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Effect of Stiffeners on Shear Lag in Steel Box Girders

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Abstract

This paper studies the effects of stiffeners on shear lag in steel box girders with stiffened flanges. A three-dimensional linear finite element analysis using STAAD.Pro V8*i* program has been employed to evaluate and determine the actual top flange stress distribution and effective width in steel box girders. The steel plates of the flanges and webs have been modeled by four-node isoparametric shell elements, while the stiffeners have been modeled as beam elements. Different numbers (4, 8, and 15) for the steel stiffeners have been used in this study to establish their effects on the shear lag and longitudinal stresses in the flange. Using stiffeners reduced the magnitude of the top flange longitudinal stresses about 40%, but didn't affect the shear lag.

Keywords: *Shear lag, effective width, box girder, stiffeners.*

1. Introduction

A box girder is a beam which has the shape of a hollow box. The box girder normally comprises either structural steel, prestressed concrete, or a composite of steel and reinforced concrete. The box is typically rectangular or trapezoidal in cross-section. Box girder bridges are commonly used for highway flyovers and for modern elevated structures of light rail transport. Although normally the box girder bridge is a form of beam bridge, box girders may also be used on cable-stayed bridges and other forms.

1.1. Advantages and Disadvantages

Compared to I-beam girders, box girders have a number of key advantages and disadvantages. Box girders offer better resistance to torsion, which is particularly of benefit if the bridge deck is curved in plan. Additionally, larger girders can be constructed, because the presence of two webs allows wider and hence stronger flanges to be used. This in turn allows longer spans. On the other hand, box girders are more expensive to fabricate, and they are more difficult to maintain, because of the need for access to a confined space inside the box.

1.2. Shear Lag

The conventional engineering theory of bending assumes that plane sections remain plane, which means that shearing strains are neglected. The term shear lag is used to describe the discrepancies between the approximate engineering theory, and the real behavior that results in both the increases in the stresses in the flange component adjacent to the web component in a steel box girder, and to the decreases in the stresses in the flange component away from the web.

As shown in Figure (1), the longitudinal stress $\sigma_x(y)$ at the flange of a box section distributes uniformly with σ_b along the y-axis based on the elementary beam theory. However, at the intersection of the flange and web where y = ±b, the actual maximum longitudinal stress $\sigma_{x,max}(y = \pm b)$ is higher than the average longitudinal stress of σ_b. This high stress of the transfer of the shear force from the web to the

flange edge is called the shear lag phenomenon (Timoshenko and Goodier 1970).
In the analysis of any box girder, it is important to take the effects of shear lag into account since these effects can lead to a significant increase in the longitudinal stresses developed in the flanges.

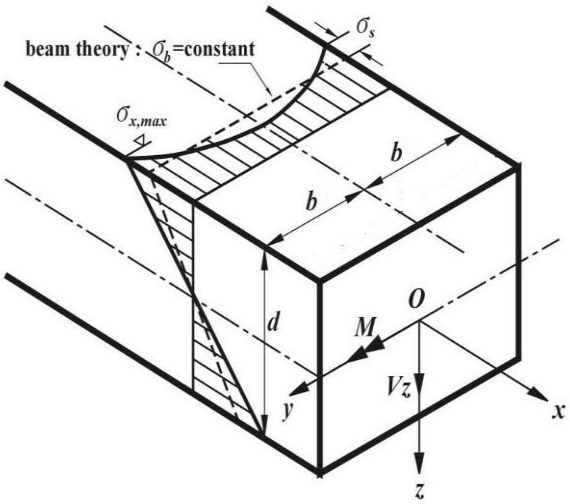


Fig. 1. Typical Box Section under Bending (Timoshenko and Goodier, 1970) .

1.3. STAAD.Pro V8i

STAAD.Pro V8*i* is a comprehensive and integrated finite element analysis and design offering, including a state-of-the-art user interface, visualization tools, and international design codes. It is capable of analyzing any structure exposed to static loading, a dynamic response, soil-structure interaction, wind, earthquake, and moving loads. STAAD.Pro V8*i* is the premier finite element method analysis and design tool for any type of project including towers, culverts, plants, bridges, stadiums, and marine structures

2. Review of the Previous Studies

Shear lag has long been of interest to researches. Firstly, shear lag in box girders was studied by Reisser (1946). Malcolm and Redwood (1970) suggested analytical procedure using stiffener-sheet solution. Moffatt and Dowling (1975) studied the shear lag phenomenon in steel box girder bridges by means of the finite element method of analysis. Kuzmanovic' and Graham (1981) found the minimum potential energy principle which was a suitable approach to evaluate the shear lag in box girders. Foutch and Chang (1982) investigated the effects of shear lag and shear deformation on the static and dynamic response of tapered thin-walled box beams. Dezi and Mentrasti (1985) discussed nonuniform normal longitudinal stress distribution (shear lag) in a trapezoidal box beam with lateral cantilever. Chang and Zheng (1987) analyzed shear lag and negative shear lag effect in cantilever box girders through variation approach and finite element techniques. The substructuring analysis method for shear lag stress using the conditions of compatibility and equilibrium was introduced by Fafitis and Rong (1996) Lee and Wu (2000) improved the inefficiency of traditional finite element analysis using uniform meshes in the solution of shear lag stress. Wang (1997) derived an energy equation for the lateral buckling of thin-walled members with openings considering shear lag phenomenon. Also, Luo et al. (2001) studied the negative shear lag in box girder with varying depth. However, these studies recognized that the complicated equations are not so practical for the design of steel box girders. Luo et al. (2002) carried out experimental study on the shear lag effect of box girder with varying depth. Hwang et al. (2004) presented shear lag parameters for beam-to-column connections in steel box piers. Zhibin Lin and Jian Zhao (2010) used an energy-based variation analysis to evaluate the AASHTO provisions for effective flange width.

2.1. Shear Lag in Box Beam

Under symmetrical flexure, the distributions of bending stress across wide flanges of a girder cross section are non-uniform. The bending stress near the web is much larger than that far from the web, as shown in Figure (2-a). This phenomenon is usually noted as positive shear lag (Chang and Zhang, 1987).

In a cantilever box girder with constant depth, under uniform load, at the region beyond 1/4 the cantilever length from the built-in end, the bending stress near the web is much smaller than that far from the web. This result is opposite to positive shear lag and is called negative shear lag as shown in Figure (2-b) (Chang and Zhang, 1987).

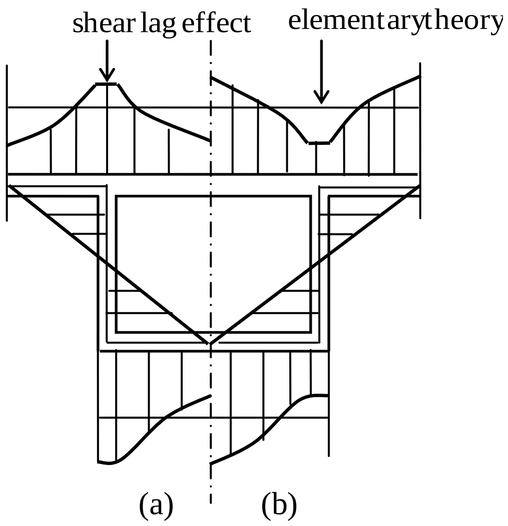


Fig. 2. Shear Lag Effecta) Positive shear lag, b) Negative Shear lag (Chang and Zhang, 1987).

2.2. Effective Flange Width

The effective width of a flange is the width of a hypothetical flange that compresses uniformly across its width by the same amount as the loaded edge of the real flange under the same edge shear forces. Alternatively, the effective width can be thought of as the width of theoretical flange which carries a compression force with uniform stress of magnitude equal to the peak stress at the edge of the prototype wide flange when carrying the same total compression force (Hamply, 1976).

