

Optimization of Sectional Dimensions of I-Section Flange Beams and Recommendations for IS 808: 1989

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Abstract

This study covers optimization of I-sectional flange beams. Scope of this study is limited to medium weight flange beams of **Table 1** of IS 808:1983 but it can be further extended for the other sections of this code. Best possible geometric shape of the cross-section is found for maximum performance of the beam with minimum material consumption. All possible loading conditions are considered in the study for which a beam in flexure undergoes in its life. ANSYS software program is used for the analysis and optimizing the sections. It is found that sections MB 125, MB 300 and MB 400 of **Table 1** of IS 808 are not the optimum sections but other alternative of these cross-sections is available which within the same material consumption performs better than these sections of IS code.

Keywords

Finite Element Analysis, Flange Beam, I-Section, Optimization

1. Introduction

Indian standard code of practice IS 808: 1989 was last incorporated for its amendments in 2002. This standard covers the nominal dimensions, mass and sectional properties of hot rolled sloping flange beam and column sections, sloping and parallel flange channel sections and equal and unequal leg angle sections. These sections are used by the designers and manufactures countrywide. Scope of this study covers studying the performance of medium weight I-section flange beams specified in **Table 1** of IS 808: 1989 [1]. Performance of the other sections of this code can be judged with the same methodology and even mega sections can be recommended for

Table 1. Nominal dimensions, mass and sectional properties of Indian standard medium flange beams.

Designation	Mass, M	Sectional Area, A	Dimensions					Sectional Properties							
			D	B	t	T	Flange Slope, Max α ,	R ₁	R ₂	I _x	I _y	r _x	r _y	Z _x	Z _y
(1)	Kg/m	cm ²	mm	mm	mm	mm	deg	mm	mm	cm ⁴	cm ⁴	cm	cm	cm ³	cm ³
MB 100	8.9	11.4	100	50	4.7	7/0	98.0	9.0	4.5	183	12.9	4.00	1.05	36.6	5.16
MB 125	13.3	17.0	125	70	5.0	8.0	98.0	9.0	4.5	445	38.5	5.16	1.51	71.2	11.2
MB 150	15.0	19.1	150	75	5.0	8.0	98.0	9.0	4.5	718	46.8	6.13	1.57	95.7	12.5
MB 175	19.6	25.0	175	85	5.8	9.0	98.0	10.0	5.0	1260	76.7	7.13	1.75	144	18.0
MB 200	24.2	30.8	200	100	5.7	10.0	98.0	11.0	5.5	2120	137	8.29	2.11	212	27.4
MB 225	31.1	39.7	225	110	6.5	11.8	98.0	12.0	6.0	3440	218	9.31	2.34	306	39.7
MB 250	37.3	47.5	250	125	6.9	12.5	98.0	13.0	6.5	5130	335	10.4	2.65	410	53.5
MB 300	46.0	58.6	300	140	7.7	13.1	98.0	14.0	7.0	8990	486	12.4	2.86	599	69.5
MB 350	52.4	66.7	350	140	8.1	14.2	98.0	14.0	7.0	13,600	538	14.3	2.84	779	76.8
MB 400	61.5	78.4	400	140	8.9	16.0	98.0	14.0	7.0	20,500	622	16.2	2.82	1020	88.9
MB 450	72.4	92.2	450	150	9.4	17.4	98.0	15.0	7.5	30,400	834	18.2	3.01	1350	111
MB 500	86.9	111	500	180	10.2	17.2	98.0	17.0	8.5	45,200	1370	20.2	3.52	1810	152
MB 550	104	132	550	190	11.2	19.3	98.0	18.0	9.0	64,900	1830	22.2	3.73	2360	193
MB 600	123	156	600	210	12.0	20.3	98.0	20.0	10.0	91,800	2650	24.2	4.12	3060	252

this code.

Since 2002, there have been tremendous improvements in the computation capabilities of software programs with high performance hardware system. Looking close to the sections of **Table 1** of IS 808: 1989, it seems unreasonable when flange slope does not change when the depth of the sections is changing from 50 mm to 210 mm. Even few of the sections like MB 300, MB 350 and MB 400 are have same width of the section when the depth of them varies from 300 mm to 400 mm.

Engineers have always tried to optimize the structural design for material saving perspective and cost reduction. Optimization can be done with respect to size, shape and topology of the structure. The most effective and efficient tool for optimization is topological optimization if loading and boundary conditions are fixed [2]. Size optimization is dealt with analysis which is called designing in engineering term.

In 2009, K. Ghabraie [3] *et al.* utilized optimization by Evolutionary Structural Optimization (ESO) method for optimizing the shape of underground excavations. In 2014, Lauren L. Beghini [4] *et al.* emphasized the benefits of using topological optimization which on one hand satisfied the need of engineers and on other hand satisfied the architectural demand.

In this paper, shape optimization is performed on I-sections flange beams. Performance of the beam is studied by changing any particular sectional dimension (**Figure 1**) within permissible geometric limits. Studying these variations helps in deciding optimum value of the input dimension.

For a particular beam section, there should definitely be a unique combination of sectional parameters (**Figure 1**) *i.e.* depth of the section (D), width of the section (B), radius of fillet (R₁), thickness of web (t), flange thickness (T) and flange slope (α) for which section gives maximum performance for applied loadings with minimum material consumption. It may also possible that for more than one combination of these parameters, section performs optimum.

For studying these realistically, let us discuss first the variation of stresses within the section as the beam is subjected to bending. For designing optimum section in flexure, beam should also be considered for torsion in case of any eccentric loading.

2. Variation of Stresses along the Cross-Section of the Beam

Figure 2 shows a beam of rectangular cross-section with concentrated loading. Variation of bending and shear-

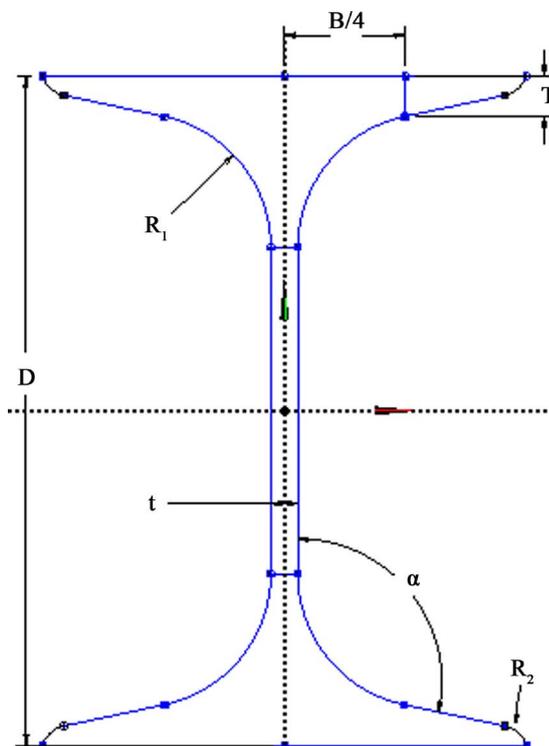


Figure 1. Nomination of sectional dimensions is shown in the figure.

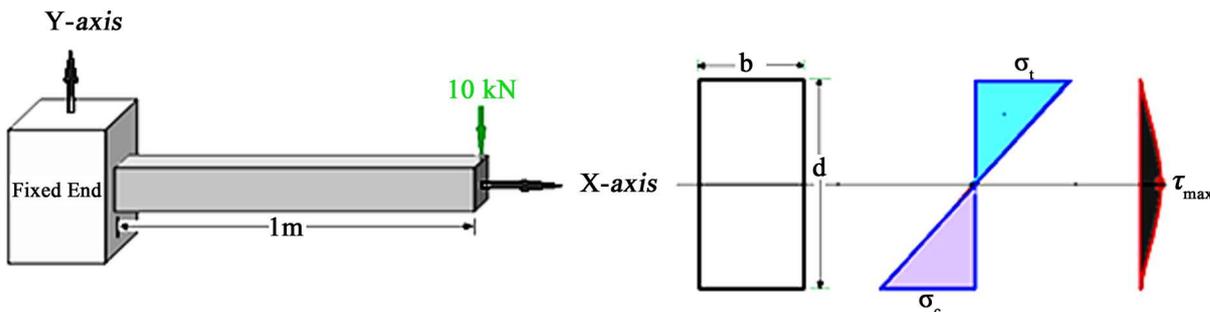


Figure 2. Beam with loading. (Distribution of stresses along the cross-section).

ing stresses across the cross-section is also shown in this figure. With the strength of material practice, it is found that magnitude of the maximum bending stress either at top or bottom layer of the cross-section is 8 to 11 times higher than that of shearing stress induces at the neutral axis [5] [6]. Numerically this variation depends upon the geometric shape of the cross-section.

Talking about the torsional stresses, these are zero at the centre of the cross-section then varies linearly and finally becoming maximum at the outer layer. Variation of bending stress along the cross-section is linear whereas that of shearing stresses is in a curved parabolic path as shown in **Figure 2**.

3. Problem Statement

Studying the numerical values of stresses along the cross section, most robust section can be decided on the basis of that best fits in compensating these stresses. **Figure 3** shows two of the alternatives of a cross section. First one is MB 350 of IS 808 and the second one is the probable robust alternative of this section.

In the alternative section, radius of fillet (R_1) is increased, depth is decreased and flange width is increased a bit. These all changes are made with an understanding of variation of stresses within the section. Finalizing any one of them as the best is not possible until unless performance of the beam is not known as each of these input

parameter changes within a section.

ANSYS is the best tool for resolving this kind of optimization problems. Beam performance is studied by varying each of these input parameters and conclusions are made for the sections of **Table 1** of IS: 808 for their shape.

4. Methodology Used for Optimisation

Geometry shown in **Figure 1** is created such that section changes symmetrically for varying any input parameter. It is imperative to keep at least one input geometric parameter constant as varying all the input geometric parameter may lead to generation of totally new optimum section which matches nowhere with the sections of IS: 808. So, depth of the section is selected as constant which also matches with the variation of sections given in **Table 1** of IS: 808. Other input sectional parameters are varied within the geometric limits of the section. For convenience beam is taken 1 meter long and kept fixed at one end (**Figure 4**). Radius R_2 (**Figure 1**) could not be taken as the input parameter as it tremendously reduces the range of other input parameters. So after analysis, whatever the value program adopt for it, is selected finally.

