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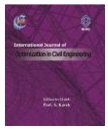

ANALYTICAL STUDY OF STEEL I-BEAM WITH STEPPED FLANGES

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ABSTRACT

This paper presents a parametric study of steel I- beam with stepped flanges by using finite element analysis. Stepped flange beam is used in structures to decrease the negative bending moments near interior supports that causes failure due to buckling. Steps in the cross section can be achieved by adding cover plates to the beam flanges, changing the size of the hot rolled section, or changing the flange thickness and/or width for built-up section. The stress concentration with variation in stepped beam configuration such as doubly and singly stepped I-beams has been examined thoroughly. The loadings are limited to those having an inflection point of zero under point load at mid span. Beams with degree of symmetry, ρ of 0.2 are investigated for the present study. Unbraced length to height ratio of the beam to be analyzed is considered as 15. In addition, to check the effect of steps, stepped parameters α, β and γ are varied. The results shows that, a change of flange thickness is more significant than a change of flange width on the lateral torsional buckling capacity of a singly stepped beam.

Keywords: Parametric Study, Stepped I-Beam, Stepped Parameters, Negative Bending Moment, Non Linear Buckling.

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1. INTRODUCTION

The researchers have continuously trying to reduce the cost of steel structure. The outcomes of this research leads to emergence of several new technologies like the Castellated Steel Beam (CSB), Corrugated Web Beams (CWB) and Stepped Flange Beams (SFB). Castellated Steel Beam (CSB) could reduce the floor to floor height of buildings by

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passing the service pipes, wires and ventilating ducts passing through web openings [1-10]. Compared to plain web beam over Corrugated Web Beams (CWB), the weight of beam can be condensed up to 30%, enhancement in the horizontal rigidity and resistance against lateral torsional buckling without adding the transverse stiffeners. To achieve the economy in design, the use of non-prismatic section is implemented in steel structures is called as Stepped Flange Beams. Stepping the beams will increase the cross section at essential parts along the span instead of providing the same cross section throughout the span. The results of stepping the beams is in savings of steel material. Park and Kang have been investigated the behaviour of stepped beam under pure bending on a continuous multi span beam to withstand maximum negative moments [11].

The nonlinear buckling capacity of singly symmetric stepped I-beams with non-compact flanges and changing degree of symmetry under uniform bending has been investigated by Albert. Moving to several loading conditions, the study of Surla [12] reveals that the critical moment does not always correspond to pure bending moment by analyzing the beams subjected to different loading conditions and also with different monosymmetric ratios. The analysis has been performed by changing bottom flange width whereas keeping the top flange width unchanged. The influence of load height on buckling resistance has been studied by Lay [13]. The beams has been analyzed for three critical load positions and its effects on buckling resistance has been studied [14]. Recently, researchers investigated and developed a formulation for the inelastic lateral torsional buckling strength equation of doubly symmetric stepped beams. In this study, stepped sections were located at the mid span of the beam [15].

This study focuses on the FE analysis of continuous supported stepped beam with a combination of one doubly stepped beam and two singly stepped beam on either side of doubly stepped beam under midspan concentrated load. To realize the influence of steps, the stepped parameters α, β and γ are taken in analysis and by changing β and γ, lead to 9 cases for stepped beam. Fig. 1 shows Continuous Supported Stepped Beam, having the arrangement of two types of beam in which singly stepped beam is located on either side of doubly stepped beam. There are total four number of supports that are placed on both ends of singly supported beam.

Since the use of stepped beams results in material saving as well economical design solution over a prismatic beams, it becomes essential to study the behaviour this beams. Till date no one have provides a technique that can be freely used for design of stepped beams also, there have been no studies made on the lateral buckling of doubly symmetric stepped beams and the available studies did not clearly mention the styles in the buckling strength of stepped beams as the strength-steel ratio changes. This paper addresses these latter cases which are significant in design of continuous support with doubly symmetric stepped beams.

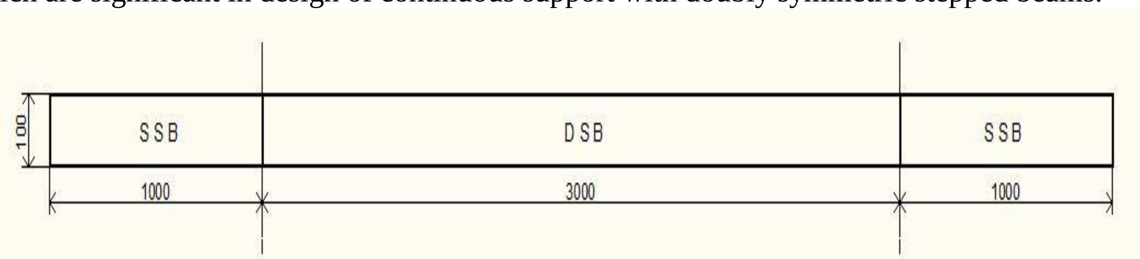


Figure 1 Continuous Supported Stepped Beam.

