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Original Article

Enhancing the Adequacy of Indian Standard Rolled Steel I Sections by Increasing the Width of Flange

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Abstract - *The scientific background behind the dimensioning of Indian Standard rolled I-sections available in IS 808 1989 may have been based on the Working Stress Method (WSM) of the design of steel structures. Due to the recent developments in the design philosophies (i.e., Load and Resistance Factor Design (LRFD)) for the design of steel structures, it is important to establish the adequacy of Indian standard hot rolled steel sections. It is also necessary to assess the need to revise the dimensions of the rolled sections. The study presented in this paper evaluates the suitability of Indian standard hot-rolled steel I-sections as per the design guidelines given in the latest revision of the Indian Standard Code of Practice for General Construction in Steel (IS 800 2007). Laterally unsupported simple beams of spans 3 m, 6 m, 9 m, and 12 m that are subjected to uniformly distributed load over the entire span are examined in this study. The maximum bending moment and Elastic section modulus of Indian Standard Wide Beams (ISWB) after an increase in the width of the flange (if necessary) are grouped and plotted with the help of a C program developed by the authors. The results show that the variation of bending moment with section modulus is parabolic. Also, the rate of increase in load-carrying capacity with respect to section modulus decreases with an increase in the span. However, the increase in the width of the flange results in a lower rate of decrease comparatively.*

Keywords - *IS 800 2007, Wide flange beams, Flange width, Proportioning of cross-section, C program.*

1. Introduction

1.1. Steel Structural Historical Development

Structural steel has a history dating back to about 3000 BC. Steel is one of the most popular options for building construction given its unparalleled advantages over other construction materials like aesthetics, ease of design, increased floor space, recyclability, reusability, reliability in quality, future adaptability, durability, etc. Rolled I-sections are the most usual form of structural steel used in metallic carpentry. The patented technique for producing rolled I-sections was introduced in 1849 by Richard Turner et al., 1980. Table 1 presents a summary of historical progress in the production and application of iron and steel as Structural steel. Dimensions of structural steel sections adopted by different countries are available in British Standard EN 10025-1:2004, EN 10024, CSN EN 10034: 1993, British Standard EN 10162: 2003, EN 10162: 2003, DIN 1025 – Part 1 to Part 5, ASTM A6 / A6M-16a, 2016, British Standard BS 4-1:1993, IS 808 1989 and SP: 6 (1) – 1964. The designations of structural steel sections for different countries are entirely different. In the USA, steel I-Sections are denoted by 'W' followed by the depth in inches and the beam's self-weight in pounds per foot (AISC Manual of Steel Construction 14th Edition, 2011).

Table 1. Historical background of iron and steel

Period (From-To)	Historical Background
500 BC – 400 BC	First known use of Foam steel in China and Europe.
300 BC	Iron and steel were used in the Ashoka pillar (India).
500 AD – 1200 AD	The use of iron and steel is known in several Indian temples like Puri Jagannath, among others.
1350 AD	Steel manufacturing without Blast furnace technology
1740 AD	First manufactured for the structural steel
1855 AD	Patent for Sir Henry Bessemer-England for his steel-making process
1865 AD to 1980 AD	The open-hearth process of Siemens and Martins for structural steel production
1953 AD	A Basic Oxygen Steel (BOS) making process using a CD converter was invented in Austria. This technology is being widely used even today.

In Canada, the steel sections are labelled as 'W' with the depth in millimeters and the beam weight in kilograms per meter (Handbook of Steel Construction, 9^{th} Ed. 2006). Despite this difference, most of the Canadian I-beam dimensions align with those in the USA. In Mexico, steel I-beams are denoted by 'IR' followed by the depth in millimeters and beam weight in kilograms per meter (IMCA Manual of Steel Construction, 5th Ed.). In the United Kingdom, steel structural sections use a code comprising major dimension (depth in mm) - minor dimension (width in mm) - mass per meter in kg/m, ending with the section type.

For instance, "152×152×23UC" represents a column section (UC = universal column) with approximately 152 mm depth, 152 mm width, and weighing 23 kg/m ("Structural sections" to BS4: Part 1: 1993 and BS EN10056: 1999*)*. In Australia, steel sections are referred to by approximate beam height, followed by beam/column type (Universal Beams (UB) or Columns (UC)), and then weight per meter run in kg/m. For example, "460UB67.1" signifies an approximately 460 mm deep universal beam weighing 67.1 kg/m ("Structural sections" to BS4: Part 1: 1993 and BS EN10056: 1999*)*.

The situation in India is similar. A set of Indian Standards on beam, channel, and angle sections was developed in 1957 and published as IS 808 1957. After several revisions, it was published as IS 808 1989. Currently, as per IS 808 2021, Indian standard I-beams are denoted as Indian Standard Medium Weight Beam (ISMB), Indian Standard Junior Beams (ISJB), Indian Standard Light Weight Beams (ISLB), and Indian Standard Wide Flange Beams (ISWB), respectively followed by the depth of the section.

For example, for "ISMB 450", 450 represents the section's depth in millimeters. Indian Standard Angle sections, Channel sections, and Plate sections are denoted in similar lines. The Indian Standard Code of Practice for General Construction in Steel, developed in 1984 (IS 800 1984), was revised in 2007 (IS 800 2007).

Paul et al. (1999) observed that local buckling can happen in Indian hot-rolled I-sections at low post-yield strains due to the existence of residual stresses. For residual stresses of 70 MPa and 140 MPa, respectively, it was shown that material non-linearity starts at 70 to 43 percent of the plastic moment capacity. Flexural plastic capacity is therefore attained at High fibre strain, measured in the range of 2.4 to 2.8 times the yield strain.

Local buckling may result from this high strain (Paul et al., 1999; Paul et al., 2000). A method is available for determining shear-moment interaction boundaries at various axial stress levels for widely available Indian steel I-sections (Goswami et al., 2003). It is necessary to update the design process described in SP: 6 (6) and remould the existing Indian sections to have wider flange widths.

To achieve the intended performance in severe seismic circumstances, the sectional qualities (strength and stability) of Indian hot-rolled I-sections are examined considering the various code requirements and were observed to be unsuitable for application in tall structures (Goswami et al., 2006). As per Indian standards, hot rolled parallel flange, narrow parallel flange, wide parallel flange and tapered parallel flange beam sections, with yield stress, 250 MPa, 300 MPa, 350 MPa, and 410 MPa are being manufactured for application in metallic carpentry.