The effective width concept has been widely recognized and implemented into different codes of practice around the world.

The effective width of a girder flange varies along the span and depends significantly on the load distribution, cross-sectional properties, and boundary conditions, as well as the plan dimensional of the girder (Moffatt and Dowling, 1975).

Effective width may be defined in a variety of ways depending on which design parameter is deemed more significant. It is generally obtained by integrating the rigorously calculated longitudinal stress in the flange, and dividing by the peak value of stress. And therefore $\bar{b}$ is calculated here by considering flange stress and is given by:

$$\bar{b} = \frac{\int_0^b \sigma_x \, dy}{(\sigma_x)_{max.}} \qquad \ldots(1)$$

Where $\bar{b}$ is one-side effective flange width, b is half flange width, σ_x represent the normal stress in the longitudinal direction, and $(\sigma_x)_{max.}$ is the maximum normal stress between $0 \leq y \leq b$. In this work, the numerator of Equation (1) was calculated by the approximate method by using trapezoidal rule; these calculations have been done by a computer program written for that purpose.

The main aim of the present study is to investigate the effect of the stiffeners on the top flange longitudinal stress distribution and effective width in steel box girders by using finite element method to idealize the steel box girder.

3. Finite Element Modeling

STAAD.Pro 2007 program was used to create three dimensional finite element model of the steel box girder. Three-dimensional four-node isoparametric shell elements were used to model the steel plates, while the stiffeners were modeled by beam elements. The steel model used for all components in the girder model was linear/elastic, the elastic modulus used was 29,000 ksi and the Poisson's ratio was 0.3 (ASTM A36).

The steel box girder used as a reference throughout this paper is based on the cross-section shown in Figure (3). The simply supported girder has a width that equals 144 in., a depth that equals 72 in., and a length that equals 720 in. The thickness of the steel plates equals 0.5 in. The stiffeners of each flange is 4.5 in. ×1 in. @ 9 in. c/c (total = 15). Same stiffeners wear used for top and bottom flanges to fix the distance between the neutral axis and the top flange as the stiffener ratio changed.

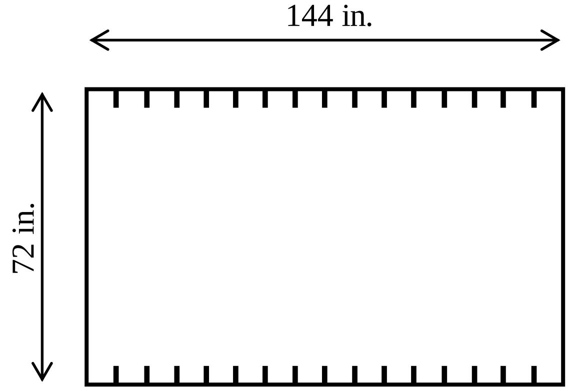


Fig. 3. Cross Section of the Reference Steel Box Girder .

The three-dimensional finite element mesh for the reference steel box girder used in STAAD.Pro V8*i* program is shown in Figure (4).

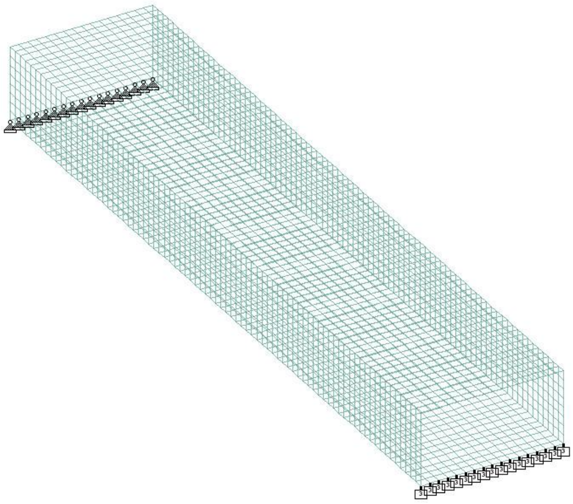


Fig. 4. Three-Dimensional Finite.

4. Parametric Study

In this section, influence of various parameters on top flange stress distribution and effective width in steel box girders were investigated. The parameters studied can be summarized as follows:

1. Stiffener ratio (area of stiffeners/area of top flange).
2. Distribution of Stiffeners.
3. Type of loading.
4. Depth/width of the section.
5. Length of girder.

In this work, two types of loading are investigated, the magnitude of the two loads was selected to give equal deflection at the mid-span, and these two cases will be referred to in the following as:

a. Uniformly distributed load (UDL) (150 kips) (on the overall flange).

b. Two concentrated loads (CL) (2×47 kips) at midspan (one on each web).

The maximum top flange stresses (over the web) for different stiffener ratios with respect to the two types of loading (UDL and CL) are listed in Table (1), and the distributions of the top flange stresses are shown in Figures (5 and 6) respectively. Each set of lines represent the edge of the effective width for one web. Adding stiffeners with area that equals the flange area decreases the maximum top flange stress in about 40%. The effective flange widths for different stiffener ratios with respect to the two types of loading are shown in Table (2), and the distribution of the effective flange widths is shown in Figures (7 and 8) respectively. It can be seen from the results obtained that:-

- The top flange longitudinal stresses decrease as the stiffener ratio increases. The decreasing ranged between 18% and 40%. This is due to the share of the stiffeners in the forces makes the stresses in the flange decrease.
- The maximum top flange longitudinal stress over each web decreases as the stiffener ratio increases. The decreasing reached 40%.
- The addition of stiffeners to the flanges results no effect on shear lag because the shear lag phenomenon does not affect the shape of the flange.
- The effective width decreases slightly as the stiffener ratio increases (5% in case of UDL and 13% in case of CL).

Table 1,
Maximum Top Flange Stresses for Different Stiffener Ratios with Respect to the Two Types of Loading (UDL and CL).

Stiffener Ratios	Maximum Top Flange Stress									
	UDL					CL				
	Beam Length Percentage					Beam Length Percentage				
	0.1 L	**0.2 L**	**0.3 L**	**0.4 L**	**0.5 L**	**0.1 L**	**0.2 L**	**0.3 L**	**0.4 L**	**0.5 L**
0.0	1067	1551	1964	2234	2328	664	1109	1627	2211	3356
0.5	880	1190	1464	1653	1719	521	813	1178	1625	2642
1.0	780	999	1195	1334	1385	436	646	930	1302	2239

Table 2,
Effective Flange Widths for Different Stiffener Ratios with Respect to the Two Types of Loading.

Stiffener Ratios	Effective Flange Width									
	UDL					CL				
	Beam Length Percentage					Beam Length Percentage				
	0.1 L	0.2 L	0.3 L	0.4 L	0.5 L	0.1 L	0.2 L	0.3 L	0.4 L	0.5 L
0.0	93	127	135	136	136	104	139	143	140	111
0.5	80	119	129	132	133	92	134	140	135	103
1.0	73	113	125	128	129	86	131	138	132	96

Another parameter, investigated is changing the number (4, 8, and 15) of the stiffeners with keeping the same area of the stiffeners. Effect of distribution of stiffeners on maximum top flange stress and the effective flange widths are listed in Table (3). Figures (9 and 10) show the distribution of the top flange stress and the effective flange respectively. The results declare that there are no effects because the stiffeners have the same area in all three cases.

Table 3,
Effect of Distribution of Stiffeners on Maximum Top Flange Stress and the Effective Flange Widths.

