# Design of Structural Steel I -Beams -an Investigation of the Code Crovisions

**Idupulapati Anusha, VSM Vishnu, Batta Jaya Naga Satish**

***Abstract:*** ***Different codes have different recommendations for the design of structural steel flexural members in terms of determining the compactness, slenderness, strength, requirement of stiffeners etc. In this study, the provisions of IS 800-2007, and AISC Steel Construction Manual are compared. Deign is performed for a few rolled and built-up I-sections as per the provisions of these two standards. The root cause for the differences is investigated and presented. Based on this investigation, a set of conclusions are arrived at.***

***Index Terms:*** ***Moment of resistance, utilization ratio, section classification, section modulus, radius of gyration.***

## I. INTRODUCTION

Beams are of different shapes viz. I-sections, channels, hollow square/rectangular sections, hollow circular sections and so on. These sections can be either rolled or built-up.

As per IS 800-2007 – Pg18, table 2, classification of sections has been as follows.

**Plastic section:** Plastic sections or class 1 sections are cross-sections which can develop plastic hinges and have a rotation Capacity required for failure of structure by formation of plastic mechanism.

**Compact section:** Compact sections or class 2 sections are cross-sections which can develop plastic moment resistance, but have inadequate plastic hinge rotation capacity because of local buckling**.**

**Semi-compact section**: Cross-section in which elastically calculated stress extreme compression fibre of steel can reach yield strength.

**Slender section:** Cross-section in which local buckling occurs even before reaching yield stress.

AISC 360-10 has a slightly different classification which is as follows:

**Compact section**: Section capable of developing a fully plastic stress distribution and possessing a rotation capacity of approximately three before the onset of local buckling.

**Non-compact section:** Section that can develop the yield stress in its compression elements before local buckling occurs, but cannot develop a rotation capacity of three.

**Slender-element section:** Cross-section possessing plate components of sufficient slenderness such that local buckling in the elastic range will occur.

The division is mainly based on the flange width to flange thickness ratio and also the web depth to web thickness ratio. The ratios slightly vary between AISC and IS standards and are as prsented in table1.

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Based on the section classification and unbraced length of the member, equations are developed for determining the section moment capacity. This is discussed further in the latter parts of the report.

## II. PROBLEM STATEMENT

It is known in the industry that the AISC design is more economical in comparison to IS 800 based designs. G.saikiran, A Kailasa Rao, R. Pradeep Kumar, have done a case study on pre-engineered buildings (PEB) and have demonstrated the steel quantities when designed as per IS 80-2007 are significantly higher compared to the AISC designs. In Consultation with clients and approval authorities, sometimes the PEB suppliers as well as structural steel consultants/contractors propose to design as per the AISC standard. This conveys that there is a significant disconnect between the approaches of the two standards. This study investigates the reasons for this disconnect.


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**TABLE-1: SECTION CLASSIFICATION**

| | | | | | | |
|---|---|---|---|---|---|---|
| | | **IS 800-2007** | | | | |
| | | $\epsilon=(250/F_y)$^1/2 for $F_y$=250 | Ratio | plastic section | compact section | Semi-compact section |
| 1 | **ROLLED SECTION** | 1 | $b/t_f$ | 9.4 | 10.5 | 15.7 |
| | | | $d/t_w$ | 84 | 105 | 126 |
| 2 | **WELDED SECTION** | 1 | $b/t_f$ | 8.4 | 9.4 | 13.6 |
| | | | $d/t_w$ | 84 | 105 | 126 |
| | | | **AISC 360-10** | | | |
| | | $\epsilon=(250/F_y)$^1/2 for Fy=250, | Ratio | compact /non compact | | Non-compact/slender |
| 1 | **ROLLED SECTION** | 1 | $b/t_f$ | $0.38(E/F_y)$^0.5 =10.74 | | $1.0(E/F_y)$^0.5=28.284 |
| | | | $h/t_w$ | $3.76*(E/F_y)$^0.5 =106.34 | | $5.7(E/F_Y)$^0.5=161.22 |
| 2 | **WELDED SECTION** | 1 | $b/t_f$ | $0.38(E/F_y)$^0.5 =10.74 | | 0 .95 (kc E/ $F_L$)^0.5=19.16($F_L$ = 175) |
| | | | $h/t_w$ | $3.76*(E/F_y)$^0.5 =106.34 | | $5.7(E/F_Y)$^0.5=161.22 |

