea.ac.kr
[***] Ph.D. candidate, Dept. of Civil and Environmental Engineering, Korea Univ.,E-mail: magach7@korea.ac.kr
[****] Prof. Dept. of Civil and Environmental Engineering, Korea Univ., E-mail: yjkang@korea.ar.kr

Yoo 1988. A comprehensive survey of experimental and analytical works on curved steel girders (including box girders) can be found in A.Zureick et al (1994) and composite box girder bridge in Sherif and Ayman report 2002. Popular current codes pertaining to analysis and design of curved girders include Guide Specifications for Horizontally Curved Highway Bridges (2003) and Guidelines for the Design of Horizontally Curved Girder Bridges - The Hanshin Expressway Public Corporation (1988)

In all above mentioned, distortional behavior in curved box girder distortional load was not considered as much as it deserves to be. Hence, a study on sectional properties considering the distortional behavior is necessary. Therefore, a Parametric Study of Trapezoidal Section in Curved Box Girder Bridge Including Distortional Warping is certainly introduced.

2. Distortional formulas

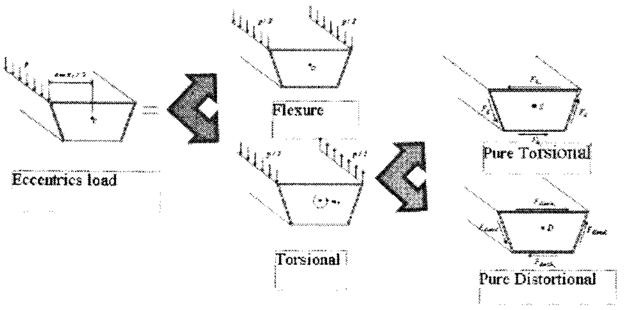

Fig. 1. Load disposition of single cell trapezoidal box girder bridges

Generally, when subjected to eccentric loads on the web, the major behaviors of box beam are divided into three parts: flexure, torsion, and distortion as presented in Fig. 1. In the case of flexure and torsion cases the cross section is assumed to be nondeformable, whereas for the transverse bending due to distortion it is assumed to be deformable section. For the trapezoidal single box girder bridge, Dabrowski (1968) had suggested the formulas to compute the torsional force, and the distortional force as in Table 1. In the case of curved girder bridge the formulas are similar, but the difference thing is the torque forces; the torque moment should be considered in two terms: Eccentric term and an additional part represent curvature term.

Table 1. Formulas of Torsional and Distortional loads

PureTorsional	PureDistortional
$F_{tor.h1} = \frac{B_1}{A_0} m_T$ $F_{tor.h2} = \frac{B_2}{A_0} m_T$ $F_{tor.d} = \frac{b}{A_0} m_T$	$F_{dist.d} = \frac{m_T}{B_1 \sin\theta} - \frac{b}{A_0} m_T$ $F_{dist.h_1} = \frac{B_1}{A_0} m_T - \frac{2m_T}{B_1} \cot\theta$ $F_{dist.h_2} = \frac{B_2}{A_0} m_T$

where mT : Torsional moment; B1 : Upper section width
B2 : Lower section width b: web's length
θ: Internal angular (web's slope) A0 : 2 times enclosed section area

3. Description of Finite Element Analysis

The finite element analysis program LUSAS was used to simulated three dimensional modeling of bridges. A four node shell element QSI4, with six degrees of freedom (three displacements and three rotations) at each node was used to model the girders. The boundary conditions and geometric properties are explained in Fig. 2. The typical element meshing of the models is shown as Fig. 3.

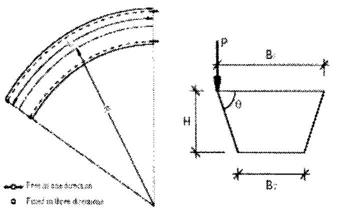

Fig. 2. Boundary conditions and geometric properties

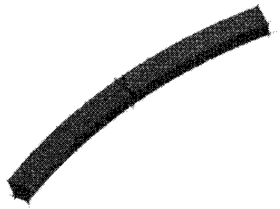

Fig. 3. Typical element meshing

The parametric study was based on the following assumptions: 1. There is completely interaction between the concrete deck slab and the top of the steel flanges of the box girders; 2. the materials, steel and concrete, are elastic and homogeneous; and 3. support lines are assumed to be radial to the bridge centerline. In the present state of the art, sine some nonlinear methods of analysis have not yet been fully embraced, the Codes still require the use of linear analysis for design. All North American codes of practice (AASHTO LRFD 1998; AASHTO 2003) recommend the use of linear elastic analysis to obtain the bridge internal forces due to live loads.

