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Effect of load height on buckling resistance of steel beams

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Abstract

This paper presents a detailed investigation of effect of load height on buckling resistance of steel beams. Shapes that are intended to be used primarily as a beam are generally proportioned so that moment of inertia about the principal axis is considerably larger than that about minor axis. Hence monosymmetric sections are preferable. The lateral stability of beam subjected to transverse loading is very complicated in monosymmetric sections. The distance of transverse load from shear centre axis may significantly affect the buckling resistance of a simply supported beam. When transverse concentrated load W acts at (Yq-Yo) below the shear centre and moves with the beam it acts as an additional torque W(Yq-Yo)ط about shear centre which opposes twist ط and increases resistance to buckling. Conversely, when load above shear centre, additional torque increases the twist rotation and reduces buckling resistance of beam. To verify the effect of load height on buckling resistance, a simply supported beam subjected to concentrated and uniformly distributed load is considered. The effect of load height on buckling resistance has been plotted.

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Keywords: Load height, Buckling, monosymmetric section, Shear centre.

Nomenclature

b_{tf}	width of flange
t_{tf}	thickness of flange
E	Young's modulus of elasticity
G	Shear modulus of elasticity
J	Torsional sectional constant
L	unbraced length of beam
C	shear centre
I_{yc}	Moment of inertia of compression flange
I_{yt}	Moment of inertia of tension flange
Greek symbols	
βx	monosymmetric parameter
ط	degree of monosymmetry

1. Introduction

With the advantages of durability, high strength-to-weight ratio and excellent ductility steel members are used as the main load-bearing skeleton in building structures. In a structural system, beams are subjected to transverse loads and then transfer them to vertical members. Steel I-section beam, with the radius of gyration about major axis greater than one about minor axis, may become unstable in lateral direction under transverse loading. Hence, lateral-torsional buckling occurs, even though the stress level is far below the yield strength of the material. Buckling behavior is characterized by deformations developed in the direction [or plane] normal to that of loading that produces it. When the applied loading is increased the buckling deformation also increased. Buckling occurs only in members subjected to compressive forces. If the member has high bending stiffness, its buckling resistance is high. Also, when the member length is increased, the

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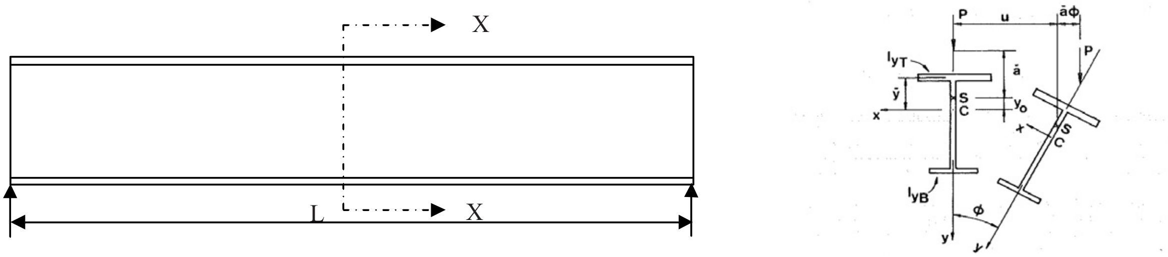
buckling resistance is decreased. Most research work on the elastic buckling of I-beams has been focused on beams of doubly symmetric cross section. Here an attempt is made to study to the buckling behavior of monosymmetric beam i.e. the beam is symmetric about minor axis with bending about major axis [Fig.1]. Monosymmetric I-sections are generally more efficient in resisting loads, provided the compressive bending stresses are taken by the large flange. However, the effects of monosymmetry introduce certain complications in the elastic buckling analysis. When such a beam twists during buckling, the longitudinal bending stresses exert a torque about the axis of twist of the member. This torque causes an effective change in the torsional Stiffness from GJ to [GJ + Mxںx], in which Mx = the major axis moment; and ںx= the monosymmetry property, commonly referred to as the "Wagner effect" [4, 8]. Because the smaller flange of the section is further from the shear center than the larger flange [see Fig. 1], the stress in the smaller flange has a greater lever arm and thus predominates the Wagner effect. Consequently, the lateral buckling capacity for beams under uniform moment is increased when the smaller flange is in tension and decreased when in compression. When the applied moment is not uniform, the Wagner effect interacts with the moment gradient. As a result of these combined effects, the buckling behavior of monosymmetric I-beams is quite complex [6]. Investigations into the buckling behavior of monosymmetric beams have so far been restricted mainly to the elastic range. Elastic buckling solution for such beams has been obtained for common loading and boundary conditions [3, 5, and 8] and their accuracy can be confirmed by experimental verification.