Strategies are used for selecting best output parameter that optimizes the section while consuming minimum analysis time. Different simulations are tried using output parameters such as area of cross-section, different stress, different strains, material volume and strain energy etc. Three output parameters mass of the beam, safety factor and total deformation are found to be capable enough for optimizing these sections. Numerically, program

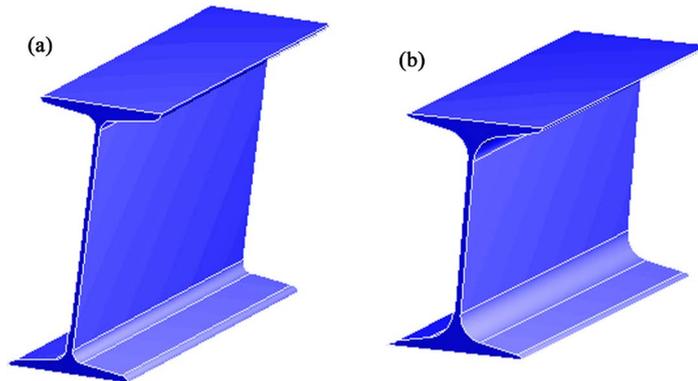


Figure 3. Two alternate sections with different geometric shapes. (a) IS section, (b) proposed optimum section.

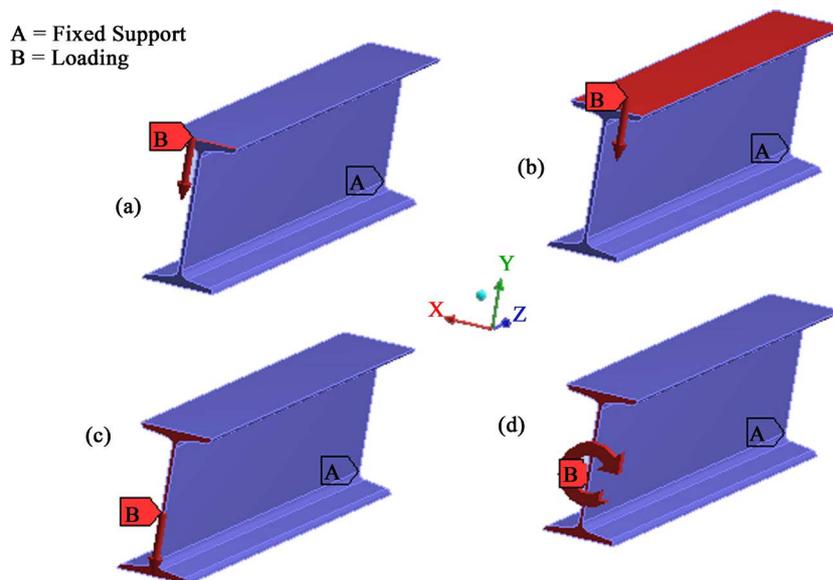


Figure 4. Different loading conditions (a) Line load, (b) pressure load, (c) surface load and (d) moment at the free end.

calculates safety factor from stresses induced in the structure. So, theoretically, stresses and strains (deformation) are enough to measure the performance of the beam. Mass of the beam is also opted as output parameter as it has to be minimized. Each model is subjected to all possible loading conditions which it can undergo in its life-time and are depicted in **Figure 4**.

5. Modelling & Meshing

With several trials of meshing, element shape and size is selected which converges with the theoretical results. Shape and size of the element is adopted such that within minimum analysis time it best converges to theoretical results.

Geometry of the structure in the present study possesses curved boundaries. Hence tetrahedral shape of the elements is adopted for the analysis to avoid generation of distorted and badly shaped elements by warping or skewing [7]-[10]. A good support for this is also found in the meshing statics. **Figure 5** shows the statistics of meshing of section MB 125 of IS: 808 using tetrahedral elements with minimum size limit 0.015 m.

Statistics shown in this figure are found to be in the approximate match for the other sections as well using these types of elements.

In this figure, aspect ratio of elements does not increase beyond 8.86 and the average value is 2.163. For the same element size and same geometric section if hexahedral elements were used than aspect ratio goes till 1136 with an average of 7.69. So with these statistics, using tetrahedral elements for analysis is preferable.

Another reason for adopting tetrahedral elements is observed in the convergence results of **Figure 6**. In this

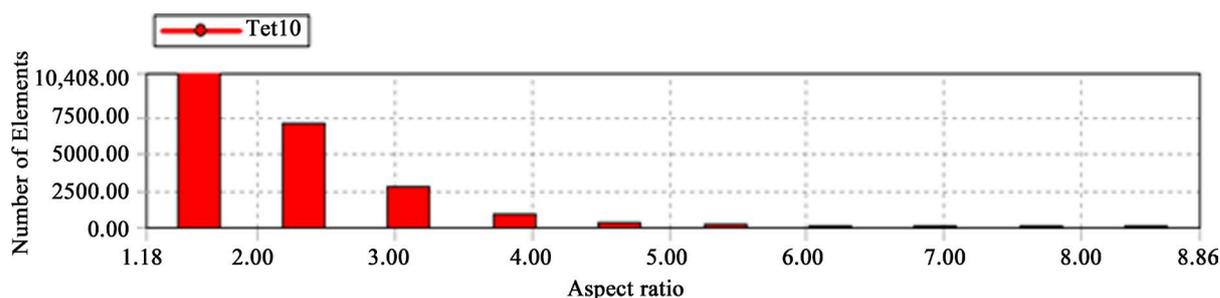


Figure 5. Figure shows the statistics of meshing using tetrahedral elements.

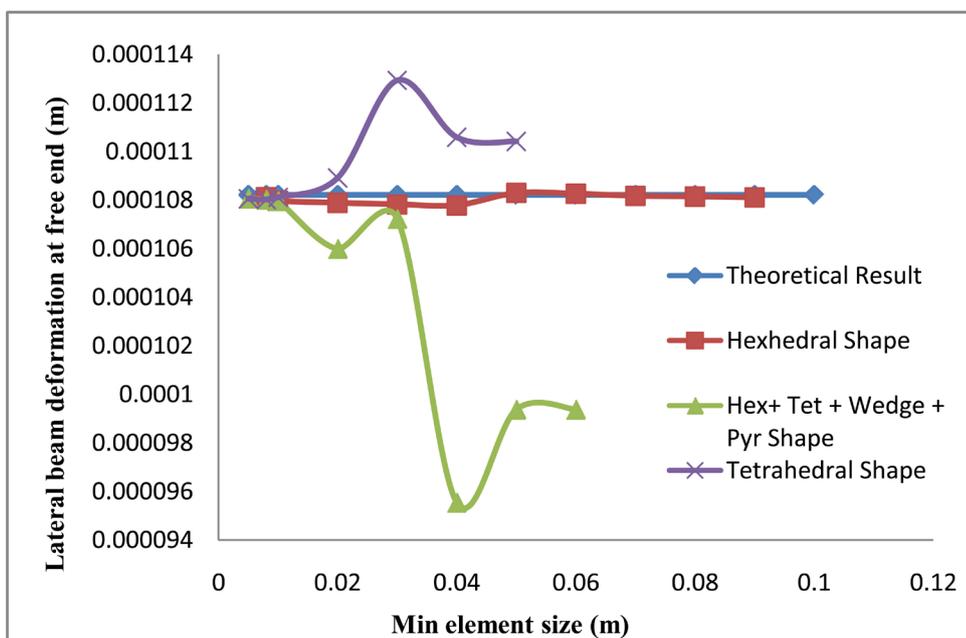


Figure 6. Figure shows the convergence results obtained for MB 125 section.

figure, a smooth convergence of tetrahedral elements after 0.02 m element size is found which is not same in case of hexahedral elements. Smooth convergence again supports its use in the analysis.

Three dimensional, 10-node solid tetrahedral shape element that exhibits quadratic displacement behaviour is used for the analysis (Figure 7). This element possesses three degrees of freedom at each node in each spatial direction.

Although, using hexahedral elements when used with small elements size gives reasonable results but it in turn increases the running time of analysis because of increased degrees of freedom.

Furthermore, results of error estimation [11] in meshing are also found to be satisfactory (Figure 27).

6. Validation of Results

Total deflection of the beam is calculated considering both effects bending as well as shear. As for all sections, beam length is chosen to be 1 m. So it is also possible that for increasing sectional dimensions, in case of deep sections shear deformations become high. So, for validation of results, following Timoshenko beam equation [5] [6] and [12] is used for calculating the total deflection:

$$\frac{d^2 y}{dx^2} = \left[\frac{M}{EI} + \frac{kq}{AG} \right] \tag{1}$$

where M and q is moment and shear force at any cross-section, E is modulus of elasticity of material, G is shearing modulus, A and I are the area and moment of inertia of the cross-section and k is the shear constant which depends upon the shape of beam cross-section. For I-section shear constant is calculated as under [6].

$$k = \frac{A}{It} \left[\frac{BD^2}{8} - \frac{h_1^2}{8}(B-t) \right] \tag{2}$$

In this equation, all other parameters are as shown in Figure 1 and Figure 8. Area A and moment of inertia I of the section are calculated geometrically with the dimensions of Figure 8.

Solving the equation for a cantilever beam loaded with uniformly distributed load, deflection at the free end comes out to be.

$$y = \frac{ql^4}{8EI} + \frac{k}{AG} \frac{wl^3}{3} \tag{3}$$

where w is the magnitude of uniformly distributed load and l is the length of the beam. Putting all the numerical values of these parameters, total deflection of beam at free end was calculated for validation of result.

7. Variations in Parameters

This section describes the behavior of the beam as the sectional dimensions vary in a section. Each parameter *i.e.* depth, radius of fillet, thickness of web, flange thickness, flange slope and width of the section, is varied by keeping all other parameters constant to understand the behavior of section thoroughly.

