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Finite Element Analysis of Lateral Torsional Buckling Behaviour of Tapered Steel Section with Perforation

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Abstract. This paper presents the finite element analysis of lateral torsional buckling of tapered steel section with perforation. The numerical analysis consists of four main models with a ratio of tapering 0.3 for 3.5m and 5.5m span and ratio of tapering 0.5 for 3.5m and 5.5m span. This study has 94 models in order to investigate the effect of thickness and the openings on the buckling moment. LUSAS software was used to carry out the finite element analysis to study the effect of web opening on the buckling behavior which had five variables such as thickness of web and flange, opening size, ratio of tapering, and opening arrangement. The opening size from 0.2D to 0.4D is recommended because buckling moment capacity difference only around 2% was observed for the opening size exceeds 0.4D. Ratio of tapering 0.3 and ratio of tapering 0.5 was observed increase with the web opening area. The deformation patterns are almost similar for the different sizes of web openings and ratio of tapering. Based on the finite element results, tapered steel section without perforation has higher buckling moment capacity. The comparison of the buckling moment between non-perforated sections with the recommended section is around 2% to 4%.

1 Introduction

Tapered steel section is a section consisting of two flanges connected by tapered web as shown as in Figure 1. Lateral buckling of tapered members were first investigated by Boley and Zimnoch [1] in 1952. This paper indicated the investigations of the application of a numerical method that had developed for the problem of the lateral buckling. Trahair [2] carried out research on the interaction buckling of tapered beams. The results show the elastic lateral buckling of braced and continuous beams is influenced by the separate effects of moment distribution, taper, and restraints between adjacent segments. Elastic lateral-torsional buckling behavior of discretely restrained tapered beams show inaccurate to model a web-tapered I-beam as an assembly of prismatic segments through theoretical and numerical results [3].

Lagaros et al. [4] stated that the arrangement of multiple openings in the beams has also been adopted for aesthetical considerations. The effects of circular or square web openings on the ultimate strength of horizontally curved composite plate girders had conducted by Basher et al. [5]. They found that the reduction of ultimate shear strength is small and can be neglected when the opening size is small. Abidin and Izzudin [6] carried out meshless local buckling analysis of steel beams with irregular web openings. The combination of the element-free Galerkin method with the rotational

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spring analogy yields accurate and efficient buckling predictions. Liu and Chung [7] used finite element method to analyze the characteristics of steel beams with large openings of various shapes and sizes. The result shows that perforated section under a global moment Mo,Sd and a global shear force Vo,Sd, three local actions are induced in the tee-sections above and below the web opening.

Lateral torsional buckling strength of unsymmetrical plate girders with corrugated webs subjected to uniform moment demonstrated a good agreement between the finite element results and the proposed formula [8]. The un-symmetrical corrugated web girder has an elastic lateral torsional buckling capacity up to 11% more than the corresponding plate girder with the conventional flat web. Lateral torsional buckling analysis of steel frames with corrugated webs has been studies by Sabat [9]. Finite element analysis and Eurocode 3 show very close value of the result and similar lateral-torsional buckling behavior is obtained for both of frame with corrugated webs and the frame with plane webs. Moon et. al [10] had investigated theoretical and finite element analysis of the lateral torsional buckling of I-girder with corrugated webs under uniform bending. They had found the elastic lateral-torsional buckling strength is increased up to 10% for I-girders with corrugated webs compared to I-girder with flat webs.

In this regard, this paper studies the lateral torsional buckling behavior of tapered steel section with perforation using finite element analysis. The objectives of this study are to study the behavior of tapered steel section with perforation subjected to lateral torsional buckling, to determine the lateral torsional buckling moment for tapered steel section with perforation and to investigate the effect of section properties on the buckling moment resistance of tapered steel section with perforation.

2 Finite Element Analysis

In this research analysis, concentrated load, P is applied at the end of flange at the top part of the flange in vertical y-axis direction. The web is restrained at one end so it acts as cantilever or fixed-free. The following material properties and loading are kept constant throughout the analysis:

a) Ungraded Mild Steel
   - Young's Modulus, $E = 209$ GPa
   - Poisson Ratio, $v = 0.3$

b) Loading, $P = 10$kN

A convergence study had been done to get the optimum meshing that will reduce the computational effort to render the surface. The details of the model used to get the appropriate meshing size in convergence study is shown in Table 1. The convergence study was done by decreasing the element size to obtain increasing number of element of the model simultaneously will get the deflection value. Both number of element and deflection value was used to plot a graph, the graph converged and element size of 25 was used.