Number of Stiffeners	Maximum Top Flange Stress					Effective Flange Width				
	Beam Length Percentage					Beam Length Percentage				
	0.1 L	0.2 L	0.3 L	0.4 L	0.5 L	0.1 L	0.2 L	0.3 L	0.4 L	0.5 L
4	797	1022	1220	1361	1411	72	115	126	129	130
8	784	1005	1202	1339	1389	73	113	125	129	130
15	781	999	1195	1335	1385	73	113	125	128	129

Table (4) shows the maximum top flange stresses and effective flange widths according to type of loading. The distribution of longitudinal normal stresses in the top flange has different shapes along the flange according to type of loading as shown in Figure (11). The distribution of the effective flange widths which is due to type of loading is shown in Figure (12).

Table 4,
Maximum Top Flange Stresses and Effective Flange Widths According to Type of Loading.

Type of Loading	Maximum Top Flange Stress					Effective Flange Width				
	Beam Length Percentage					Beam Length Percentage				
	0.1 L	0.2 L	0.3 L	0.4 L	0.5 L	0.1 L	0.2 L	0.3 L	0.4 L	0.5 L
UDL	781	999	1195	1335	1385	73	113	125	128	129
CL	436	647	930	1302	2240	86	131	138	132	95

Effect of the ratio depth/width on the maximum top flange stresses and the effective flange widths is listed in Table (5), and the effect on the top flange stresses distribution and the effective flange widths distribution for different ratios is shown in Figures (13 and 14) respectively.

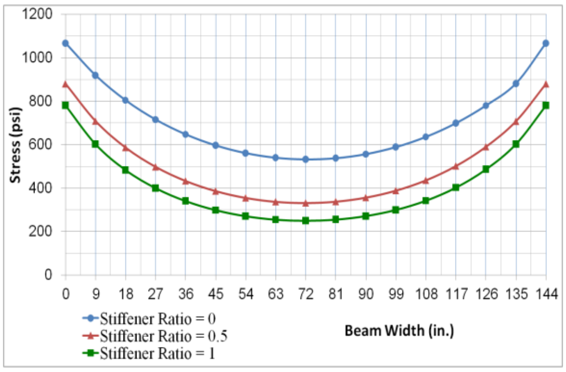
Table 5,
Effect of the Ratio of Depth/Width on Maximum Top Flange Stresses and Effective Flange Widths.

Depth/Width	Maximum Top Flange Stress Beam Length Percentage					Effective Flange Width Beam Length Percentage				
	0.1 L	**0.2 L**	**0.3 L**	**0.4 L**	**0.5 L**	**0.1 L**	**0.2 L**	**0.3 L**	**0.4 L**	**0.5 L**
0.5	781	999	1195	1335	1385	73	113	125	128	129
1.0	151	420	541	606	630	116	111	122	127	128

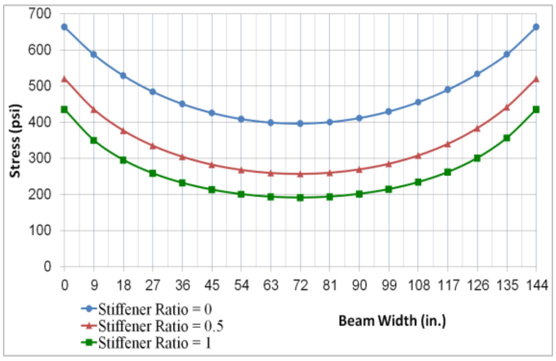
Table (6) shows the effect of length of girder on the maximum top flange stresses and effective flange widths and Figure (15 and 16) show the top flange stress distribution and the distribution of the effective flange widths for different lengths of the girder.

Table 6,
Effect of Length of Girder on Maximum Top Flange Stresses and Effective Flange Widths.

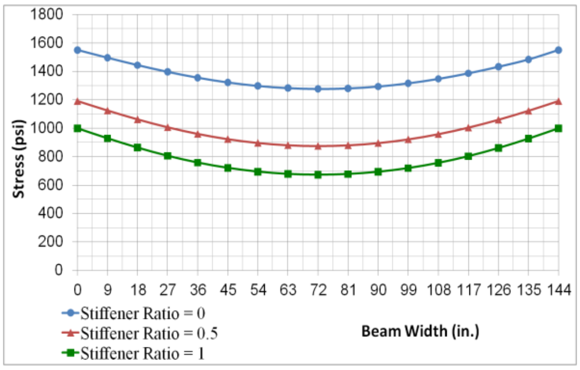
Length of Girder	Maximum Top Flange Stress Beam Length Percentage					Effective Flange Width Beam Length Percentage				
	0.1 L	**0.2 L**	**0.3 L**	**0.4 L**	**0.5 L**	**0.1 L**	**0.2 L**	**0.3 L**	**0.4 L**	**0.5 L**
37.5	333	560	603	636	651	52	78	98	107	110
60.0	781	999	1195	1335	1385	73	113	125	128	129
82.5	1203	1667	2112	2392	2487	96	128	134	135	136
105.0	1676	2579	3330	3787	3940	114	135	137	138	139



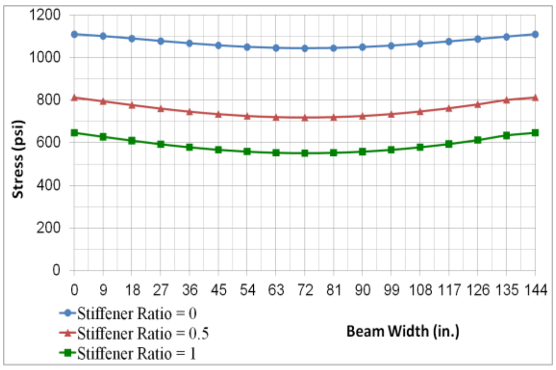
(a)



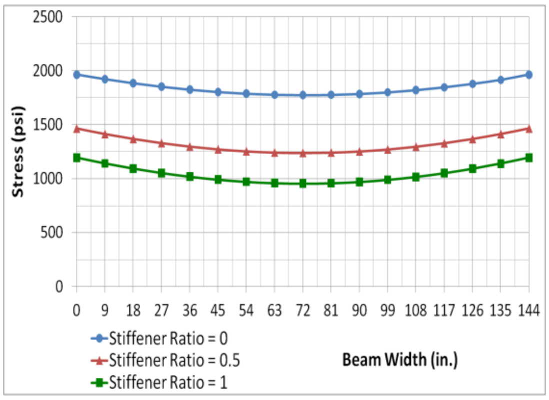
(a)



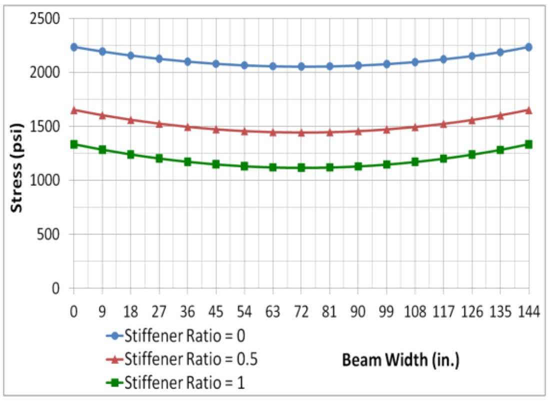
(b)



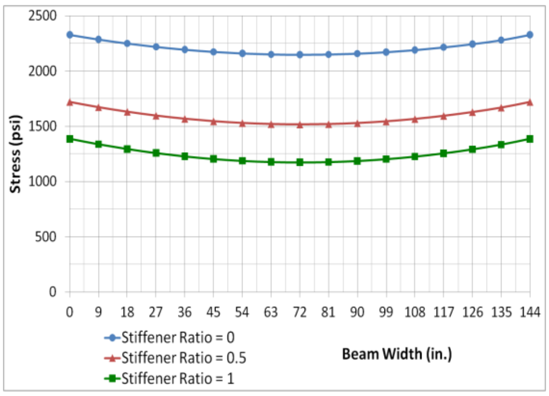
(b)



(c)

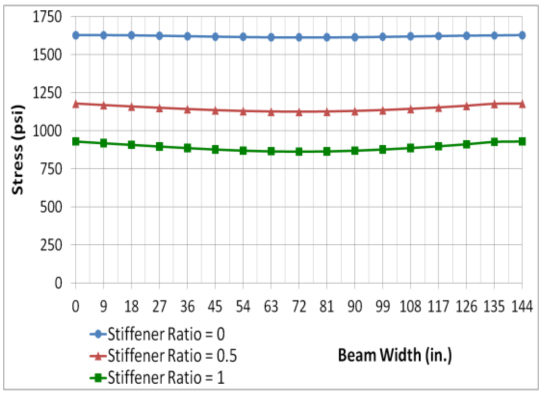


(d)



(e)

Fig. 5. Effect of Stiffener Ratio on Top Flange Stress Distribution (UDL). (a) At 0.1 L (b) At 0.2 L (c) At 0.3 L (d) At 0.4 L (e) At 0.5 L.