2. Lateral Buckling Strength of Monosymmetric Sections:

For beams symmetrical only about the minor axis e.g. unequal flanged I-sections, the non-coincidence of the shear centre and the centroid complicates the torsional behavior of beam. The monosymmetric I-sections are generally more efficient in resisting loads provided the compressive flange stresses are taken by larger flange.



(a) (b)

Fig.1. Lateral torsional buckling of monosymmetric beam (a) longitudinal view and (b) cross-section of beam

The beam as shown in fig.1 [4] is elastic and monosymmetric I-section. The beam supports prevent both lateral deflection and twist, but the flange ends are free to warp. The beam will buckle at an elastic critical moment when a deflected and twisted equilibrium position is possible. The uniform moment M at elastic buckling is given by,

$$\frac{M}{M_{yz}} = \pm\sqrt{1+\left(\frac{\beta_x P_y}{2M_{yz}}\right)^2} + \left(\frac{\beta_x P_y}{2M_{yz}}\right) \tag{1}$$

+ ve sign when the top flange is in compression

-ve sign when the bottom flange is in tension

$$M_{yz} = \sqrt{\left(\frac{\pi^2 EI_y}{L^2}\right)\left(GJ+\frac{\pi^2 EI_w}{L^2}\right)} \tag{2}$$

$$P_y = \frac{\pi^2 E I_y}{L^2} \tag{3}$$

$$\beta_x = \frac{1}{I_{xx}}\left[(h-h_1)\left\{\frac{b_{tf}^3 t_{tf}}{12}+b_{tf}t_{tf}(h_{ct}-h_1)^2\right\}-\left\{\frac{b_{bf}^3 t_{bf}}{12}+b_{bf}t_{bf}h_1^2\right\}+\left\{\left\{h-h_1-\frac{t_{bf}}{2}\right\}^4-\left(h_1-\frac{t_{tf}}{2}\right)^4\right\}\frac{t_w}{4}\right]-2y_o \tag{4}$$

The evaluation of monosymmetric parameter β_x is not straightforward and it has been suggested that a more easily calculated measure of monosymmetric of cross-section should be used such as:

$$\rho = \frac{I_{yc}}{I_{yc} + I_{yt}} \tag{5}$$

I_{yc} = Second moment of area of compression flange.
I_{yt} = Second moment of area of tension flange.

The values of ρ ranges from 0 (Tee beam with flange in compression □) to 1(Tee beam with flange in tension □). Studies by Kitipornchai and Trihar [4] have shown that a simpler alternative instead of complicated equation can be used,

$$\beta_x = 0.9 h_{ch} (2\rho - 1)\left[1 - \left(\frac{I_y}{I_x}\right)^2\right] \tag{6}$$

The solution of equation [1] for elastic buckling moment requires the use of the section constants I_y, J, I_w, β_x. while this can be determined from section of dimensions as follows,

$$I_w = \rho(1-\rho) I_y h^2 \tag{7}$$

$$J \approx \sum bt^3/3 \tag{8}$$

The positive solutions for the elastic buckling resistance M given by equation [1] and are shown in fig.2 [11]. These solutions correspond to positive moment M which causes compression in the top fiber of the section. It is noted that tensile longitudinal stresses reduce twisting while compressive stresses increases twisting. When larger flange is in compression, the resistance to buckling is increase. Conversely, when the larger flange is in tension, the resistance to bucking is decreased.