Table 1. Section properties of tapered I-beam.

Section	Tapered I-Beam
D_{max}	250 mm
B	100 mm
t_w	13 mm
t_f	9 mm
L	1000 mm
Opening Dimension	0.5D
Tapered Ratio (D_{min}/D_{max})	0.5

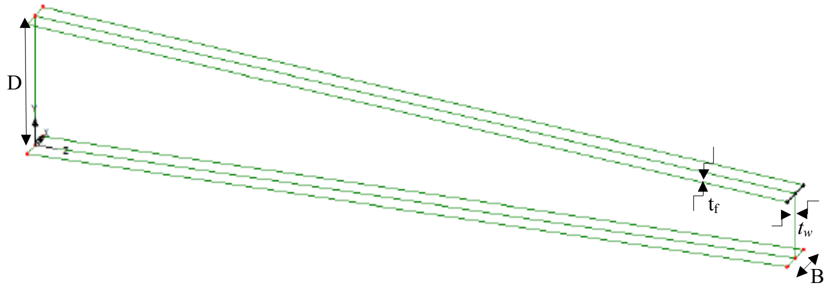

Figure 1. Three dimensional view of tapered steel beam section.

The formula used to calculate the buckling moment is:

$$P_b = \text{eigenvalue x concentrated load} \quad (1)$$

$$M_b = P_b \text{ x } L/4 \quad (2)$$

3 Results and Discussion

Finite element analysis was used to assess the engineering properties and performance of tapered steel section with perforation. The buckling moment capacity with different opening size and area, thickness of web and flange, arrangement and number of openings and ratio of tapering was found from eigenvalue buckling analysis. When the ratio of tapering and opening size increases, the buckling moment capacity decreases as can be seen in Figure 2 to Figure 5.

Buckling moment capacity reduces when ratio of tapering changed from 0.3 to 0.5. The results shows around 30% of decreasing moment of buckling for 3.5m span and decreases around 40% for 5.5m span. Ratio of tapering 0.3 was recommended because it can withstand buckling failure more than ratio of tapering 0.5. The opening areas are inversely proportional to the buckling moment. The rate of decrease of buckling moment is around 3% to 6%. Opening size from 0.2D to 0.4D is recommended because when opening size exceeds 0.4D, buckling moment capacity difference of only 2% is observed.

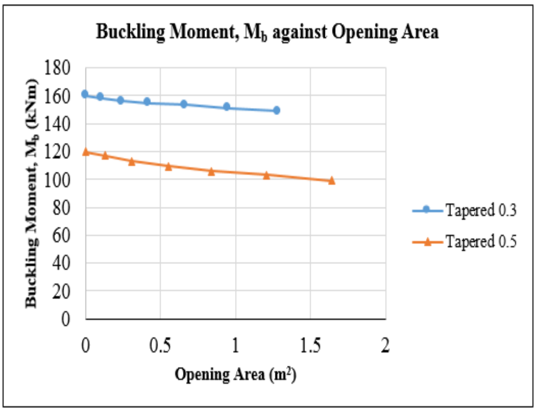

Figure 2. Graph of buckling moment, M_b against opening area for 3.5m span (effect of tapering ratio).

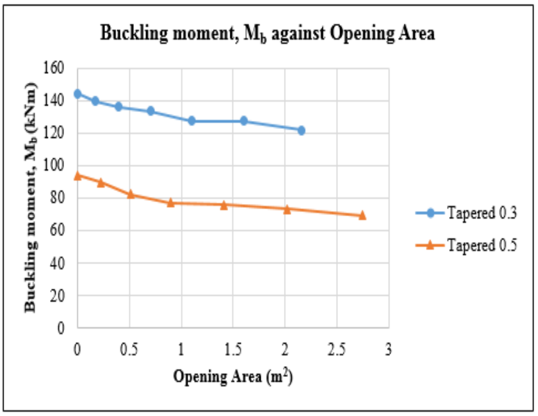

Figure 3. Graph of buckling moment, M_b against opening area for 5.5m span (effect of tapering ratio).