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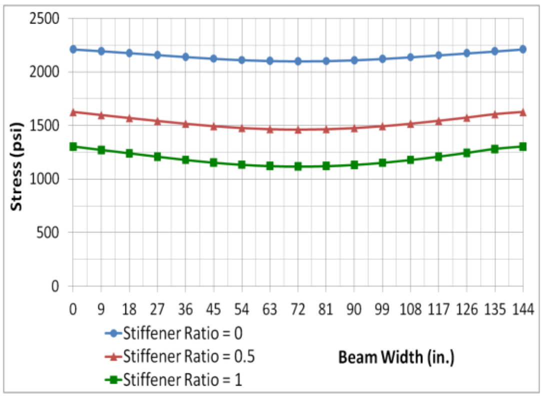
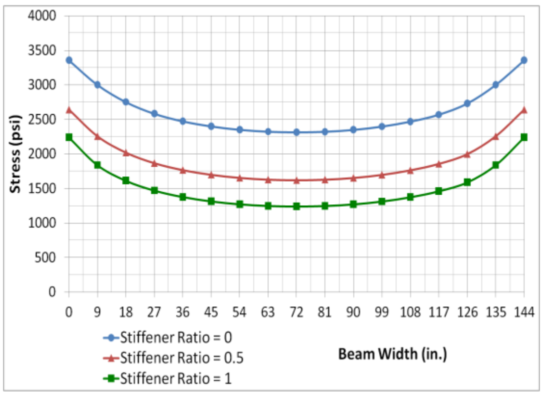


(d)



(e)

Fig. 6. Effect of Stiffener Ratio on Top Flange Stress Distribution (CL). (a) At 0.1 L (b) At 0.2 L (c) At 0.3 L (d) At 0.4 L (e) At 0.5 L

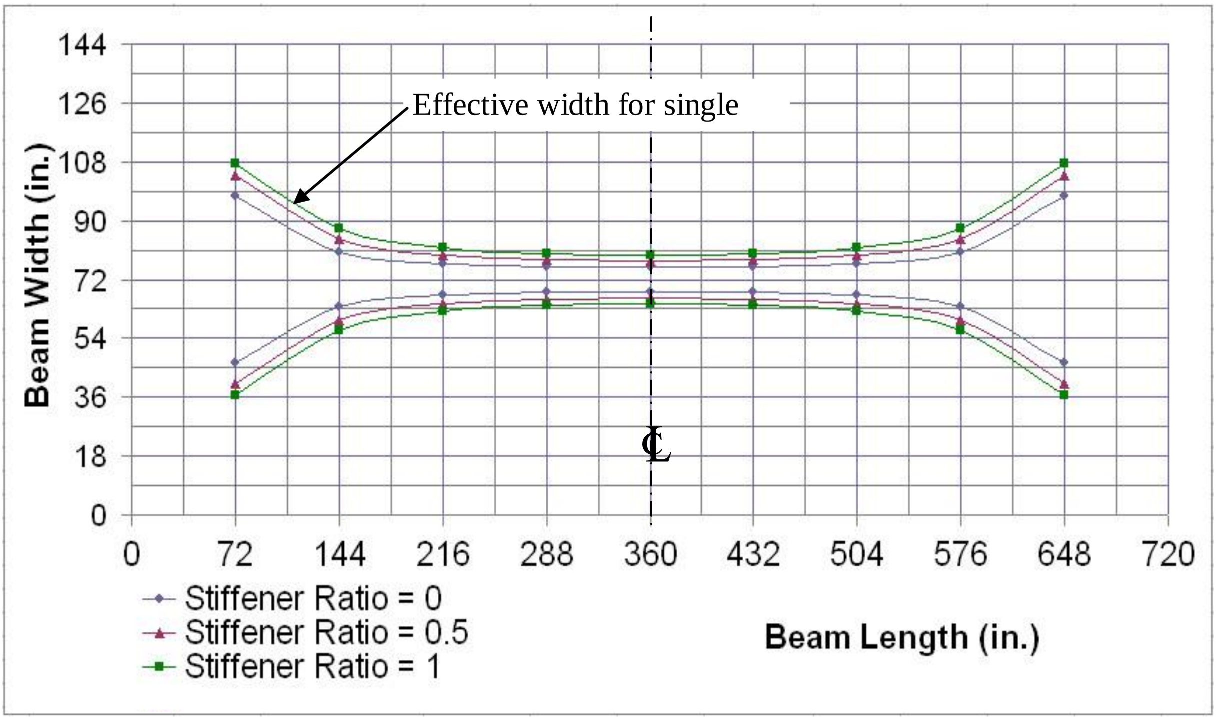


Fig. 7. Effect of Stiffener Ratio on the Distribution of the Effective Flange Widths (UDL).