Some of these sections are feasible for use in Steel Moment Resisting Frames (SMRFs). By adopting a suitable width-to-thickness ratio of component plates, the failure of a section can be avoided (Kulkarni et al., 2012). Due to their ease of welding and bolting, increased lateral stiffness, reduced cost (10–15 %), and versatile availability, parallel flange I-sections are the most adopted flexural members in seismic resistant steel buildings (Kulkarni et al., 2015).

1.2. Concluding Remarks in Review of Literature

From the review of relevant literature, a consistent methodology for dimensioning distinct types of structural steel sections across different countries has not been established. Further, the scientific basis for dimensioning of Rolled I-sections is not known. However, the dimensions of these structural steel components may have been arrived at by considering one or a combination of numerous factors not limited to the following.

1. Bricks size used in respective countries in olden days versus the size of beams adopted.
2. Out-stand requirements for Beam-to-Beam joints and Beam-to-Column joints.
3. The dimensions originally finalized may have been later converted to mm, leading to fractional values.
4. The limitation in thickness of each component of an I-section may have been based on limits to avoid residual stresses (especially at the web flange intersection) due to longer cooling time. Therefore, the element's thickness is limited to avoid capacity reduction.
5. Based on optimization criteria, the dimensions may be efficient with certain depth-to-width ratios.
6. Hot-rolled sections are typically proportioned to avoid issues with local buckling, which will result in a slender configuration that will lead to reduced capacity.
7. Ease of manufacture
8. It may be arbitrary since the rollers and "dies", once established, will not vary for an exceedingly long time due to the significant investment required to change them.

It can be considered that the scientific background behind the dimensioning of Indian Standard rolled I-sections available in codes of practices of different countries, including IS 808 1989, may have been based on the Working Stress Method (WSM) of the design of steel structures.

Given the recent developments and advances in the methodologies of structural steel design (i.e., Load and Resistance Factor Design (LRFD)) and corresponding revisions in IS 800 2007 and codes of practice of other countries, it is necessary to verify the adequacy of Indian standard rolled sections being made available to the construction industry. Although revising the dies and rollers for economical dimensions is uneconomical, it may be warranted from the sustainability point of view (steel saving). In this context, there is also a need to study the effect of minor dimensional changes in the Indian standard rolled I-section on the load-carrying capacity.

Earlier researchers have worked on the buckling behavior of I-sections adopted as beam-column members subjected to combined bending and compression in moment-resistant frames for buildings in seismic zones. From the review of the literature (Paul et al., 1999; Paul et al., 2000; Goswami et al., 2003; Goswami et al., 2006; Kulkarni et al., 2012; Kulkarni et al., 2015), it is evident that there is a need for change in dimensions of the standard rolled steel parallel flange sections being manufactured in India.

In this paper, the authors have tried to assess the adequacy (well-proportioned nature) of Indian standard hot rolled steel sections given the recent developments in the design philosophies (Load Resistance and Factor Design (LRFD)) in the Indian scenario. The analytical studies tried to quantify the dimensional change required in terms of the increase in section modulus and cross-sectional area required. They quantified the advantage of changing the dimensions of IS steel I-sections in terms of an author-defined factor called the "Economic factor."

2. Objective, Scope, and Methodology

2.1. Objective and Scope

The following are the specific objectives of the study.

1. To find the adequacy of IS hot rolled sections by assessment of limiting loads in shear and bending and find the modified section modulus (by increasing width of the Flange) for equal limiting loads in shear and bending.
2. To quantify the advantage of increasing the section modulus (by increasing the width of the Flange) on the Economic Factor (an author defined parameter) that represents the well-proportioned nature of cross-section.
3. To quantify the improvement in the performance of the modified section (for an increased cross-sectional area (by increasing the width of the Flange) in terms of load-carrying capacity

This study is limited to support laterally unsupported ISWB beams limited to plastic and compact sections of spans 3 m, 6 m, 9 m, and 12 m subjected to Uniformly Distributed Load (UDL) over the entire span.

In general, the architectural plans of high-rise residential buildings consider spans of at least 3 m and at most 12 m. In industrial sheds, the economical spacing of roof trusses (spans of purlins) is also in the range of 4 m to 8 m. Hence, in this study, the analytical results have been presented for laterally unsupported simple flexural members of spans in the range of 3 m to 12 m that have a lot of practical applications in residential as well as industrial sheds.

2.2. Methodology

2.2.1. Well-Proportioned Cross-Section

The effectiveness of a cross-section for a span can be assessed based on two criteria.

- The minimum of the load-carrying capacities of the section at flexure and shear failure and
- The variation of actual stresses developed at the extreme top and bottom fibers with the permissible stresses

In the flexure members, while resisting the external load, the main internal forces developed are Bending Moment (BM) and Shear Force (SF). Therefore, for any beam section, the Moment of Resistance (M_d) and Shear Resistance (V_d) should be more than the developed BM and SF, respectively. That is, all the rolled sections will have to limit the Moment of Resistance (M_d) and Shear Resistance (V_d). For a given span of a simply supported beam subjected to uniformly distributed load on the entire span, let w_b be the maximum load for which the maximum bending moment in the beam is equal to the M_d of the section.

Similarly, let w_v is the maximum load for which the maximum shear force is equal to V_d of the section. M_d of I-sections depends on the dimensions of the flanges and depth of the web, whereas Shear strength depends on the dimensions of the web. Therefore, all the rolled sections have the limiting moment of resistance (M_d) and (shear resistance) V_d. Then, the safe load that the beam can carry can be considered as the least of w_b and w_v. Using the least value of w_b and w_vBM is calculated, and a graph can be plotted between BM and Elastic section modulus (Z_e) for all ISWBs as defined by the Bureau of Indian Standards.

For the beams with w_b (load-carrying capacity in bending) are less than w_v (load capacity of the beams in shear), if the width of the flange is only increased, keeping the depth of the section same, w_b increases. If the width of the flange is increased until w_b is equal to w_v, the cross-section can be well proportioned. The variation of BM to Z_e of the modified sections can be obtained. The cross-section can also be considered as well-proportioned if the extreme fibre bending stresses are close to their respective permissible bending compressive and tensile stresses.