4. Verification of Finite Element Analysis

To verify the finite element model, the load composition is again checked for the case of curved girder. A bridge with 50m single span length, 80m horizontal curvature radius, and cross section whose is 4m in width for top flange, 3.5m in height and internal angle between web and top flange is 750 . The torsional forces and distortional forces were calculated as shown in Fig. 4a and Fig. 4b.

a) Torsional Forces

b) Distortional Forces

c) Deformed shape due to torsional forces

d) Deformed shape due to distortional forces

Fig. 4. Force disposition and deformed shape for DL 24 load case

Table 2 was shown the verifying result of load composition for curved box girder bridge for the first load case, the distributed load DL 24. We can see that the total normal stress summarizing by load disposition is 304.535KN and the exact normal stress given by eccentric load is 295.187KN so the error is 3.167% (<5%), this is a reasonable result. We can also verify the model by checking the deformed shape as show in Fig. 4c and Fig. 4d.

Table 2. Verify load deposition for load case DL 24

Torsional	Distortional	Flexure	Total	Eccentric	Error
22.817kN	44.605kN	237.113kN	304.535kN	295.187kN	3.167 %

Similarly, for concentrated load DB 24 we can derive an error which is 2.616% (<5%), it is also an acceptable result.

5. Parametric Study

The parametric study was done as the following process: Firstly, select a suitable interval investigate range of the considered parameter; the other parameters will be fixed, then we will investigate the structure behavior under changing of the considered parameter. According to literature reviews, represent to distortional behavior of structure is have two quantities, the first is the ratio of distortional normal stress (σdw) to bending normal stress (σb) and the second is the transverse bending normal stress due to distortional force (σts). Relate to those quantities, AASHTO Guider Specifications for Horizontally Curved Steel Girder Highway Bridge (2003) had suggested the limit of σdw/ σb is 10%; and of σts The limit is 20000psi (1400KN). HANSHIN Expressway Public Corporation in Guider for the Design of Horizontally Curved Girder Bridge (1988) had suggested as 0.5% and 50KN for σdw/ σb and σts, respectively.

In this paper following parameters were considered: span length, curvature radius, section height, section width, and internal angle (web slope). Webs thickness, flange thickness, diaphragm thickness were not considered in this research due to the insignificant effect of those parameters on distortional behavior.

5.1 Influence of internal angle θ

The use of the web slope in box girder bridges was known to reduce the width of the bottom flanges and provide a more efficient cross section; they also provide an aesthetic appearance to the bridge. In this study, we will investigate the effects of this angle on distortional behavior. According to Hall and Yoo (1999) the web slope of plane normal to the flange is recommended not to exceed 1 to 4, that means q should not smaller than 750. To investigate the influence of internal angle θ, θ will be considered as variables, θ varies from 70 to 90 for bridge span length L=50 m, horizontal curvature radius R=80m and with three different cross sections: 4.0x3.0m , 4.0x3.5m and 3.5x3.0m. Diaphragm space for single span box girder bridge was suggested by Im Da Su (2002), the ratio of diaphragm space to span length is 1/4. And in all cases, the web thicknesses, flange thicknesses, and diaphragm thicknesses was fixed as 25mm, 30mm and 35mm, respectively.

As can be observed from Fig. 5, the effect of web slope on the ratio of distortional normal stress to bending normal stress are significant, and it has a direct proportional relationship with the ratio. It is shown on the diagrams, when internal angle increases about 5 degree, the ratio of distortional normal stress to bending normal stress will increase about 3%. Fig. 6 has shown us the effect of internal angle on transverse bending normal stress due to distortional force. We can observe when internal angle increases 5 degrees, transverse bending normal stress will increase about 50 KN.

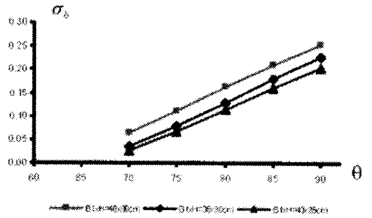

Fig. 5. Effect of θ on σdw/σb ratio

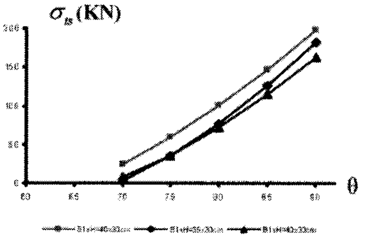

Fig. 6. Effect of θ on σts

5.2 Influence of B1/H ratio

The ratio of width to height of section have discussed in a number of researches. According to previous literature reviews, this ratio can be suggested base on many parameters. Usually in practical designs, the height of cross section will be firstly selected basing on span length and the type of bridge. In this study we consider to a single span bridge, base on bending behavior the height of cross section is suggested as 1/16~1/18 times of the span length. And the ratio of width to height of section is suggested from 1.1~1.5. To observe the influence of the ratio of width to height of a section on distortional behavior, height and width of section will be considered as variables: width of top flange will be change from 3.0m to 5.0m; and height of section will be changed from 2.0m to 3.5m.

