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Optimization of Stepped I-Beams for Lateral Torsional buckling

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Abstract**—** In this paper lateral torsional buckling of stepped I beams are analysed using finite element software. Continuous multispan beams with steps are common in construction of steel buildings and bridges. Beams with degree of symmetry 0.5(doubly symmetrical sections) investigated for both singly stepped beams and doubly stepped beams. Stepped length ratio 0.167, 0.25, 0.333, 0.5 with increase in flange width 20% to 40% are also considered. Span of 5m, 7m and 9m are considered along with span to depth ratios 15, 20 and 25. Buckling analysis of stepped I-beams subjected to transverse loading applied at different heights (top flange , shear centre, bottom flange) on the cross section were also conducted. Buckling load is found increasing as length ratio increased from 0.167 to 0.5 for singly stepped beams and 0.167 to 0.333 for doubly stepped beams. As the span to depth ratio increases load carrying capacity found to be decreasing for given span. Compression flange load has lesser load carrying capacity compared to tension flange loading and mid height loading.

Keywords**:** Stepped beams, Lateral-torsional buckling, load height.

I. INTRODUCTION

The use of stepped beams in construction has gained popularity especially in steel bridges for the reason that this member is often used when the maximum moment is only reached locally and the moment at the remaining span of the beam is significantly reduced. Hence, material economy can be achieved by reducing the member section in the low moment area. Steps in beams are achieved by either adding cover plates to beam flanges, changing the size of the cross section for hot rolled beams or by changing the flange dimension for built up sections. Stepped beams are the most efficient when laterally supported because the strength of the material is used to its full extent. When lateral support is inadequate, its failure is often governed by lateral torsional buckling. Lateral torsional buckling is a complex out-of-plane phenomenon characterized by minor axis flexure, torsion and warping. Even so, the use of stepped beams can still be economical as long as the flange material is distributed to improve its resistance.

Kitipornchai and Trahair (1980) Determined the section properties required for calculating the elastic critical moment of a mono-symmetric I- beam. These properties are related to the ratio of the second moments of area of compression flange to that of the

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whole section. And they derived a new method of calculating the elastic critical stresses of mono-symmetric beams

Helwig *et al. (*1997) suggested a simplified equation for monosymmetric I-beams subjected to general load cases with load height effect**.** They have demonstrated that when transverse loading are applied at mid height (not at shear center) moment gradient factor does not vary with monosymmetric ratio. Results showed that, for single-curvature bending, traditional values of moment gradient factors can be used to estimate the buckling capacity of singly symmetric girders with transverse loads applied at mid-height. The C_b equation in the second edition of the AISC LRFD specification was modified to account for effects of reverse-curvature bending for singly symmetric sections.

Park and Stallings (2003, 2005) conducted series of lateral torsional buckling moment resistance study focused on two general types of stepped beams, which are doubly stepped beams (DSB) and singly stepped beams (SSB). They suggested an equation for the lateral torsinal buckling of the DSB and the SSB subjected to pure bending.

Trahair (2012) Presented graphical solutions for simply supported monosymmetric I-beams with a concentrated load or uniformly distributed loads and varying end moments, and investigated the effect of load height on elastic critical moment.

El-Mahdy & El-Saadawy (2014) found the ultimate load carrying capacity of mono-symmetric I- beams. They analyzed a simply supported beam with udl using ANSYS. They proposed a formula for load carrying capacity.

Dessouk *et al* (2015) studied the effect of boundary condition at the cantilever tip of a an overhanging beam, mono-symmetric ratio, ratio of cantilever length to the radius of gyration of lateral-torsional bucking, depth of the stiffener at cantilever tip. Report showed that, when boundary conditions preventing the twist of the top flange at the root support are considered, higher buckling capacities could attained. Adding full depth vertical stiffener at the root support is found to be very effective and increases the ultimate moment capacity of singly- symmetric overhanging I-beams.

Many researchers have been carried out on elastic buckling of stepped I-beam and mono symmetric I beam using energy method , Rayleigh-Ritz energy approach, finite integral method.

Very limited researches have been reported on stepped I-beams and the optimization of material consumption to achieve an efficient section using finite element software.

B. Objectives

This study aims to investigate numerically the behaviour of stepped I- beams using finite element software package ABAQUS.