2.2.2. Studies Conducted to Realize the Stated Objectives
Study 1

Modified section modulus (by increasing the width of the Flange) for equal limiting loads in shear and bending. The section modulus of all the ISWBs in the scope of the study is determined for different spans.

For a simply supported beam subjected to Uniformly Distributed Load (UDL) of 'w_b / unit length' over the entire span of 'L,' the maximum BM occurs at the centre of the beam and is equal to $w_b l^2/8$. For the beam to be safe in bending, the design moment M_d should be greater than or equal to the Maximum Bending moment in the beam.

$$M_d = {w_b L^2}/{8} \Rightarrow w_b = {8M_d}/{L^2} \quad (1)$$

Similarly, the maximum load the beam can carry without shear failure w_v is given by equating the design shear V_d to the maximum shear force in the beam.

Therefore,

$$V_d = \frac{w_v L}{2} \Rightarrow w_v = \frac{2V_d}{L} \quad (2)$$

The minimum values of w_b and w_v, is the safe load-carrying capacity of the beam, and the corresponding moment of carrying capacity is calculated.

Based on this concept, graphs showing the relationship between BM carrying capacity and elastic section modulus are developed for all I-sections specified by the Bureau of Indian Standards. The Moment of Resistance (M_d) of doubly symmetric prismatic members is determined as per Clause 8.2.2 of IS 800 2007.

For the beams whose w_b is less than w_v, the width of the flange can be increased, keeping the depth of the section same so that w_b increases. The width of the flange is increased until w_b is equal to the w_v. The section is limited to plastic and compact. As executing the procedure manually for all the rolled sections in the steel tables is a tedious process, a C program has been developed.

Study 2: Effects of increasing the section modulus (by increasing the width of the Flange) on the Economic Factor.

Economic factors of sections in flexure are introduced to compare the economy of various IS rolled sections for their maximum load-carrying capacity for a given span. This assumes that a well-proportioned cross-section will have its extreme fibre stresses close to their respective permissible bending compressive/tensile stresses. The expression of economic factor is given by,

$$\text{Economic Factor} = \left\{2 - \left(\left[\frac{f_{act}}{f_{per}}\right]_{comp.} + \left[\frac{f_{act.}}{f_{per\cdot}}\right]_{ten.}\right)\right\} \quad (3)$$

$$f_{act} = \text{Actual bending stress} = {BM}/{Z_p} \quad (4)$$

$$BM = {wL^2}/{8} \quad (5)$$

Where, w is the load, which is the least of w_b, w_v

$f_{perm.}$ = permissible Bending stress

For the laterally unsupported beam,

$(f_{perm\cdot})_{comp.} = f_{bd}\ N/mm^2$

$(f_{perm.})_{ten.} = f_y = 250\ N/mm^2$

For a cross-section that is safe in flexure,

$$\left[\frac{f_{act\cdot}}{f_{per\cdot}}\right] < 1 \text{ (in both bending compression and bending tension)} \quad (6)$$

(in both compression and tension)

Hence, the expression

$$\left(\left[\frac{f_{act.}}{f_{per\cdot}}\right]_{comp.} + \left[\frac{f_{act.}}{f_{per\cdot}}\right]_{ten.}\right) < 2 \quad (7)$$

So, from the expression for the Economic factor given by Equation (3), it can be understood that the lesser the economic factor, the more effective the utilization of the cross-section and, hence, better the proportioning of dimensions of the cross-section. So, higher is the economy. The Economic factors are calculated for all ISWBs for spans of 3 m, 6 m, 9 m, and 12 m with and without an increase in the width of the flange and compared.

For making these calculations for all the I-sections in IS 808 1989, a C program is developed. It calculates the increased load-carrying capacity for a suitable increased width and the corresponding economic factor. The flow chart of the C Program shown in Figure 1 briefly explains the entire methodology adopted.

Study 3: Performance of modified Steel I - Beams

An increase in the width of the flange results in an increase in the cross-section and hence increases the load-carrying capacity of the section. The choice of the modified section can be based on the improvement ratio, which is defined as the percentage increase in load-carrying capacity to the percentage increase in area. The performance of modified steel I-sections by increasing the width of the flange is quantified by determining the performance of the section for a minor increase in cross-sectional area.