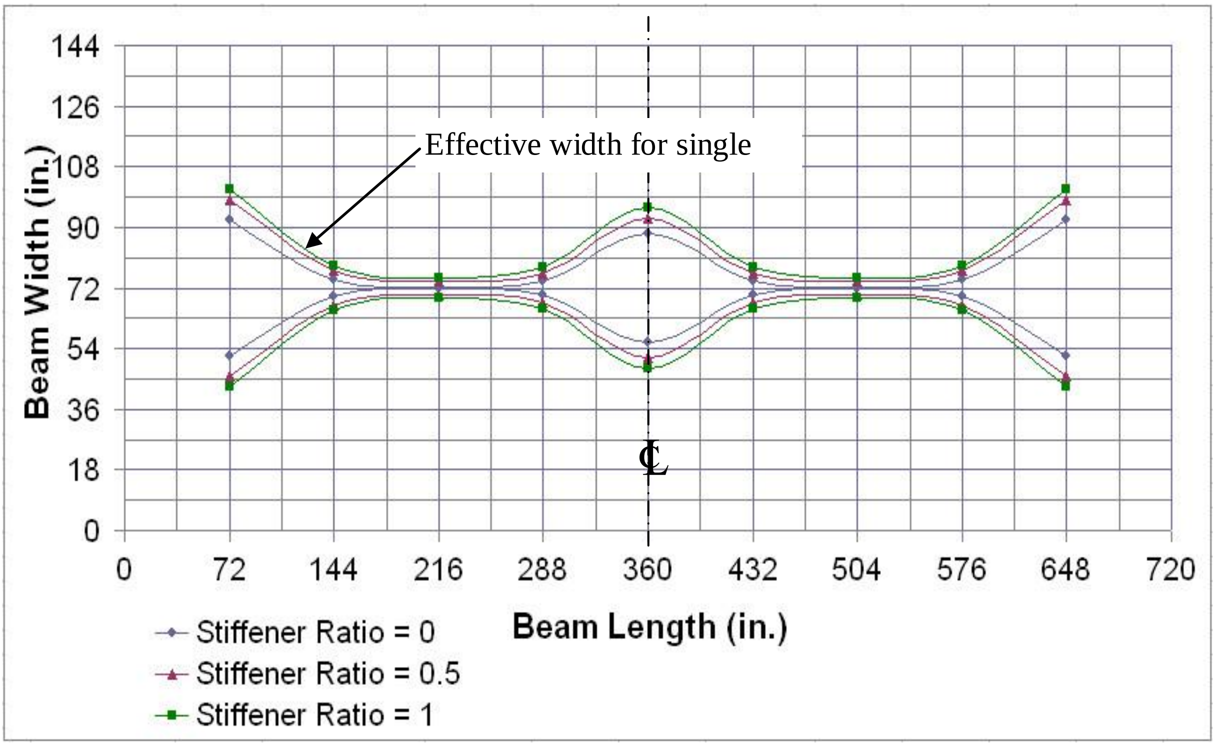


Fig. 8. Effect of Stiffener Ratio on the Distribution of the Effective Flange Widths (CL).

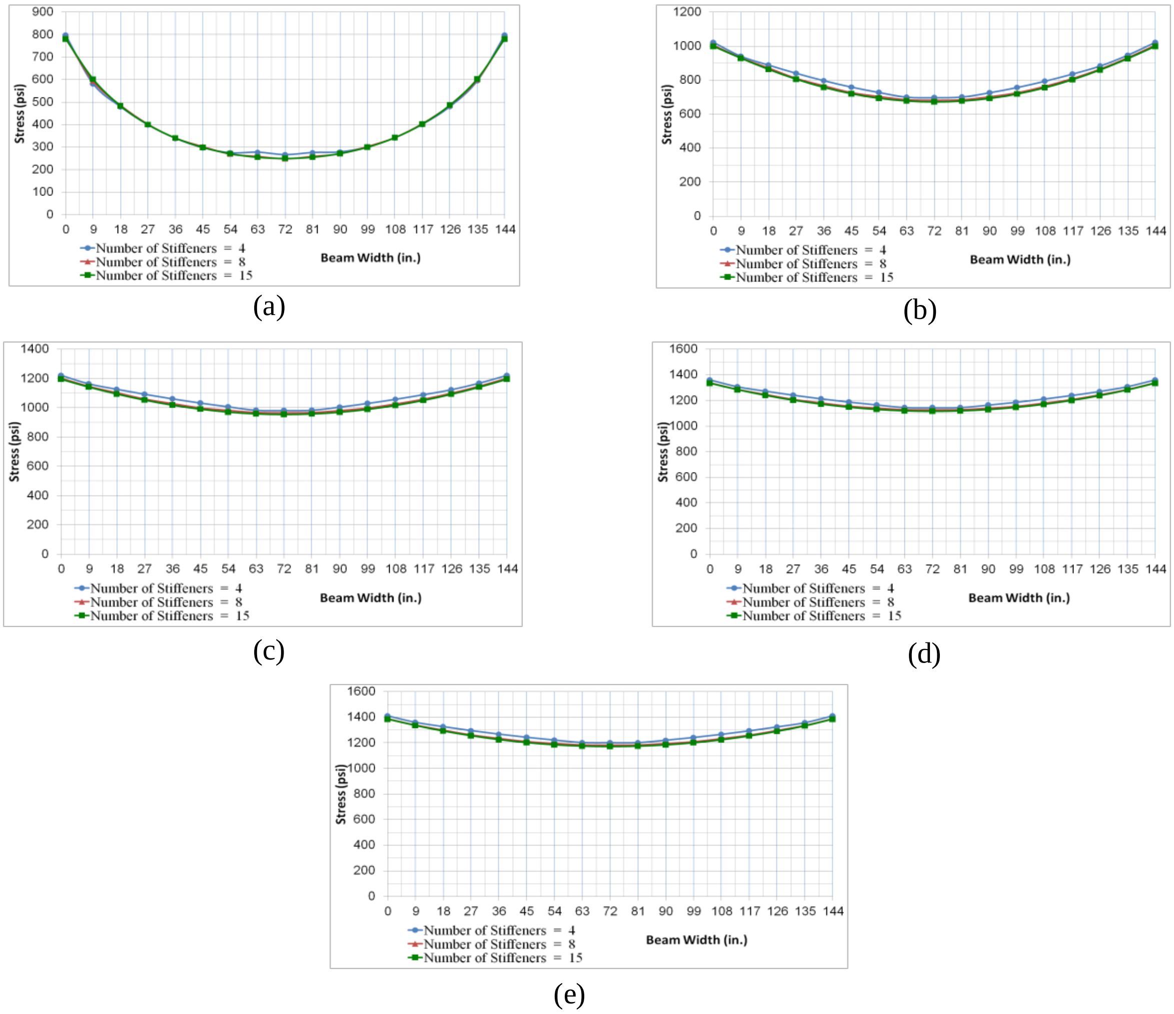


Fig. 9.Effect of Distribution of Stiffeners on Top Flange Stress Distribution .
(a) At 0.1 L (b) At 0.2 L (c) At 0.3 L (d) At 0.4 L (e) At 0.5 L.

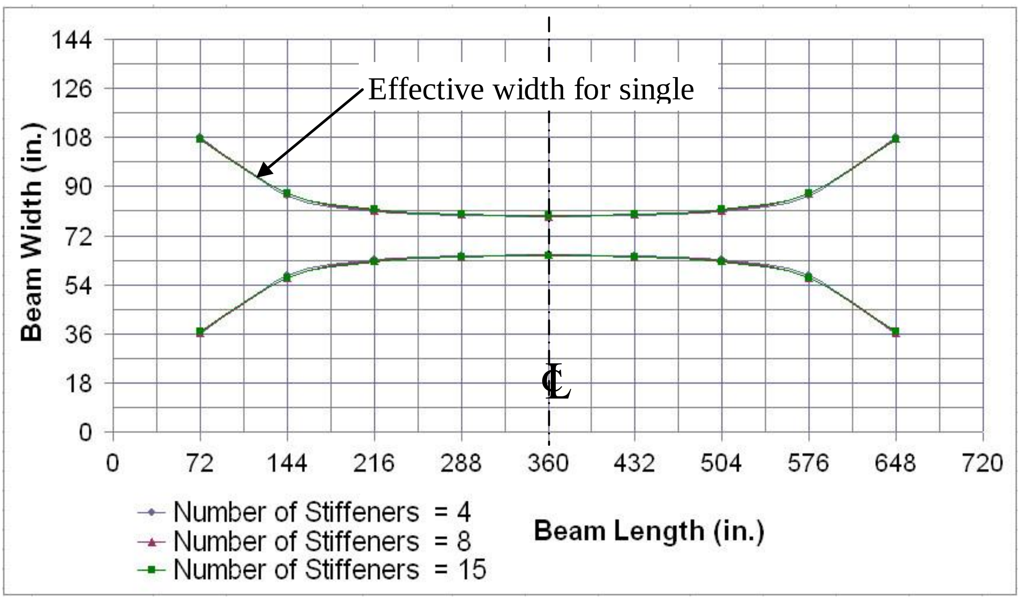


Fig. 10. Effect of Distribution of Stiffeners on the Distribution of the Effective Flange Widths.