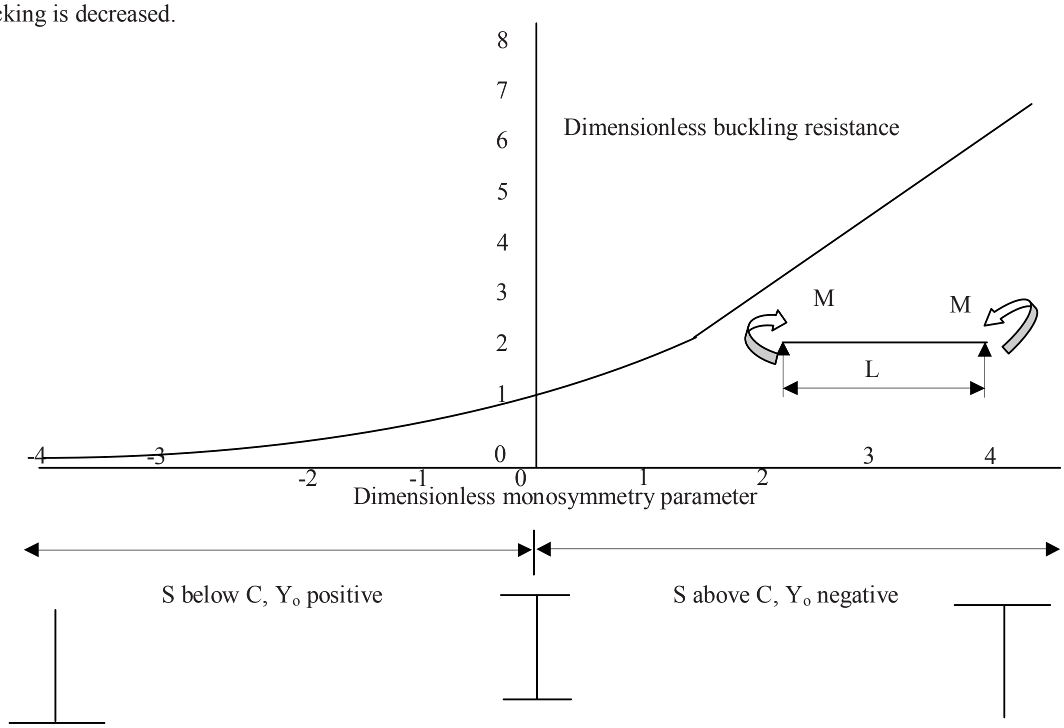


Fig.2.Monosymmetric beams in uniform bending.

3. Effect of Load Height

The buckling resistance of a simply supported beam may be significantly affected by the distance of transverse load from the shear centre axis. For beam carrying central concentrated load at the shear centre this may be expressed as**:**

$$\frac{M}{M_{yz}} = \frac{M_m}{M_{om}} = \alpha_m \left[\sqrt{1+\left(\frac{0.4\alpha_{mf}\,{}_3\beta_x}{2M_{om}/P_y}\right)^2} + \frac{0.4\alpha_{mf}\,{}_3\beta}{2M_{om}/P_y} \right] \tag{9}$$

Where,

$$M_m = \frac{WL}{4}, \qquad \alpha_m = 1.35\,,\ f_3 = \frac{\pi^2}{8} - \frac{1}{2} \approx 0.73$$

And, M_{om}= Elastic critical moment for monosymmetric beam.