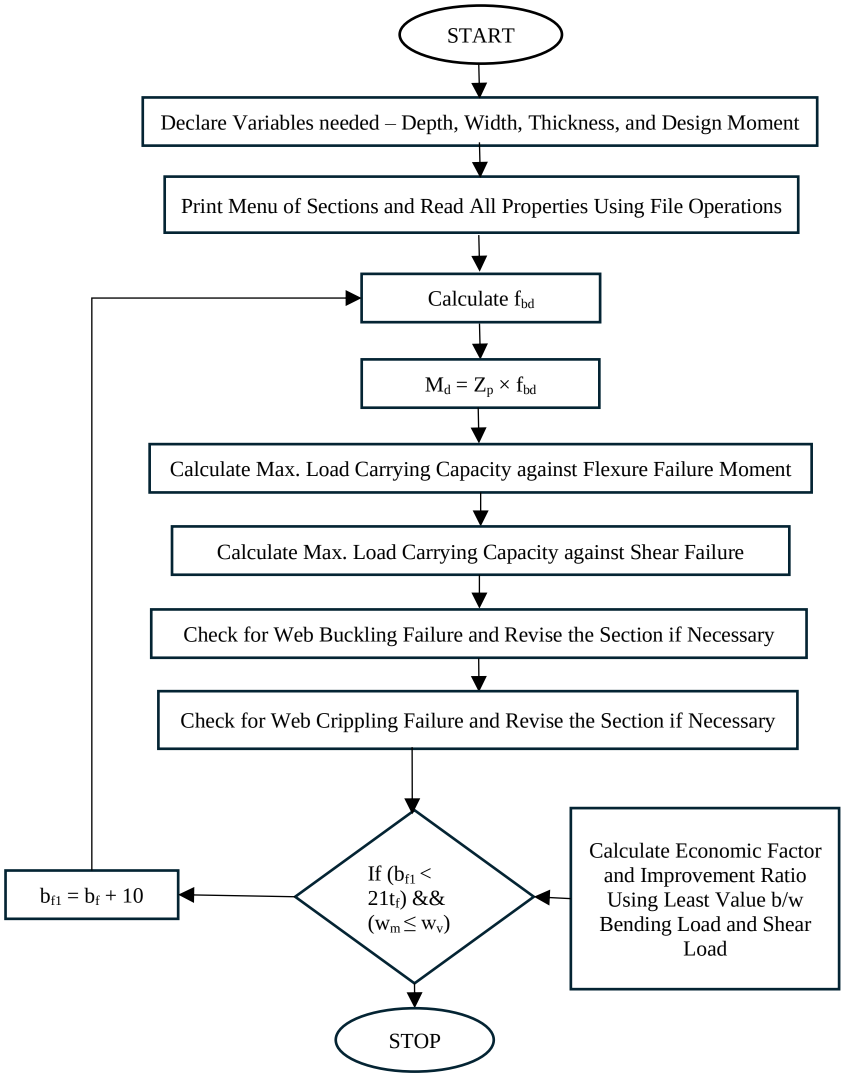


Fig. 1 Flowchart for calculation of economic factor

Table 2. Maximum bending moment and elastic section modulus of IS wide beams

IS Section	BENDING MOMENT FOR A SPAN of				Ze
	3 m	6 m	9 m	12 m	
WB150	16.63	8.69	5.87	4.50	111900
WB175	29.12	15.17	10.13	7.56	172500
WB200	49.37	27.68	18.63	14.04	262500
WB225	67.92	38.84	26.02	19.62	348500
WB250	89.94	53.42	34.53	25.38	475400
WB300	137.16	78.44	49.71	36.36	654800
WB350	186.67	105.98	66.83	48.60	887000
WB400	242.15	137.61	86.67	63.18	1171300
WB450	333.65	195.80	124.94	91.44	1558100
WB500	470.55	303.48	188.83	134.28	2091600
WB550	568.33	417.78	267.00	192.06	2723900
WB600 1	661.33	573.53	379.18	277.02	3540000
WB600 2	696.76	653.22	446.72	331.56	3854200

3. Results and Discussion

3.1. Study 1

3.1.1. Moment Carrying Capacity of ISWBs for Various Spans

The maximum moment carrying capacity (as per IS 800 2007) and Elastic section modulus of Indian Standard Wide beams are tabulated (Table 2) and plotted (Figure 2). From Figure 2, it can be observed that the variation of bending moment with Section modulus is parabolic. Performing Regression analysis, the variation of the Bending moment with Section modulus with an

$R^2 = 0.9938$ is given by

$$BM = 32653 \times Ze^2 - 143694 \times Ze + 321912 \quad (7)$$

3.1.2. Validation

The maximum moment carrying capacity of a laterally un-supported 9 m span simple ISWB600-2@145.1 as per IS 800 2007 (LSM) from Table 2 is 446.72 kN/m and as per IS 800 1984 (WSM) is 343.83 kN.m from Annexure A. The % difference in moment carrying capacity is 23.03 %. Pasnur & Patil (2013) compared the moment carrying capacities of Indian standard rolled I-sections from ISJB150 to ISHB450 over laterally supported and unsupported simple spans in the range of 1 m to 6 m as per Limit State and Working Stress Design Philosophy. The authors concluded from the study that for Laterally Supported Beams, the moment carrying capacity is more in the limit state method than by the elastic method by about 8% for smaller sections and decreases up to 3% for higher sections. However, for laterally unsupported spans up to 2 m, the moment capacity is more in the limit state method for most of the sections (except ISHB200 to ISHB350) by about 5%. But for most of the sections with spans more than 3 m and up to 6m, the moment of resistance of Indian standard I-sections as per LSM is about 23% higher than that calculated as per WSD.

It can be further concluded that the shear resistance as per the elastic method is more than that determined by the limit state method by 13%. This brings the load-carrying capacity of the section as per shear criteria close to that calculated per moment criteria in WSD. This means that the cross-sections are well proportioned as per WSD criteria. This is in corroboration with the % difference in moment carrying capacities between changes calculated for ISWB600-2@145.1 in the first paragraph of the Validation in the 3.1 Section.

Ashish Goyal (2011), as a part of his master's thesis, analysed a foot over bridge by STAAD.Pro. and designed all basic structural members for axial, flexural and combined stresses as IS 800 2007 and IS 800 1984 and compared. In "Page 113 Section C.2:- Design by both codes (Table C.2.1 - Sl. No. 18), the Scholar tabulated the load-carrying capacity of ISMB 175 as per LSM and WSM as 21 kN/m and 17.5 kN/m, respectively. The load-carrying capacity in bending compression calculated as per LSM is 16.67% higher than that calculated as per WSM.