2. FINITE ELEMENT MODELLING

Finite element analysis has been performed to evaluate the strength capacity of stepped I-beams using finite element program ANSYS v12. Beam element (2 node 188) including both torsional and transverse for shear stress output was used to model the beams because it is suitable for analysing slender to moderately thick beam structures which includes shear deformation effects. This element is well suited for linear, large rotation, and large strain nonlinear applications. ISMB200 section beam as shown in Fig. 2 has been used in the analysis. The material and geometrical properties are as listed in Table 1. All the beams are fixed supported which means that all ends are restricted against vertical and longitudinal deflection, out-of-plane deflection and twist rotation. All beams were subjected to concentrated load at midspan to determine the effect of steps on strength capacity of beams.

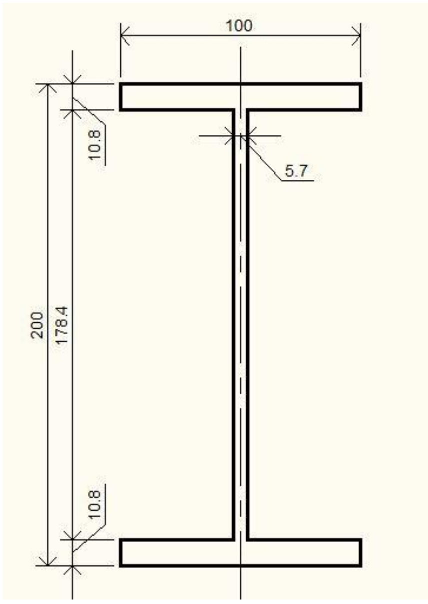


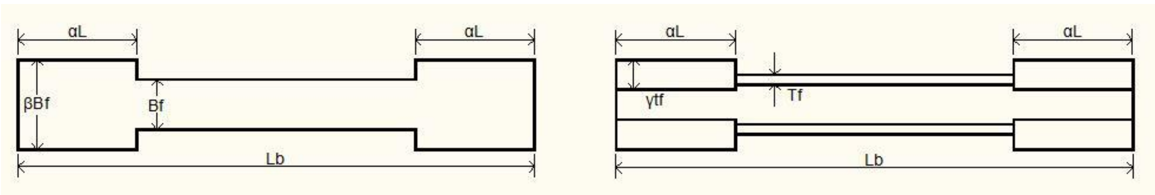
Figure 2 Section of ISMB 200

Table 1 Geometrical and Material Beam Properties

Properties	Values
Flange width	100 mm
Flange thickness	10.8 mm
Web thickness	5.7 mm
Beam depth	200 mm
Unbraced length	3000 mm
Modulus of Elasticity, E	2,00,000 MPa
Modulus of Rigidity, G	80,850 MPa
Yield Stress, Fy	250 MPa
Poisson’s Ratio, μ	0.3

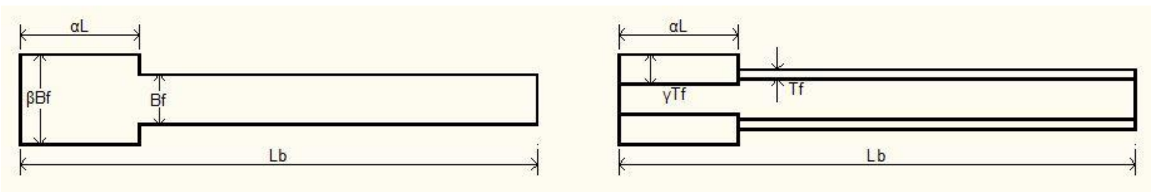
3. PARAMETRIC STUDY

A parametric study has been carried out to assess the effect of various parameters on the behaviour of steel beams with stepped flanges. Here an attempt is made to see the strength performance of stepped flange and prismatic beams. Continuous supported beam section as subjected to concentrated load at top flange and material properties as given in Table 1 are considered in the study. Load-bearing stiffeners are provided under concentrated load and at supports to avoid any premature failure in the analysis. From the Fig. 3 and 4 it can be observed that α corresponds to the ratio defining the relative length, β and γ corresponds to the ratio defining the relative width and thickness of the cross sections respectively. Fig. 5 and 6 shows the plan and cross section of stepped beams, which gives a clear idea of stepped flange geometry. Table 2 shows the stepped beam factors. The increase in section is made by using the stepped beam factor α, β and γ as given in Table 2.