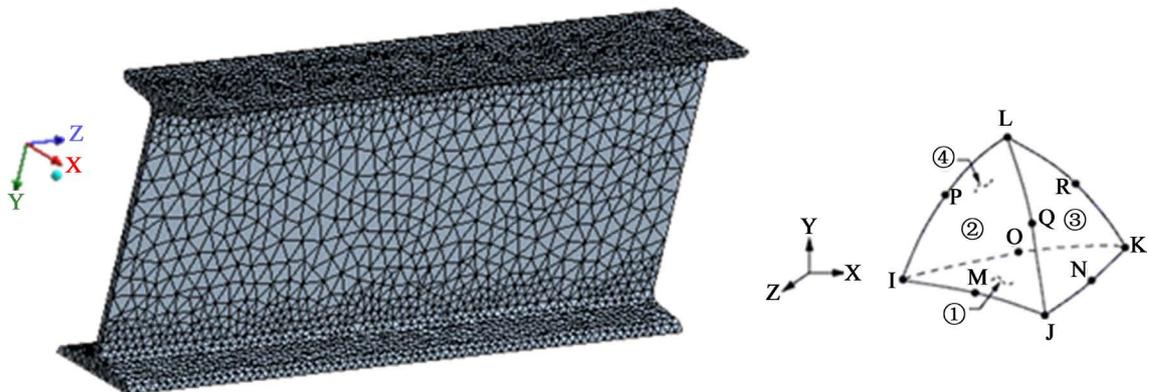


Figure 7. Meshing of the model with element shape (0.015 m minimum size, 21,129 elements).

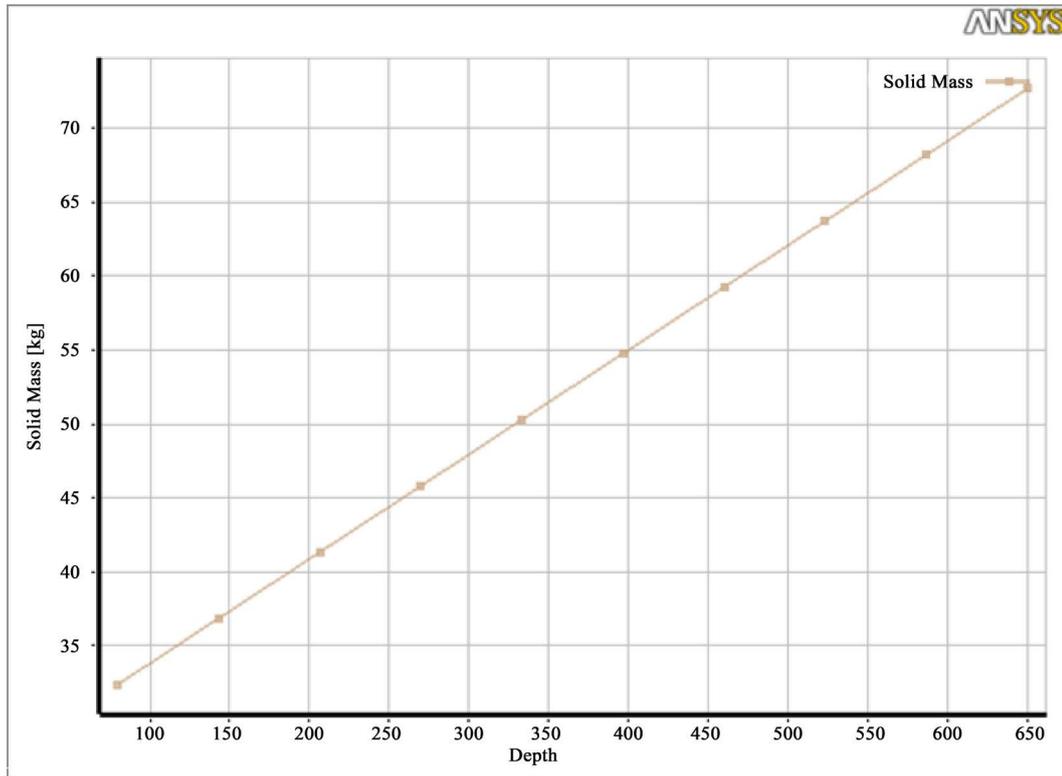


Figure 9. Variation of mass of the beam (per meter length) as depth of the section varies.

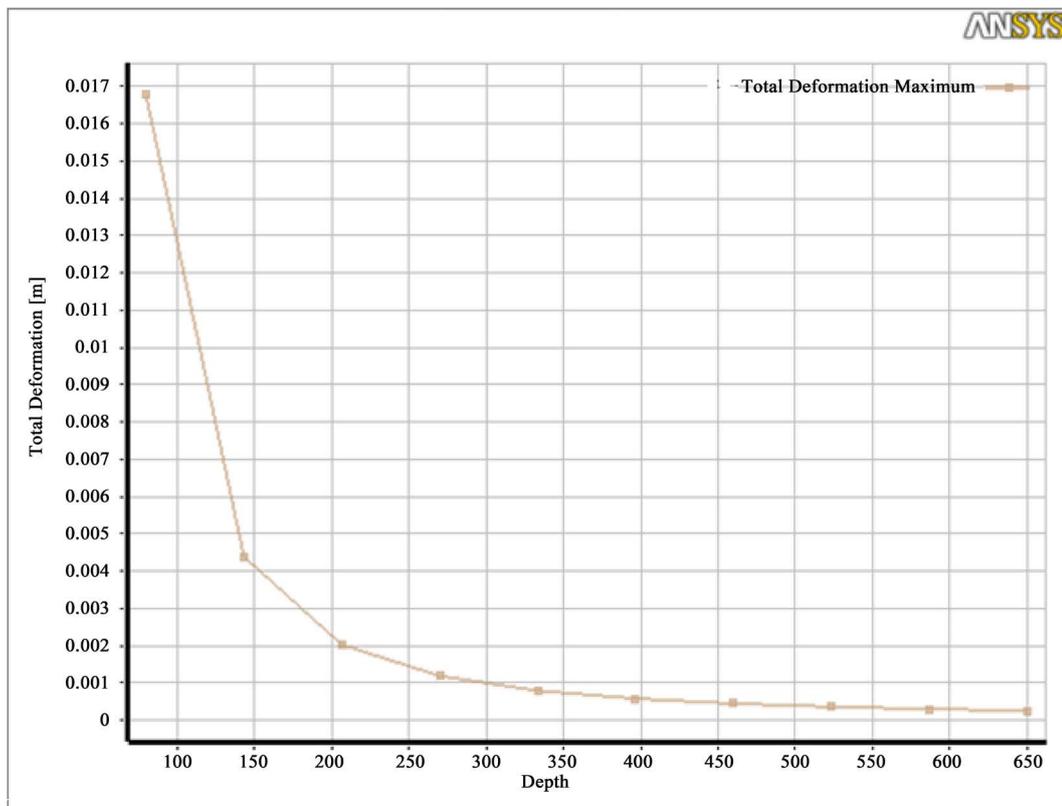


Figure 10. Variation in max. total deformation of the beam as depth (D) of the section varies.

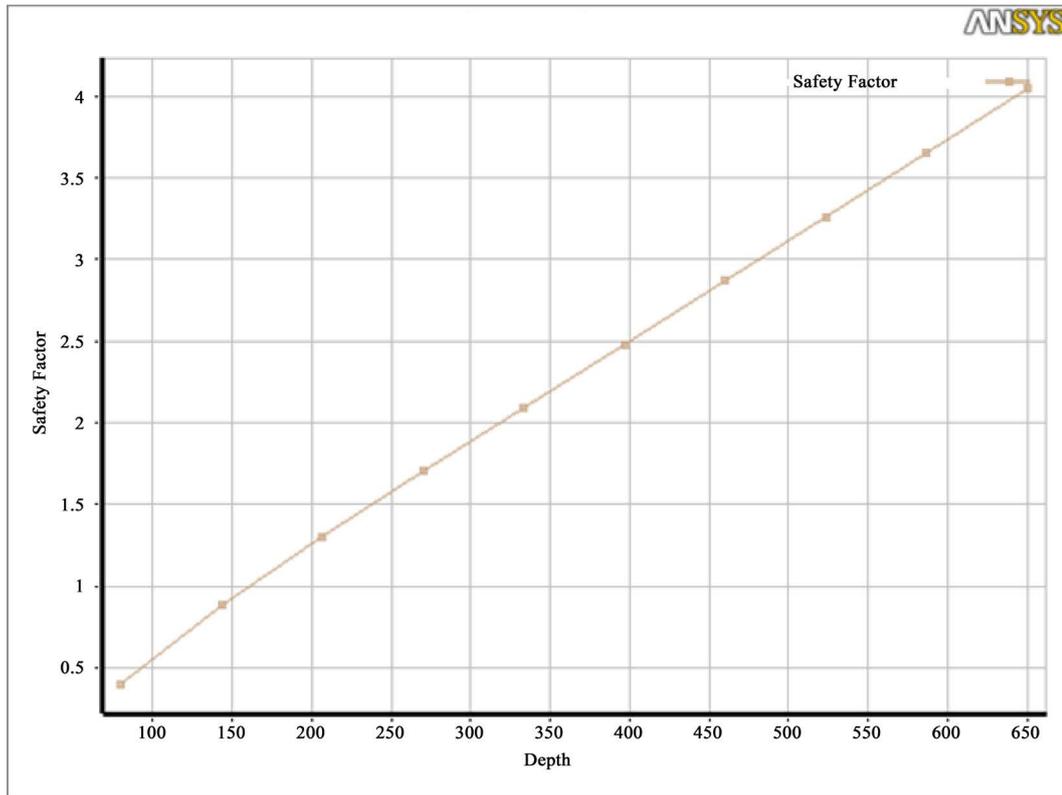


Figure 11. Variation in safety factor as depth (D) of the section varies.

