

제형 단면을 갖는 곡선 박스거더교량의 뒤틀림 특성에 대한 매개변수 연구

Parametric Study on Trapezoidal Section in Curved Box Girder Bridge Including Distortional Warping

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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 an extensive parametric study on distortional behavior. 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.*

최근에 빠른 발전을 이루고 있기는 하나, 하중 저항 계수나 미관효과 면에서 박스 거더를 고속도로 분야에 폭넓게 사용하고 있는 실정이다. 최근의 박스 거더 설계를 기반으로 살펴보면 뒤틀림 하중은 그다지 고려되지 않았다. 특히 직선교에서는 뒤틀림 하중의 효과가 작지만 곡선에서는 어떻게 작용하는지 조차 알려진 것이 없었다. 그러한 이유에서 이 연구는 뒤틀림 거동에 미치는 주요한 변수들에 대해 다루었다. 그리고 유한요소법을 사용하는 Dabrowski formula 를 바탕으로 하여 다양한 변수의 교량에 대해 연구하였다. 이 연구에서는 다음과 같은 변수들이 사용된다. : 지간장, 곡률반경, 단면높이, 단면폭, 그리고 내부단면각(internal section angle) 연구된 결과로부터 적당한 초기 기하형상에 대한 변수들을 구할 수 있을 것이다.

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

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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 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.

Distortional formulas

Generally, when subjected to eccentric loads on the web, the major behaviors of box beam are divided into three parts: flexure, torsion, and distortion. For flexure and torsion cases the cross section is assumed to be nondeformable, and for the case of 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 as Eqs. (1), and the distortional force as in Eqs.(2). 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.

$$\text{Pure Torsional: } F_{tor.h1} = \frac{B_1}{A_0} m_T \quad ; \quad F_{tor.h2} = \frac{B_2}{A_0} m_T \quad ; \quad F_{tor.d} = \frac{b}{A_0} m_T \quad (1)$$

$$\text{Pure Distortional: } F_{dist.d} = \frac{m_T}{B_1 \sin \theta} - \frac{b}{A_0} m_T \quad ; \quad F_{dist.h1} = \frac{B_1}{A_0} m_T - \frac{2m_T}{B_1} \cot \theta \quad ; \quad F_{dist.h2} = \frac{B_2}{A_0} m_T \quad (2)$$

where m_T : Torque moment; B_1 : Upper section width
 B_2 : Lower section width b : web's length
 θ : Internal angle (web's slope) A_0 : 2 times enclosed section area

Description of Finite Element Analysis

The finite element analysis program LUSAS was used to simulated three-dimensionl 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. 1. The typical element meshing of the models is shown as Fig. 2.

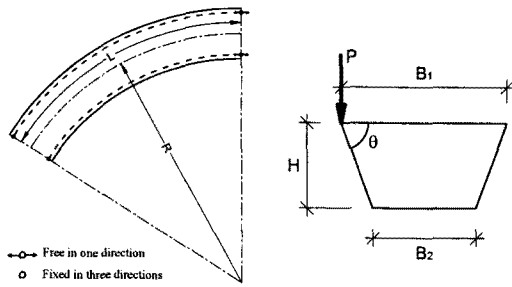


Fig. 1. Boundary conditions and geometric properties

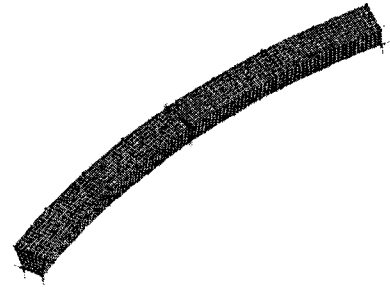


Fig. 2. Typical element meshing

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.

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 75° . The torsional forces and distortional forces were calculated as shown in Fig. 3a and Fig. 3b.



Fig. 3. Force disposition and deformed shape for DL-24 load case

- a) Torsional Forces b) Distortional Forces c) Deformed shape due to torsional forces
 d) Deformed shape due to distortional forces

Table 1 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. 3c and Fig. 3d.

Table 1. 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.