(a) (b)

Figure 3. Doubly Stepped Beam. (a) Plan, (b) Section

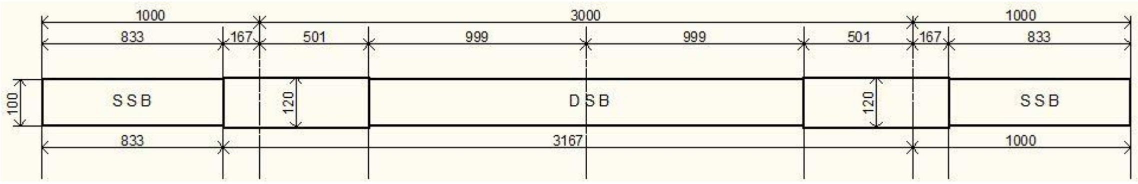


(a) (b)

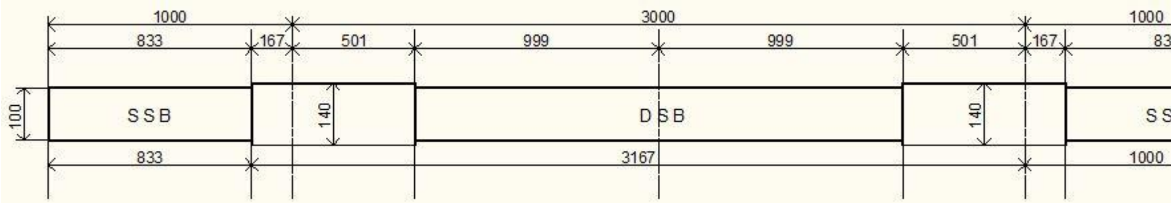
Figure 3. Singly Stepped Beam. (a) Plan, (b) Section

Table 2 Stepped Beam Factor.

Case	α	β	γ
1			1.2
2		1	1.4
3			1.8
4			1
5	0.167	1.2	1.4
6			1.8
7			1
8		1.4	1.4
9			1.8

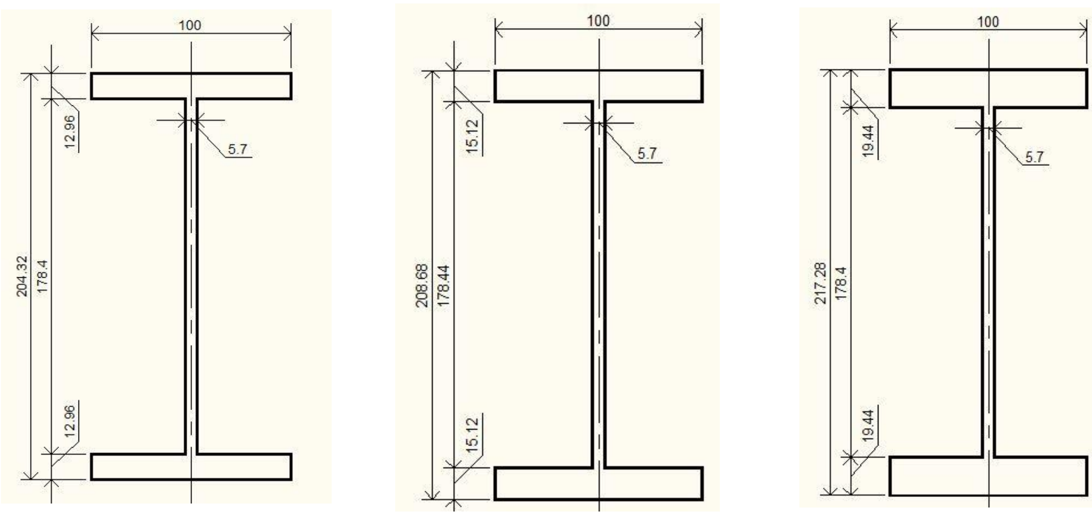


(a)



(b)

Figure. 5 Plan of Stepped Beam. (a) β = 120 mm, (b) β = 140 mm.



(a) (b) (c)

Figure. 6 Cross section of Stepped Beam. (a) γ = 1.2, (b) γ = 1.4, (c) γ = 1.8.

4. RESULTS AND DISCUSSION

The values of ultimate loads obtained from the finite element analysis are presented along with the comparison between the two values for all beams in Table 3. Total length for all the beam models analysed is 5000 mm in which doubly stepped beam is located in middle of 2 singly stepped beam of 1000 mm resulting three span continuous beam. Concentrated load of 500 kN is applied at the midspan of the beam. The static nonlinear analysis has been performed to study the load deflection behaviour of stepped flange beams. Table 3 shows the values of ultimate load obtained using the ANSYS for both prismatic as well as stepped beams. Fig. 7 represents the bar chart to discuss about ultimate load carrying capacity obtained from the finite element analysis for both type of beams. The effects of the different stepped beam parameters on flanges were investigated in terms of load-deflection curves at mid-span of the beams as shown in Fig. 8-16. For stepped beams having minor changes in comparison with original configurations of the beam, the studied trends are more vibrant to the trends of prismatic beam. Out of the total 9 cases, in order to determine the most effective case, the ratio of the increase in buckling strength and the increase in steel section per cases were observed. Cases with strength-steel ratio greater or equal to 1.00 are considered to be effective. Fig. 17 shows that the strength-steel ratios of the cases mentioned above have values greater than 2.0 which indicates the effectiveness of the stepped beam. The highest ratio was on C 2 with a values of 3.66 and least ratio was on C 9 with a value of 1.73.

Table 3 Comparison between Prismatic Beam and Stepped Beam.

