Investigation the using of internal diaphragms in horizontally curved box girders by ANSYS program

Hawraa sami malik and David A.M. Jawad

Abstract - Horizontally curved tub girder bridges exhibit torsional and distortional behaviour in additional to the bending caused by initial curvature of bridge. The distortion causes in two major stress components, transverse bending and Distortional warping normal stresses, these two components are usually limited to a particular level for effective use of the cross-section by adding internal bracing elements. The objectives of the current study are to check the validity and reliability of the equations by using three-dimensional finite element analyses of the internal diaphragms and also examine the effect of the number of cross-frames. Two and three spans continuous horizontally curved steel tub girder bridges with K- frames provided at one and two panel spacing are used.
ANSYS (19.2) program are used to find internal and strut bracing force, those forces are compared very well with the results obtained from the Equations.

Keyword - box girder; internal bracing; ANSYS program.

1 INTRODUCTION

In the recent years, the use of horizontally curved girders in highway bridges and interchanges design especially in the approaches has been increased. Actually, in these days over 0.25 of all steel bridges build up are curved.The reason for the increase in the use of curved bridges is that they satisfy an economical means of providing the demand used on Highway Bridge by determined roadway alignment and geometric constraints to sustain the needed traffic design speed. Also, curved bridges made an aesthetically solution that has caused raised use of designs that employ curved configurations. [1]

In box girders the internal stiffening is needed in order to withstand distortional loads and retain their original cross-sectional shape. Box girders distort mostly due to the torsional moments produced from eccentrically applied loads. Torsional moments on the steel tub girder can be divided into two forces, these forces will rotate the girders about the longitudinal axis and distort the cross-sectional shape.

The installation of internal cross-frames can be used to control this distortion. There are two preferred types of internal bracing; K-shaped frames and X-shaped frames as shown in Figure (1).

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For the spacing and minimum stiffness requirements, no guidelines are available for the internal bracing member design as a function of the produced forces and spacing

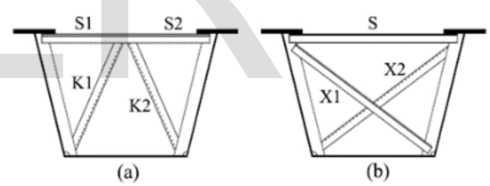


Figure 1 internal bracing for trapezoidal box girder: (a) K-frame and (b) X-frame [2]

Different studies have been dealt with the using of box girder on curved bridges.
In 2003 Khaloo and Mirzabozorg [3] studied the effects of the arrangement of internal diaphragms on the behaviour of bridges. they modelled a 3D finite element of the simply supported bridge with different skew angles and fourteen arrangements of the diaphragms to compare the results between each model, they used the distribution factor that represent the ratio between bending moment in the composite action and bending moment due to single girder line of wheel load. They concluded that the best load distribution arrangement in skew bridge occur when the deck with internal bracing perpendicular to the longitudinal line of the girder. Whisenhunt (2004) [4] used 3D finite element method to study the effect of the type of cross-frame to the deflection behaviour of the steel plate girder bridges.

From the results of bridge models with k-type and x-type of cross-frames, he found out that different configuration of cross-frame has variant effects on the bridge behaviour .Nam-Hoi Park, ET. Al, (2005) [5] studied the spacing of internal bracing in horizontally curved steel tub girder bridge, finite element modelling are used to find the maximum spacing of internal bracing members. The result shown that the distortional warping moment can be effectively controlled by using diaphragms. The connection between the intermediate diaphragm spacing and the ratio of the distortional warping to the bending normal stresses was studied and the results were showed in the form of temporary design charts. These charts will help engineers for determining the adequate intermediate spacing for a given particular stress ratio

The present work aims to explore the validity of ANSYS program in simulating internal bracing of curved box girder bridges.