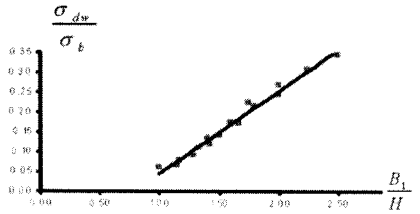

Fig. 7. Effect of B1/H on σdw/σb

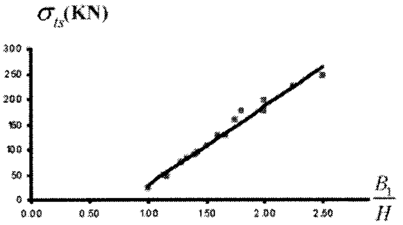

Fig. 8. Effect of B1/H on σts

According to 16 bridges was examined and the result shown as diagrams on Fig. 7 and Fig. 8 , ratio of top flange width to section height is significantly effect on the ratio of distortional normal stress to bending normal stress and also transverse bending normal stress. We can see that when B1/H increases 1 the σdw/σb increases more than 10% and σts increases about 120 KN. If consider to Hanshin limit, corresponding to σdw/σb ≤ 5%; B1/H is obtained as 1.1. And corresponding to σts ≤ 50KN; B1/H is obtained as 1.2. And basing on AASHTO guideline specification limit, σdw/σb ≤ 10%; B1/H is obtained as 1.3, and for σts ≤ 1400KN limit we can say that any selected sections are satisfied.

5.3 Influence of curvature L/R ratio

In practice, the designer always tries to design the bridges as straight as possible. AASHTO LRFD Bridge Design Specification (2004) suggests that the curvature is negligible if the central plane angle (Φ = L/R) is smaller than 12 degrees. A more commonly specification related to curved girder, AASHTO Guide Specifications for Horizontally Curved Steel Girder Highway Bridges (2003) had suggested this angle should be smaller than 17 degrees. The bridges were checked for in investigation have four different span lengths 30; 40; 50 and 60 meters. The horizontal radius of span centerline is changed among four values 60; 80; 100 and 120 meters. Diaphragms exist at the end of the span and at the one four position the intermediate diaphragms also exist. Cross section's height is 3.5 meters; top flange's width is 4 meters; internal angle is 75 degrees and web, flange, diaphragm thicknesses are 25mm, 30mm 35mm, respectively.

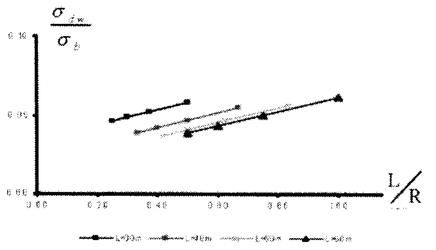

Fig. 9. Effect of L/R on σdw/σb ratio

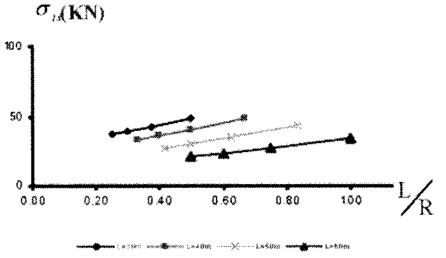

Fig. 10. Effect of L/R on σts

As we can observe, the horizontal curvature has significant effects on distortional behavior. Fig. 9 and fig. 10 show that the relationship between horizontal curvature and distortional warping normal stress is direct proportional. For each 0.2 radian (11.5 degrees) increase of horizontal curvature, the ratio of distortional warping normal stress to bending normal stress will increase 1%. For the case of transverse bending stress, when span length increases, the transverse bending normal stress will reduce but distortional warping normal stress will increase and of course, bending normal stress will also increase. That means the effect of eccentric loads will transfer to longitudinal effect when span length increases.

6. Conclusions

The purpose of this study is to increase the knowledge on distortional behavior of structures. According to over 200 bridges analyzed to investigate the influence of numerous parameters on distortional behavior in curved girder bridge, this study has upgraded and verified Dabrowski formulas of normal stress deposition. The notice when applying the formulas is the method to calculate toque moment mT, this moment should be calculated in considering two terms which are related to eccentric effect and the additional curvature effect.

Different from the case of straight box girder, this study has shown the significant effect of distortional forces. It is asserted that the distortional can not be neglected in designing curved bridges.

Considering parametric study, we have following conclusions:

- The internal angle has significant effect on distortional behavior in curved box girder bridge. The trapezoidal section should be used in curved box girder bridges, and it is suggested to use with the internal section angle of 75 degree
- The ratio of top flange width to section height has a direct proportional relationship to distortional behavior of structures. It is suggested to increases section height and reduce flange width under control by the limits of the ratio of distortional warping normal stress to bending normal stress to bending normal stress and transverse bending normal stress. It is recommended to use the limits given by HANSHIN Corporation or AASHTO guideline.
- The curvature effect on distortional behavior is significant, this parameter should be always considered when analysis distortional behavior in curved girder bridges.

Acknowledgment

This work is a part of a research project supported by Korea Ministry of Construction & Transportation (MOCT) through Korea Bridge Design & Engineering Research Center at Seoul National University. The authors wish to express their gratitude for the financial support.

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