Sr. No.	Beam Type	Load Carrying Capacity (kN)	Deflection (mm)	Increase in Load (%)	Beam Weight (kg)	Increase in Weight (%)	Strength/ Steel Ratio (%)
1.	PB	260	62.50	-	124.51	-	-
2.	C 1	295	71.12	13.46	129.13	3.71	3.63
3.	C 2	330	78.40	26.92	133.68	7.36	3.66
4.	C 3	375	76.64	44.23	142.71	14.62	3.03
5.	C 4	295	72.72	13.46	129.13	3.71	3.63
6.	C 5	355	74.88	36.54	140.04	12.48	2.93
7.	C 6	400	71.91	53.85	150.88	21.18	2.54
8.	C 7	320	74.83	23.08	133.68	7.36	3.13
9.	C 8	380	73.49	46.15	146.32	17.52	2.63
10.	C 9	385	48.76	48.08	159.04	27.73	1.73

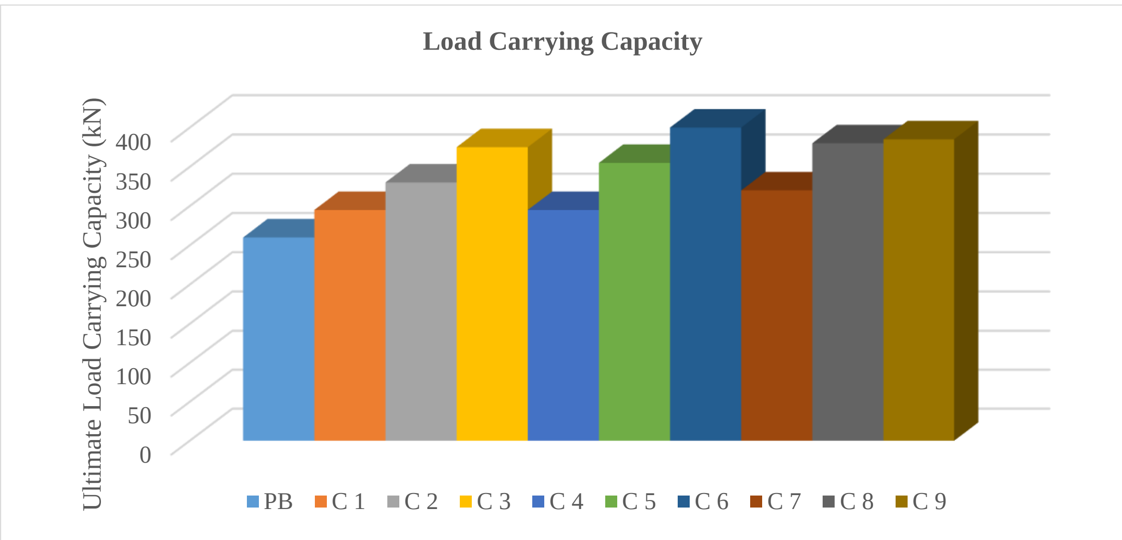


Figure 7. Comparison between prismatic and stepped beams.

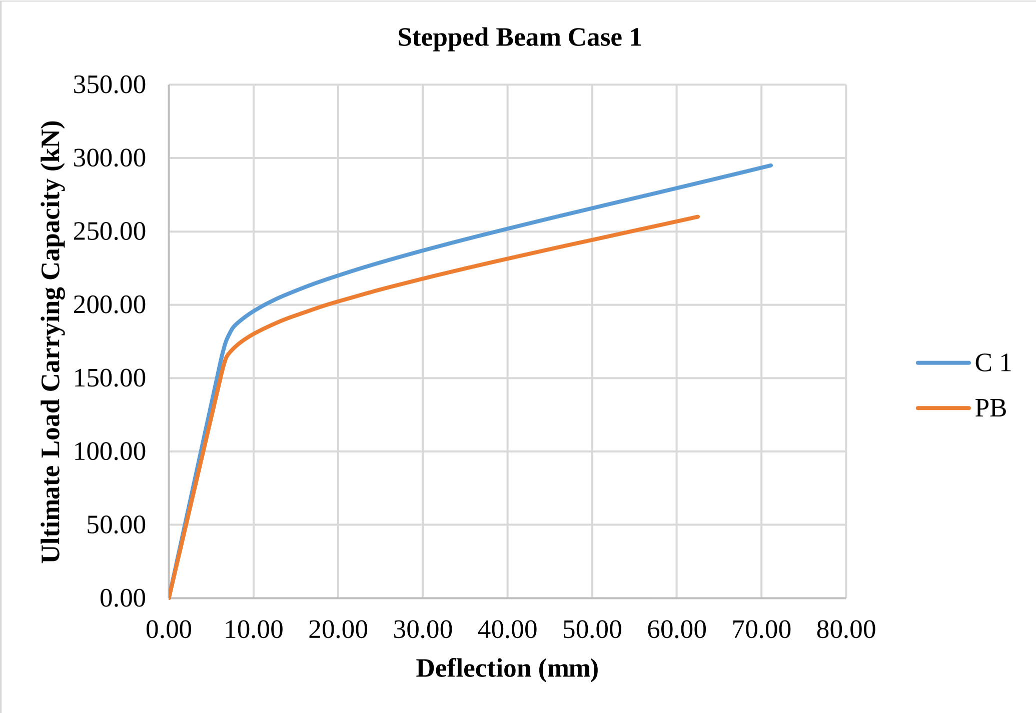


Figure 8. Load vs deflection curve for stepped beam case 1.

