Eccentric Load Coefficient of Live Load Normal Stress of Continuous Composite Box-girder Bridge with Corrugated Steel Webs

MA Lei, Zhou Linyun, Li Shuqin, WAN Shui, a*

School of Transportation, Southeast University, Nanjing 210096, China

Abstract

A study of the eccentric load coefficient of continuous composite box-girder bridge with corrugated steel webs due to eccentric loading at the transverse position on the top flange were presented. The distribution laws of the eccentric load coefficient along the spans were developed by the finite element analysis comparing with several simplified methods commonly used in engineering. The results show that, for the continuous composite box-girder bridge with corrugated steel webs, it is not advisable to use a uniform eccentric load coefficient of each section along the bridge. A selection of practical analysis methods for the eccentric load coefficient is proposed for the engineering design.

© 2011 Published by Elsevier Ltd. Selection and/or peer-review under responsibility of Society for Resources, Environment and Engineering.

Keywords: continuous composite box-girder bridge ; corrugated steel webs ; spatial effect ; normal stress ; eccentric load coefficient

1. Introduction

The thin-walled structures subjected to transverse vertical point or distributed loads on any position of the top flange carry the bending normal stress, warping normal stress, warping shear stress and distortion shear stress which can cause not only the bending deformation, but also the rigid torsion and cross-section distortion[1]. For the simple concrete constant cross-section beams without intermediate diaphragm, the longitudinal warping normal stress can reach to 24%-26% of the longitudinal bending normal stress caused by live loads and dead loads[1]. Compared with the concrete box girder, the elastic modulus and longitudinal stiffness of the composite box-girder bridge with corrugated steel webs are smaller. So the
distortion is only restricted by the top and bottom flanges [2]. For this reason the magnitude of the forces and stresses due to torsion and distortion introduced by eccentric loading is significant compared with the bending normal stress. Usually the eccentric load coefficient is used to describe the magnitude [3].

When the transverse vertical point or distributed loads on any position of the top flange, it is resolved (Fig.1) into one symmetric and one antisymmetric loading, which can be further analyzed into two components of load: first, a torsional load component that has a resultant torque \( T = Py \) and tends to rotate the section as a rigid body about the longitudinal of the beam; and second, a distortional load component that tends to deform the cross section.

![Fig.1. Analysis of Nonsymmetric Loading](image)

So the normal stress of the cross section is present as:

\[
\sigma_z = \sigma_m + \sigma_{\omega} + \sigma_{d\omega} \tag{1}
\]

The eccentric load coefficient is defined as:

\[
\xi = \frac{\sigma_m + \sigma_{\omega} + \sigma_{d\omega}}{\sigma_m} \tag{2}
\]

In which \( \sigma_m \) is the bending normal stress, taken by the symmetric loading, \( \sigma_{\omega} \) is the restrained torsion normal stress, taken by the antisymmetric loading, \( \sigma_{d\omega} \) is the distortion normal stress by the antisymmetric loading.

2. Eccentric Load Coefficient Analytical Methods

Several analytical methods, such as theoretical method, numerical method and simplified calculation method, have been proposed to take into account the eccentric load coefficient. The simplified calculation method includes empirical coefficient method, eccentric compression method and modified eccentric compression method (see Ref.[4]). The theoretical method uses the thin-walled beam theory to analyze the bending normal stress and warping normal stress (see Ref. [5]). The numerical method, considering the bending normal stress and warping normal stress comprehensively, via the finite element analysis software to create a three-dimensional solid model to analyze the eccentric load coefficient. However, those methods have its own disadvantages. The simplified methods are convenient for the engineering
design but inaccurate. The empirical coefficient method is most simple but too leather sweeping. The beam stiffness is assumed infinite in the eccentric compression method and modified eccentric compression method. When the beam width is wide, the stiffness can no longer be seen as infinite, the analysis results will bring a great error (see Ref.[6]). The theoretical method is accurate but difficulty in calculating the restrained torsion bimoment and the distortion bimoment.

