Brace Forces in Horizontally Curved Steel Box Girder with Two Types of Lateral Bracing System by Using ANSYS Program

Hawraa Sami Malik¹*, David A.M. Jawad¹

¹Department of Civil Engineering, University of Basra, Basra, Iraq
*Corresponding author’s e-mail address: hawraasa12@gmail.com

Abstract. The U-shaped steel trapezoidal box girder is designed to work compositely with the concrete deck to form a closed-section for live loading. The critical stage of these girders are during construction since the fresh concrete and the whole construction load must be support by the non-composite steel section. At the top flange level, a lateral bracing system is typically mounted to form a quasi-closed section and thus increase the torsional stiffness at construction stage. In the current study, A horizontally curved steel box girder with two and three spans were used, lateral bracing includes two types of bracing system; Single Diagonal (SD) and a Crossed Diagonal (XD). Equations from prior studies estimate the lateral bracing forces for box girders with a good accuracy. The axial forces evaluated by 3-D Finite Element Analyses (ANSYS 19.2) are compared with the axial forces computed from the equations, there are excellent correlations between the finite element analysis and the equations, where the average of difference in the first case study with SD and XD was equal to 0.66% and 2%, respectively, while in the second case study it was 1.3%. Also it can be note that the deflection diagram for girder with XD bracing type is more uniform than the girder with SD bracing type. ANSYS software has been an efficient, inexpensive method and easy to use for designers of bridges.

Keywords: ANSYS program, Box girder, Horizontally curve, Lateral bracing

1. Introduction

Because of the developments in technology of fabrication, the use of steel box girders for curved interchange structures has become common. The economics, rapid erection, long span capability and aesthetics of these girders make them more suitable compared with other structural systems. The trapezoidal box girder is an open cross-section with low torsional rigidity. This causes a problem in bridge construction during its early stages as the steel girder may be under large torques. In order to improve the box torsional stiffness horizontal truss added near the top flanges of the girder is generally used [1]. In particular, the effects of vertical bending of the U shape girder on the lateral bracing forces will be addressed. Most design methods ignored the effects of bending stresses of girders on the horizontal truss behavior; however, in many instances, maximum truss forces caused by the torsional moments is less than the member forces in the maximum bending area. In addition, large lateral bending stresses may occur in the top flanges depending on the type of bracing system that is used, Box girders physically are not closed sections. The top of the girder is left open to reduce material and facilitate construction. A truss, framework or lattice at the top of the girder replaces the top plate and provides the equivalent effect of a plate connecting the top flanges. This allows box-girders to be considered as closed or quasi-closed sections that are able of transferring the torsional effects. Dabrowski (1968) [2] and Kollbrunner and Basler (1969) [3] found equations to estimate the contribution of the top truss
into the system to be replaced as a fictitious equivalent plate known as the Equivalent Plate Method. The equivalent plate thickness can be determined for different truss layouts and cross-sectional areas of all lateral bracing members. This method provides a simplified analytical way to estimate the torsional properties of the box-girder as a closed box section. The equations and associated dimensions for different lateral bracing truss layouts are shown in Figure 1.

![Figure 1. Equivalent plate thickness for the top flange lateral bracing system. [4]](image)