## III. METHODOLOGY

The following methodology is adopted for this investigation:

- ISMB sections are checked for section classification as per IS 800-2007 And AISC 360-2007.
- The sections are assumed to be laterally supported throughout.
- Design comparison is provided for the ISMB sections.
- Different built-up I-sections are considered and their section classification is determined as per IS 800-2007 And AISC 360-2007.
- The sections are assumed to be laterally supported throughout.
- Design comparison is provided for the built-up sections.
- The above sections (ISMB and built-up) are considered to be laterally unsupported for chosen spans and designed in STAAD.pro as per is 800-2007 and AISC 360-10
- The UDL and span are adjusted such that the utilization ratio as per the IS 800-2007 is nearly 1.0. For the same span and loading, AISC design is performed.
- Design comparison is provided for the laterally unsupported beams (ISMB and built-up).

## IV. ASSUMPTIONS

- All beam sections are treated are non-composite.
- The design calculations are limited to I- sections that include ISMB hot rolled sections and built-up sections.
- Steel grade is assumed to be E 250 code as per IS 2060-2011 with a yield strength of 250 MPa.
- Physical properties of structural steel are assumed as per 2.2.4.1 of IS 800-2007 and are as follows.

a) Unit mass of steel, p = 7850 $kg/m^3$
b) Modulus of elasticity, E = 2.0 x $10^5 N/mm^2$ (MPa).
c) Poisson ratio, $\mu$= 0.3
d) Modulus of rigidity, G = 0.769 x $10^5$ $N/mm^2$ (MPa).
e) Co-efficient of thermal expansion $\alpha_t$= 12 x $10^{-6}$ /$^0$c

- All beams are assumed to be simply supported.
- For laterally supported beams, the effective length for lateral torsional buckling is assumed to be the same as the effective length for minor axis bending.
- For laterally unsupported beams, all effective lengths are assumed to be equal to span.

## V. RESULTS

1. Compact flange and compact web(AISC360-10)
Compact flange and compact web (IS800-2007)

| Varying $b/t_f$ | Constant $d/t_w$ | MR (IS/AISC) | Utilization ratio (AISC/IS) |
|---|---|---|---|
| 8.75 | 104.8 | 1.01 | 0.634 |
| 9.0625 | 104.8 | 1.01 | 0.635 |
| 9.375 | 104.8 | 1.01 | 0.685 |