2 Controlling Distortion of box girder

The torsional stiffness of box girders include Saint Venant and warping components; the large Saint Venant component that is caused by a closed cross-section will lead to high torsional stiffness in these sections. Torsional warping stresses in box girder are relatively small because the St.Venant term control the torsional stiffness. Depending on the applied torsional loads distribution, the box girder cross-section may distort from its original shape. This deformation can cause considerable warping stresses, beside the torsional warping stresses, the created warping stresses caused by the cross-section distortion are properly referred to as distortional warping stress. While torsional warping stresses in steel box girders may be relatively small, but the bracing distortional warping stresses can be significantly large. Usually, tub girder distortion is restrained by placing internal bracing members along the girder length. Forces promote in these internal members and other bracing elements because of the box girder distortion. Torsion in tub girders is mainly due to horizontal curvature or unbalanced gravity loading that lead to an eccentric load on the cross-section. The torque on box girders can be created as a vertical or horizontal couple, depending on the loading type as represented in Figure (2). The (M/R) method leads to an effective torque as in Figure (2a). When an eccentric load is applied, the adequate torsional loading can be represented as clear in Figure (2b). Figure (3) shows that when the girder is subjected to eccentric loading, then the gravity loading will split into two component, pure flexural load and torque consisting of a vertical couple. [1]

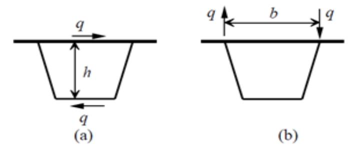


Figure 2 Representation of Torque on Box Girder [1]

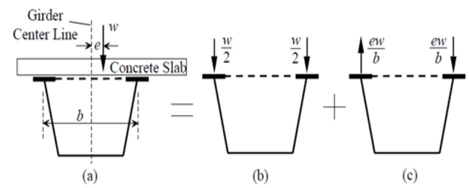


Figure 3 Effective Loading from Eccentric Gravity Loading [1]

In 2002 Fan and Helwig gave an explanation for the distortional caused by components in the diagonals and struts of the internal bracing (K-frames) depending on the horizontal curvature of the girder and eccentric gravity loading [1]

$$D = \mp \frac{S_K L_{DK}}{2A_0}\left(\frac{M}{R} - \frac{a}{b} ew\right) \qquad [1]$$

$$S = \mp \frac{S_K a}{4A_0}\left(\frac{a}{b} ew - \frac{M}{R}\right) \qquad [2]$$

Where:

D, S; axial force in the diagonal and strut of K-frame, respectively.

S_k; spacing between intermediate diaphragms

L_{DK}; diagonal length of internal member

A_0= ((a + b)/2h)

a,b,h : Dimensions of cross-section

e; eccentricity of the load ;

w; distribution load (N/mm);

M; bending moment of tub girder; and

R; radius of curvature.

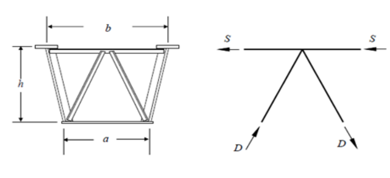


Figure 4 Internal force of the strut and diagonal of K-Frame

Similarly, in 2002 Fan and Helwig derived expressions for the brace forces in the internal X-frame considering applied torque and box girder curvature as following

$$X = \mp \frac{s_X}{8L_X}\left(\frac{a+b}{h} + \frac{4h}{a+b}\right)\left(\frac{a}{b}ew - \frac{M}{R}\right) \qquad [3]$$

Where:

X is axial force in the diagonal of X-frame, R = radius of curvature; M = bending moment; e = eccentricity of load relative to box girder centroid; a and b = web spacing at bottom and top flanges level, respectively; w = uniformly distributed load.