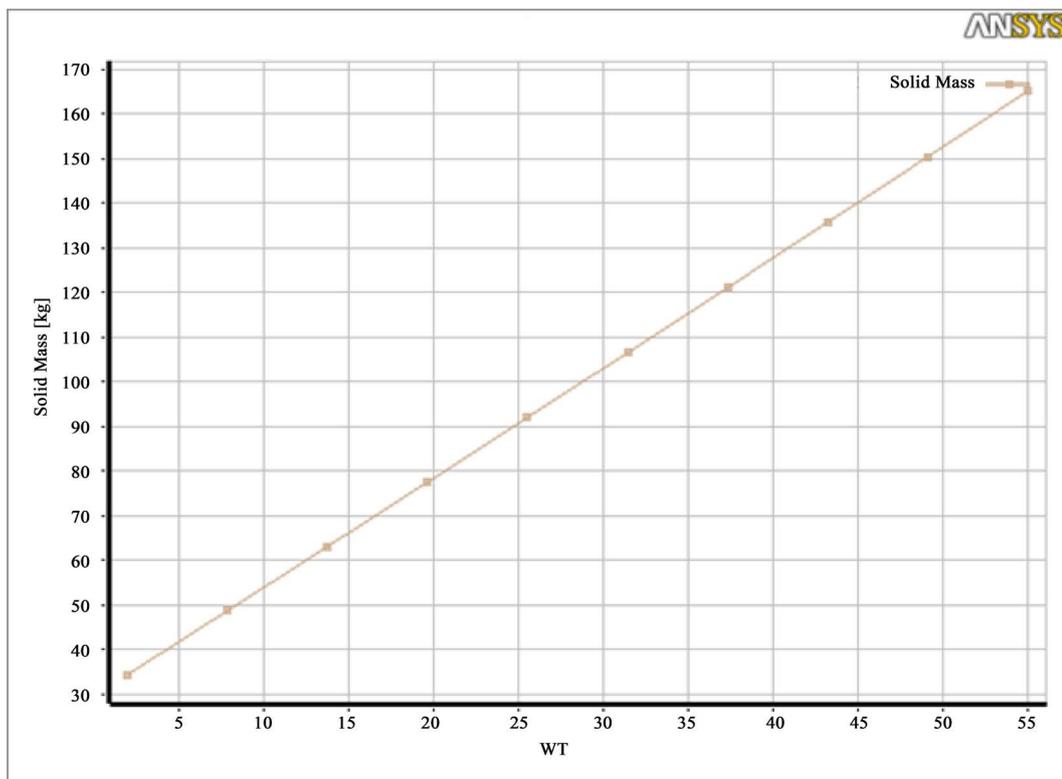


Figure 12. Variation of mass of the beam (per meter length) as web thickness (t) of the section varies.

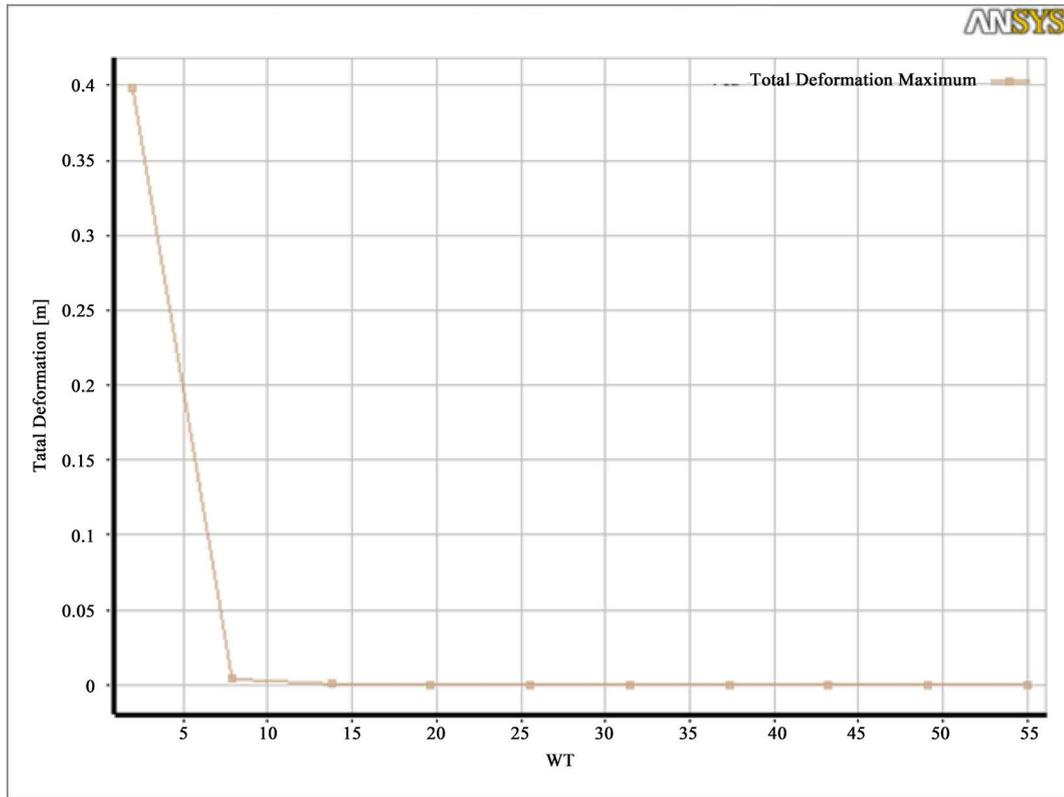


Figure 13. Variation in max. total deformation of the beam as web thickness (t) of the section varies.

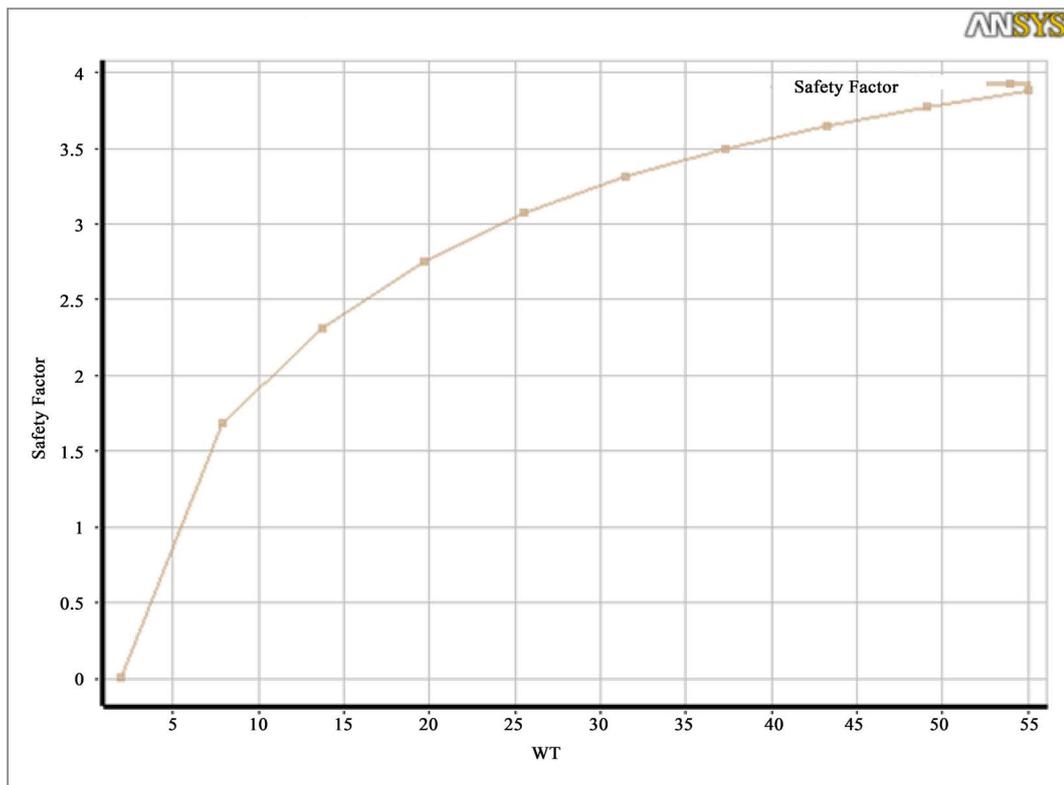


Figure 14. Variation in safety factor as web thickness (t) of the section varies.

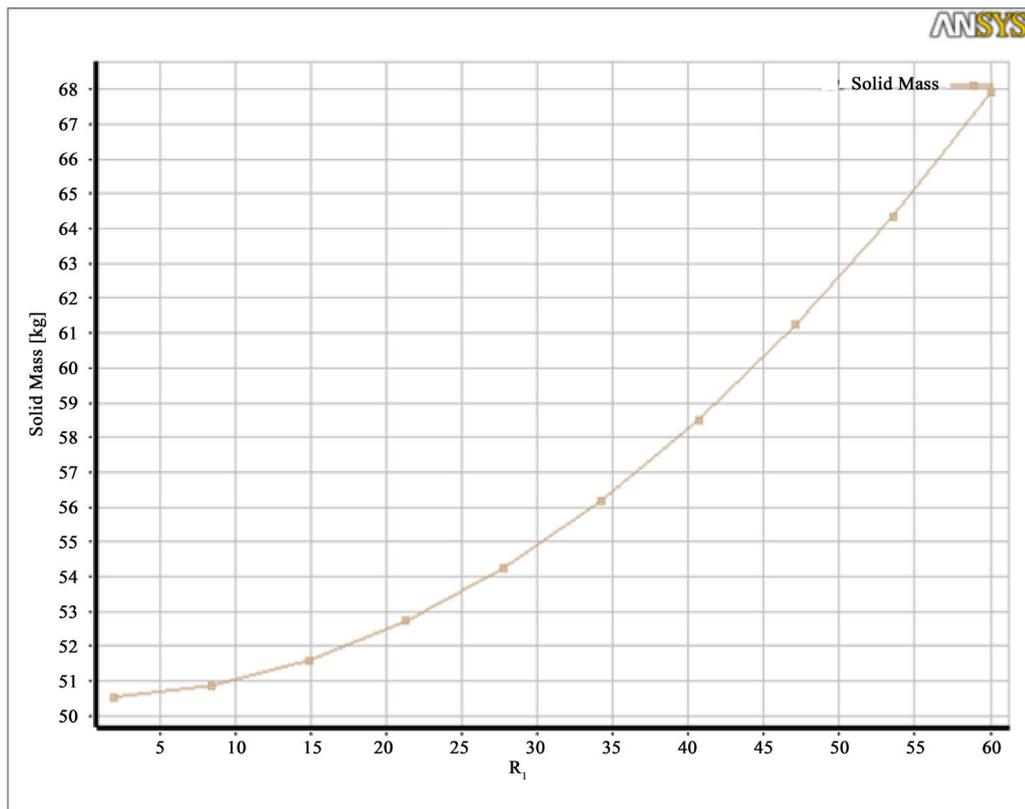


Figure 15. Variation of mass of the beam (per meter length) as fillet radius (R_1) of the section varies.