For a simply supported monosymmetric I-beam under uniform moment, the elastic critical moment, M_{om}, can be expressed as,

$$M_{yz} = M_{om} = \frac{\pi}{L}\sqrt{EI_yGJ}\left[\sqrt{1+K^2+\left(\frac{\pi\delta}{2}\right)^2}\right] \tag{10}$$

In which K is the beam parameter,

$$K = \sqrt{\frac{\pi^2 EI_w}{GJL^2}} \tag{11}$$

Ely is the minor axis flexural rigidity; GJ is the torsional rigidity; EI_w is the warping rigidity; L is the length o f the beam; and

$$\delta = \frac{\beta_X}{L}\sqrt{\frac{EI_y}{GJ}} \tag{12}$$

The term ںx is the monosymmetry parameter,

$$\beta x = \frac{1}{I_x}\left(\int_A x^2 y\,dA + \int_A y^3 dA\right) - 2y_o \tag{13}$$

In which x and y are coordinates with respect to the centroid and y_0 is the coordinate of the shear center. Anderson and Trahair [8] presented tabulated results for simply supported monosymmetric I-beams and cantilevers with concentrated and distributed loads, and investigated the influence of load height on the elastic critical buckling moment. These approximate equations are reported to be good accuracy generally except for very monosymmetric section for which ρ approaches to 0 or 1.0. In this paper also the effect of load height on buckling resistance of monosymmetric beam has been plotted. A good approximation can be obtained for central concentrated load on monosymmetric beam [expect for very monosymmetric].

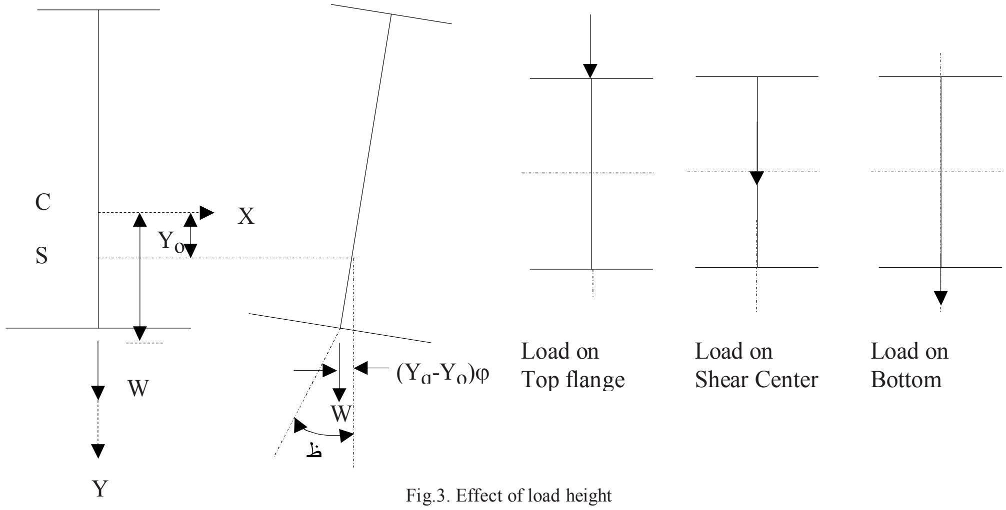


Fig.3. Effect of load height

In order to verify the effect of load height on the buckling resistance of simply supported beam carrying central concentrated load beam dimensions are calculated considering:

Iy/Ix=0.1
Depth of beam= Span/10
Span varying from 1m to 20m
Degree of monosymmetry (ρ) from 0.0 to 1.0

A computer program is prepared to get the parameters of I-beam which satisfied all above requirements.

```
function Monosymmetric()
L = input('Enter the span of the beam from 1 to 20 m =');
dw = L*1000/10;
tw = input('Enter the thickness of web in mm =');
bft =input('Enter the width of top flange in mm =');
tft = input('Enter the thickness of top flange in mm =');
Ift = bft*(tft^3)/12;
row = input('Enter the degree of monosymmetry from 0 to 1 =');
Ifb = (Ift/row)-Ift;
tfb = input('Enter the thickness of bottom flange in mm=');
bfb = Ifb*12/tfb^3;
Xbar = ((bfb*tfb*tfb/2)+(tw*dw*(tfb+dw/2))+(bft*tft*(tfb+dw+tft/2)))/(bfb*tfb+tw*dw+bft*tft);
Ixx = ((bfb*tfb^3/12)+bfb*tfb*(Xbar-tfb/2)^2)+((tw*dw^3/12)+tw*dw*(Xbar-(tfb+dw/2))^2)+((bft*tft^3/12)+bft*tft*(Xbar-(tfb+dw+tft/2))^2);
Iyy = (tft*bft^3/12)+(dw*tw^3/12)+(tfb*bfb^3/12);
Ratio = Iyy/Ixx;
End
```