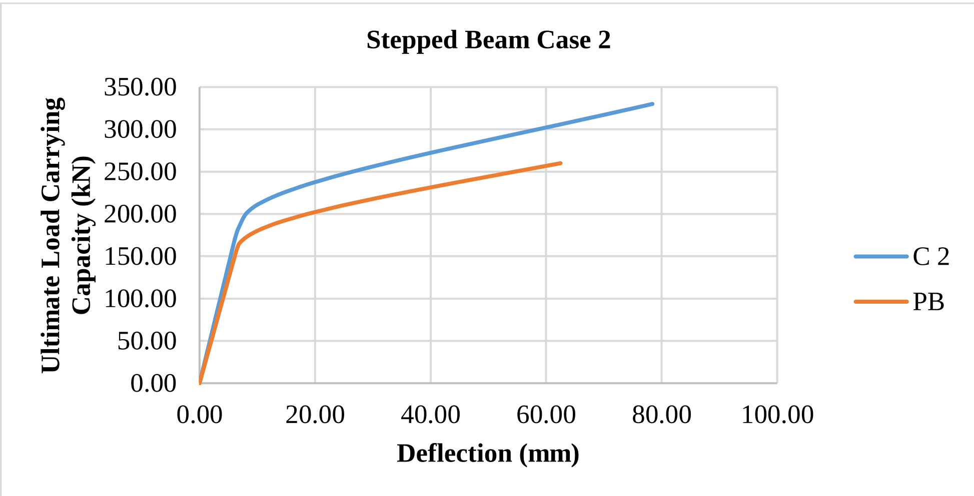


Figure 9. Load vs deflection curve for stepped beam case 2.