The equations shown in Figure 1 represent the most common layouts used in Tub-girder systems with equal top flange dimensions [4]. Different studies have been dealt with the using of box girder on curved bridges. In 2003, C. Topkaya, And B. Williamson developed a computational software for curved girders analysis under construction loads. In this study, an alternative analysis approach was presented by the Finite Element Method (FEM). In the proposed method the shell elements are used for modeling steel section and brick elements for the concrete deck, the axial forces in lateral bracing members and stresses were measured during casting the concrete in different segments and compared with the program results [5]. Kyungsik Kim and Chai H. Yoo, F.Asce (2006), investigated the interaction of internal and lateral bracing systems in steel box girders. The purpose for using lateral bracing system is to increase the box girder torsional resistance of tub girders and retaining its original shape. Both lateral bracing type (SD or XD) are adopted along with internal bracing member that are placed at odd or even numbered spacing, significant coupling action between internal bracing and lateral bracing (SD) has been occur in the case internal bracing at odd numbered panels, the lateral bracing forces are (25–30%) higher than those when the internal bracing are placed at even numbered panels. Matrix equations were formulated to calculate the SD bracing forces, the results of bracing force showed a good agreement between equations and three-dimensional finite element analysis [6]. In 2012, Ahmed Rageh, et. Al investigated top flange bracing forces of steel tub girders. U-shape girders without the concrete slab do not have a full closed cross section during the construction. A lateral truss system is usually installed in a level near the top flange to form a quasi-closed section, these lateral bracing are need for stabilize the top flanges of the tub sections in compression during the pouring of concrete deck, it also helps to form the shape of the box. There are various truss system arrangements needed to stabilize steel tub girders. This study includes an analytical investigation on the possible different bracing systems which includes, XD, (SD), Pratt (N) and K
types. A 3D Finite Element Method is used for modeling thin walled box girders to predict diagonal and strut forces acting on these bracing systems. The models are chosen to simulate the construction phases of the bridge. The comparisons made between the different bracing types and behavior was informative and may provide a useful tool for bridge designers [7]. In 2015, Mehri, Hassan discussed the bracing system of steel bridges during construction, this study included full-scale laboratory testing, numerical modeling and analytical solutions. The results showed that by adding lateral bracing, the load-carrying capacity could be improved at 10-20% of the span near the supports. The analytical approach was used for finding the critical moment of the girders at the compression flange level. Also the experimental studies were performed on I-girder bridges in which the location of the bracing was varied along the girders depth. [8].

In the current study, non-composite curved steel boxes are analyzed and their behavior is investigated. The FEM is the most effective method for construction load analysis, It has the ability to model the construction in great detail and it is more accurate than the other methods of analysis [1]. In this study two analytical approaches used for analyzing curved box girder includes: the approximate hand method and the computer method (Finite Element Method FEM). The Finite Element Method is useful as it can be used to design horizontally curved box girder bridges in an economical way, and we don’t need experimental and laboratory tests so in this study the validity of ANSYS program has been examined.

2. Methodology:
2.1 Determining the Brace Forces
The top lateral bracing forces due to sloping webs, bending and torsion can be found directly by using 3D-FEM, analytical methods for determining the lateral member forces found by Fan and Helwig (1999) [9] will be summarized.

2.1.1 Vertical Bending
The axial force in top flange bracing is created due to the girder bending. When the lateral bracing members are jointed with the girder top flanges, the deformations of the longitudinal top flange between panel points due to bending stresses presents a longitudinal deformation and axial force in the diagonals of lateral member. Figure 2 shows the effect of lateral bracing in resisting the vertical bending, if only the box girder is used to support the bending forces, the dashed line will represent the stress distribution through the tub girder depth, but when the box girder is braced by lateral truss member it will reduce the bending stresses as shown by the solid line [9].

Figure 2. Tub Girder Vertical Bending Stresses.
The equations in Figure 3 are used to predict the truss forces resulting from the vertical bending of the girder [9]. The compatibility of forces of the top bracing will be tensile for negative moments (-M) and compressive in the positive moment (+M) region.

2.1.2 Torsional force
The torsional analysis of box girders can be done by using the M/R method to find the torsional moment along the span coupled with the equivalent plate method for defining the cross section geometric properties. The resulting torsional properties are used in the structural analysis to find out the torsional moment in the box girder. The shear flow (q) in a closed cross section is equal to \( T / (2A_0) \) where \( T \) is the torsional moment and \( A_0 \) is the enclosed area of the box. The shear flow influence on the imaginary plate is then transformed to axial forces in the diagonal lateral bracing as:

\[
D_{\text{tor,sd}} = \pm \frac{qb}{\sin \alpha} = \pm \frac{b}{2A_0 \sin \alpha} T \\
D_{\text{tor,xd}} = \pm \frac{qb}{2 \sin \alpha} = \pm \frac{b}{4A_0 \sin \alpha} T
\]

Where;
$D_{\text{tor,SD}}, D_{\text{tor,XD}} =$ diagonal forces in SD type and XD type bracing due to applied torque, respectively; $\alpha =$ angle between the top flange and the diagonal and $b =$ width of top flanges between webs.