1. To find the load carrying capacity of mono-symmetric I-beam using ABAQUS by varying the following parameters
   a. Length ratio, α (0.167-0.5)
   b. load height (top flange, mid-height, bottom flange)
   c. flange width ratio, β

Table 1. Cross sectional properties

2. To optimize flange width to get an efficient section

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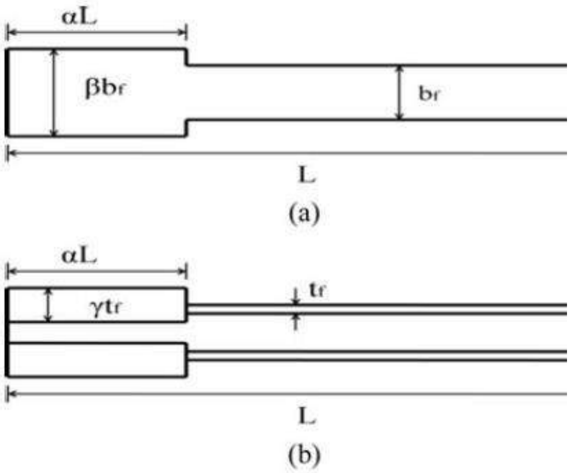

Fig.1 Stepped I beam showing the parameters

C. Methodology

The analytical investigation process essentially consists of following.

1) Identification of Parameters
2) Finite element modelling of stepped I-beam using finite element software package ABAQUS.
3) Linear analysis and Model validation
4) Nonlinear Static analysis of stepped I

I. GEOMETRIC MODELING

A. ***Element type and meshing***

The stepped I-beam sections are modelled using shell element. S4R element type was chosen. S4R is a 4-noded shell element, reduced integration, hourglass control. A mesh convergence study was made and a mesh size of 40mm was chosen

B. ***Boundary conditions***

The models were analysed for both ends simply supported and at one end of the beam allowing for the shortening of the beam along the beam's axis and also, compression flange is laterally restrained only at supports. Support condition was provided at the mid-point of the cross section at the ends and additional lateral supports at the corners of the flanges in the cross-section.

Simply supported condition- All the translational degrees of freedom were restrained at both the ends except the translational degrees of freedom in the axial direction at one end.

C. Loading

Loads were applied to top and bottom flange and at the mid-height of the cross-section. Concentrated load considered for buckling and nonlinear analysis in ABAQUS.

D.Geometric and material nonlinearity

Initially, buckling modes were established by doing linear perturbation analysis under point load, the eigenvalues were obtained from which the elastic buckling load was calculated.

Table 2.Load carrying capacity with span 5m for different L/d

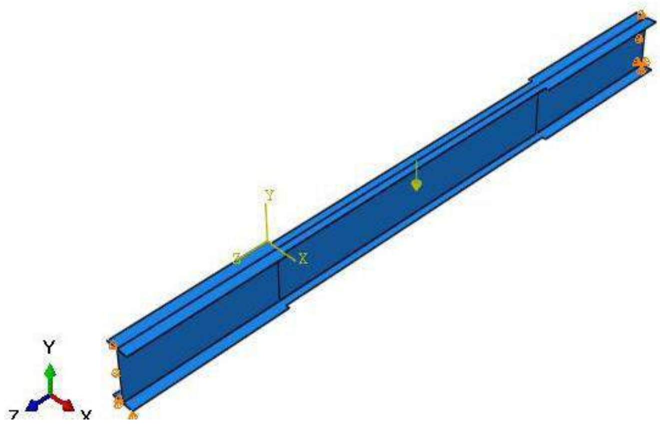

Fig.2. Boundary Conditions and point Loading

In the next step, the RIKS analysis was performed to establish non-linear behaviour

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wherein geometrical non-linearity was incorporated. Material nonlinearity was also incorporated as a function of depth of web. An imperfection of 1/100 of depth of web was adopted in appropriate mode shape. Finally, load displacement plots were obtained.

II. RESULTS AND DISCUSSIONS

Ultimate buckling loads of a total of 144 models were extracted using non-linear analysis in ABAQUS by varying the *L*/dratio (15, 20, 25), length ratio, α (0.167, 0.25, 0.333, 0.5) , width ratio, β (1, 1.2, 1.4) and load position (top flange, shear centre, bottom flange) for a span of 5m.

Concentrated load is applied to the top flange, mid-height and bottom flange at the mid-span of the stepped I beam for the various width ratios considered. The critical buckling load is determined.