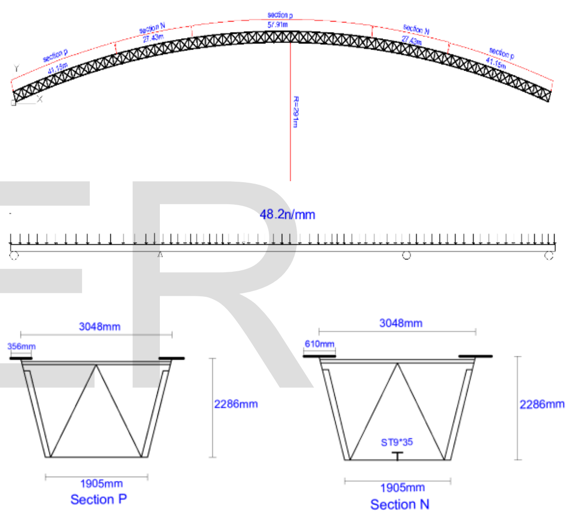
3 Finite Element Modelling

The finite element structural software can be used to undertaken simple analysis as (linear, elastic analysis) and complex analysis as (nonlinear, dynamic analysis). Due to the software suitability for many engineering branches, and to increase the process speed and reduce the required space, the program is divided to groups and subgroups each have their own finite elements, instructions and specifications.
ANSYS software has three main parts:
1 – Model Construction,
2 – Applying Loads and analysis, and
3 – Reading the results.
The selection of right elements is most important part of the model construction. This computer program has 180 elements each of them has a certain conditions, so, the elements selection with the required specifications can be done easily.
For the second part, analysis type, the loading cases and conditions must be entered. The analysis type is depending on loading and response considered.
ANSYS program consists of static, modal, harmonic, spectrum, semi-structural, transient and flexural analysis. There are two ways for observing the results of analysis. First one is to see the results of a part or for the whole model in the form of model deformations, table or colored curve and the second way is to find the results according to a specific point in the model in the form of curves with respect to table.

In the numerical analysis of this study, ANSYS (19.2) program was used, The tub box girder cross section and the end diaphragms were model with three-dimensional SHELL181 element with four-node and six degrees of freedom at each one. All bracing members were modelled by using (beam188) element. Internal diaphragms were placed at all strut locations. When K-frames are used, then the struts act as top members of internal bracing. Linear-elastic finite element analyses were used on modelling non-composite steel girder with modulus of elasticity equal to (200000) and Poisson's ratio (0.3). The Boundary Conditions at one of the middle bearings were restrained in all directions, while the other mid bearing and end bearings were restrained against y and z directions only.

4 Case study one

A three span curved continuous box girder with concentric loading was studied, the total length of bridge is (195m) divided to 64 panels (18+28+18), the diagonal lateral member is WT6 × 13 sections and equal angle L4 × 4 × 5/16'' section for the struts and internal bracing. A uniformly distributed vertical load of 48.2 N/mm is applied on the top flanges (24.1 N/mm per each flange), the whole bridge details were shown in Figure 5.
Using the bending moments at the location of internal diaphragm, the internal bracing forces are calculated with the equations (1) and (2) with e = 0 [2], and compared with the results from F.E.M. (ANSYS19.2)
The diagonals and struts bracing force on horizontally curved steel box girders with internal K-frames and XD type lateral bracing are plotted along the girder length in Figures 6 to 9 and induced in Tables (1), (2)



Cross section	Top flange(mm	Web(mm)	Bottom flange (mm)
P	22	16	13
N	57	48	19

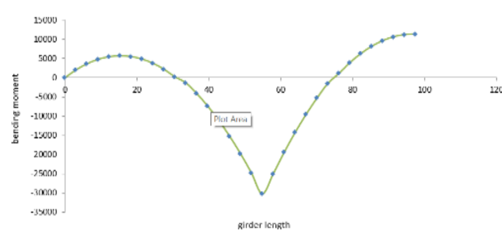
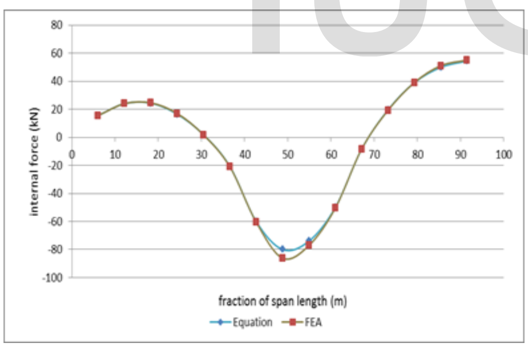