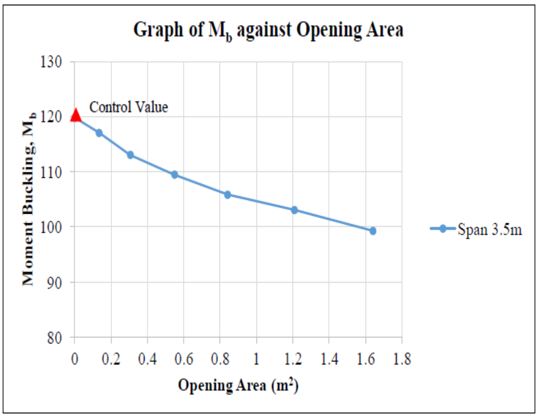

Figure 4. Graph of buckling moment, M_b against opening area for span 3.5 m.

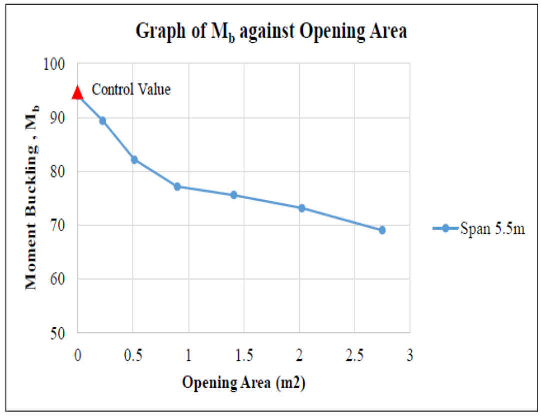

Figure 5. Graph of buckling moment, M_b against opening area for span 5.5 m.

The buckling moment capacity will increase with the decreasing number of opening and increasing thickness of web and flange of the section as shown in Figure 6 to Figure 9. Different length of span gives different results and rate of increases and decreases. Besides that, different opening arrangement was also give different buckling moment capacity. Meanwhile, Figure 10 to Figure 12 demonstrates the failure pattern of tapered steel section with perforation.

The best arrangement chosen was open-close-open (OCO) because it does not have too many or too few number of opening. It also has an average buckling moment compared to the other two arrangement which is open-open-open (OOO) and close-open-close (COC). Thickening the web simultaneously increase the depth and width. Not to mention thicker section should be considered for the optimum design in bending since the results show that the thicker the section, the higher the buckling moment capacity. The difference between non-perforated section with the recommended perforated section buckling moment is around 2% for 3.5m span and 4% for 5.5m span.

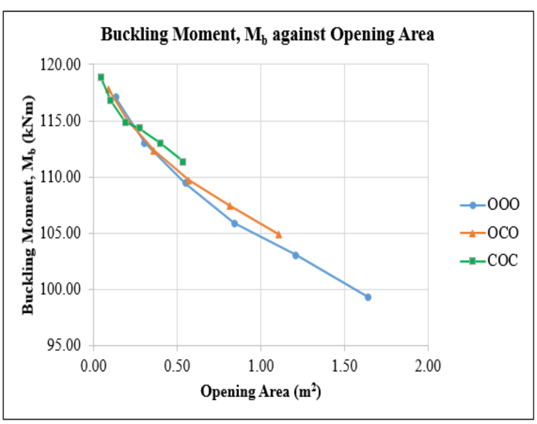

Figure 6. Graph of buckling moment, M_b against opening area for span 3.5 m span (effect of opening arrangement).

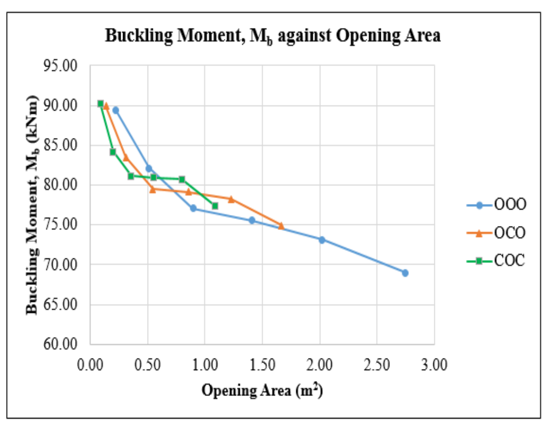

Figure 7. Graph of buckling moment, M_b against opening area for span 5.5 m span (effect of opening arrangement).