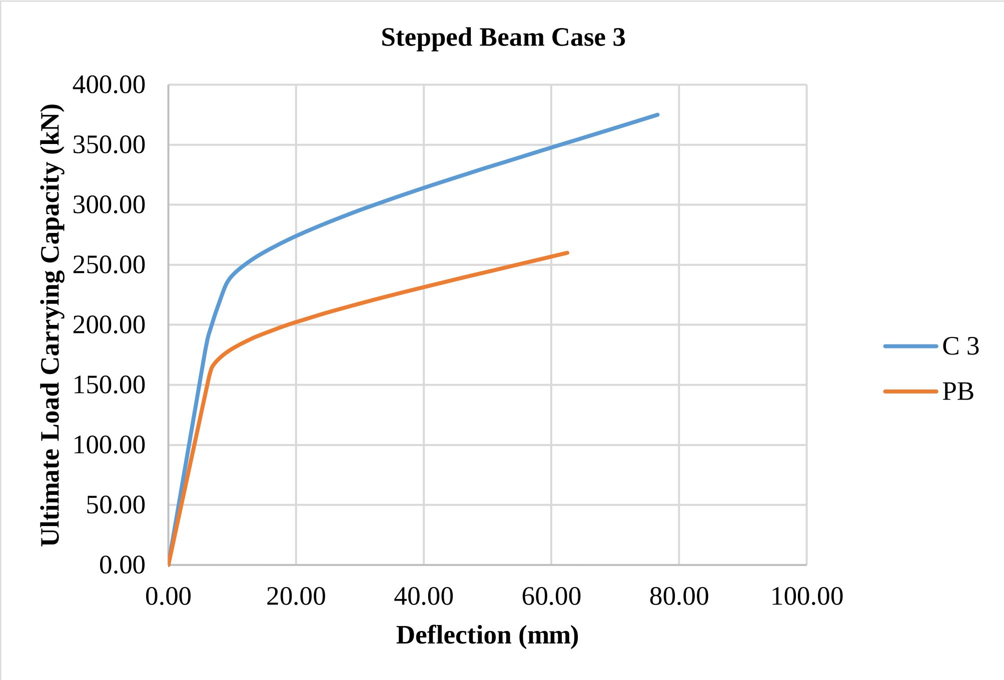


Figure 10. Load vs deflection curve for stepped beam case 3

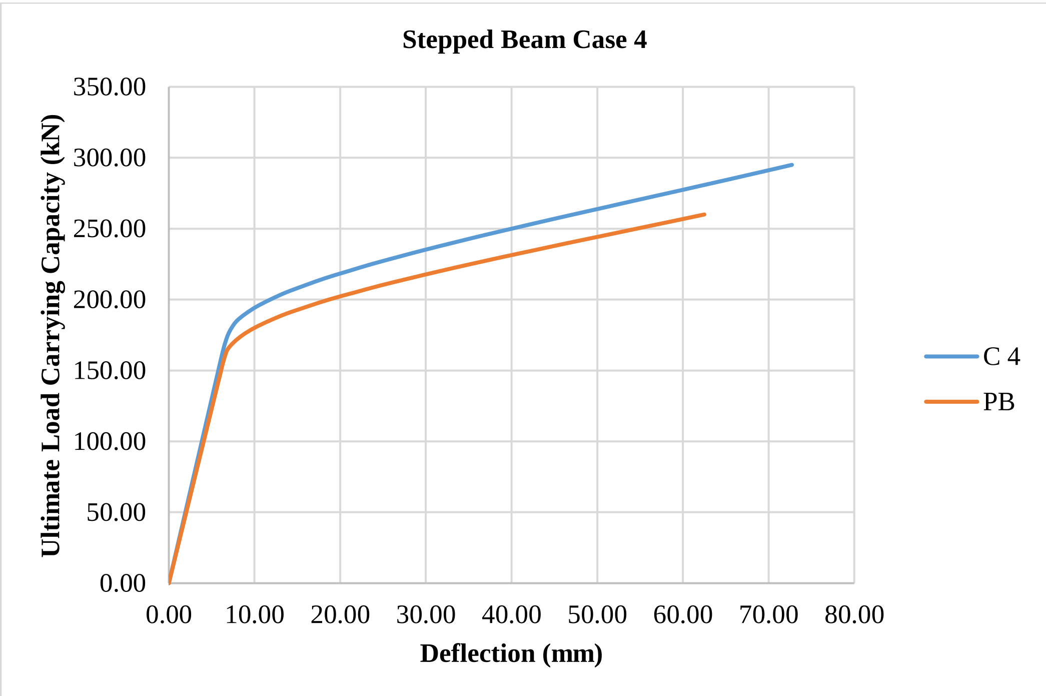


Figure 11. Load vs deflection curve for stepped beam case 4.

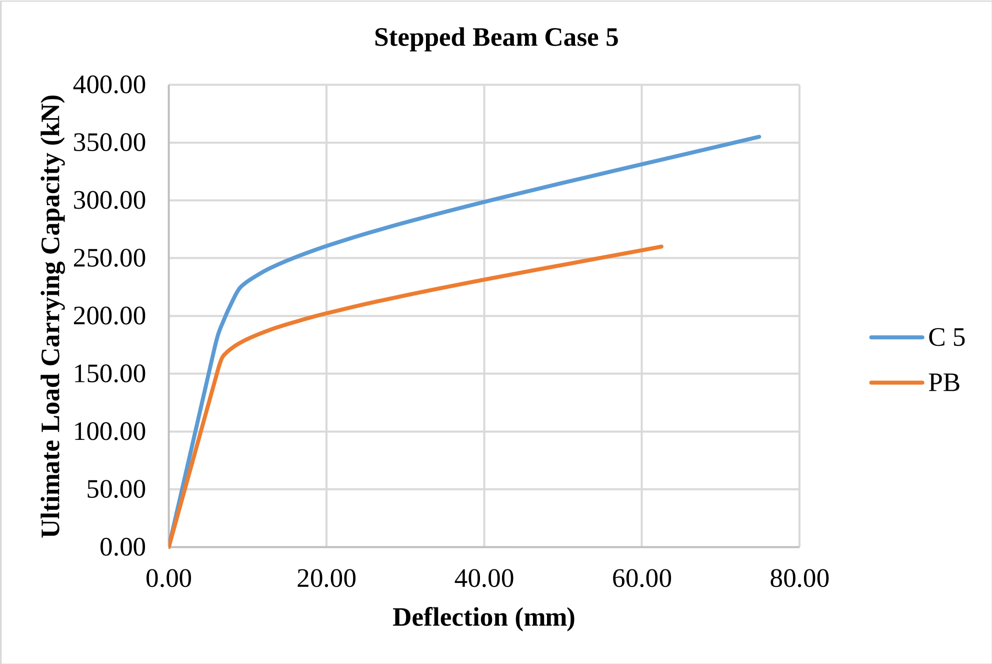


Figure 12. Load vs deflection curve for stepped beam case 5.