3. Eccentric Load Coefficient of Continuous Composite Box-Girder Bridge with Corrugated Steel Webs

Because of the disadvantages of the simplified method and theoretical method, the numerical method is used in this study to discuss the distribution laws of the eccentric load coefficient of continuous composite box-girder bridge with corrugated steel webs.

3.1. Numerical Method

- (1) Modeling principle
  Creating a three-dimensional solid model for the bridge, and considering the loading position in advance, guaranteeing the model’s precision through elaborate grid density of control section region.
- (2) Loading principle
  The live load is performed according to the general code for design of Highway Bridge and culverts (JTG D60-2004). The control sections are chosen as the mid-span section, L/4-span section and pier top along the bridge in axial direction. According to the influence lines, which play an important role in bridge design, determining the loading position.

3.2. Calculation and Analysis

3.2.1. Engineering Situation

Taking Weihe bridge for an example, calculating and analyzing the eccentric load coefficient of continuous composite box-girder bridge with corrugated steel webs. It is a three spans of continuous composite box-girder bridge with corrugated steel webs and constant cross-section. The spans are 47m, 52m and 47m. The top flange width of the box-girder is 16.85m, the thickness is 25cm; the width of the floor is 11.85m, the thickness is 22cm; the height is 3.2m; the webs are corrugated steel webs whose thickness is 12mm. The concrete is C50 which proportion is 2650kg/m³, the elastic modulus is 3.5×10⁴MPa and Poisson’s ratio is 0.1667; the webs are steel Q345D, which proportion is 7850kg/m³, the elastic modulus is 2.06×10⁵MPa and Poisson’s ratio is 0.3.

3.2.2. Finite Element Model

The three-dimensional solid model for the bridge is created by using ANSYS. The spatial effect of the eccentric load is analyzed, including the bending normal stress and warping normal stress. The bending normal stress under the symmetrical load is also calculated. Then taking the both results into equation (2), the eccentric load coefficient can be derived. The finite element model of middle span segment is shown as Fig. 2 (a).

According to the loading principle, the control sections are chosen as the mid-span section, L/4-span section and pier top section. Loading layout of each section along the bridge in transverse direction is shown as Fig. 2 (b).
3.3. Analysis Results

The results of normal stress under the symmetrical load and the eccentric load, the eccentric load coefficients of the control sections are shown as Tab.1.

Tab.1 Eccentric Load Coefficients of Control Sections

<table>
<thead>
<tr>
<th>Control section</th>
<th>Normal stress under symmetrical load (MPa)</th>
<th>Normal stress under eccentric loads (MPa)</th>
<th>Eccentric load coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>L/4 side span</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top flange</td>
<td>-3.67</td>
<td>-5.54</td>
<td>1.51</td>
</tr>
<tr>
<td>Bottom flange</td>
<td>5.73</td>
<td>6.47</td>
<td>1.13</td>
</tr>
<tr>
<td>Middle side span</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top flange</td>
<td>-5.74</td>
<td>-8.17</td>
<td>1.42</td>
</tr>
<tr>
<td>Bottom flange</td>
<td>9.29</td>
<td>9.94</td>
<td>1.07</td>
</tr>
<tr>
<td>Pier top</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top flange</td>
<td>3.51</td>
<td>5.51</td>
<td>1.57</td>
</tr>
<tr>
<td>Bottom flange</td>
<td>-3.12</td>
<td>-7.20</td>
<td>2.31</td>
</tr>
<tr>
<td>L/4 middle span</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top flange</td>
<td>-2.93</td>
<td>-4.66</td>
<td>1.59</td>
</tr>
<tr>
<td>Bottom flange</td>
<td>4.56</td>
<td>5.29</td>
<td>1.16</td>
</tr>
<tr>
<td>Middle span</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top flange</td>
<td>-4.06</td>
<td>-7.02</td>
<td>1.50</td>
</tr>
<tr>
<td>Bottom flange</td>
<td>7.77</td>
<td>8.24</td>
<td>1.06</td>
</tr>
</tbody>
</table>

The results show that the eccentric load coefficients vary rapidly not only along the bridge in axial direction but also in the same section. It is not reasonable to use a uniform eccentric load coefficient of each section along the bridge by empirical method. The larger value of the same section is chosen for the engineering design to ensure the safety of the structure. Compare with the suggestion value of the eccentric load coefficients of continuous variable beam in Ref [7], the value is larger on the corresponding sections of continuous composite box-girder bridge with corrugated steel webs along the spans.