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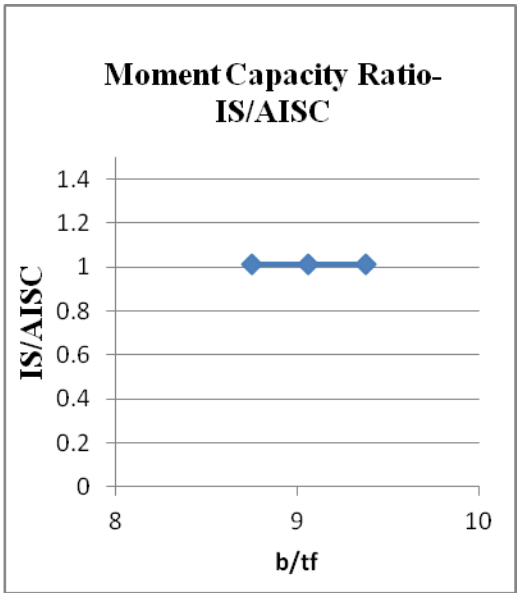
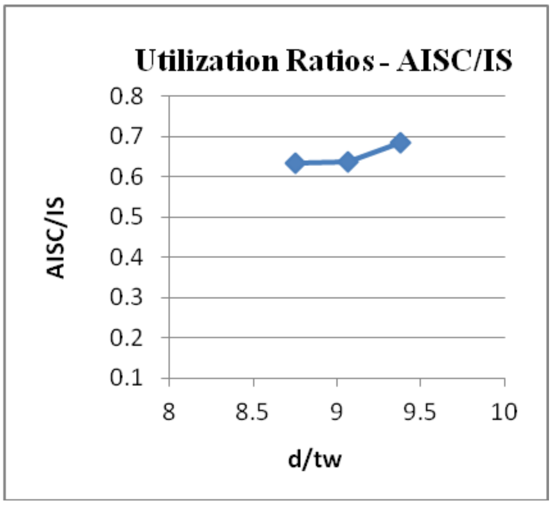
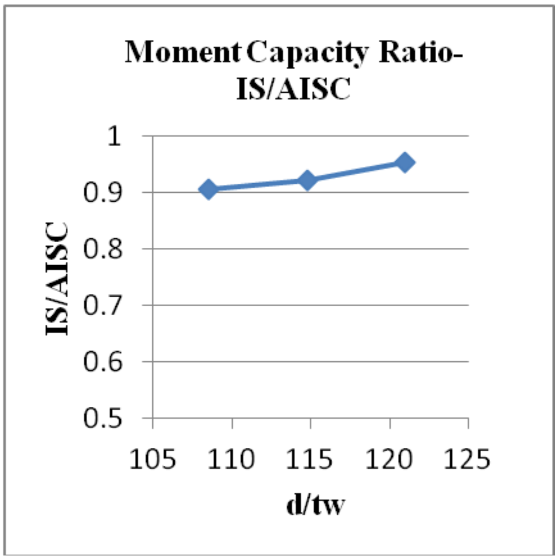
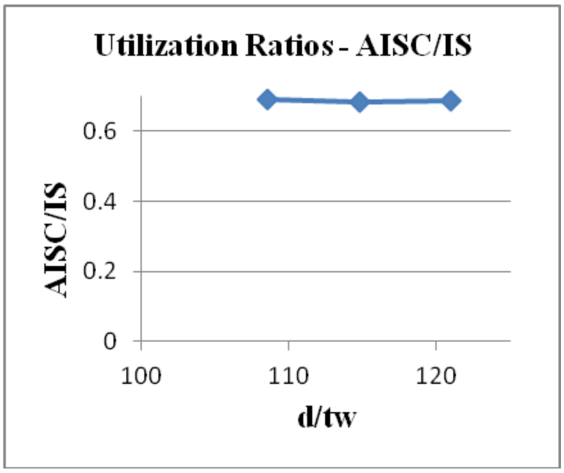



2. Compact flange and non-compact Web (AISC360-10) Compact flange and semi-compact web (IS800-2007)

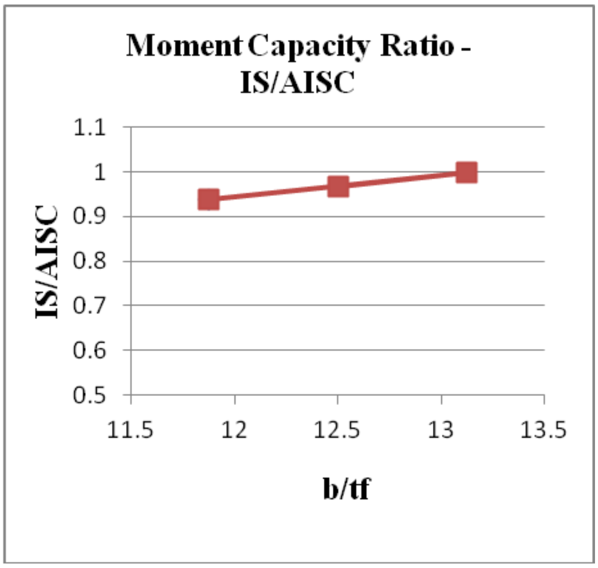
| Constant $b/t_f$ | varying $d/t_w$ | MR (IS/AISC) | Utilization ratio (AISC/IS) |
|---|---|---|---|
| 9.375 | 108.5 | 0.9062 | 0.69 |
| 9.375 | 114.75 | 0.92325 | 0.682 |
| 9.375 | 121 | 0.95315 | 0.686 |