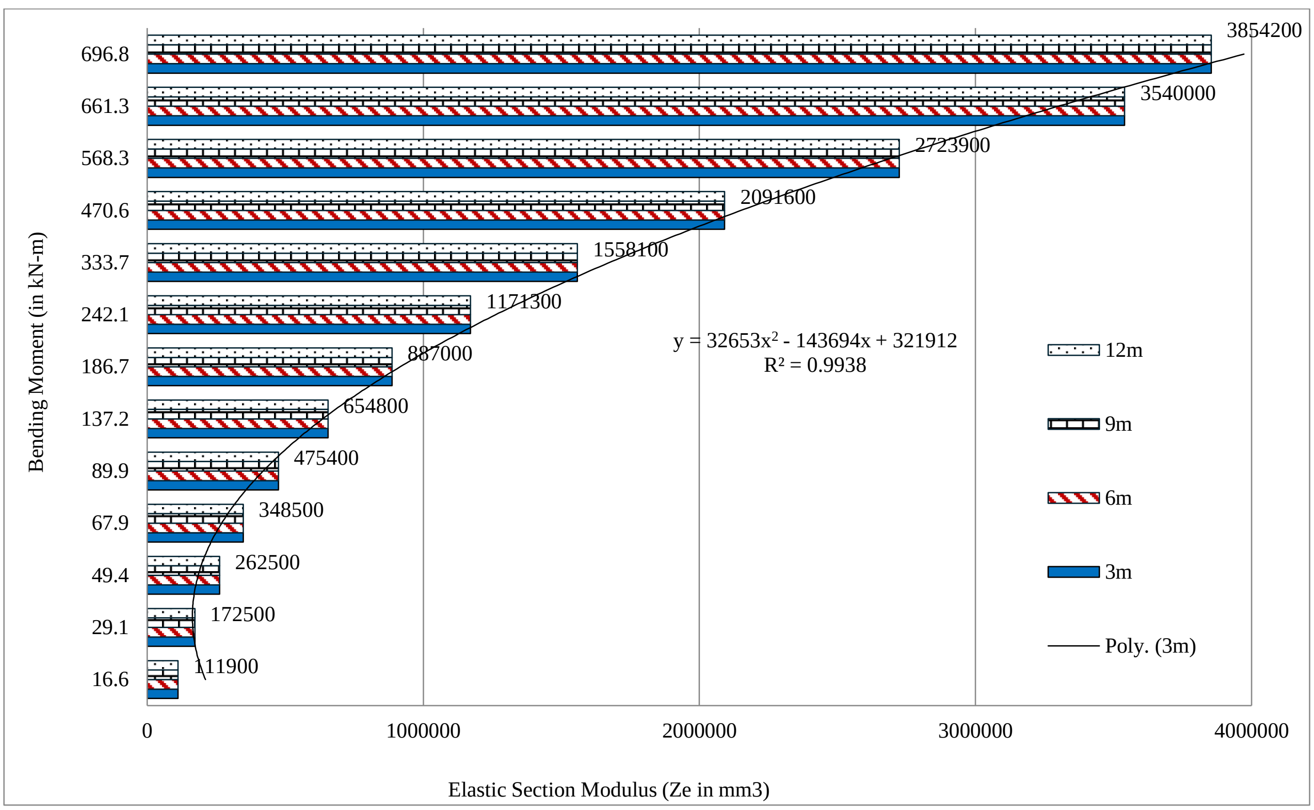


Fig. 2 Maximum bending moment and elastic section modulus of IS wide beams

Table 3. Maximum bending moment and elastic section modulus of IS wide beams after increase in width of flange (if necessary)

S/C	3m		6m		9m		12m	
	NEW Ze	BM	NEW Ze	BM	NEW Ze	BM	NEW Ze	BM
WB150	157474.7	27.9	157474.7	17.1	157474.7	11.6	157474.7	8.8
WB175	217407.5	39.5	217407.5	24.3	217407.5	16.2	217407.5	12.2
WB200	346641.0	66.5	346641.0	46.3	346641.0	31.9	346641.0	24.1
WB225	476887.7	93.5	476887.7	68.6	476887.7	47.9	476887.7	36.2
WB250	475400.0	89.9	475400.0	53.4	475400.0	34.5	475400.0	25.4
WB300	700835.6	137.3	700835.6	92.5	700835.6	59.6	700835.6	43.2
WB350	1024208.3	204.3	1024208.3	145.8	1024208.3	95.1	1024208.3	68.4
WB400	1555511.0	319.2	1555511.0	253.0	1555511.0	174.8	1555511.0	126.2
WB450	1937171.8	391.3	2422461.3	437.5	2422461.3	335.1	2422461.3	250.0
WB500	2340851.8	477.0	2487894.0	421.7	2487894.0	295.7	2487894.0	210.8
WB550	2778903.8	568.3	3844067.3	720.2	3844067.3	574.0	3844067.3	432.9
WB600	3540000.0	661.3	6071646.5	1207.0	6071646.5	1064.1	6071646.5	883.1
WB600	3854200.0	696.8	6827711.5	1364.8	7394404.0	1370.0	7394404.0	1199.9

3.1.3. Modified Section Modulus for Equal Limit Loads in Shear and Bending

The maximum bending moment and Elastic section modulus of IS Wide beams after increasing the width of the flange (if necessary) are tabulated (Table 3) and plotted (Figure 3). For all the ISWB sections for which the study has been made, it is observed that the variation of BM with the section modulus is parabolic, and the rate of increase in load-carrying capacity with respect to section modulus is decreasing with an increase in span. However, the increase in the width of the flange results in a lower rate of decrease comparatively. Observations from Table 3 show that ISWB250 (for spans 3 m to 12 m), ISWB550 (for 3 m span), ISWB600-1 (for 3 m span) and ISWB600-2 (for 3 m span) had equal load-carrying capacity with respect to the shear as well as bending resistance. Hence, no modifications in terms of an increase in the width of the flange were required to enhance load-carrying capacity. The section modulus for each type of ISWB section defined for all spans with and without an increase in the width of the flange is shown in Table 4, and the Maximum Bending Moment for each type of ISWB section defined for all spans with and without an increase in width of the flange is shown in Table 5. The bending moment values highlighted in Table 5 are those of the sections for which the flexure and shear load-carrying capacities were the same; hence, there is no increase in the flange width, and hence, there is no increment in the moment of resistance.

Table 4. Maximum BM for each type of ISWB section for all spans

S/C	Actual Ze	Modified Ze	
		3m	6m, 9m and 12m
WB150	111900	157475	157475
WB175	172500	217408	217408
WB200	262500	346641	346641
WB225	348500	476888	476888
WB250	475400	475400	475400
WB300	654800	700836	700836
WB350	887000	1024208	1024208
WB400	1171300	1555511	1555511
WB450	1558100	1937172	2422461
WB500	2091600	2340852	2487894
WB550	2723900	2778904	3844067
WB600 1	3540000	3540000	6071647
WB600 2	3854200	3854200	6827712