3.4. Test

The load test is conducted for the above project by using six trucks with payloads of 30 t. Loading layout along the bridge in axial direction is shown as Fig.3(a) and transverse loading layout shown as
Fig. 3(b). The load efficiency are separately 88% and 85% for the side span and the middle span. The normal stress under the eccentric load and the symmetrical load can be obtained. Then taking the both results into equation (2), the eccentric load coefficient can be derived.

Fig. 3. (a) Axial Direction Loading Layout (unit: m); (b) Transverse Loading Layout (unit: cm)

3.5. Several Methods Comparison

The calculation results are shown as Tab. 2 by several methods, such as empirical coefficient method, eccentric compression method, modified eccentric compression method, test and finite element method.

Tab. 2 The Eccentric Load Coefficient Results

<table>
<thead>
<tr>
<th>Control section</th>
<th>Eccentric load coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Finite element method</td>
</tr>
<tr>
<td>L/4 side span</td>
<td>1.51</td>
</tr>
<tr>
<td>Middle side span</td>
<td>1.42</td>
</tr>
<tr>
<td>Pier top</td>
<td>2.31</td>
</tr>
<tr>
<td>L/4 middle span</td>
<td>1.59</td>
</tr>
<tr>
<td>Middle span</td>
<td>1.50</td>
</tr>
</tbody>
</table>

The results show that the calculation of above methods varies widely. Compared with the results of the empirical coefficient method and the result of test, the difference is -13%. Compared with the results of the eccentric compression method and the result of test, the difference is 55%. Compared with finite element method, the difference is 35%~44% in the side span and 28%~36% in the middle span. The eccentric compression method is conservative. But in the pier top, the difference is -12%, which is unsafe. The results of the modified eccentric compression method are most close to the results of finite element method and the test. Compared with the result of the test, the difference is -2.3%~6.9%. Compared with finite element method, the difference is -9.2%~14.6% in the side span and -18.7%~23.3% in the middle span.

The results of the modified eccentric compression method are most close to the results of finite element method and the test. However, the load efficiency of this test is 85%~90% which is not the design load. It will lead to unsafe to calculate the eccentric load coefficients by using the modified eccentric compression method, while using the finite element method there will be some security reserves.

The finite element method is suggested for the accurate calculation for the eccentric load coefficients.
chosen for the continuous composite box-girder bridge with corrugated steel webs. To simplify the calculation, the modified eccentric compression method can be used with a proper correction factor. The empirical coefficient method can be used in the preliminary design stage.

4. Conclusion

The distribution laws of the eccentric load coefficient of continuous composite box-girder bridge with corrugated steel webs along the spans are shown as follows. For the continuous composite box-girder bridge with corrugated steel webs, it is different along the spans. So it is not advisable to use an uniform eccentric load coefficient for the whole bridge. It reaches the maximum at the pier top and the values of the L/4 sections of the side span and middle span are rarely larger than the middle of corresponding spans.

There are large deviation in the results of the ordinary used calculation methods. The result of empirical coefficient method is unsafe. The result of the eccentric compression method is conservative in spans and unsafe at the pier top. The results of the modified eccentric compression method are most close to the results of finite element method and the test, but it will be unsafe. The finite element method is suggested for the accurate calculation for the eccentric load coefficients chosen for the continuous composite box-girder bridge with corrugated steel webs. To simplify the calculation, the modified eccentric compression method can be used with a proper correction factor. The empirical coefficient method can be used in the preliminary design stage.

References