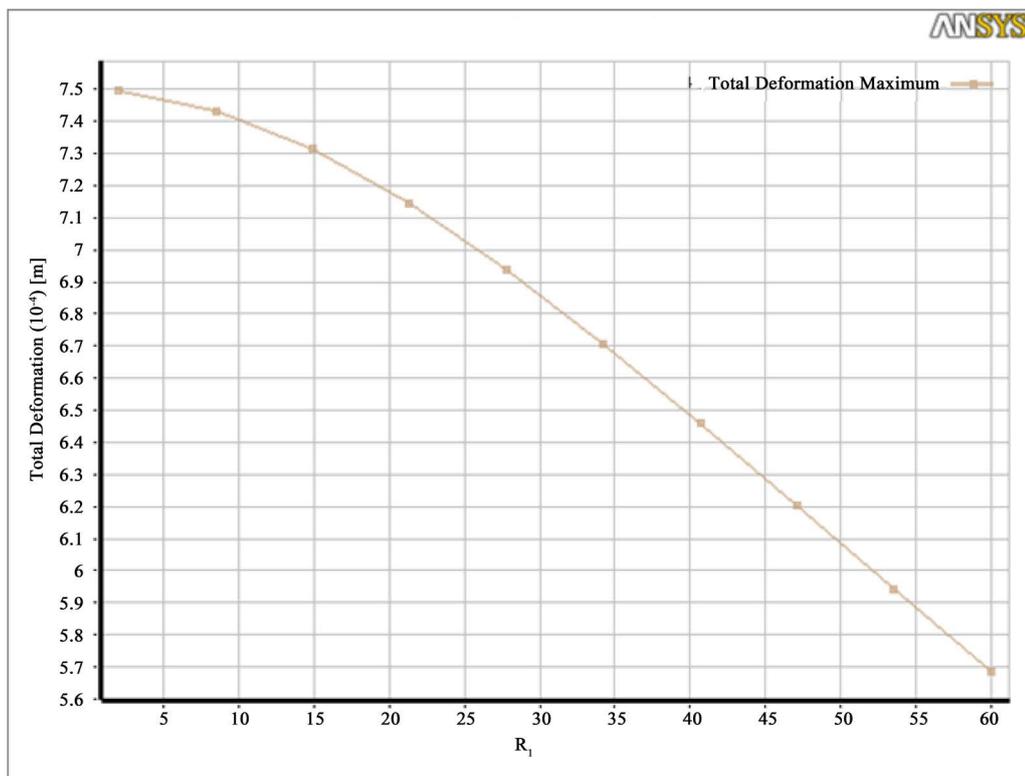


Figure 16. Variation in max. total deformation of the beam as fillet radius (R_1) of the section varies.

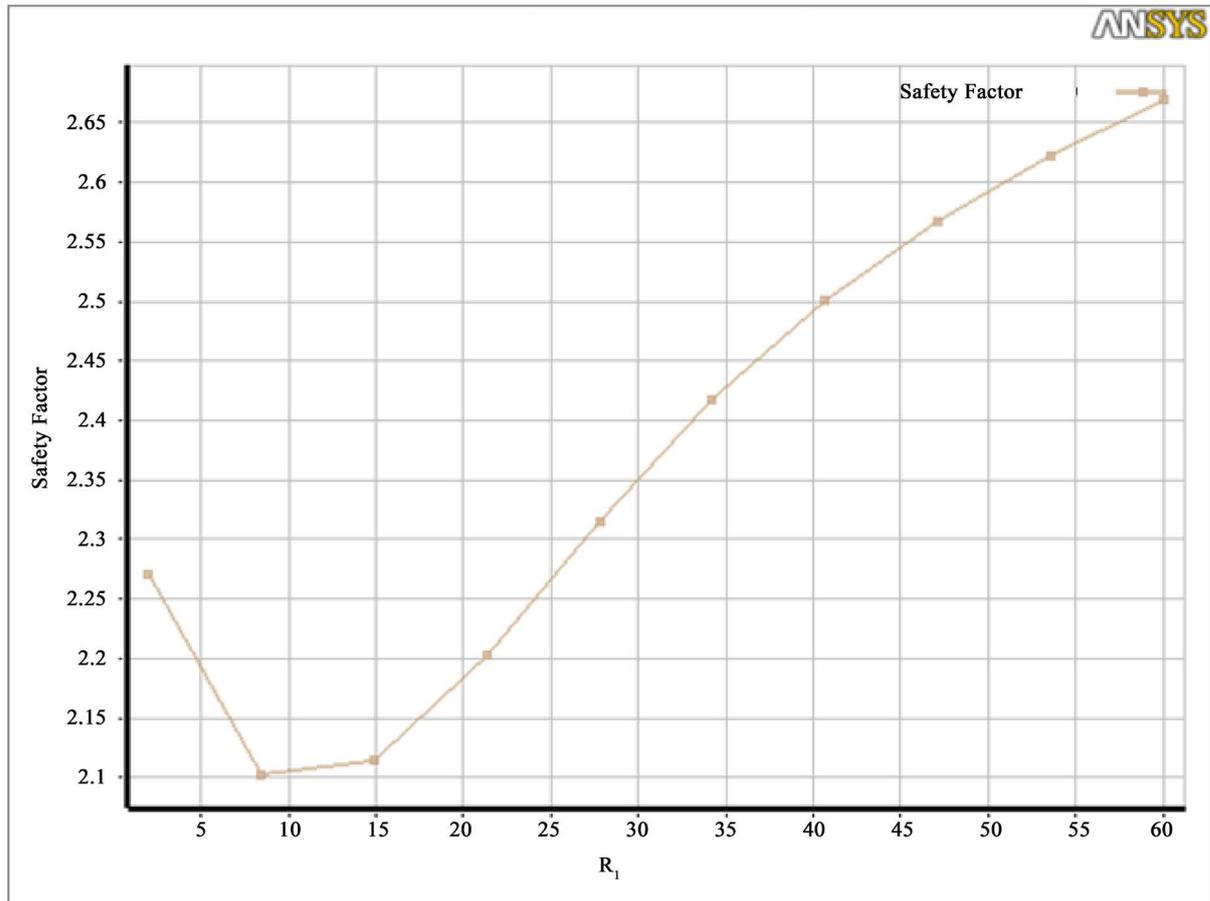


Figure 17. Variation in safety factor as fillet radius (R_1) of the section varies.

Using very small radius of fillet is not suitable for designing the section (**Figure 17**).

7.4. Effect of Changing Flange Width (B) of the Cross-Section

In the following **Figures 18-20**, on the horizontal axis, numerical values are for $B/4$ (**Figure 1**). Geometry of the beam was created such that putting the $B/4$ value makes this dimension. This was because of the constraint that flange thickness has to be decided at the $B/4$ distance from the centroidal axis.

Performance of the section with both the parameters, flange width and flange thickness, is almost same and can also be compared with the graphs of **Figures 21-23**.

7.5. Effect of Changing Flange Thickness (T) of the Cross-Section

In the graphs of **Figures 19-23**, it can be observed that with increasing the width and depth of the flange improves the performance of the section with increasing gradient whereby increasing the mass linearly (**Figure 18** and **Figure 21**).

So increasing the flange width or thickness of the section is the effective way of increasing the performance of the section. It increases the mass in a linear path whereby increases the performance of the section with higher gradients.

7.6. Effect of Changing Flange Slope (α) of the Cross-Section

Astonishing results are found for any section when flange slope changes within the geometric limits. In **Figure 24**, mass of the section is decreasing rapidly as the flange slope increases. Instead performance of the section increases rapidly (**Figure 25** and **Figure 26**).

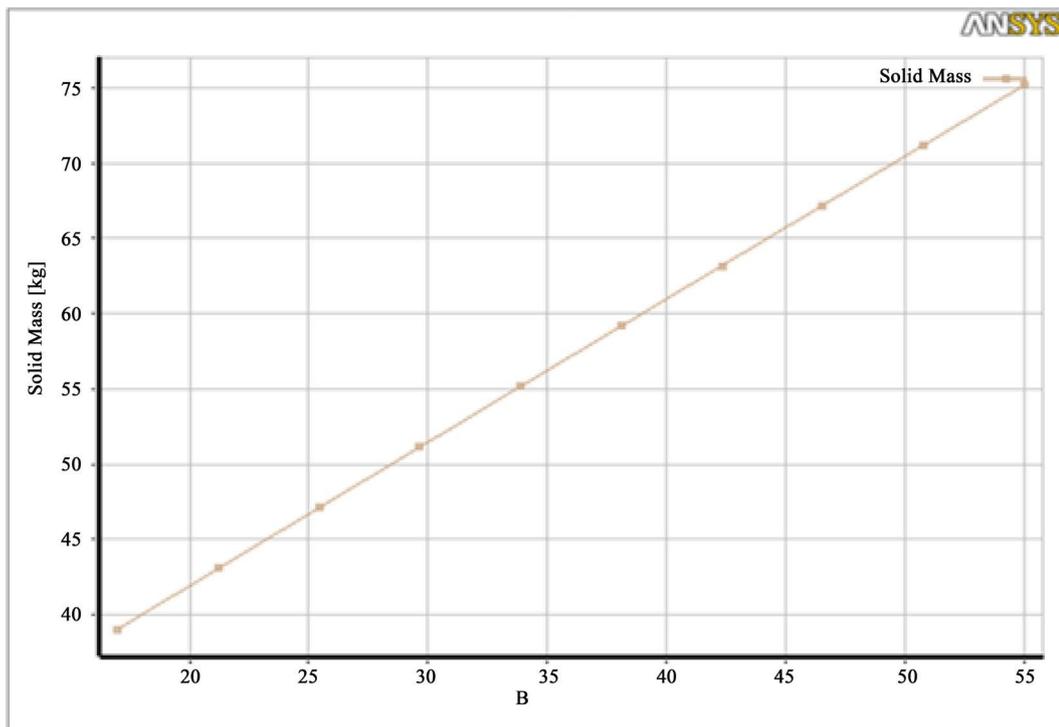


Figure 18. Variation of mass of the beam (per meter length) as flange width (B) of the section varies.