Figure 5 Curved continuous box girder

Table (1) Forces in the K-frame elements (kN)

Panel	Bracing at 3.05			Bracing at 6.1		
	Equation	FEM	Dif.	Equation	FEM	Dif.
1	5.588	4.831	-0.135			
2	9.949	7.886	-0.207	15.6	15.546	-0.003
3	13.085	10.483	-0.199			
4	14.995	12.197	-0.187	24	24	0
5	15.680	12.879	-0.179			
6	15.138	12.515	-0.173	24.2	24.56	0.006
7	13.369	11.119	-0.168			
8	10.375	8.703	-0.161	16.5	16.977	0.029
9	6.156	5.308	-0.137			
10	0.771	1.055	0.369	1.8	1.733	-0.037
11	-5.461	-3.833	-0.298			
12	-13.859	-9.270	-0.331	-20.8	-21.111	0.014
13	-22.982	-16.686	-0.273			
14	-33.331	-31.005	-0.069	-60.1	-60.593	0.008
15	-44.907	-41.930	-0.066			
16	-57.708	-54.105	-0.062	-80	-86.188	0.077
17	-70.735	-55.557	-0.214			
Diaphragm						
19	-68.679	-49.683	-0.277			
20	-53.274	-48.365	-0.092	-74	-77.100	0.042
21	-39.099	-37.038	-0.052			
22	-26.156	-26.269	0.004	-50	-50.500	0.010
23	-14.443	-11.800	-0.183			
24	-3.962	-3.058	-0.228	-8.4	-8.326	-0.009
25	3.132	3.646	0.164			
26	10.841	9.704	-0.104	19.6	19.302	-0.015
27	17.319	15.093	-0.128			
28	22.566	19.622	-0.130	39	39.01	0.0002
29	26.582	23.175	-0.128			
30	29.367	25.713	-0.124	49.92	51.033	0.022
31	30.921	27.236	-0.119			
32	31.244	27.747	-0.112	54.5	55.068	0.010
Symmetry						



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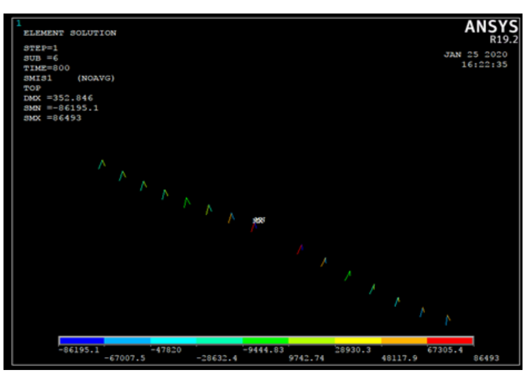

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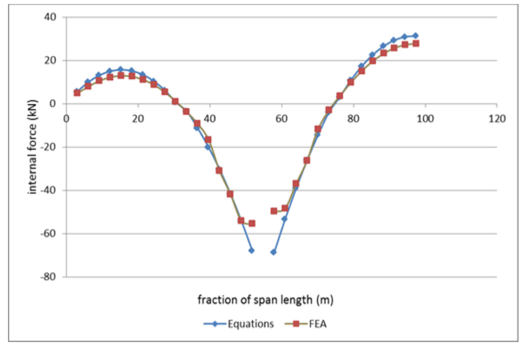
Figure 6 axial force in internal bracing at every two panel