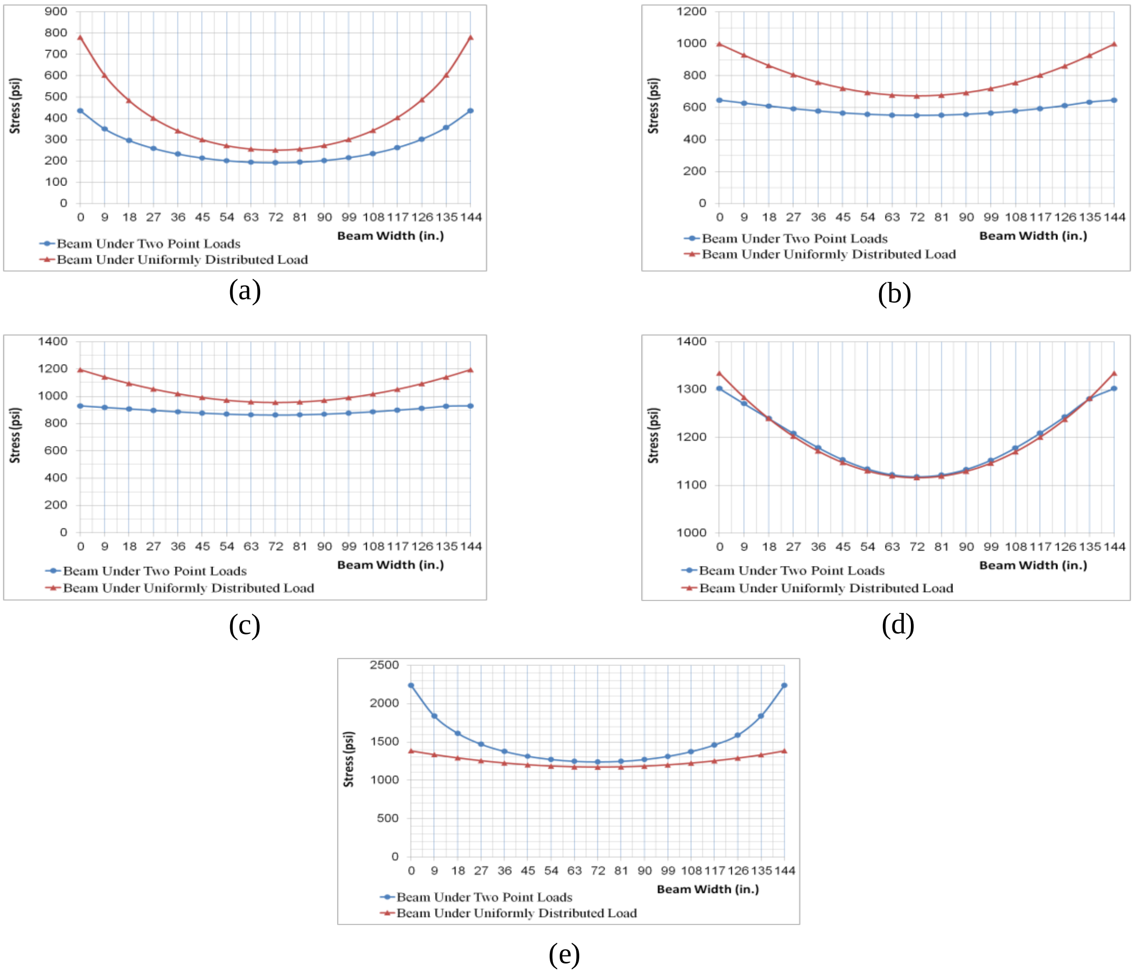


Fig. 11. Effect of Loading on Top Flange Stress Distribution.
(a) At 0.1 L (b) At 0.2 L (c) At 0.3 L (d) At 0.4 L (e) At 0.5 L.

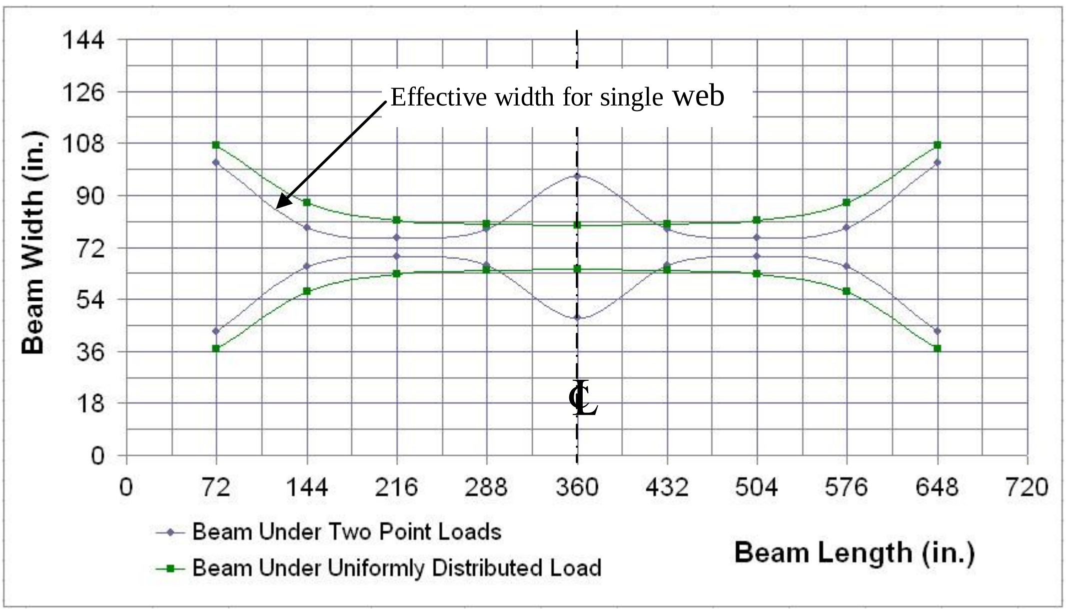


Fig. 12. Effect of Loading on the Distribution of the Effective Flange Widths .