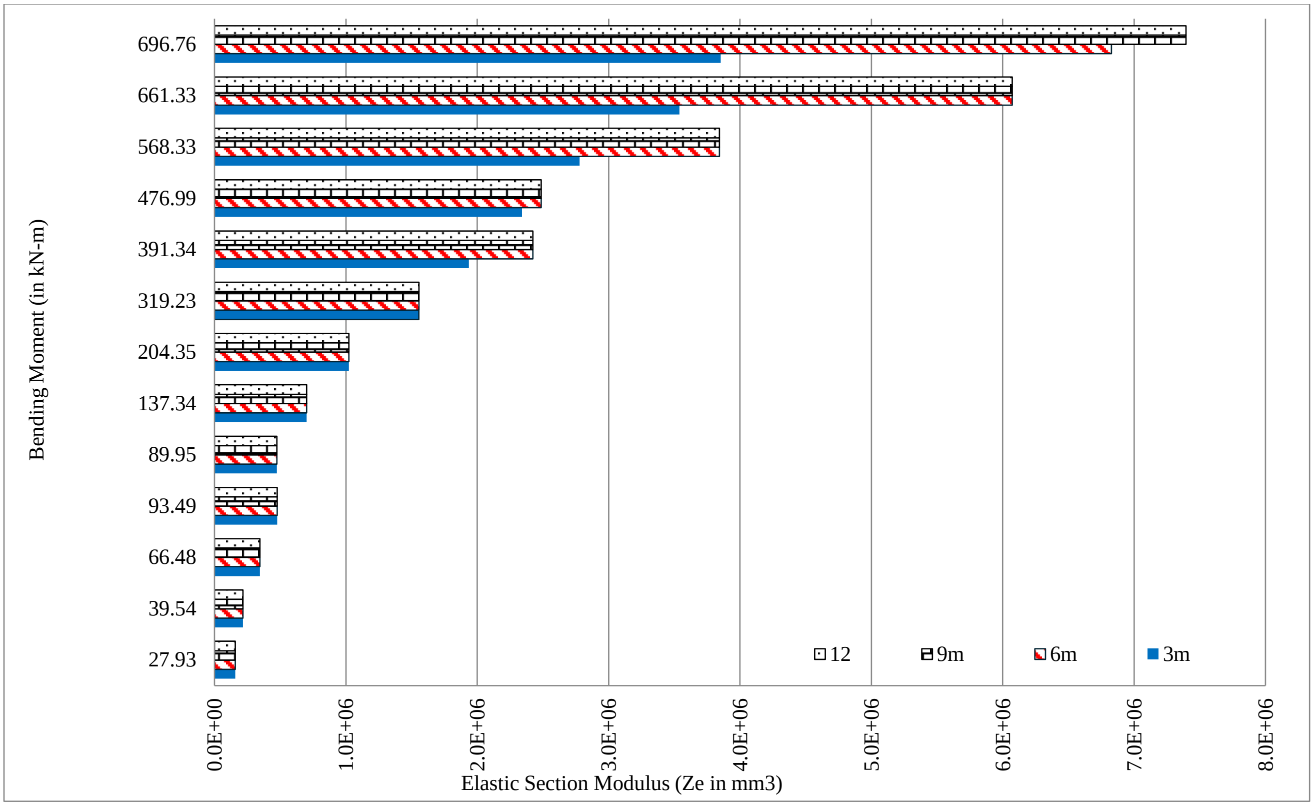


Fig. 3 Maximum bending moment and elastic section modulus of IS Wide beams after increase in width of flange (if necessary)

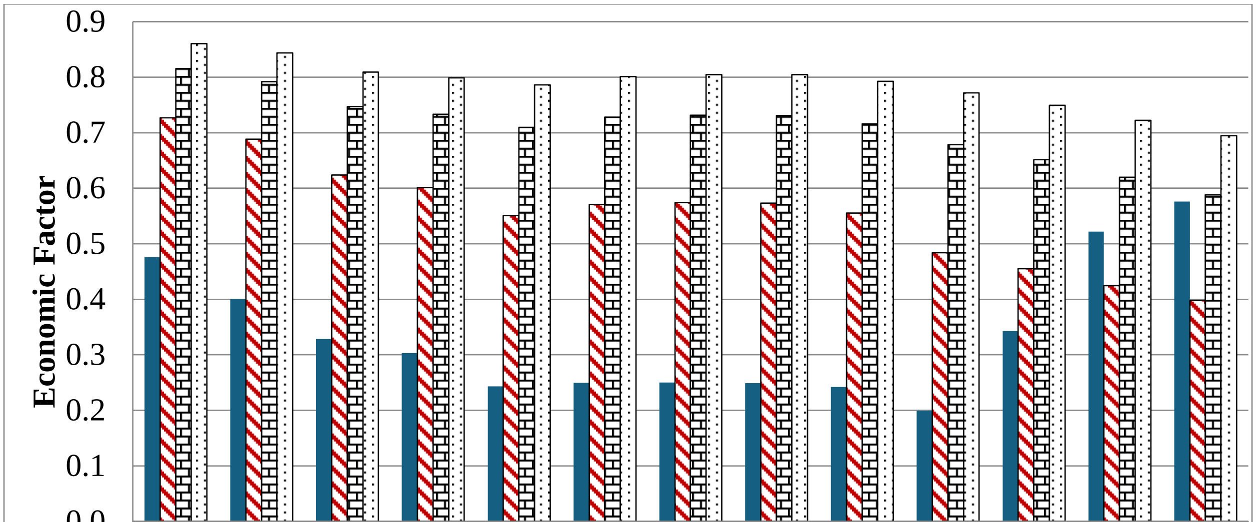
Table 5. Maximum BM for ISWB sections for all the spans

S/C	The bending moment for a span							
	3m		6m		9m		12m	
	Actual Value	Modified Value	Actual Value	Modified Value	Actual Value	Modified Value	Actual Value	Modified Value
WB150	16.63	27.9	8.69	17.1	5.87	11.6	4.5	8.8
WB175	29.12	39.5	15.17	24.3	10.13	16.2	7.56	12.2
WB200	49.37	66.5	27.68	46.3	18.63	31.9	14.04	24.1
WB225	67.92	93.5	38.84	68.6	26.02	47.9	19.62	36.2
WB250	89.94	89.9	53.42	53.4	34.53	34.5	25.38	25.4
WB300	137.16	137.3	78.44	92.5	49.71	59.6	36.36	43.2
WB350	186.67	204.3	105.98	145.8	66.83	95.1	48.6	68.4
WB400	242.15	319.2	137.61	253	86.67	174.8	63.18	126.2
WB450	333.65	391.3	195.8	437.5	124.94	335.1	91.44	250
WB500	470.55	477	303.48	421.7	188.83	295.7	134.28	210.8
WB550	568.33	568.3	417.78	720.2	267	574	192.06	432.9
WB600 1	661.33	661.3	573.53	1207	379.18	1064.1	277.02	883.1
WB600 2	696.76	696.8	653.22	1364.8	446.72	1370	331.56	1199.9