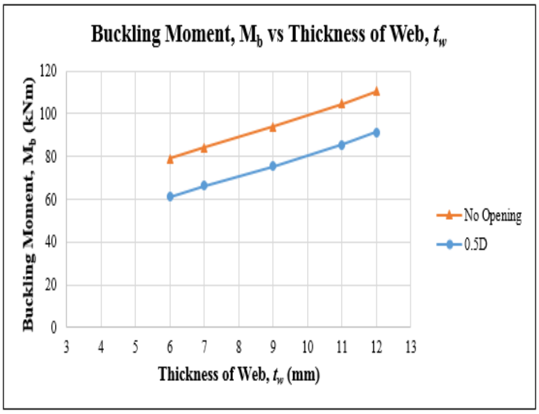

Figure 8. Graph of buckling moment, M_b against thickness of web, t_w.

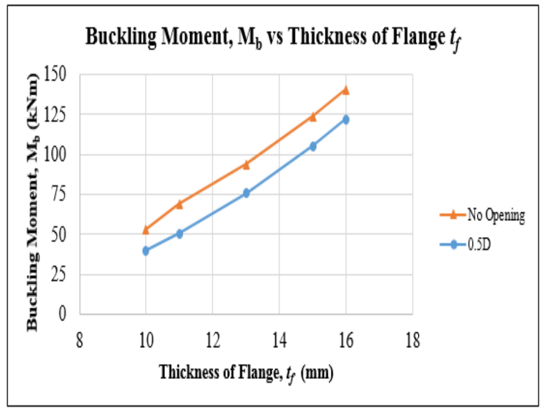

Figure 9. Graph of buckling moment, M_b against thickness of flange, t_f.

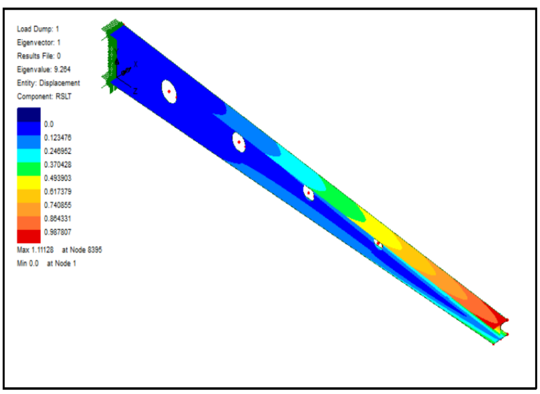

Figure 10. Contour displacement for tapered steel section with perforation with eigenvalue = 9.264.

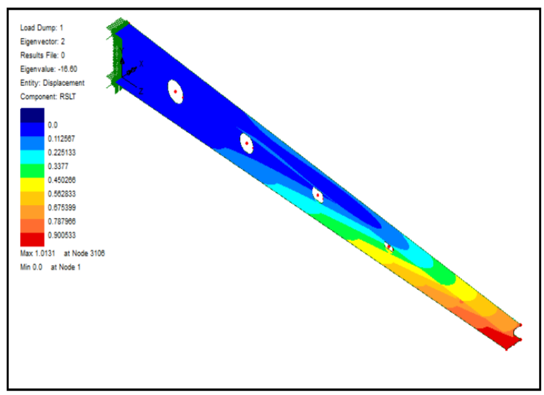

Figure 11. Contour displacement for tapered steel section with perforation with eigenvalue = 16.60.

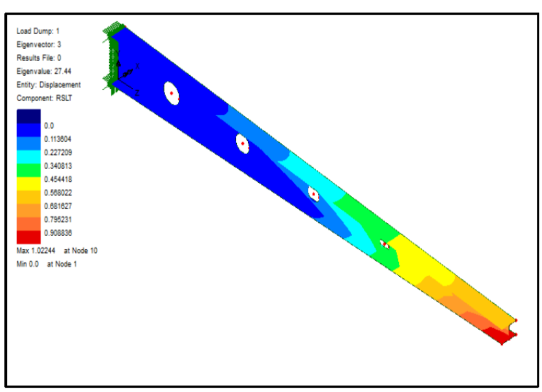

Figure 12. Contour displacement for tapered steel section with perforation with eigenvalue = 27.44.

4 Conclusion

The conclusions obtained from this study are the failure pattern for tapered steel section with and without perforation practically do not to have large dissimilarities. The buckling moment capacities of tapered steel section with perforation decreases when the ratio of tapering and opening size increases. Meanwhile, the buckling moment capacity will increase with decreasing number of opening and increasing the thickness of web and flange of the section. The buckling moment capacity for both tapered steel section with and without perforation increases for the increasing the thickness of flange and web. However, tapered steel section with perforation has lower buckling moment capacity compared to tapered steel section without perforation.

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