In 2002, Fan and Helwig [10] studied box girders distortion and separated the pure torsional and distortional components from the applied torque as in Figure 4.

Both vertical bending and torsion produce forces in top truss members. Diagonal of lateral bracing and top flanges are subjected to the same total longitudinal deformation as shown in Figure 5a. The sloping webs of the girders also produce a lateral load component on the girder top flange. This lateral load component creates additional axial forces in the struts as well as lateral bending stress at the top flange the struts are generally designed to carry the horizontal component caused by the sloping webs. Figure 5 explains the vertical load transformation into a horizontal component and web shear, $f$ (force per unit length).

In 1999, Fan and Helwig [9] developed equations for the estimation of brace forces in SD and XD types, and suggested the following design expressions:

$$D_{\text{tor}} = D_{\text{EPM}} + D_{\text{bend}} + D_{\text{lat}}$$

Where

$D_{\text{lat}} =$ total force in diagonal, $D_{\text{bend}} =$ diagonal force due to bending and $D_{\text{lat}} =$ diagonal force due to components of lateral force, $D_{\text{EPM}} =$ diagonal force came from the torsional moment calculated using the Equivalent Plate Method (EPM) suggested by Equations (1) and (2)
For simplicity, Fan and Helwig proposed to design the strut to carry the full lateral load, where: \( s \) = spacing between struts, \( S_{\text{lat}} = s \) times \( w_{\text{lat}} \) and \( D_{\text{lat}} = 0 \), \( w_{\text{lat}} \) = lateral load portion, It basically amounts to saying that the struts hold all the lateral force components.

### 2.1.3 Equations for Brace Forces

The diagonal forces, \( D \) in the lateral bracing system of type SD due to torsional loading and vertical bending are summarized as:

\[
D = D_{\text{tor}} + D_{\text{BPM}} + D_{\text{bend}} + D_{\text{lat}}
\]

Where subscripts, tor, dist, bend and lat, denote brace forces that are caused by pure torsion and distortion, vertical bending and lateral load, respectively.

\[
D_{\text{bend}} = \frac{f_{\text{stopt}} \cdot s \cdot \cos \alpha}{AD + \frac{a}{As} \cdot \sin^2 \alpha + \frac{s^3}{24lf}}
\]

\[
f_{\text{stopt}} = \frac{M}{S_{\text{stopt}}}
\]

Where

- \( f_{\text{stopt}} \) = longitudinal stress at the center of top flange.
- \( M \), is the girder moment at the middle of panels
- \( S_{\text{stopt}} \) is the section modulus based on the extreme fiber distance to the top flange

\[
D_{\text{lat}} = \frac{24A_D A_S \sin \alpha}{24A_S d l_f + A_D (A_S S^3 + 24a_1 l_f) \sin^2 \alpha} \cdot w_{\text{lat}}
\]

\[
D_{\text{tor}} = \frac{a}{2A_D \sin \alpha} \cdot T
\]

\[
D_{\text{dis}} = \frac{A_D A_S S^3 \sin \alpha}{48A_S d l_f + 2A_S A_D S^3 \sin^2 \alpha + 48A_D a_1 l_f \sin^2 \alpha}
\]

It must be noted that the components of force are functions of torsional and bending moments. It is appropriate to measure diagonal forces by superimposing only \( D_{\text{bend}} \) and \( D_{\text{tor}} \), since the \( D_{\text{lat}} \) and \( D_{\text{dist}} \) magnitudes are relatively small.