3.1 Nonlinear finite element model

To investigate the effect of load height on buckling resistance of steel beam, a nonlinear 3-dimensional finite element modeled is developed. The nonlinear computations were performed using the commercial finite element software package ANSYS [9]. ANSYS has the ability to consider both geometrical as well as material nonlinearity in a given model. Four side shell element SHELL 43 from the ANSYS element library were used to model the web, flange (top and bottom). The steel is modeled as bilinear isotropic hardening and a stress-strain curve that consists of an elastic region and a strain hardening region is assumed. In the elastic region, a typical value modulus of elasticity (*E* = 210,000 MPa) and nominal yield stress value (*Fy*) of 250 MPa are assumed. The strain hardening modulus was considered as E_{st} = 1000 MPa and Poisson's ratio was set to 0.3. Simply supported monosymmetric I-beam, the parameter as per computer program above with different spans are chosen. The concentrated loads are applied at top flange, shear center and bottom flange and from the obtained results a comparison were made between critical load versus span.

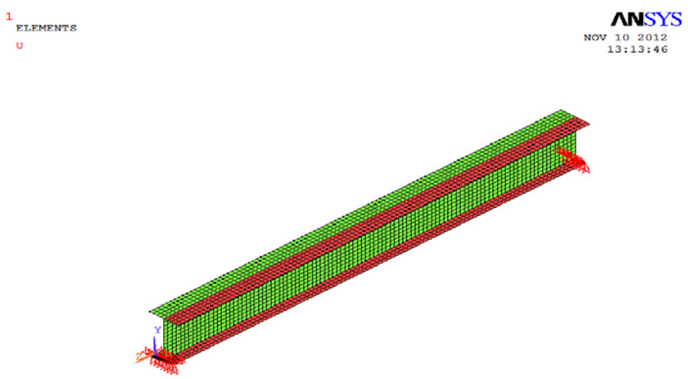


Fig.4. Three-dimensional finite element model with mesh

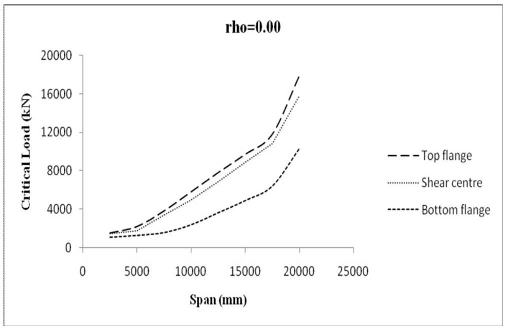


Fig.5. Critical load Vs span

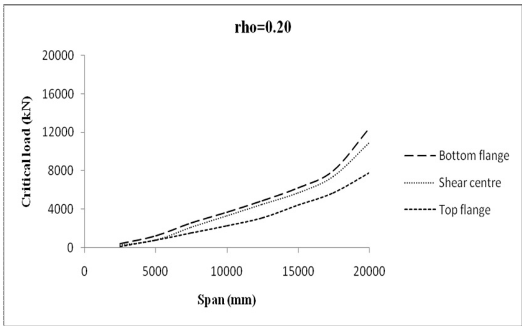


Fig.6. Critical load Vs span

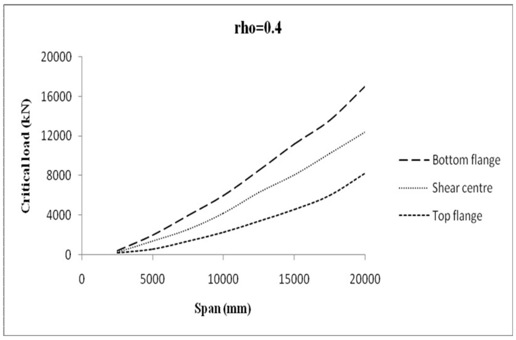


Fig.7. Critical load Vs span

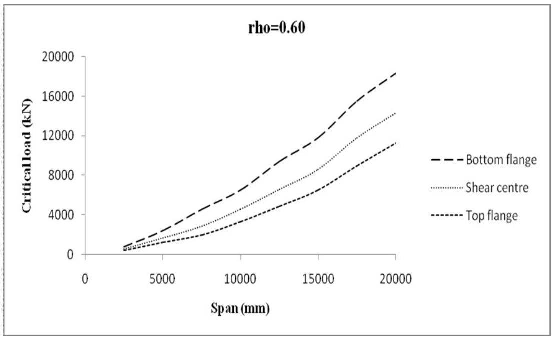


Fig.8. Critical load Vs span

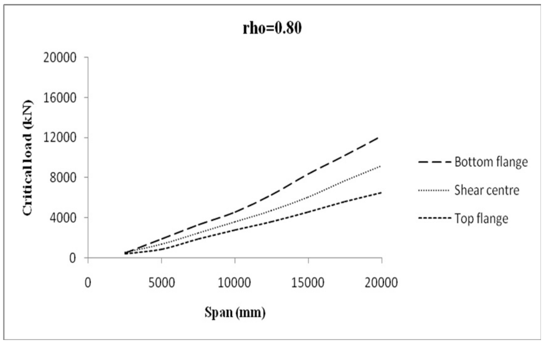


Fig.9. Critical load Vs span

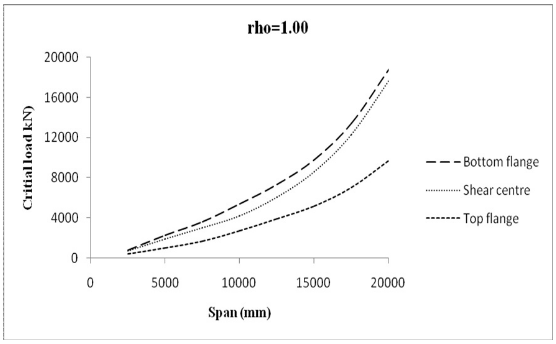


Fig.10. Critical load Vs span

For the simply supported beams with uniformly distributed shear center loading buckling load can be approximately calculated by using equation [9] and [10] with

$$M_m = \frac{WL^2}{8}\ , \ \alpha_m = 1.13\,, \qquad f_3 = \frac{\pi^2}{6} - \frac{1}{2} \approx 1.14$$

Once again in order to verify the effect of load height on the buckling resistance of simply supported beam carrying uniformly distributed load beam dimensions are calculated considering:

Iy/Ix=0.1
Depth of beam= Span/10
Span varying from 1m to 20m
Degree of monosymmetry (ρ) from 0.0 to 1.0