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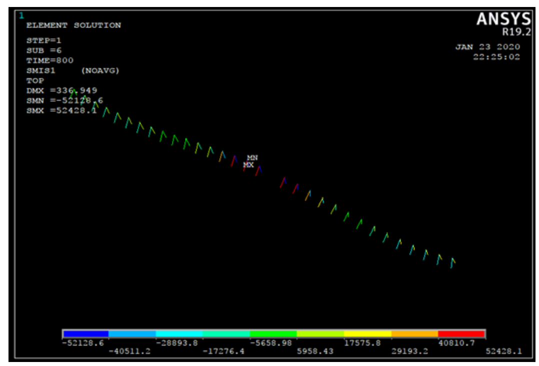
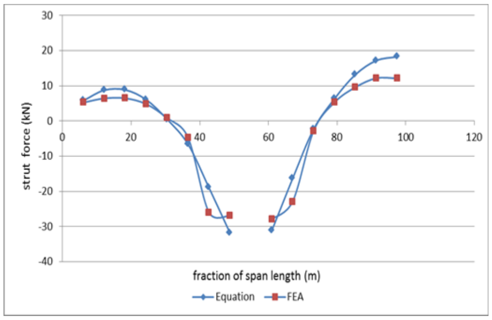


(b)

Figure 7 axial force in internal bracing at every two panel

Table (2) bracing forces in the strut elements (kN)

Panel	Bracing at 3.05			Bracing at 6.1		
	Equation	FEM	Dif.	Equation	FEM	Dif.
1	2.095	1.663	-0.206			
2	3.731	4.121	0.104	5.825	5.275	-0.094
3	4.907	5.344	0.089			
4	5.623	6.138	0.091	8.779	6.456	-0.264
5	5.879	6.439	0.095			
6	5.676	6.248	0.101	8.862	6.4852	-0.268
7	5.013	5.570	0.111			
8	3.890	4.394	0.129	6.074	4.8383	-0.203
9	2.308	2.728	0.181			
10	0.266	0.419	0.573	0.5	0.876	0.752
11	-1.336	-1.933	0.446			
12	-4.216	-5.850	0.387	-6.58334	-4.6605	-0.292
13	-7.556	-8.987	0.189			
14	-11.355	-10.656	-0.061	-18.9258	-25.954	0.371
15	-15.614	-13.826	-0.114			
16	-20.333	-23.505	0.155	-31.7465	-26.844	-0.154
17	-25.511	-32.156	0.260			
Diaphragm						
19	-25.755	-33.551	0.303			
20	-19.97	-24.310	0.216	-31.191	-27.85	-0.107
21	-14.66	-13.012	-0.112			
22	-9.808	-8.859	-0.096	-16.347	-22.862	0.398
23	-5.416	-6.617	0.221			
24	-1.486	-1.870	0.258	-2.319	-2.837	0.223
25	1.174	1.661	0.414			
26	4.065	5.148	0.266	6.347	5.3132	-0.162
27	6.494	8.184	0.260			
28	8.462	10.599	0.252	13.212	9.6193	-0.271



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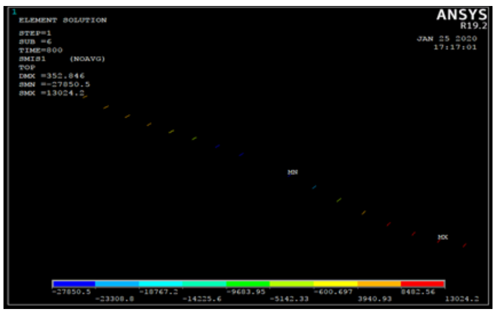

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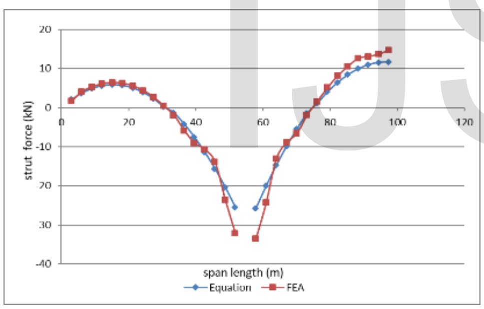
Figure 8 bracing force in strut at every two panel