### 2.2 Finite Element Modeling

#### 2.2.1 Case study 1

For numerical analysis of the three-span continuous curved box girders a general purpose Finite Element System (ANSYS19.2) [11] has been used. The box girder cross section and the solid diaphragms were modeled with (SHELL281) elements. The shell elements are eight-node with six degrees of freedom at each node. The solid diaphragms were placed at every support of the continuous box girder. All bracing members were modeled with three-dimensional quadratic three-node beam elements (beam189) having six degrees of freedom. In this model, (SD) type of lateral bracing and X-shape internal bracing were examined, an internal bracing member was positioned at each strut position, these struts were placed at the top flanges of the box girders, see Figure 6 [12]. Linear-elastic finite element analysis was adopted for non-composite steel constructions using values of modulus of elasticity equal to (200000 MPa) and Poisson’s ratio equal to 0.3. The boundary conditions at one of the middle bearings of the three span box girder are restrained in all \( x \), \( y \) and \( z \) directions, the ends and the second middle bearings are restrained.
against the vertical movement (y-direction) and against the z-direction movement (towards the bridge transverse direction) as shown in Figure 7.

2.2.2 Case study 2
The bridge studied in this case is located at Al Terbia intersection in Basra city. The steel portion of this bridge consists of twin steel trapezoidal box girders for the two span continuous bridge with a radius of curvature of 150 m at the centerline of the cross-section and a concrete deck placed on the two trapezoidal box girders. The two curved steel continuous spans of the bridge are symmetric and 40 m long each. The concrete slab has 9500 mm width and thickness of 250 mm, as shown in Figure 8.
The top lateral bracing of the continuous box girder are shown in Figure 9. The internal diaphragms are spaced every 4m. The locations of these diaphragm are also known as panel points. L100x100x10 angle section members were used for internal K. frame and for top lateral bracing. L125x125x12.5 angle sections were used for the strut beams. Intermediate external diaphragms are made up of two L125x125x12.5 angle sections welded together.

In order to study lateral bracing system single box girder under weight of fresh concrete that can be calculated by multiplying the cross section area of the deck by the concrete density (15.5kN/m on each flange) will be used, Figure 10 shows the dimensions of the box girders. There is lateral brace within each panel. The plates' thicknesses of the box girder are given in Table 1.

| Plate          | Thickness (mm) |
|----------------|----------------|
| Top flange     | 25             |
| Web            | 16.5           |
| Bottom flange  | 25             |
| End Diaphragm  | 20             |
| Web plate      | 14.1           |
| Bottom stiffeners | 20         |

A general purpose Finite Element Program, ANSYS (19.2), was used in the analyses of the two-span continuous curved girders shown in Figure 11. The cross sections of the girders and the
solid diaphragms were modeled with shell elements (SHELL181). The solid diaphragms, were placed at each supports of the continuous box girder. Diagonals of the bracing system were modeled by using (Beam188). The modulus of elasticity is 200000 MPa and Poisson’s ratio is equal to 0.3.

The boundary conditions of the two span box girder are restrained in all x, y and z directions at mid span of the bridge, while restrained against vertical movement (y-direction) and against the movement in the transverse (z-direction) at the ends of bridge.

![Two-span continuous curved girders.](image)

**Figure 11.** Two-span continuous curved girders.

3. Results

**3.1 Comparison of Lateral Bracing Forces**

The lateral bracing forces computed from the afore mentioned equations were compared with the finite element results of the continuous box girder bridge using (ANSYS 19.2). Cross-frames with X- shape are used for internal bracing, Figure 12 shows the dimension and the loads of the girder, the girder has 54 panels (16+22+16) with SD type of lateral bracing. The bending moment diagram for this girder is shown in Figure 13.

![Horizontally curved tub girder with three-spans](image)

**Figure 12.** Horizontally curved tub girder with three-spans [11].
Figure 13. Bending Moment Diagram.

Figure 14. Comparison results of the axial force on (SD) lateral bracing.