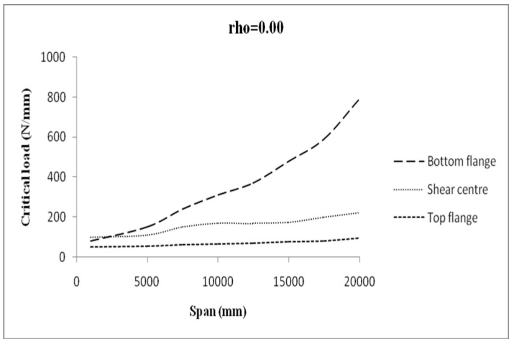


Fig.11. Critical load Vs span

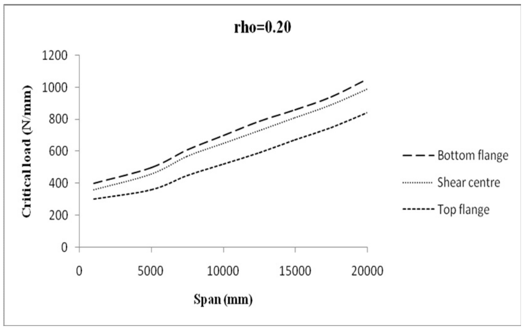


Fig.12. Critical load Vs span

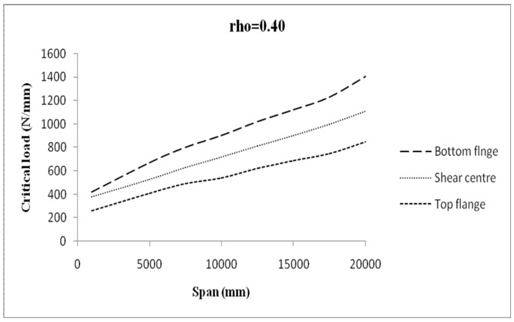


Fig.13. Critical load Vs span

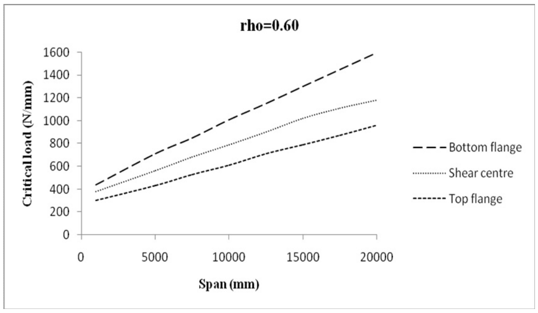


Fig.14. Critical load Vs span

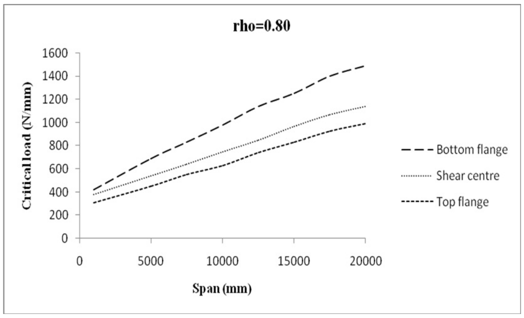


Fig.15. Critical load Vs span

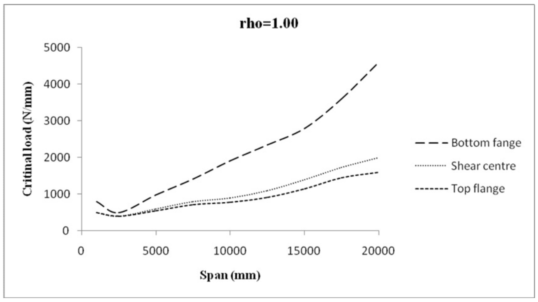


Fig.16. Critical load Vs span

4. Conclusion.

The effect of load height on buckling resistance of simply supported monosymmetric I-beams subjected to concentrated load at center and uniformly distributed load has been investigated. The beam properties required in the determination of the elastic buckling moment may be grouped into three basic parameters: [1] The degree of beam monosymmetry ρ, which is the ratio of the second moment of area about the section y-axis of the top flange to that of the whole section; [2] the beam parameter, $K = \sqrt{\pi^2 EI_y h^2 / 4GJL^2}$; and [3] the end moment ratio, β. The two main factors that influence the buckling capacities of monosymmetric I-beams are: [1] The monosymmetry parameter, β_x or the so-called Wagner effect; and [2] the effect of load height i.e. whether the load is acting either above or below the shear center axis. In general, the buckling capacity is greatly reduced when a significant portion of the smaller flange is in compression. The distance of transverse load from shear center axis significantly affects the buckling resistance to buckling. When transverse load acts below the shear center and moves with the beam during buckling it increases resistance to buckling. On the other hand when transverse load acts above shear center, it reduces buckling resistance of beam. Finally, it was found that highly monosymmetric sections [i.e. ρ > 0.9] may not be the optimum sections for achieving the maximum buckling load. For the optimal value of the degree of beam monosymmetry, ρ could be as low as 0.7. A good approximation can be obtained both for central concentrated and uniformly distributed load.

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