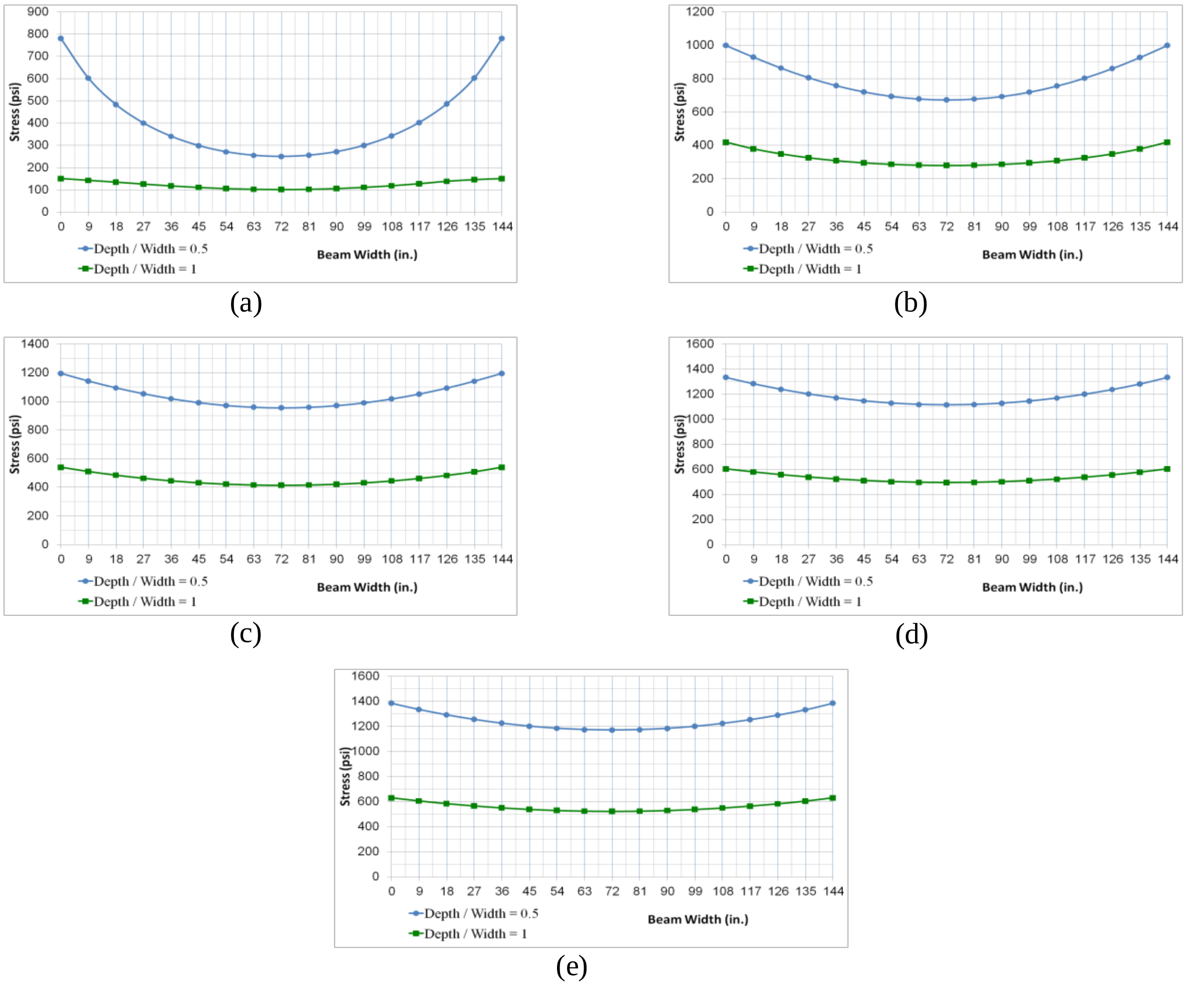


Fig. 13. Effect of Depth/Width on Top Flange Stress Distribution.
(a) At 0.1 L (b) At 0.2 L (c) At 0.3 L (d) At 0.4 L (e) At 0.5 L.

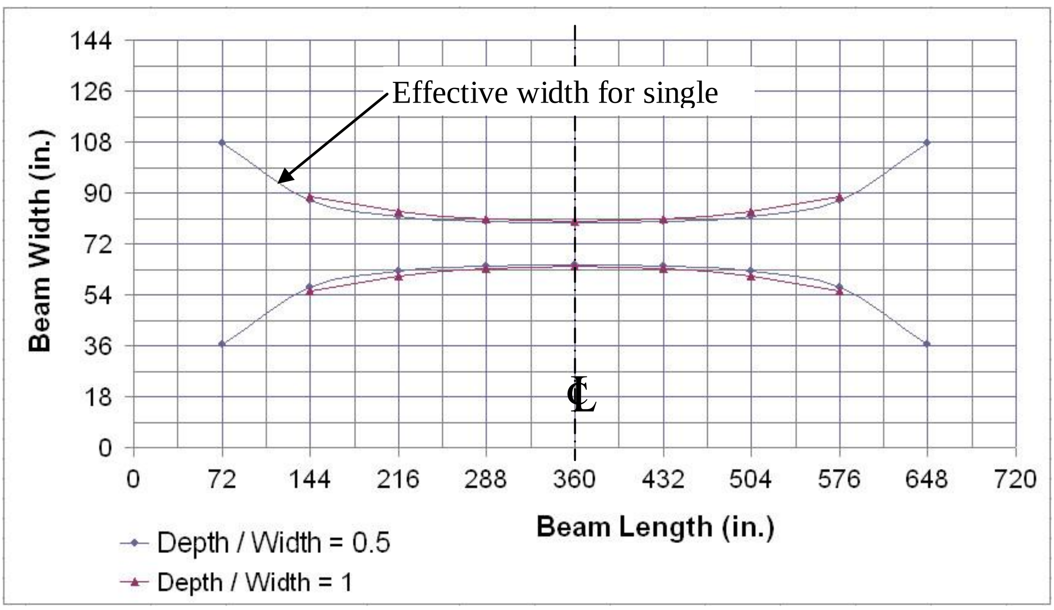


Fig. 14.Effect of Depth/Width on the Distribution of the Effective Flange Widths.

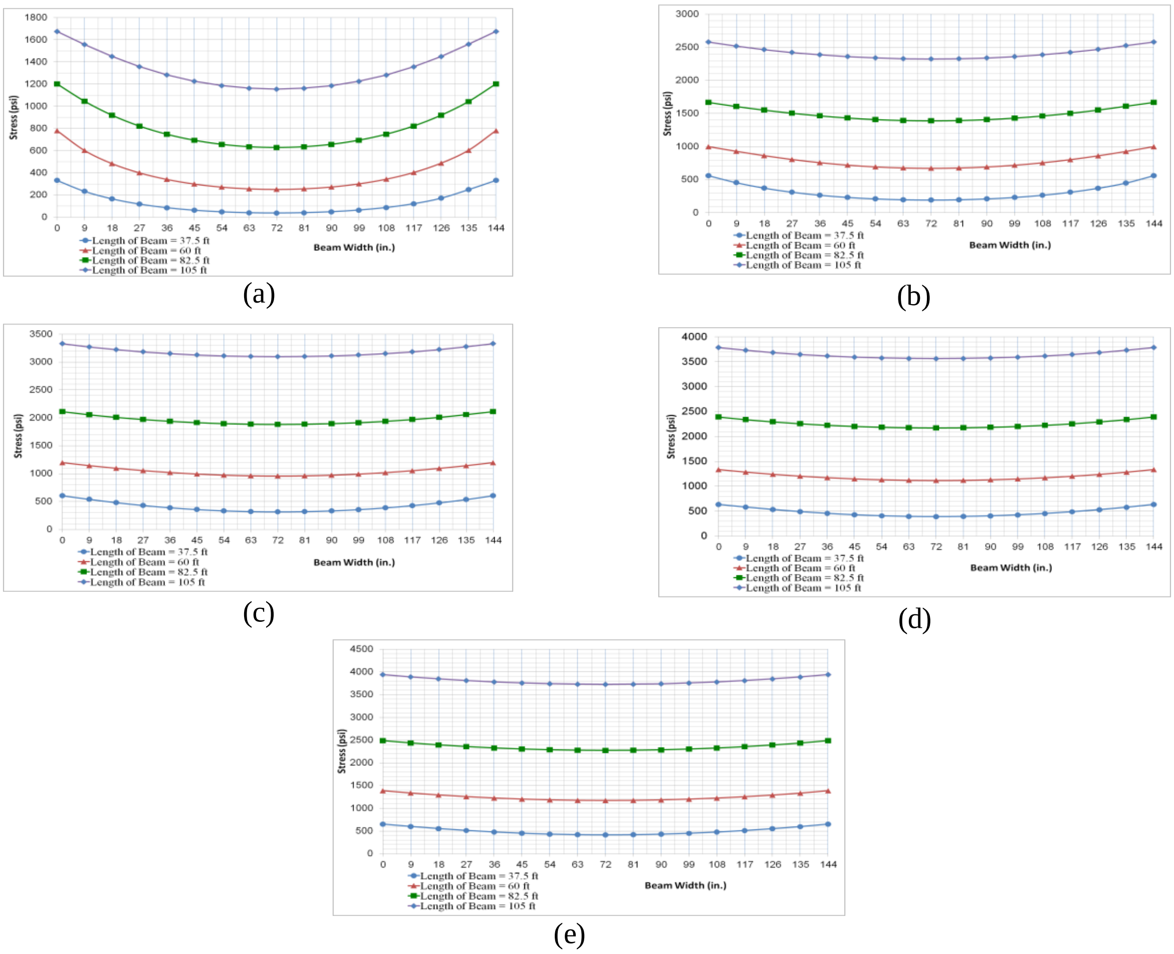


Fig. 15. Effect of Length of Girder on Top Flange Stress Distribution.
(a) At 0.1 L (b) At 0.2 L (c) At 0.3 L (d) At 0.4 L (e) At 0.5 L.