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 (σ_{dw}) to bending normal stress (σ_b) and the second is the transverse bending normal stress due to distortional force (σ_{ts}). Relate to those quantities, AASHTO Guider Specifications for Horizontally Curved Steel Girder Highway Bridge (2003) had suggested the limit of σ_{dw}/σ_b is 10%; and of σ_{ts} 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 σ_{dw}/σ_b and σ_{ts} , 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.

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 θ should not smaller than 75° . 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 $R=80$ m 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.

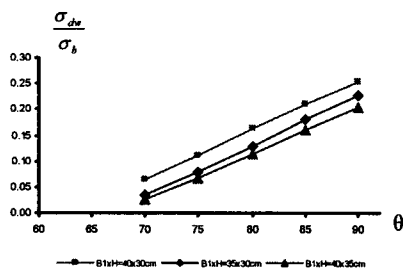


Fig. 4. Effect of θ on σ_{dw}/σ_b ratio

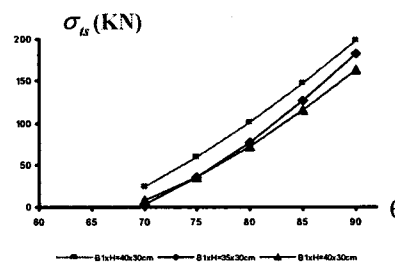


Fig. 5. Effect of θ on σ_{ts}

As can be observed from Fig. 4, 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. 5 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.

Influence of B_1/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.

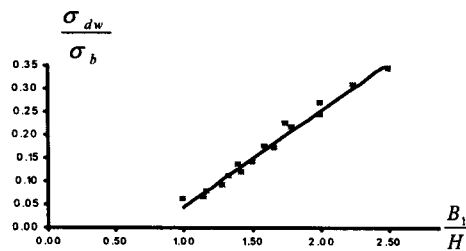


Fig. 6. Effect of B_1/H on σ_{dw}/σ_b

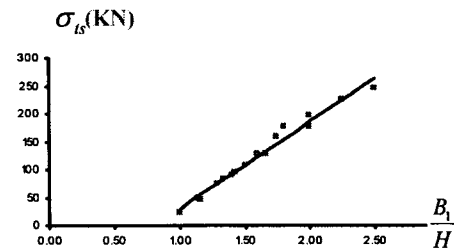


Fig. 7. Effect of B_1/H on σ_{ts}

According to 16 bridges was examined and the result shown as diagrams on Fig. 6 and Fig. 7 , 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 B_1/H increases 1 the σ_{dw}/σ_b increases more than 10% and σ_{ts} increases about 120 KN. If consider to Hanshin limit, corresponding to $\sigma_{dw}/\sigma_b \leq 5\%$; B_1/H is obtained as 1.1. And corresponding to $\sigma_{ts} \leq 50\text{KN}$; B_1/H is obtained as 1.2. And basing on AASHTO guideline specification limit, $\sigma_{dw}/\sigma_b \leq 10\%$; B_1/H is obtained as 1.3, and for $\sigma_{ts} \leq 1400\text{KN}$ limit we can say that any selected sections are satisfied.

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 ($\Phi = L/R$) 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.

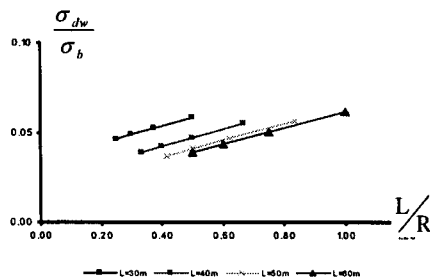


Fig. 8. Effect of L/R on σ_{dw}/σ_b ratio

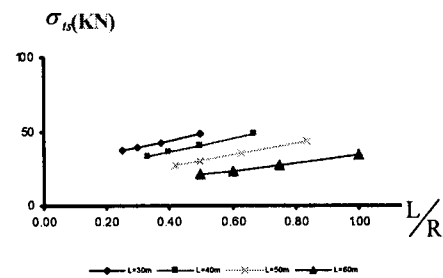


Fig. 9. Effect of L/R on σ_{ts}

As we can observe, the horizontal curvature has significant effects on distortional behavior. Fig. 8 and fig. 9 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.

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 torque moment m_T , 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 increase 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.

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