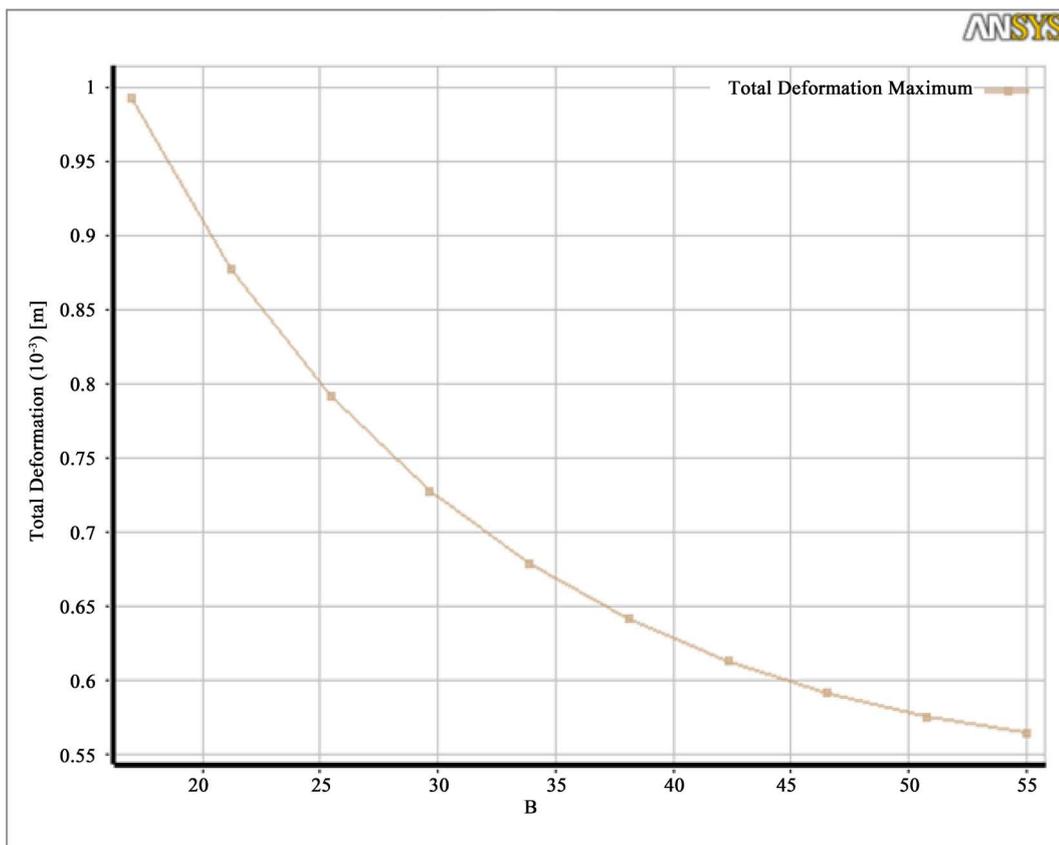


Figure 19. Variation in max. total deformation of the beam as flange width (B) of the section varies.

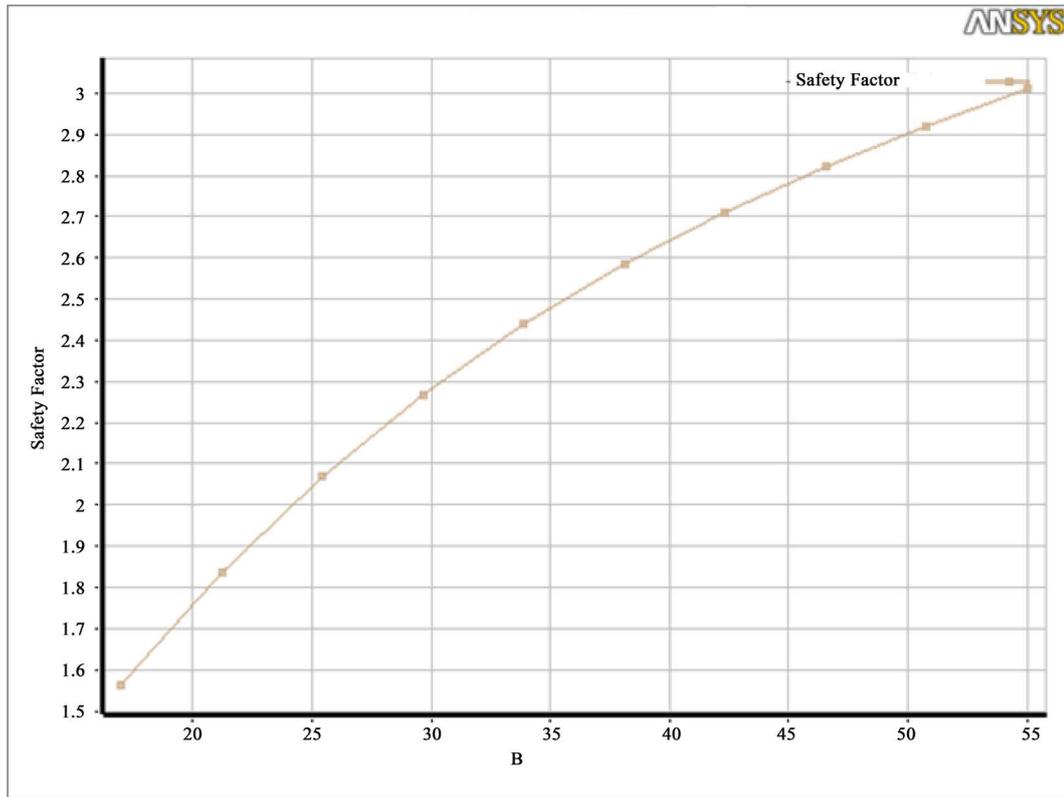


Figure 20. Variation in safety factor as flange width (B) of the section varies.

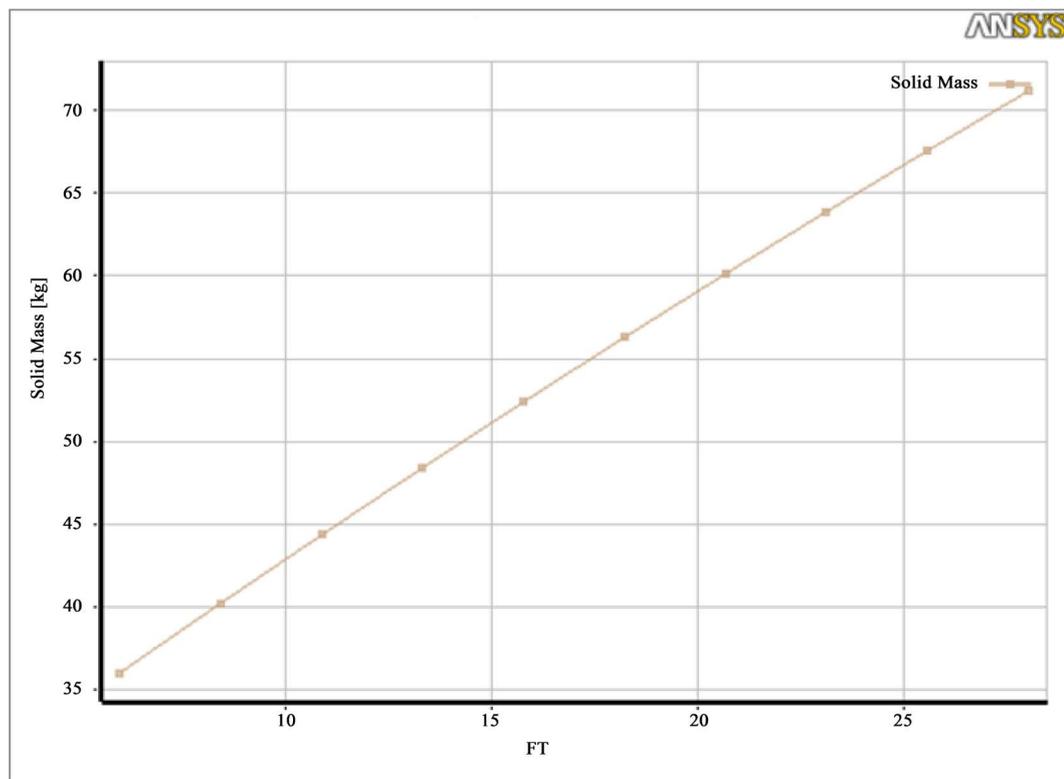


Figure 21. Variation of mass of the beam (per meter) as flange thickness (T) of the section varies.

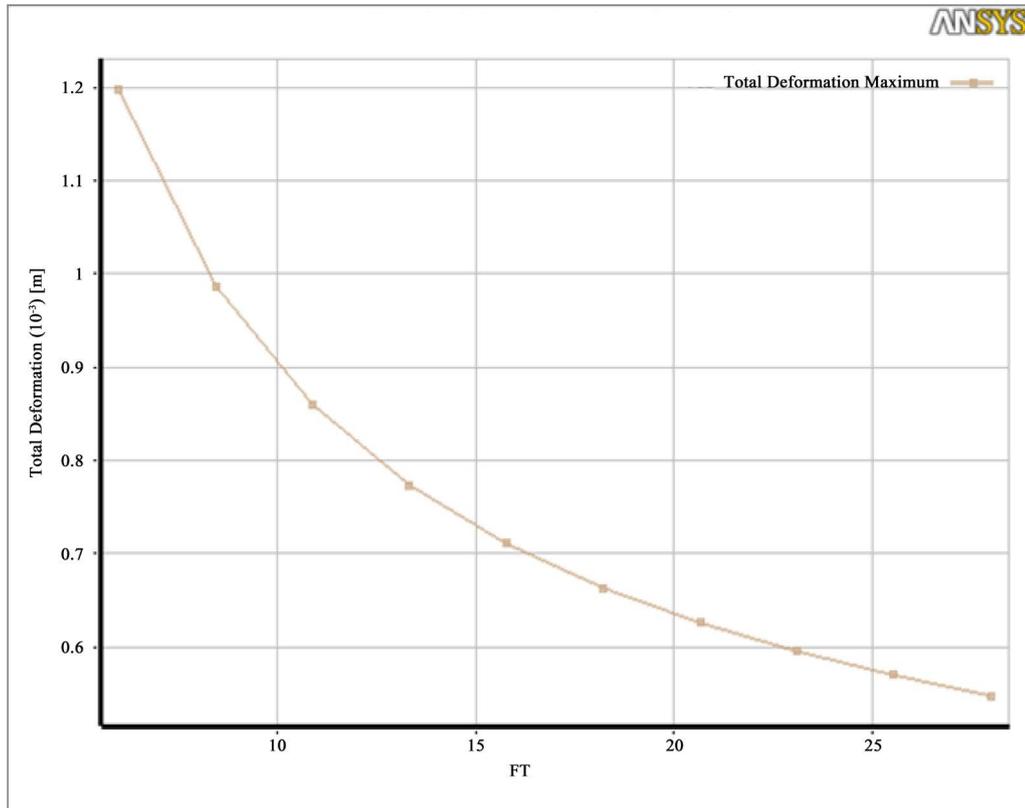


Figure 22. Variation in max. total deformation of the beam as flange thickness (T) of the section varies.