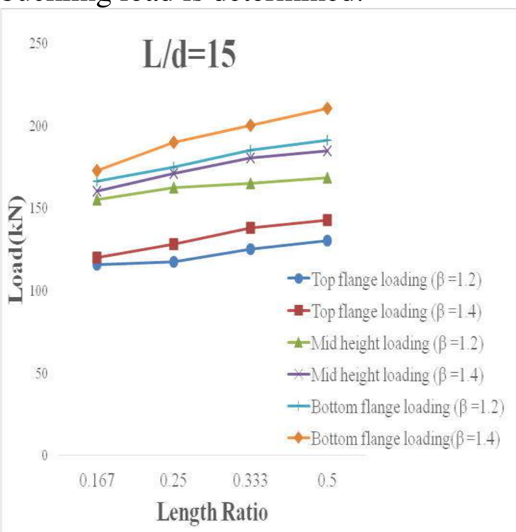

Fig.3 Ultimate load vs. length ratio (α) for *L* = 5m and *L*/d = 15 for different load positions

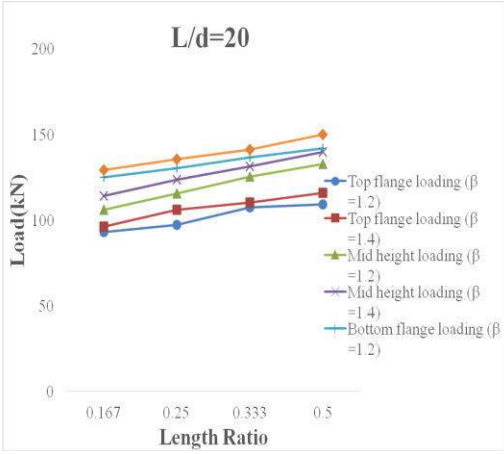

Fig.4 Ultimate load vs. length ratio (α) for *L* = 5m and *L*/d = 20 for different load positions

From the graph, it can be observed that

- Load carrying capacity increases as the flange width increases.
- Also load carrying capacity increases with the length ratio increases.

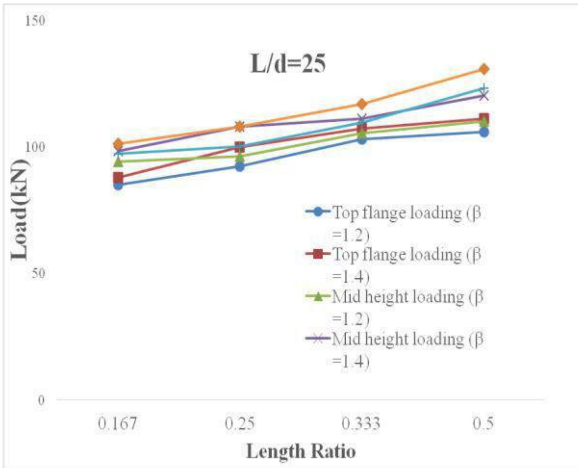

Fig.5 Ultimate load vs. length ratio (α) for *L* = 5m and *L*/d = 25 for different load positions

From the above graphs, it can be observed that

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- As the span to depth ratio increases load carrying capacity decreases.
- Also top flange loading leads to lesser load carrying capacity compared to other load heights.

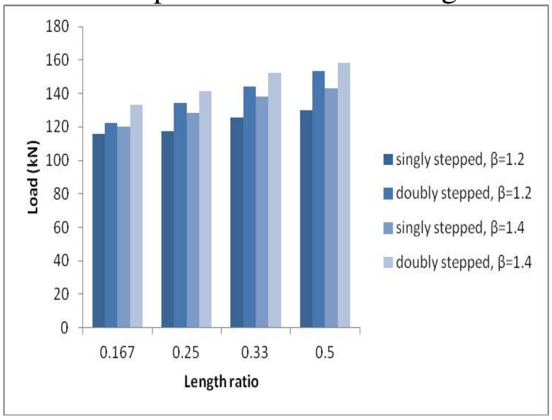

Fig.6 Comaprison between singly stepped and doubly stepped beam

From the above graph, comapring with singly stepped beam with doubly stepped beam, it is found that doubly stepped beam has more load carrying capacity

I. SUMMARY AND CONCLUSIONS

The stepped doubly symmetric I-beams with variable flange width for different span were modeled and linear and non-linear analyses were carried out using general purpose FEA software ABAQUS. Based on the results obtained from the finite element modeling following conclusions can be made.

1. As the length ratio increases from 0.167 to 0.5, inelastic load carrying capacity also increases.
2. Doubly stepped beam has more load carrying capacity than singly stepped beams.
3. For 40% increase in flange width (i.e. β=1.4) found to be optimum for stepped beams.
4. The height of loading on the cross section has significant effect on the buckling capacity. Compression flange loading has lesser load carrying capacity than shear other two cases.
5. As L/d ratio increases, load carrying capacity decreases for a given span.

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