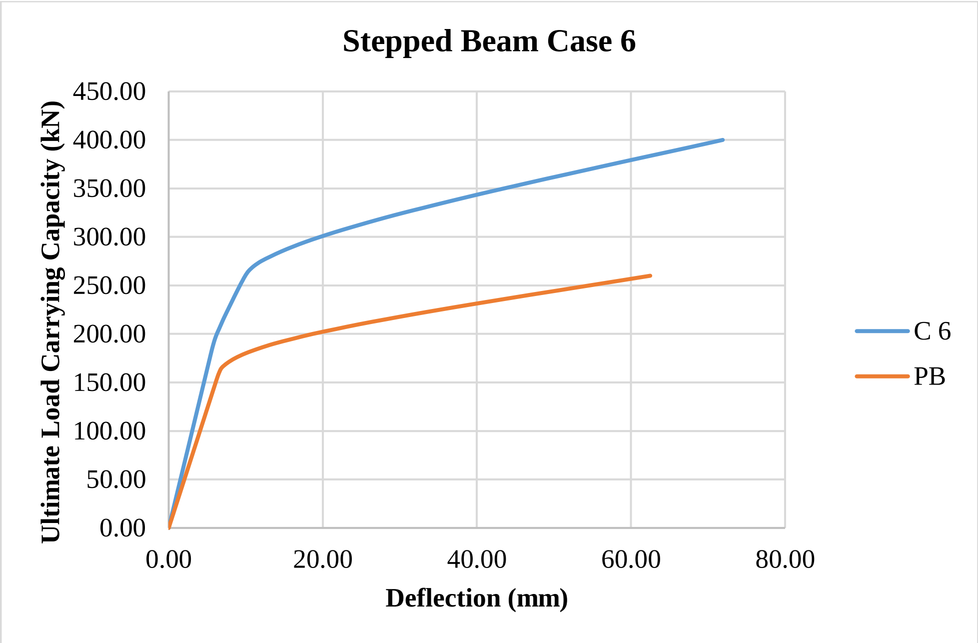


Figure 13. Load vs deflection curve for stepped beam case 6.

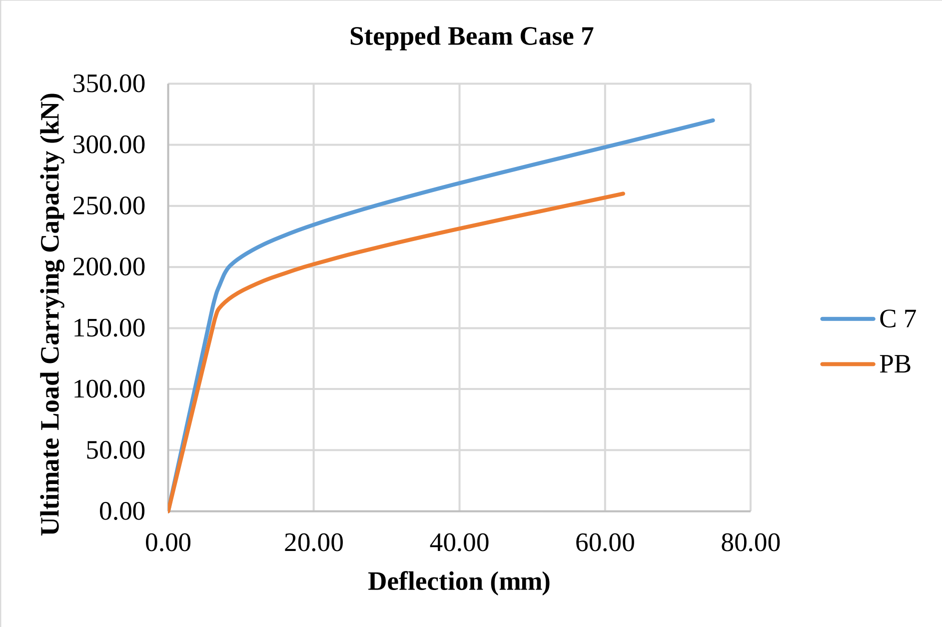


Figure 14. Load vs deflection curve for stepped beam case 7.

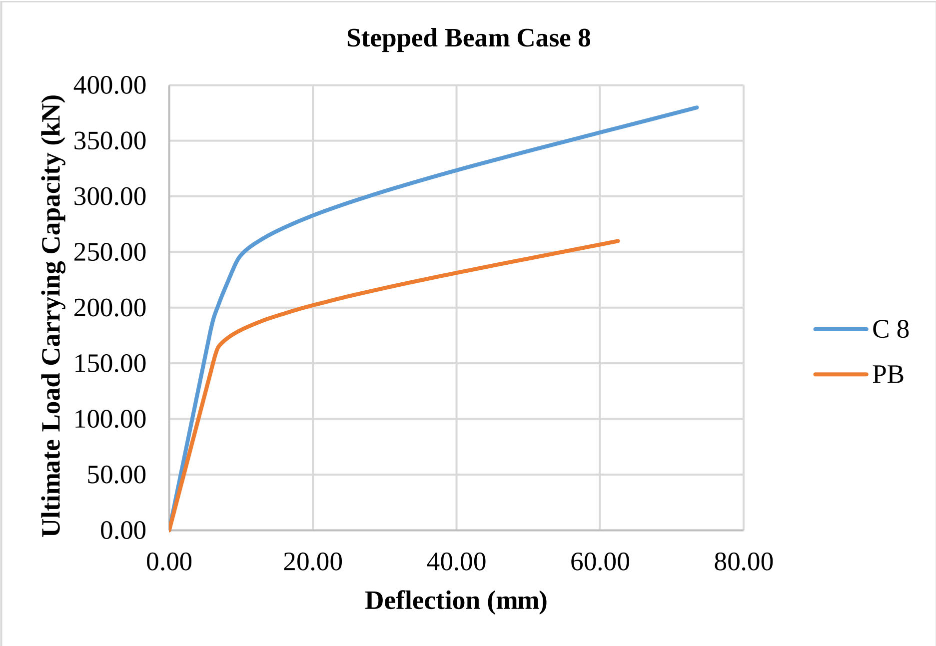


Figure 15. Load vs deflection curve for stepped beam case 8.