Figure 15. Displacement on top flange of box girder with SD lateral bracing.
Table 2. Diagonal forces of three-span continuous horizontally curved box girder with SD type (kN)

| Panel no. | Proposed equations (kN) | FEM (kN) | Diff. (%) |
|-----------|-------------------------|----------|-----------|
|           | Dbend  | Dlat  | Dtor  | Ddist | Sum   |           |           |
| 1         | -7.918 | 3.69  | -150.44 | -1.423 | -156.088 | -156.04 | 0.0003    |
| 2         | -21.796 | 3.692 | 137.495 | -3.9144 | 115.520 | 114.47 | 0.009     |
| 3         | -32.427 | 3.692 | -114.14 | -5.827 | -148.66 | -156.766 | -0.054    |
| 4         | -39.856 | 3.692 | 83.093  | -7.117 | 39.857 | 36.235 | 0.091     |
| 5         | -44.037 | 3.692 | -47.151 | -7.873 | -95.369 | -102.84 | -0.078    |
| 6         | -45.061 | 3.692 | 8.941   | -8.051 | -40.434 | -44.471 | -0.099    |
| 7         | -42.836 | 3.692 | 28.691  | -7.651 | -18.104 | -25.47 | -0.407    |
| 8         | -37.365 | 3.692 | -63.075 | -7.651 | -103.466 | -106.82 | -0.032    |
| 9         | -28.735 | 3.692 | 91.544  | -5.159 | 61.385 | 53.615 | 0.126     |
| 10        | -16.859 | 3.692 | -111.25 | -3.024 | -127.397 | -128.81 | -0.011    |
| 11        | -3.779  | 3.692 | 119.479 | -0.311 | 121.081 | 113.29 | 0.064     |
| 12        | 15.613  | 4.759 | -113.60 | 2.535  | -90.699 | -93.984 | -0.036    |
| 13        | 35.942  | 4.759 | 90.788  | 5.827  | 137.272 | 133.23 | 0.029     |
| 14        | 59.294  | 4.759 | -48.352 | 9.608  | 25.310 | 13.5 | 0.466     |
| 15        | 75.486  | 5.872 | -16.369 | 11.432 | 76.375 | 80.438 | -0.053    |
| 16        | 101.375 | 5.872 | 106.179 | 0 | 213.425 | 198.25 | 0.071     |
| 17        | 100.974 | 5.872 | 26.555  | 0 | 133.402 | 137.35 | -0.029    |
| 18        | 74.241  | 5.872 | 62.364  | 11.209 | 153.686 | 149.43 | 0.027     |
| 19        | 56.937  | 4.759 | -125.39 | 9.208  | -54.491 | -64.419 | -0.182    |
| 20        | 32.605  | 4.759 | 165.251 | 5.293  | 207.909 | 204.24 | 0.017     |
| 21        | 11.343  | 4.759 | -184.60 | 1.824  | -166.675 | -171.49 | -0.028    |
| 22        | -7.295  | 3.692 | 186.292 | -1.289 | 181.399 | 174.51 | 0.037     |
| 23        | -23.397 | 3.692 | -172.90 | -4.181 | -196.789 | -200.42 | -0.018    |
| 24        | -36.253 | 3.692 | 147.236 | -6.494 | 108.181 | 102.04 | 0.056     |
| 25        | -45.905 | 3.692 | -112.01 | -8.229 | -162.449 | -168.43 | -0.036    |
| 26        | -52.355 | 3.692 | 67.926  | -9.385 | 9.877 | 5.98 | 0.326     |
| 27        | -55.558 | 3.692 | -23.754 | -9.964 | -85.584 | -92.403 | -0.079    |

Symmetry
Table 3 and figure 18 comparatively show forces in the diagonals lateral bracing system for the model, the diagonal forces find out from Equations have a good agreement with those competed from the finite element modelling as shown in Figure 18. The largest difference is observed in diagonals with lower force values. As it is possible that the same section will be used for all
diagonals, this broad difference in the diagonals that are subjected to the lowest forces tends to be inconsequential. As the diagonal forces due to lateral bending and distortion are relatively small that ignored in Fan and Helwig (1999) [9], major differences are not expected between the two analytically defined values. The normal stresses and deflection on the three span bridge with SD type lateral bracing are shown in figures 20 and 21, respectively.