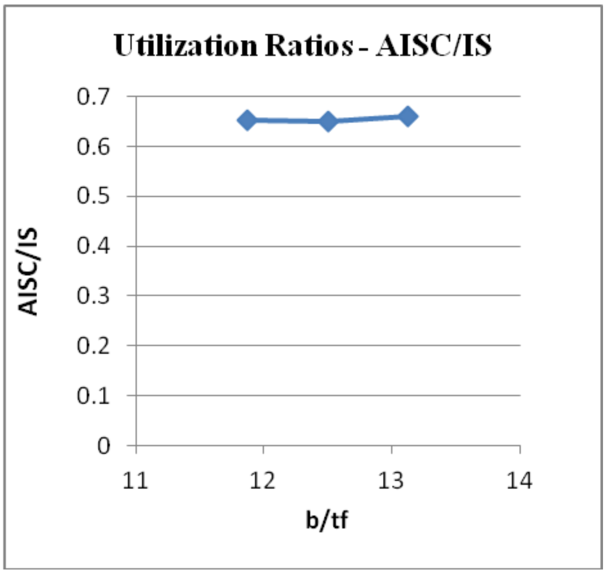


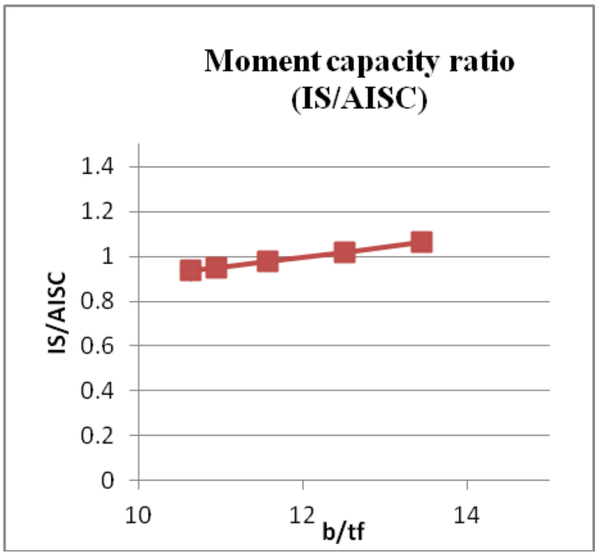

| Varying $b/t_f$ | Co nstant $d/t_w$ | MR (IS/ AISC) | Utilization ratio (AISC/IS) |
|---|---|---|---|
| 11.875 | 102.25 | 0.93 94 | 0.653 |
| 13.125 | 102.25 | 0.99 | 0.65 |
| 12.5 | 102.25 | 0.968 | 0.661 |

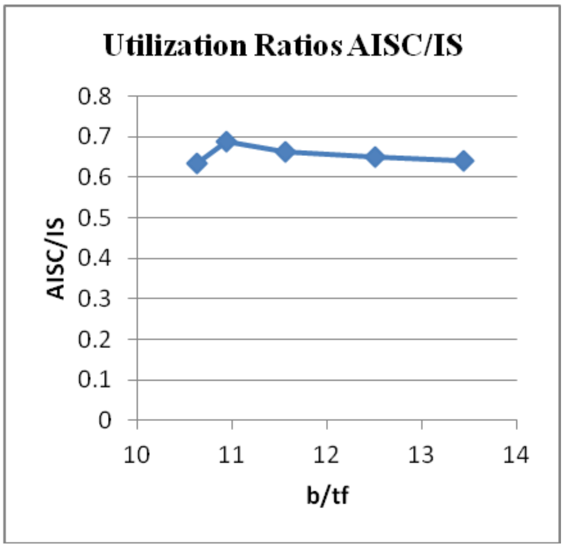
3. Non-compact flange and compact web (AISC360-10) Semi-compact flange and compact web (IS800-2007)




4. Non compact flange and non-compact web (AISC360-10)
   Semi compact flange and semi-compact web (IS800-2007)




**Note**: In the above charts, moment capacity ratio is for the laterally fully supported case.
Utilization ratios are for the laterally unsupported case.

## VI. INVESTIGATION OF RESULTS

**Case 1:** For sections that are compact as per AISC and plastic/compact as per IS 800 and laterally fully supported, the capacities are almost equal.
The capacity ratio (IS/AISC)

$$= \frac{\frac{1}{\gamma mn}}{\phi} = \left[\frac{\left(\frac{1}{1.1}\right)}{0.9}\right] = 1.0101$$

**Case 2:** For sections that are compact as per AISC and semi compact as per IS 800-2007 and laterally fully supported, the IS code capacity is always less than the AISC code capacity. The same equations as in the compact case apply (IS: 800-2007 Section 8.2.1.2 and AISC equation no.F2-1).