3.2. Study 2 Economic Factors Representing Well-Proportioned Nature of Cross-Section

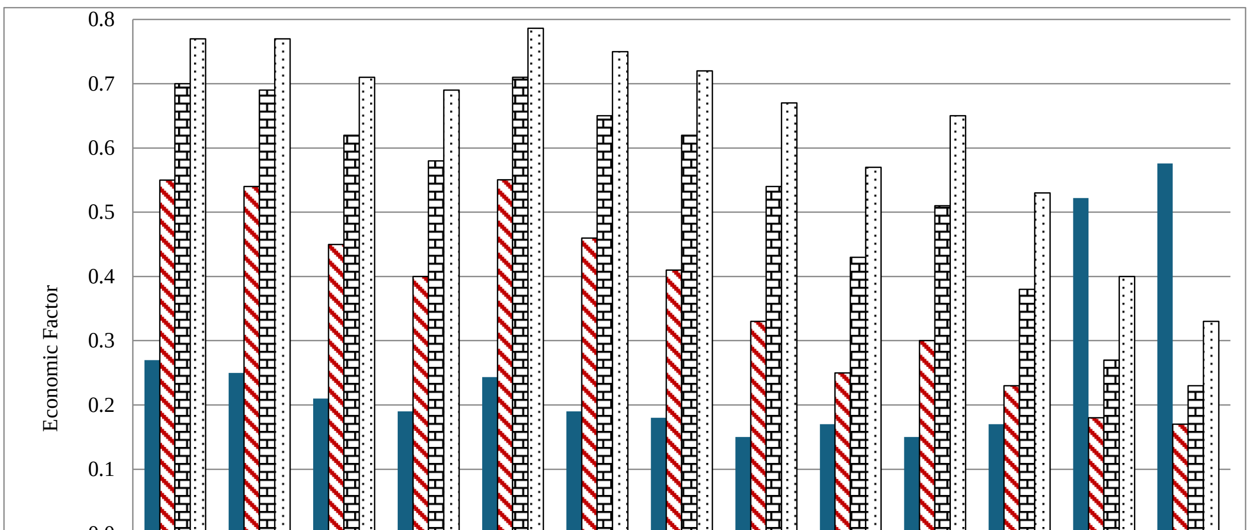
The Economic factors for different spans of IS Wide beams are tabulated and plotted in Figure 4. The Economic factors for different spans of IS Wide beams after increasing the width of the flange (if necessary) are plotted in Figure 5. From the graphs presented in Figures 4 and 5, it can be observed that the economic factors are different for different spans. Hence, the bar graphs can be used to choose an ideal section for a known span and load-carrying capacity. In general, the economic factor increases with increasing span. From the other graphs drawn for sections that are modified by increasing the width of the flange, it can be observed that the economic factor is decreased. The minimum economic factors for different spans for both cases under study are presented in Table 6. From Figures 4 and 5, it can be observed as a general trend that sections of smaller depth are not very economical for smaller spans compared to sections of higher depth.

Table 6 gives sections with smaller economic factors for their maximum load-carrying capacities, each span in the range of 3 m to 12 m before and after modifications adopted to the sections. Table 6 shows that the economic factors were reduced by 50% due to the modifications made.



	WB150	WB175	WB200	WB225	WB250	WB300	WB350	WB400	WB450	WB500	WB550	WB600 1	WB600 2
3m	0.476	0.400	0.328	0.303	0.243	0.250	0.250	0.249	0.242	0.200	0.343	0.522	0.576
6m	0.727	0.688	0.624	0.602	0.551	0.571	0.574	0.573	0.555	0.484	0.455	0.425	0.398
9m	0.816	0.792	0.747	0.733	0.710	0.728	0.732	0.731	0.716	0.679	0.652	0.620	0.588
12m	0.861	0.844	0.809	0.799	0.786	0.801	0.805	0.804	0.792	0.772	0.749	0.722	0.695

Fig. 4 Economic factors for IS wide flange beams



	WB150	WB175	WB200	WB225	WB250	WB300	WB350	WB400	WB450	WB500	WB550	WB600 1	WB600 2
3m	0.270	0.250	0.210	0.190	0.243	0.190	0.180	0.150	0.170	0.150	0.170	0.522	0.576
6m	0.550	0.540	0.450	0.400	0.551	0.460	0.410	0.330	0.250	0.300	0.230	0.180	0.170
9m	0.700	0.690	0.620	0.580	0.710	0.650	0.620	0.540	0.430	0.510	0.380	0.270	0.230
12m	0.770	0.770	0.710	0.690	0.786	0.750	0.720	0.670	0.570	0.650	0.530	0.400	0.330

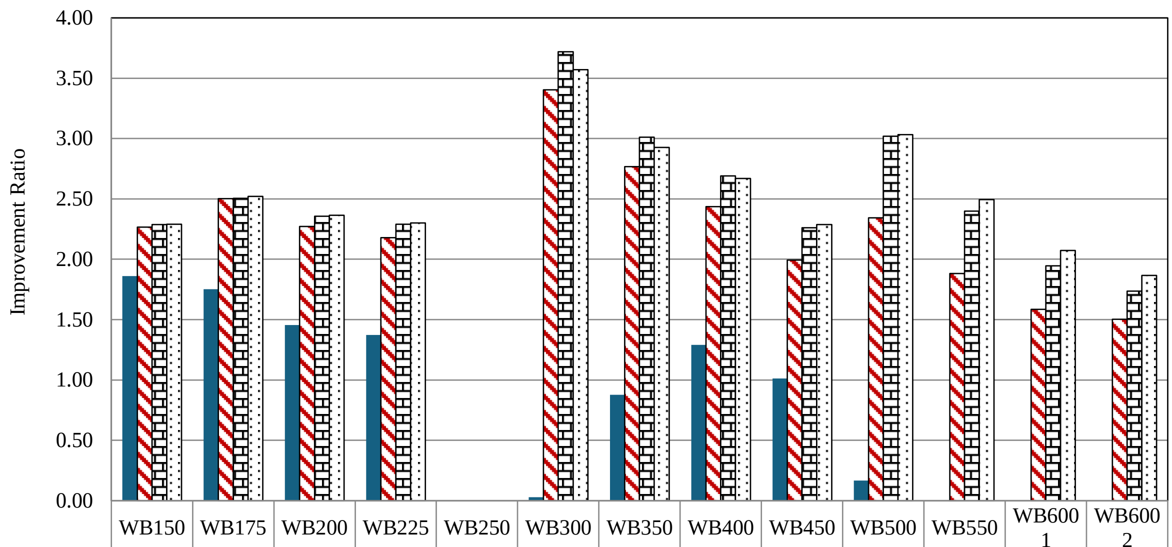
Fig. 5 Economic factors for modified IS wide flange beams