Table 3. Diagonal force in XD type for three span continuous box girders (kN)

| Panel no. | Proposed equations (kN) | FEM (kN) | Diff. (%) |
|-----------|-------------------------|----------|-----------|
|           | $D_{\text{bend}}$ | $D_{\text{lat}}$ | $D_{\text{tor}}$ | $D_{\text{dist}}$ | Sum |        |
| 1         | -16.64                | 3.692    | -75       | -1.423               | -89.44 | -78.48 | 0.122 |
| 2         | -45.34                | 3.692    | 68.5      | -3.914               | 22.856  | 18.282  | 0.200 |
| 3         | -67.39                | 3.692    | -57       | -5.827               | -126.59 | -122.3  | 0.034 |
| 4         | -82.91                | 3.692    | 41.5      | -7.117               | -44.929 | -45.87  | -0.021 |
| 5         | -91.52                | 3.692    | -23.5     | -7.873               | -119.32 | -113.5  | 0.048 |
| 6         | -93.81                | 3.692    | 4.45      | -8.051               | -93.808 | -94.03  | -0.002 |
| 7         | -89.02                | 3.692    | 14.35     | -7.651               | -78.724 | -73.50  | 0.066 |
| 8         | -76.96                | 3.692    | -31.5     | -6.717               | -111.56 | -114.4  | -0.025 |
| 9         | -59.69                | 3.692    | 45.75     | -5.159               | -15.506 | -12.76  | 0.177 |
| 10        | -34.94                | 3.692    | -55.5     | -3.025               | -89.844 | -96.49  | -0.073 |
| 11        | -3.744                | 3.692    | 59.75     | -0.311               | 59.306  | 59.233  | 0.001 |
| 12        | 25.428                | 4.759    | -56.8     | 2.535                | -24.112 | -37.38  | -0.550 |
| 13        | 58.68                 | 4.759    | 45.4      | 5.827                | 114.64  | 107.55  | 0.061 |
| 14        | 96.17                 | 4.759    | -24       | 9.608                | 86.09   | 73.541  | 0.145 |
| 15        | 100.11                | 5.871    | -8.2      | 11.431               | 109.183 | 89.275  | 0.182 |
| 16        | 133.92                | 5.871    | 53        | 0                    | 192.796 | 228.86  | -0.187 |
| 17        | 133.79                | 5.871    | 13.3      | 0                    | 152.963 | 199.5   | -0.304 |
| 18        | 98.124                | 5.871    | 31        | 11.209               | 146.194 | 121.75  | 0.167 |
| 19        | 92.91                 | 4.759    | -62.7     | 9.207                | 44.17   | 35.27   | 0.201 |
| 20        | 53.138                | 4.759    | 82.5      | 5.293                | 145.698 | 136.8   | 0.061 |
| 21        | 18.419                | 4.759    | -92.3     | 1.823                | -67.321 | -76.28  | -0.133 |
| 22        | -15.18                | 3.692    | 93        | -1.289               | 80.126  | 77.957  | 0.027 |
| 23        | -48.67                | 3.692    | -86.5     | -4.181               | -135.75 | -138.1  | -0.017 |
| 24        | -75.29                | 3.692    | 73.5      | -6.494               | -4.696  | -3.362  | 0.284 |
| 25        | -95.68                | 3.692    | -56       | -8.229               | -156.31 | -154.4  | 0.012 |
| 26        | -108.9                | 3.692    | 35        | -9.385               | -79.772 | -75.76  | 0.050 |
| 27        | -115.5                | 3.692    | -11.9     | -9.964               | -133.8  | -130.5  | 0.024 |

Symmetry
Figure 18. Comparison results of the axial force on (XD) lateral bracing.