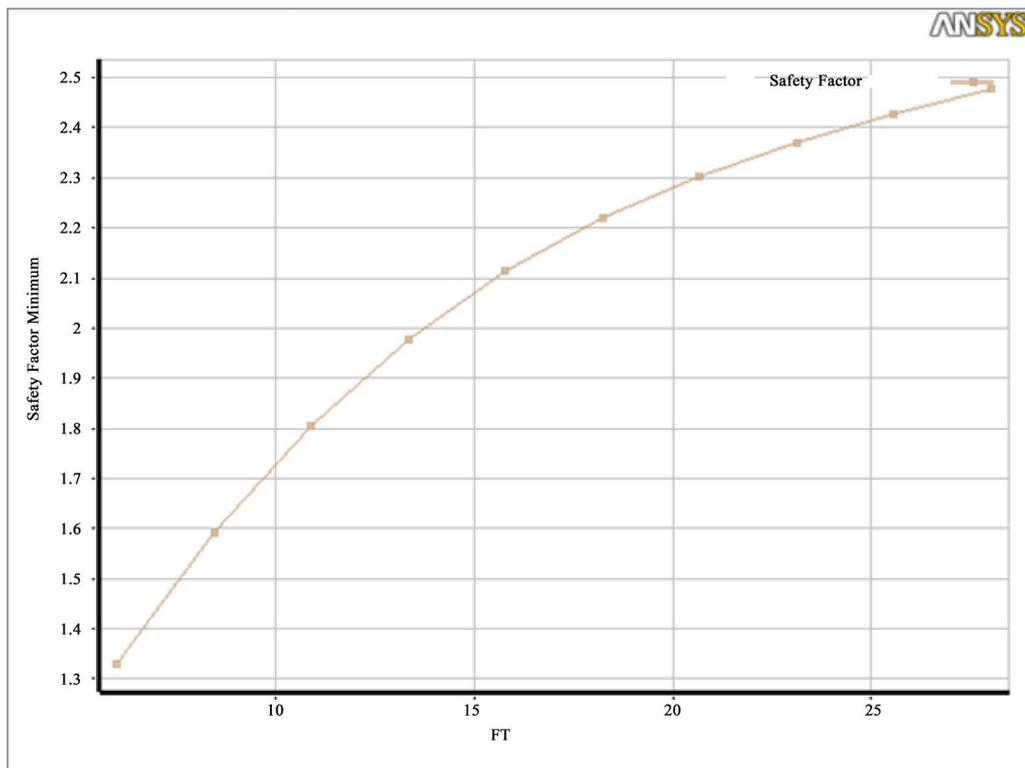


Figure 23. Variation in safety factor as flange thickness (T) of the section varies.

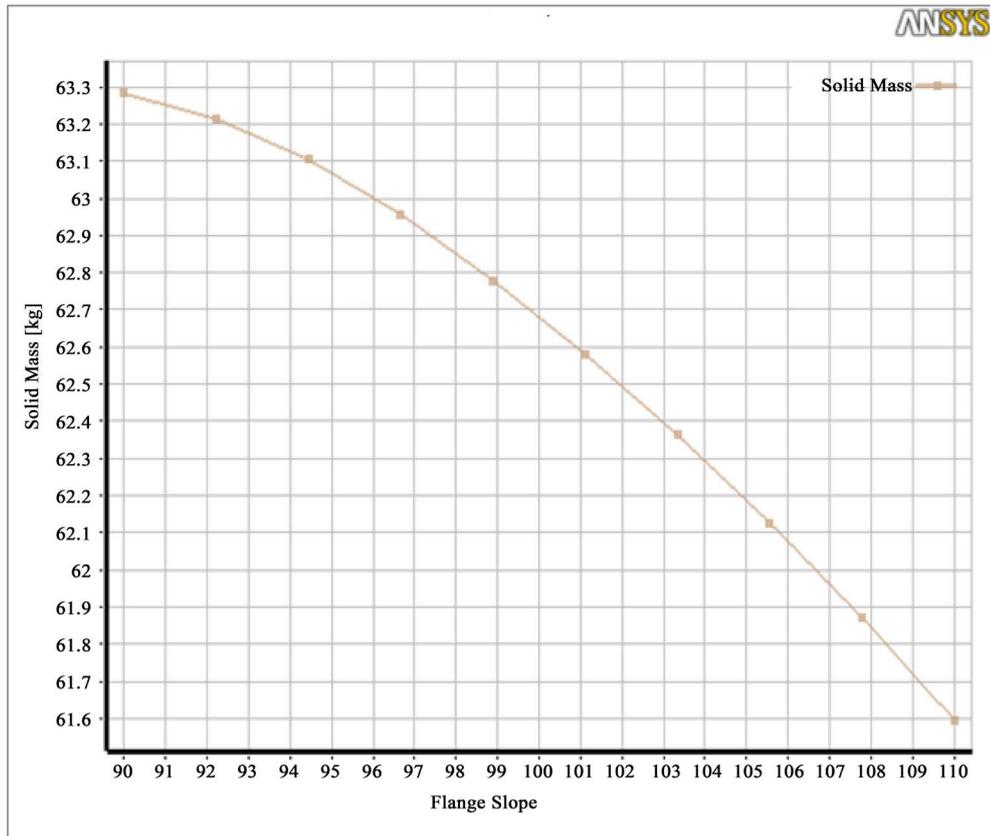


Figure 24. Variation of mass of the beam (per meter length) as flange slope (α) of the section varies.

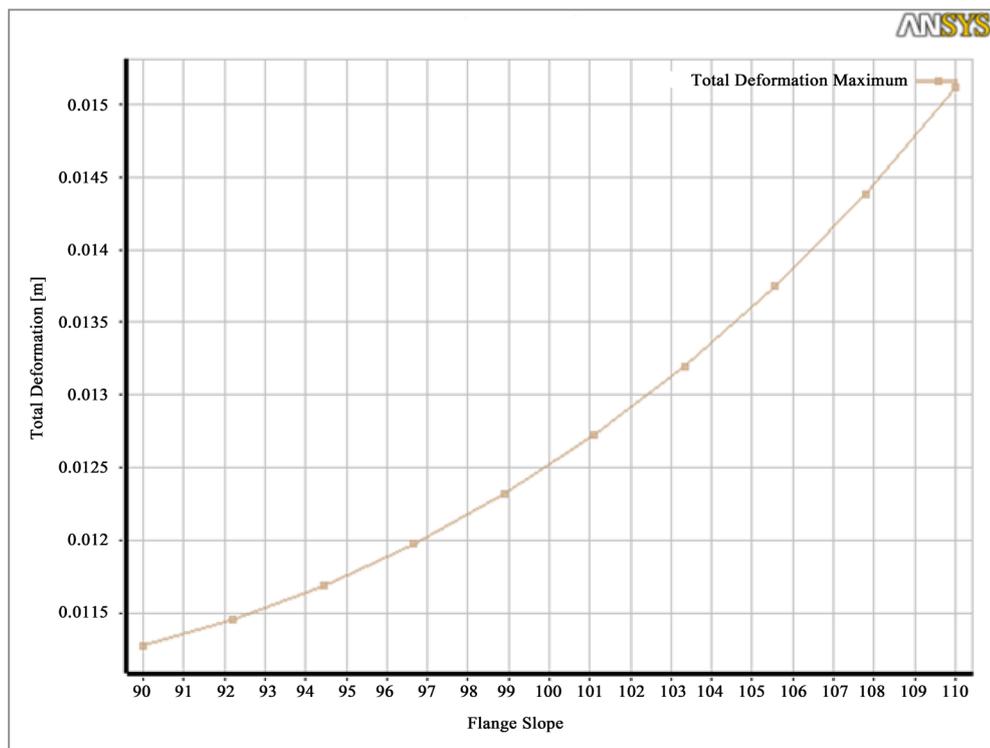


Figure 25. Variation in max. total deformation of the beam as flange slope (α) of the section varies.

This is the only parameter which is found like increasing its value decreases the mass whereby improving the performance of the section with high gradients. It improves the performance of the section without increasing the mass proportionally.

With the results of safety factor of **Figure 26**, it can be stated that flange slope is good if it is adopted within 92° to 97° . This is the peak range that is giving maximum value of safety factor and should be adopted for designing.

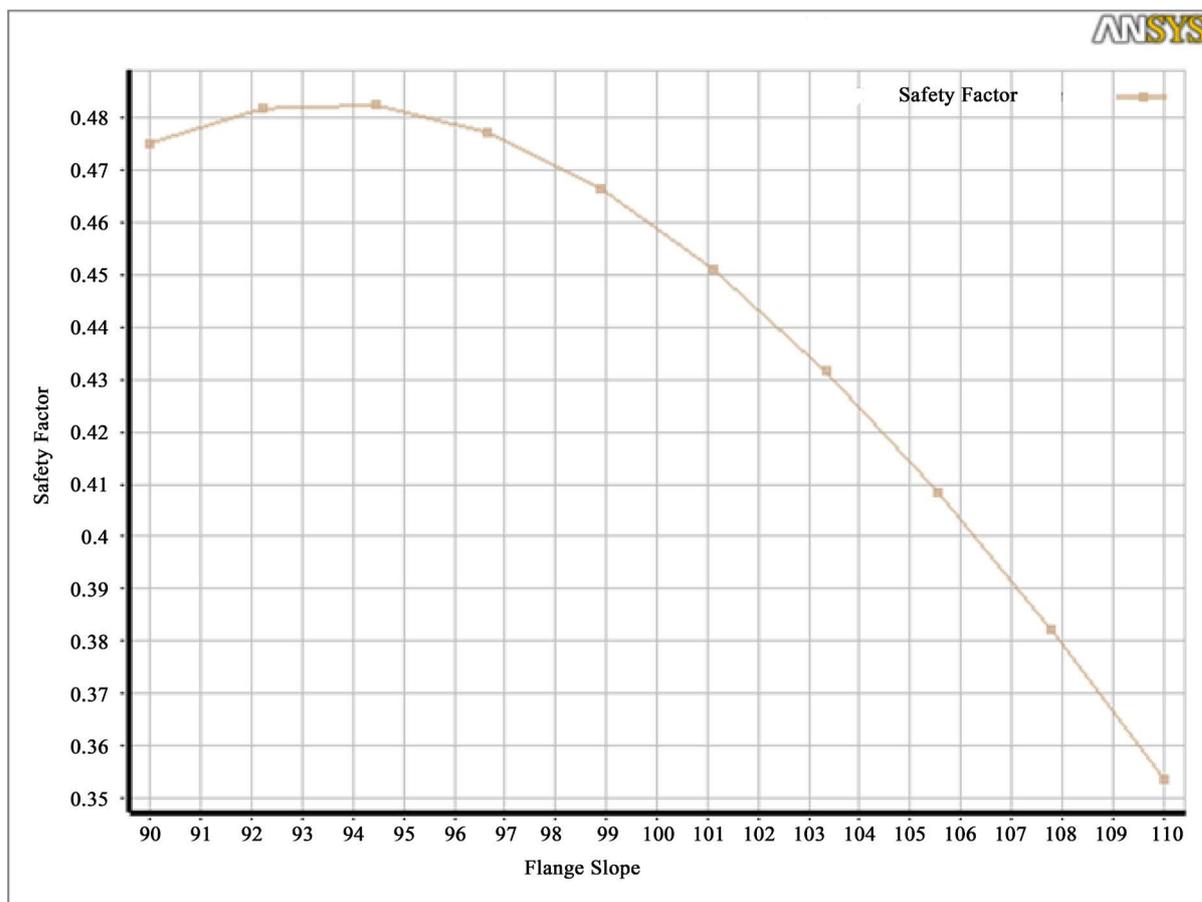


Figure 26. Variation in safety factor as flange slope (α) of the section varies.