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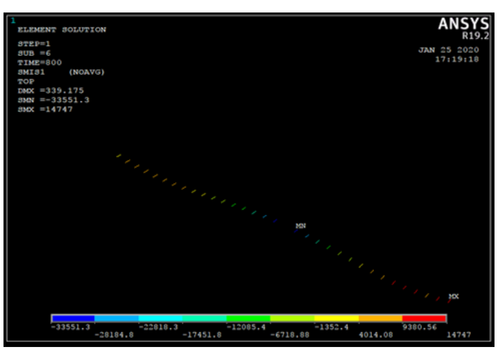

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Figure 9 bracing force in strut at every panel

The internal bracing elements are placed every one or two panel spacing in order to prevent distortion in box girders. The cross-frame spacing and cross-sectional geometry are the main parameter that effect on the bracing force as implied by Equations (1) and (2). In order to examine the spacing effects, box girders provided with bracing at one and two-panel spacing were analysed and the results are shown in tables 1 &2. The previous figures show the comparatively diagonal and strut forces, the axial forces estimated from Equations compare very well with the finite element results.

5 Case study 2

The bridge studied in this case is located at Al Tarbia intersection in Basra city, A two span continuous bridge with a trapezoidal cross section of two cells and 80 m long (see fig 10), both girders have the same cross section so we studied one girder with load equal to (15.5 kN/m) distributed uniformly on the top flanges of each girder .the K-frame internal bracing is considered in this analysis. The sizes of the struts were L125×125×12.5 mm and L100×100×10 mm for both lateral and internal bracing. The internal bracing members were placed at every panel

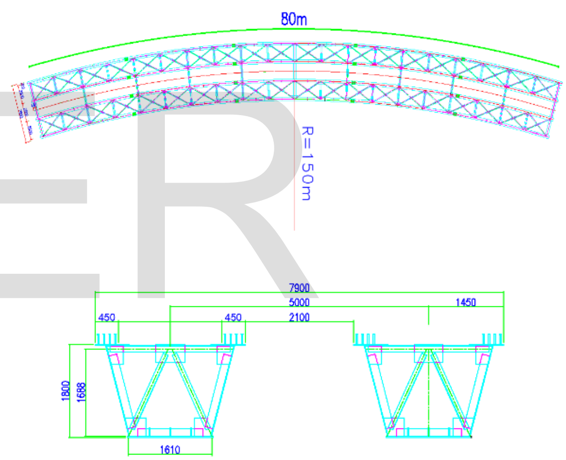


Plate	Thickness(mm)
Top flange	25
Web	16.5
Bottom flange	25
End Diaphragm	20
Web plate	14.1
Bottom stiffeners	20

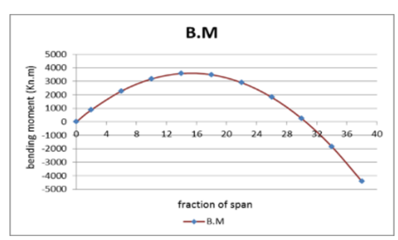


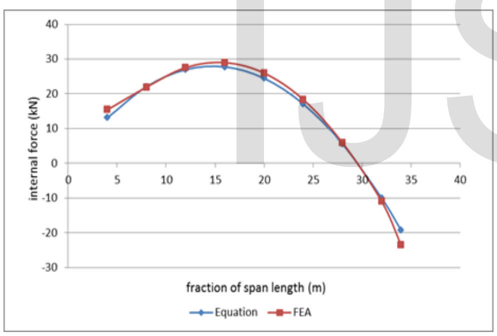
Figure 10 Curved continuous box girder

Table (3) axial force in internal bracing members (kN)

Panel	Equation	FEM	Dif.
1	13.088	15.397	0.176
2	22.080	21.938	-0.006
3	26.976	27.577	0.022
4	27.776	28.989	0.044
5	24.480	25.989	0.062
6	17.088	18.369	0.074
7	5.600	5.9424	0.061
8	-9.984	-10.951	0.096
9	-19.312	-23.539	0.218
Symmetry			