The capacity ratio will be $\left(\frac{\left(\frac{1}{\gamma mn}\right)}{\phi}\right)\left(\frac{Ze}{Zp}\right)$

For an I-section $z_e/z_p$ will be generally around 0.9. Hence, for those sections that are classified differently as semi compact in IS code and compact in AISC the Indian code capacity is always less.

| Varying $b/t_f$ | constant $d/t_w$ | MR (IS/AISC) | Utilization ratio (AISC/IS) |
|---|---|---|---|
| 10.625 | 126 | 0.938 | 0.634 |
| 10.9375 | 126 | 0.947 | 0.689 |
| 11.5625 | 126 | 0.975 | 0.661 |
| 12.5 | 126 | 1.019 | 0.650 |
| 13.437 | 126 | 1.065 | 0.642 |

**Case 3:**For an I-section which is having compact webs and non-compact flange as per AISC and semi-compact as per IS800-2007 when it is laterally fully supported.
The capacity ratios (IS/AISC) are less than 1.0 and greater than $\left(\frac{\left(\frac{1}{\gamma mn}\right)}{\phi}\right)\left(\frac{Ze}{Zp}\right)$. The reason for this is reduced plastic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Moment capacity as per AISC F3-1.Thus, the capacities as per IS 800 and AISC get closer when the section classes are similar.

**Case 4:** For an I-section which is having non-compact webs and non-compact flange as per AISC and is classified as semi-compact as per IS 800-2007, and laterally fully supported.

The capacity ratios in this case are generally less than 1.0 except at high $b/t_f$ and/or high $d/t_w$ ratios where it crosses 1.0. The reason for this is that the AISC capacity is the reduced yield moment capacity as per AISC F4-1.In case of non-compact web and compact flanges it is the plastic moment that gets modified as per AISC. In case of non-compact webs and non-compact flanges it is the elastic yield moment that gets reduced as per AISC. Thus the capacities are further closer to the IS capacities in comparison with Case 3.

**Case 5:** For an I-section that is laterally unsupported.

In this case, the IS capacities are significantly lower than the AISC capacities.

The AISC capacities are based on $F_{cr}$ value as per equation F4-5. The IS capacities are based on $f_{bd}$ value as per Section 8.2.2.

As per the calculations, the $F_{cr}$ values as per IS 800 (Section 8.2.2.1) are lower than the $F_{cr}$ values as per AISC. In addition, the design bending compressive stress $f_{bd}$ is further lower from $F_{cr}$ calculated as per IS 800.

The reason for the $F_{cr}$ value being lower in case of the Indian code is that it is based on the slenderness ratio of the whole section about minor axis $L_{Lt}/ry$. On the other hand, the AISC $F_{cr}$ value is based on a slenderness ratio that is obtained from the radius of gyration of the compressive zone. The Indian code $F_{cr}$ gets further reduced to $f_{bd}$ by factors described in the above equation.

## VII. CONCLUSIONS

- In most of the cases studied, the moment of resistance as per AISC standard is more than the moment of resistance as per IS 800.
- In a few cases where the section is semi-compact as per the IS Code and is having non-compact flange and non-compact web as per the AISC standard, the IS moment of resistance is in the same range as the AISC moment resistance.
- In case of rolled sections which are classified as plastic sections as per IS Code and compact sections as per AISC standard, the moment of resistance is same, when the beams are laterally fully supported.
- In terms of the Utilization Ratios, IS 800-2007 code ratio is more than AISC 360-10 ratio.
- The reasons for the differences are investigated. The main reason for the laterally supported case is the differences in the section classification as per the two standards.
- In the laterally unsupported case, the Indian standard section capacity is based on the minor axis slenderness ratio whereas the AISC section capacity is based on the slenderness of the compression zone which is more rational.

## RECOMMENDATIONS

- An explanatory hand book needs to be prepare for IS 800.
- This study needs to be extended to other sections like channels, tubes etc.
- A future study can also include in depth investigation of member capacities in compression, tension minor axis bending and shear.

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