8. Results and Discussions

For any arbitrary loading, following results are found out for IS sections as well as for optimally suggested sections. It can be observed in the this **Table 2** that for the same mass, performance of the suggested optimal section, in terms of safety factor as well as for total maximum deformation is better than that of IS sections.

Table 2. Comparison of sections of IS 808 and obtained optimal sections after analysis.

S.N.	Sections	D (mm)	B (mm)	t (mm)	α (deg)	T (mm)	R ₁ (mm)	R ₂ (mm)	Mass (kg/m)	S.F	T.M.D. (mm)
1.	MB 125	125	70	5	98	8	9	4.5	13.086	3.0541	1.934
	Optimal Section	125	60	6	98	8.5	9	6.4	13.045	3.7034	1.812
2.	MB 300	300	140	7.7	98	13.1	14	7	45.3	2.5854	2.1137
	Optimal Section	300	140	7	97	13.75	15	10.7	45.296	2.6381	2.0023
3.	MB 400	400	140	8.9	98	16	14	7	60.396	2.1315	2.6412
	Optimal Section	400	148	8.8	95	15	15	12.9	60.323	2.3168	2.3861

For better validation of these results, following structural errors are found in discretization of the model geometry (Figure 27). Unit of this measurement is Joule.

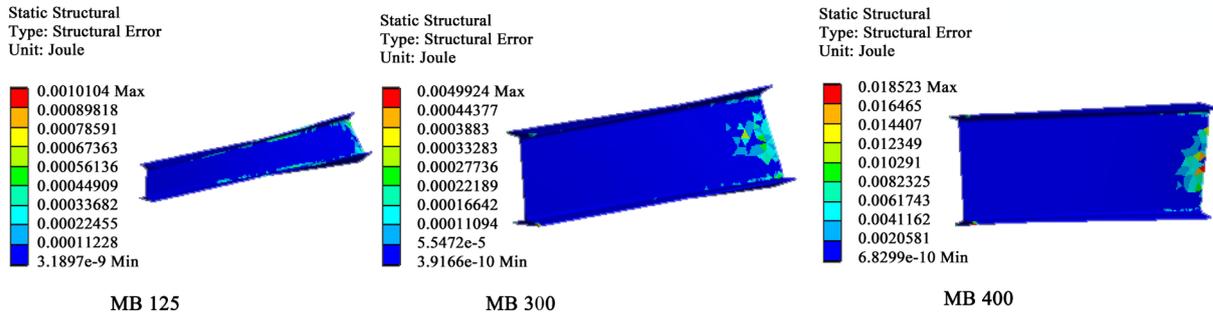


Figure 27. Figure shows discretization error in different sections.

9. Conclusions

Figure 28 and Figure 29 show statistics of results which come out from this analysis. These statistics show the potential of the inferiority of these three sections together and the need for correcting them in their dimensions. From these figures, it can be concluded that:

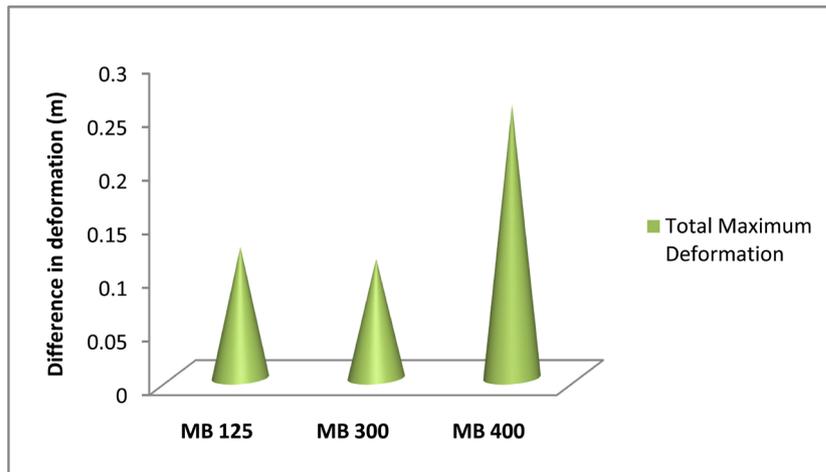


Figure 28. Figure shows difference in deformation in optimal section and IS sections.

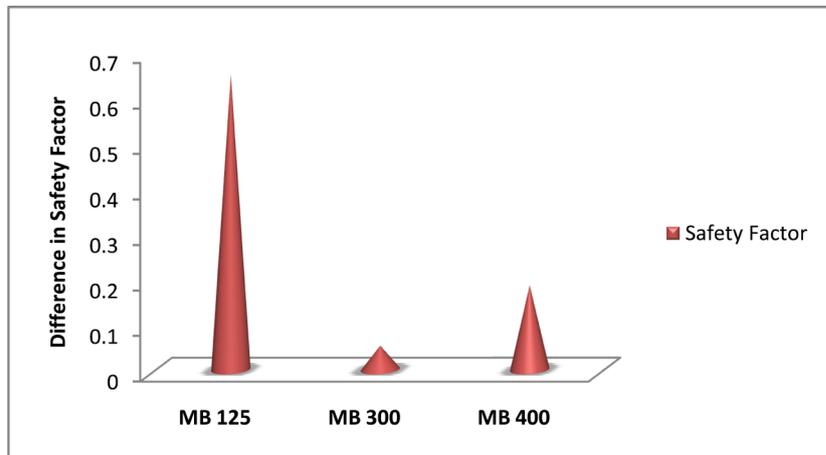


Figure 29. Figure shows difference in safety factor of optimal section and IS sections.

- Section MB 125 should be changed for the parameters, preferably flange width (B) and flange thickness (T) so that the safety factor of the section can be increased.
- Section MB 400 should be amended for the sectional dimension, preferably for flange width (B), web thickness (t) and flange slope (α) so that the total deformation of the section can be reduced.
- Section MB 300 should be amended such that deformation as well as the safety factor can be improved and the suggestions are web thickness (t), flange thickness (T) and flange slope (α).

Except these three sections of IS 808, **Table 1**, no other section is found to be performing inferiorly. With this study, it is certain that there exist better sectional dimensions for these three sections. Since IS sections are used countrywide by the designers and are manufacturers. So it will be the good practice if these sections are changed for their better alternatives.

Further, this study can be performed for the other sections of IS 808 for the better performance of the sections.

References

- [1] BIS (1987) IS 808: 1989 Indian Standard Dimensions for Hot Rolled Steel Beam, Column, Channel and Angle Sections. Bureau of Indian Standard, New Delhi.
- [2] Huang, X. and Xie, Y.M. (2010) Evolutionary Topology Optimization of Continuum Structures, Methods and Applications. A John Wiley and Sons, Ltd. Hoboken.
- [3] Ghabraie, K., Xie, Y.M. and Huang, X. (2007) Shape Optimization of Underground Excavation Using ESO Method. *Innovations in Structural Engineering and Construction*, Melbourne, 26-28 September 2007. <https://researchbank.rmit.edu.au/view/rmit:2848>
- [4] Beghini, L.L., Beghini, A., Katz, N., Baker, W.F. and Paulino, G.H. (2014) Connecting Architecture and Engineering through Structural Topology Optimization. *Engineering Structures*, **59**, 716-726. <http://dx.doi.org/10.1016/j.engstruct.2013.10.032>
- [5] Gere & Timoshenko (2004) Mechanics of Material. CBS Publishers and Distributors Pvt. Ltd., Chennai
- [6] Timoshenko, S. (2002) Strength of Materials, Vol. 1, Elementary Theory and Problems. 3rd Edition, CBS, New Delhi.
- [7] Ansys Help Manual—© 2010 SAS IP, Inc.
- [8] Benzley, S.E., Perry, E., Merkley, K. and Clark, B. (1995) A Comparison of All-Hexahedra and All Tetrahedral Finite Element Meshes for Elastic & Elastoplastic Analysis. *Proceedings 4th International Meshing Round Table Sandia National Labs*, Albuquerque, Livermore, October 1995, 179-181.
- [9] Canann, S.A., Tristano, J.R. and Staten, M.L. (1998) An Approach to Combined Laplacian and Optimization-Based Smoothing for Triangular, Quadrilateral, and Quad-Dominant Meshes. ANSYS, Inc., Canonsburg, 15317.
- [10] Ergatoudis, I., Irons, B.M. and Zienkiewicz, O.C. (1968) Curved, Isoparametric, Quadrilateral Elements for Finite Element Analysis. *International Journal of Solids and Structures*, **4**, 31-42.
- [11] Ramsay, A.C.A. and Maunder, E.A.W. (1995) Effective Error Estimation from Continuous, Boundary Admissible Estimated Stress Field. Instituto Superior Técnico, Universidade Técnica de Lisboa, Lisboa.
- [12] Cook, R., Malkus, D., Plesha, M. and Witt, R. (2010) Concept and Applications of Finite Element Analysis. John Wiley & Sons (Asia) Pvt. Ltd., Hoboken.