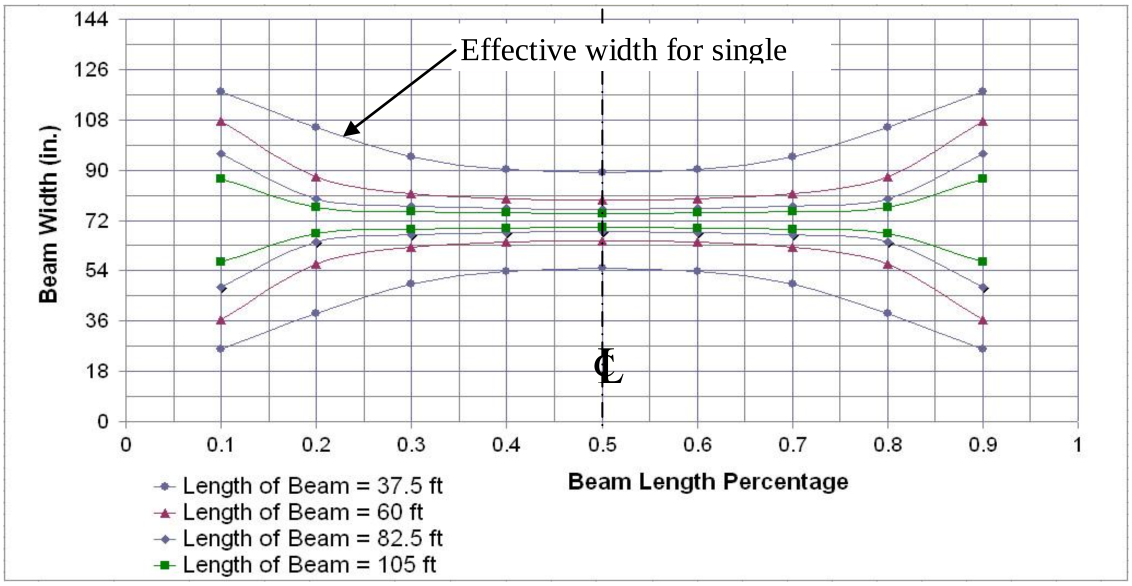


Fig. 16. Effect of Length of Girder on the Distribution of the Effective Flange Widths.

5. Conclusions

1. Using the longitudinal stiffeners in the flanges of steel box girder did not affect the shear lag in the top flange, although it reduced the magnitude of the top flange longitudinal stresses to about 40%, and decreases slightly the effective width (5%-13%) because portion of these stresses go to the stiffeners.
2. Increasing the stiffener ratio make the top flange longitudinal stresses decrease.
3. Changing the number (4, 8, and 15) of the stiffeners with keeping the same area of the stiffeners has no effects on the magnitude of the top flange longitudinal stresses due to using the same area of the stiffeners.

Notations

b	One-Side Slab Width
$\bar{b}$	One-Side Effective Slab Width
E_s	Modulus of Elasticity of Steel
L	Span Length of the Beam
ν	Poisson's Ratio
σ_x	Normal Stress in the Longitudinal Direction
$(\sigma_x)_{max.}$	Maximum Normal Stress in the Longitudinal Direction

6. References

[1] Chang, S. T., and Zheng, F. Z. (1987) "Negative Shear Lag in Cantilever Box Girder with Constant Depth." Journal of the Structural Engineering, Vol. 113, No. 1, January, pp. 20-35.

[2] Dezi, L., and Mentrasti, L. (1985) "Non-uniform Bending-Stress Distribution (Shear Lag)," Journal of the Structural Engineering, Vol. 111, No. 12, pp. 2675-2690.

[3] Fafitis, A. and Rong, A. Y. (1995), "Analysis of thin-walled box girders by parallel processing", Thin-walled Struct., 21, 233-240.

[4] Foutch, D. A., and Chang, P. C. (1982) "A Shear Lag Anomaly," Journal of the Structural Engineering, Vol. 108, No. 7, pp. 1653-1658.

[5] Hamply, E. C., (1976) Bridge Deck Behavior, Chapman and Hall, London EC4P 4EE, pp. 272.

[6] Hwang, W. S., Kim, Y. P., and Park, Y. M. "Evaluation of shear lag parameters for beam-to-column connections in steel piers" Structural Engineering and Mechanics, Vol. 17, No. 5 (2004) 691-706.

[7] Kuzmanovi , B. O. and Graham, H. J. (1981), "Shear lag in box girder", J. Struct. Div., ASCE, 107(9), 1701-1742.

[8] Lee, C. K. and Wu, G. J. (2000), "Shear lag analysis by the adaptive finite element method-1. Analysis of simple plated structures", Thin-walled Struct., 38, 285-309.

[9] Luo, Q. Z., Tang, J., and Li, Q. Z. (2001) "Negative Shear Lag Effect in Box Girders with Varying Depth," Journal of Structural Engineering, ASCE, , Vol. 127, No. 10, pp. 1236-1239.

[10] Luo, Q. Z., Tang, J. and Li, Q. S. (2002), "Experimental studies on shear lag of box girder", Eng. Struct., 24, 464-477.

[11] Malcolm, D. J. and Redwood, R. G. (1970), "Shear lag in stiffened box girders", J. Struct. Div., ASCE, 96 (ST7), 1403-1449.

[12] Moffatt, K. R., and Dowling, P. J. (1975) "Shear Lag in Steel Box Girder Bridges," The Structural Engineer, Vol. 53, No. 10, October, pp. 439-448.

[13] Reissner, E. (1946), "Analysis of shear lag in box beams by the principle minimum potential energy", Quarterly App. Math., 3 (3), 268-278.

[14] Timoshenko, S. P., and Goodier, J. N. (1970) "Theory of Elasticity." third edition, Mc Graw-Hill, New York, pp. 567.

[15] Wang, Q. F. (1997), "Lateral buckling of thin-walled members with openings considering shear lag", Structural Engineering and Mechanics, 5 (4), 369-383.

[16] Zhibin Lin, A. M. and Jian Zhao, A. M. "A Revisit of AASHTO Effective Flange Width Provisions for Box Girders" Journal of Bridge Engineering / Accepted Manuscripts in 2010.

تأثير المقويات على تخلف القص في الأعتاب الصندوقية الحديدية

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الخلاصة

هذا البحث يوثق دراسة تأثير المقويات على تخلف القص في الأعتاب الصندوقية الحديدية ذات الشفاه المقواة. أعتمد التحليل بإستعمال طريقة العناصر المحددة الخطية ثلاثية الأبعاد وبإستخدام برنامج ستاد برو في التحليل وحساب التوزيع الحقيقي للإجهادات في الشفة العليا و العرض الفعال في الأعتاب الصندوقية الحديدية. تم تمثيل الصفائح الحديدية للشفتين والوترتين بإستعمال عناصر قشرية رباعية العقد ، بينما تم تمثيل المقويات بعناصر أحادية البعد ذات عقدتين. أعداد مختلفة للمقويات (4 ، 8 ، 15) تم إستخدامها في هذه الدراسة لمعرفة تأثيرها على تخلف القص والإجهادات بالإتجاه الطولي في الشفة. إن إستخدام المقويات يقلل من قيمة الإجهادات بالإتجاه الطولي في الشفة العليا بمقدار يصل إلى40% ، لكنه لا يؤثر على تخلف القص فيها.