Table (4) axial force in strut bracing members (kN)

Panel	Equation	FEM	Dif.
1	6.544	5.497	-0.160
2	11.040	12.035	0.090
3	13.488	14.715	0.091
4	13.888	14.979	0.079
5	12.240	13.056	0.067
6	8.544	9.041	0.058
7	2.800	3.029	0.082
8	-4.992	-5.183	0.038
9	-9.656	-9.121	-0.055
Symmetry			



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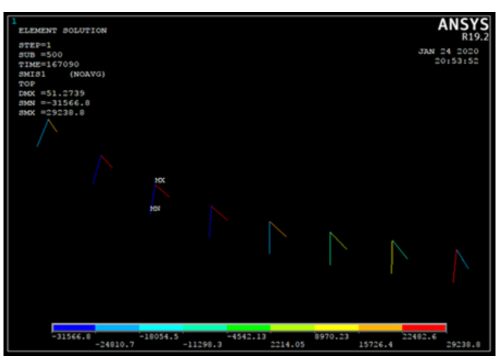

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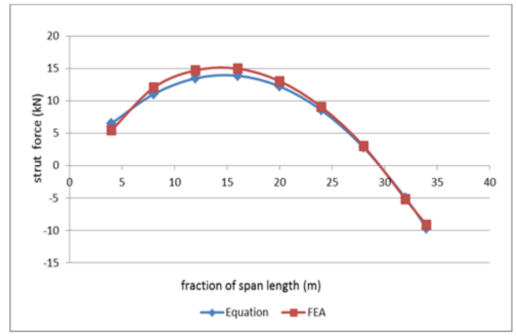
Figure 11 Internal bracing force on two span bridges (Basra Bridge)



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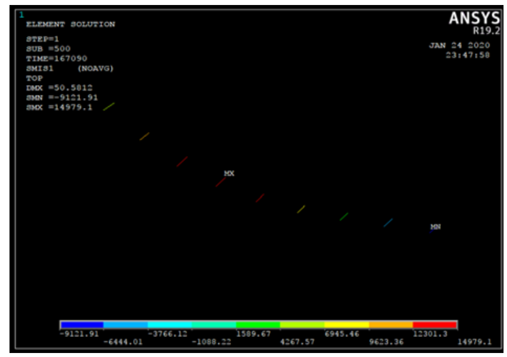

(b)

Figure 12 Strut force on two span bridges (Basra Bridge)

In order to control distortion in steel box girder, the internal bracing are provided at one or two-panel spacing, Regardless of whether X-frames or K -frames are placed, forces induced in these members are dependent upon the spacing and cross-sectional geometry of cross-frame as implied by Eq. (1)
From table (3) and (4) the axial forces estimated from the proposed equations have been compared with those obtained from 3.D finite element analyses and reasonable correlations have been observed

6 Conclusions

Many methods are available that used for curved bridges analysing. But The most powerful, flexible and versatile method is the finite element method, although the finite-element method (F.E.M.) is the most involved and time exhaustion, it is remain the most common and universal approach for both static analysis and dynamic analyses, A complex geometry, like the continuous curved steel box girder bridges, can be easily modelled by using the finite element approach. By using this methods the response of these bridges can be predicted with a good accuracy. In the current study, a 3-D finite element analysis has been used for analysing box girder bridges by using ANSYS 19.2.

The following points can be presented as a conclusion for this study:

- The figures (6, 7 and 10) show comparatively forces induced in diagonals of the internal K-frame. Values computed from Eq. (1) compare very well with the results of finite element analyses for the two case study

- the full Newton-Raphson method was used in analysing the box girder bridge, and the ANSYS software has been found to be very effective in comparing strut forces with that found from equations 2

- When the internal bracing placed at every panel then the force will be half the force when the bracing used at every two panel.

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