Table 6. Minimum economic factors for different spans

Span	**3 m**		**6 m**		**9 m**		**12 m**	
ISWB	**Actual**	**Modified**	**Actual**	**Modified**	**Actual**	**Modified**	**Actual**	**Modified**
	ISWB 500	ISWB 400, ISWB 500	ISWB 600 2		ISWB 600 2		ISWB 600 2	
Economic Factor	0.200	0.150	0.398	0.170	0.588	0.230	0.695	0.330

3.3. Study 3 Improvement in Performance of Modified Steel I - Beams

The performance of modified steel I-sections by increasing the width of the flange is quantified by determining the performance of the cross-section for a minor increase in cross-sectional area. Graphs are plotted for all ISWB beams in steel tables for different spans against their Improvement ratio. The Improvement ratios for different spans of IS Wide beams after an increase in the width of the flange (if necessary) are tabulated and plotted in Figure 6. From Table 7, a higher improvement ratio was observed for higher spans. Particularly for spans beyond 6m with ISWB 300. From observations made, it is observed that an increase of 7.03% in Ze resulted in an increase of about 18% in the load-carrying capacity. The maximum Improvement Ratio observed for different spans and distinct types of IS sections is presented in Table 7.



	WB150	WB175	WB200	WB225	WB250	WB300	WB350	WB400	WB450	WB500	WB550	WB600 1	WB600 2
3m	1.86	1.75	1.45	1.37	0.00	0.03	0.88	1.29	1.01	0.17	0.00	0.00	0.00
6m	2.27	2.50	2.27	2.18	0.00	3.40	2.77	2.44	1.99	2.34	1.88	1.59	1.50
9m	2.29	2.50	2.36	2.29	0.00	3.72	3.01	2.69	2.26	3.02	2.40	1.95	1.74
12m	2.29	2.52	2.37	2.30	0.00	3.57	2.93	2.67	2.29	3.03	2.49	2.07	1.87

Fig. 6 Improvement ratio for IS wide beams after an increase in the width of the flange

Table 7. Maximum improvement ratio observed for different spans

Span	**3 m**	**6 m**	**9 m**	**12 m**
ISWB	ISWB 150	ISWB 300		
Improvement Ratio	1.86	3.40	3.72	3.57
% increase in Z_P	40.73	7.03		
% increase in BM	67.78	17.92	19.89	18.03

4. Conclusion

The study presented in this paper evaluates the suitability of Indian standard hot rolled steel sections as per the design guidelines given in IS 800 2007. It signifies the necessity of revising the dimensions of the rolled sections. From this study on ISWB sections adopted for spans ranging from 3 m to 12 m, the following conclusions can be made.

1. Analytical results showed that the variation of BM with section modulus is parabolic. The rate of increase in load-

carrying capacity with respect to section modulus is observed to decrease with an increase in the span.

2. ISWB250 (for spans 3 m to 12 m), ISWB550 (for 3 m span), ISWB600-1 (for 3 m span) and ISWB600-2 (for 3 m span) had equal load-carrying capacity with respect to the shear and BM. Hence, modifications to the width of the flange are not required to enhance the load-carrying capacity.
3. Economic factors for maximum load-carrying capacities for each span in the range of 3 m to 12 m before modifications are made to the sections are observed to increase with the span. It is observed that the economic factors were reduced to 50% due to the modifications made in the dimensions of the flange. It is to be recalled that the lower the economic factor, the better the proportioning of the cross-section.
4. Smaller depths of sections are not economical to the smaller spans compared to sections of the higher depth.
5. A higher improvement ratio is observed for higher spans. Particularly for spans beyond 6m with ISWB 300, it was observed that for an increase of 7.03% in Zp, an increase of about 18% in the load-carrying capacity is observed.

In conclusion, very few sections among IS rolled I-sections are adequate and have equal shear and flexure load-carrying capacity. For some sections, it is noted that there is a significant increase in the Bending moment and Improvement ratio for a slight increase in Section Modulus. The program and methodology can be run/executed for all I-sections, and similar conclusions can also be arrived at for those sections.

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Annexure 1

Uniformly distributed load-carrying capacity of 9 m span simply supported ISWB600-2@145.1 as per IS 800 1984. The cross-sectional details are as follows.

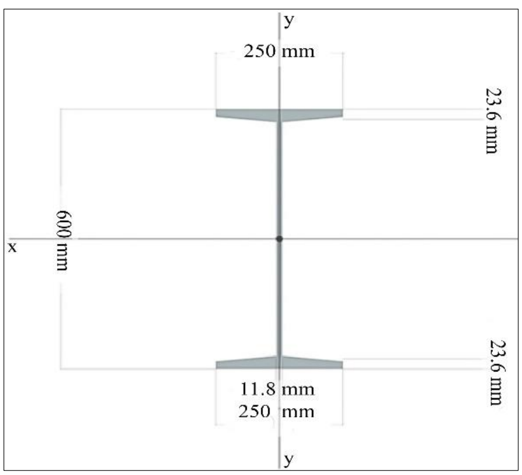

Fig. 7 Dimensions of ISWB 600-2@145.1

Section Modulus about X-X axis is $Z_x = 3854200\ mm^3$

Determination of Maximum permissible bending compressive stress:

$$\frac{t_f}{t_w} = \frac{23.6}{11.8} = 2 \text{ and } \frac{d}{t_w} = \frac{600 - 2 \times 23.6}{11.8} = 46.8$$

$$\text{As } \frac{t_f}{t_w} <= 2 \text{ and } \frac{d}{t_w} <= 85, \text{From Table 6.1b from IS 800} - 1984$$

$$\text{For } \frac{l}{r_y} = \frac{9000}{53.5} = 168.22 \text{ and } \frac{D}{t_f} = \frac{600}{23.6} = 25.42$$

Permissible bending compressive stress,

$$\sigma_{cs} = 89.208 \text{ MPa} \quad < 0.66 \times Fy$$

$$= 0.66 \times 250 = 165 \text{ MPa}$$

The maximum moment carrying capacity of the beam is,

$$M = 89.208 \times 3854200$$

$$= 343825473.6 \text{ N.mm} = 343.83 \text{ kN/m}$$