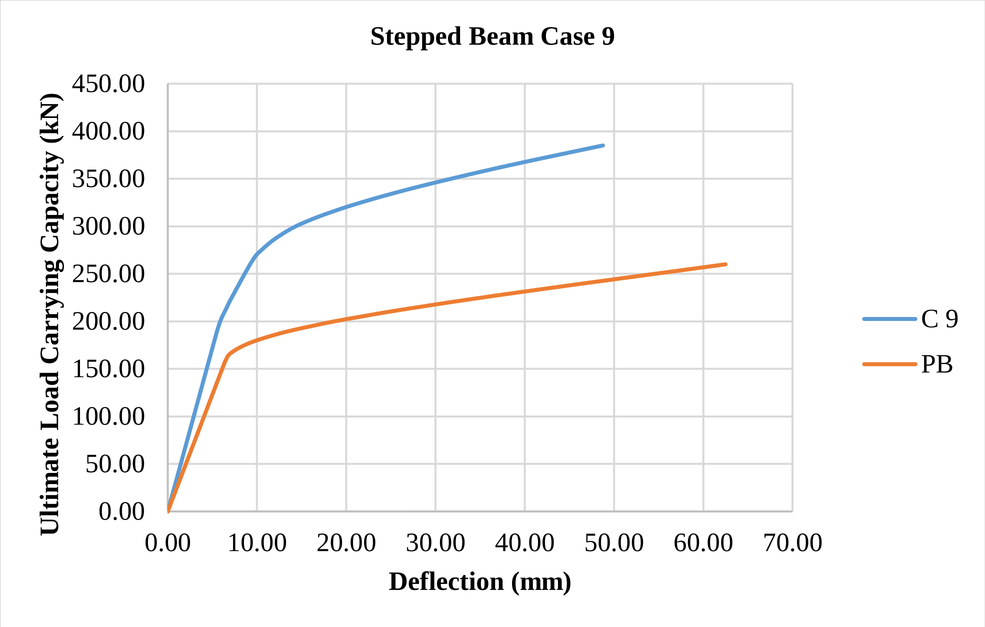


Figure 16. Load vs deflection curve for stepped beam case 9.

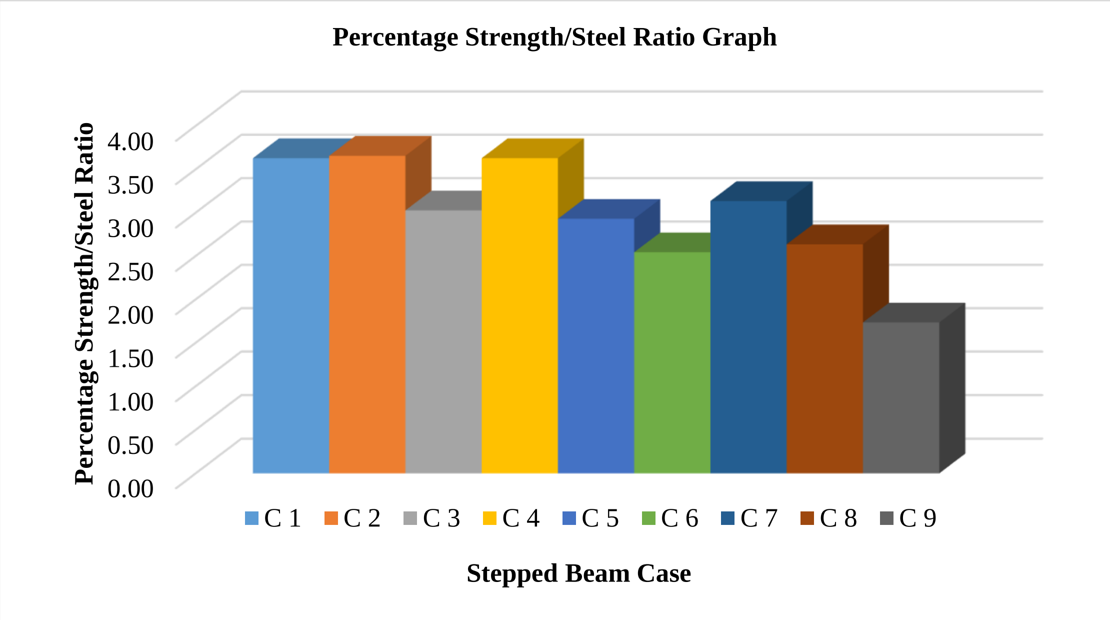


Figure 17. Strength/Steel Ratio for Stepped Beams.

5. CONCLUSION

Below are the some specific conclusions made from the study carried out in the present research article;

It was observed from the analysis results, that there is an enhancement in the strength capacity of the stepped beam by 13 to 53 % as compared to prismatic beam.

Averagely there is 12% increase in the weight of beam due to addition of cover plates to achieve steps on the flange.

Strength-steel ratio for all the stepped beam cases are greater than 1 which represents the effectiveness of stepping.

Effect of flange thickness is more noteworthy than a flange width on the load carrying capacity of non-prismatic section like stepped beam.

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