Figure 19. Displacement on top flange of box girder with XD lateral bracing.
Table 3 and Figure 18 show good agreement between forces in diagonals lateral bracing system for XD type model calculated from equations and from the finite element model (ANSYS 19.2). The normal stresses and deflection on the three span bridge with XD type lateral bracing are shown in figures 16 and 17, respectively. The stresses and the displacements for the SD type are greater than that for the XD type lateral bracing as shown in figures 20 and 21. From figures 15 and 19 it can be note that the deflection diagram for girder with XD bracing type is more uniform than the girder with SD bracing type.
For the second case study, the lateral bracing system of (XD) type has a total of 20 panels. Figure 22 shows bending moment diagrams. Table 4 and Figure 23 comparatively show forces in the diagonals lateral bracing system for the model. The normal stresses and deflection on the two span bridge with XD type lateral bracing are shown in figures 24 and 25, respectively.

![Bending moment diagram at middle of panels.](image1)

![Comparison results of the axial force on (XD) lateral bracing.](image2)

**Table 4.** Diagonal force in XD type for two span (kN)

| Panel no. | Proposed equations(kN) | FEM(kN) | Diff. (%) |
|-----------|------------------------|---------|-----------|
|           | $D_{bend}$ | $D_{lat}$ | $D_{tor}$ | $D_{dist}$ | $Sum$ |         |         |
| 1         | -7.624  | 3.86   | -31.99   | -4.950   | -40.707 | -43.912 | 0.078  |
| 2         | -19.66  | 3.86   | -22.730  | -13.68   | -52.214 | -60.169 | 0.152  |
| 3         | -27.42  | 3.86   | -12.909  | -19.08   | -55.556 | -62.366 | 0.122  |
| 4         | -30.91  | 3.86   | -3.088   | -20.07   | -50.210 | -55.606 | 0.107  |
| 5         | -30.12  | 3.86   | 6.616    | -19.55   | -39.196 | -41.622 | 0.061  |
| 6         | -25.04  | 3.86   | 16.268   | -16.26   | -21.179 | -22.02  | 0.039  |
| 7         | -16.39  | 3.86   | 24.508   | -1.344   | 31.88   | 27.99   | -0.129 |
| 8         | -2.164  | 3.86   | 31.533   | 9.18     | 68.786  | 56.432  | -0.179 |
| 9         | 15.657  | 3.86   | 40.089   | 9.18     | 116.025 | 104.71  | -0.097 |
| 10        | 37.592  | 3.86   | 49.888   | 24.684   | 116.025 |         |        |

Symmetry
Table 4 and Figure 23 show excellent correlation between the equations and results from Finite Element Modeling (ANSYS 19.2). The forces on the diagonals exhibit little differences due to the presence of support diaphragm. This localized interaction is not captured by the component force equations.
4. Conclusion
During construction of box girders, the fresh concrete and all construction load must be supported by the non-composite steel section. A top truss system must be installed to form a quasi-closed section in order to increase the torsional stiffness. The presented equations were used to predict the lateral member forces due to bending of girders and the lateral component of the applied load, these forces were compared with finite element results, the results showed that

- The Finite-Element Program (ANSYS 19.2) results have good agreement with the equations for the curved box girders, it can be noticed that the largest discrepancy occurs in diagonals with the lowest forces.
- The average of difference in the first case study with SD and XD was equal to 0.66% and 2%, respectively, while in the second case study it was 1.3%.
- For bracing systems with a Single Diagonal (SD type), the axial forces induced from bending lead to large lateral bending stresses in the top flanges of box girder, these stresses are larger than the stresses induced in XD bracing type.
- Also, the deflections in girder with XD type were less than the deflections in girder with SD type, and the deflection diagram for girder with XD type is more uniform than the girder with SD type.

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