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Comparison of Section Classification Procedure of Different Codes

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Abstract

The cross-section classification is essential to identify local buckling in steel sections. Local buckling restricts the section from attaining its maximum moment capacity. Cross section classification is based on the behavior of the element under direct and bending compressive stresses. Limit on width to thickness ratio of elements in a cross section is the governing criterion for the section classification in different national codes. In the case of seismic design, the post yield ductility is an important parameter; therefore, it is particularly essential to prevent local buckling. Design codes of different countries provide different limiting values for the section classification. The present study discusses the approach of various national codes towards cross section classification. The approach of Eurocode 3, AISC 341, AISC 360, BS 5950 and IS 800 on issues like section classification of members subjected to axial and flexural compression, sections with elements of different classes are explained and their salient features are compared with each other. It is observed from the study that, amongst the codes considered, AISC provides the most stringent limits for seismically compact section, whereas, for other class of sections Eurocode 3 limits are more stringent.

Keywords: Local buckling, section classification, design codes, width to thickness ratio, steel sections.

1. Introduction

Achievement of maximum moment capacity has remained the primary criteria in fixing the cross section of steel members. However, local buckling of elements of the section can create premature lateral yielding before achieving the maximum moment capacity. Various researchers have identified that the local buckling of elements is the primary reason for reduction of both strength and stiffness of the section which ultimately leads to failure [18] [19]. Form past studies it has been identified that the local buckling is governed by interaction between flange and web plates [2] [12] [16], limiting curvature values [7] and width to thickness ratio of elements. However, most of the current design codes provide limits on width to thickness ratio of elements as primary criteria for section classification indicating the level of local buckling resistance, considering "Individual plate rule". In this rule a section is considered as assembly of plates (elements). Based on support conditions, these elements are considered as internal (stiffened) or outstand (unstiffened elements). Buckling of an element (outstand or internal) occurs if the compressive stress (flexural or direct compression) exceeds the critical buckling stress of that element.

The cross section is generally classified into four types as Class 1, Class 2, Class 3 and Class 4. When there is a requirement of a cross section that should not buckle before reaching its plastic moment capacity, Class 1 or Class 2 sections are used and when buckling can be allowed after yielding of the section, Class 3 members are used. When buckling can be allowed even before yielding of cross section, Class 4 members are used.

"Eurocode 3: Design of Steel Structures - Part 1-1", EN 1993-1-1:2005, (hereafter EC3), is followed by various countries of Europe. EC3 classifies section as class 1, class 2, class 3 and class 4. The classification is presented for three cases, as part subjected to bending, part subjected to compression and part subjected to both bending and compression. EC3 gives bending moment variation along the cross section for all the three cases thus aiding an easy interpretation. "Specification of Structural Steel Buildings", AISC 360(2010) and "Seismic Specifications of Structural Steel Buildings", AISC 341(2005), (hereafter AISC), provides specifications for design of steel buildings. AISC 341 provides limit on width to thickness ratio for classifying a member as seismically compact and AISC 360 provides limits for compact, non-compact and slender sections. AISC gives classification of members subjected to axial compression and members subjected to flexure. BS 5950-1:2000, "Structural use of steelwork in building — Part 1", (hereafter, BS 5950) has two separate tables for classification of hollow sections (Circular hollow sections, CHS and Rectangular Hollow sections, RHS) and non-hollow sections (sections that are not CHS and RHS). For web of an I section, H section or Box section, BS 5950 provides classification for three different cases i.e. the web is subjected to only bending, the web is subjected to only axial compression and the third case depends on flange

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(equal and unequal) and classified it under heading "Generally". Indian Standard "General Construction in Steel, IS 800:2007" (hereafter IS 800), provides the limit on width to thickness ratios for the web and flange of the cross-section, similar to BS 5950. It provides the limiting values for elements under axial compression and for sections with neutrals axis at the mid-depth; i.e., the section is under bending. For the case where member is subjected to both axial compression and bending, clear guidelines for sections with unequal flange are missing. In IS 800 the condition "Generally" for web of an I section, H section or Box section, which is implicitly for the sections subjected to both bending and axial compression, is governed by terms r_1 and r_2. However, the terms r_1 and r_2 are not defined clearly. It is to be noted that the EC3, BS5950 and IS 800 allows the use of Class 1and Class 2 sections for seismic design, whereas, AISC directs the use of only seismically compact section for seismic design [18]. Eurocode and AISC were compared and observed that the AISC offers more conservative values for seismically compact sections than the corresponding Class 1 sections of Eurocode [1]. Therefore, to highlight the differences in section classification procedure between codes, a detailed study is done by comparing EC3, AISC, BS 5950 and IS 800.

The objective of this paper is to identify the approach of each code towards cross section classification and its effect on the capacity of the section. Classifying a section wrongly can result in overestimating or underestimating the capacity of the section. Each code provides different elastic properties i.e. modulus of elasticity (E) and yield strength of steel (f_y), which governs the limits of section classification. Therefore, in order to use uniform value of E ($2 X 10^5$ N/mm^2) and f_y (250 N/mm^2), conversion coefficients for each code have been determined.

2. Cross-section classification in various codes

A section is an assembly of elements. EC3, BS 5950 and IS 800, uses the term "internal elements" and AISC uses the term "stiffened element" for the compression elements attached along the both longitudinal edges to other elements (i.e. web of I-section and flanges and web of box section). The term "outside elements or outstands" in EC3, BS 5950 and IS 800 and "unstiffened elements" of AISC is used for the compression elements attached along only one of the longitudinal edges to an adjacent element, the other edge being free to displace out of plane (i.e. flange overhang of an I-section, stem of T-section and legs of an angle section).

EC3, BS 5950 and IS 800 provide similar explanation for the four classes of cross section, but the limits for categorizing the sections are different. Class 1 (Plastic) sections are those which can develop plastic hinge i.e. the section will reach plastic moment (M_p) and undergo sufficient rotation before failure without buckling. Class 2 (Compact) sections are those which can develop their full plastic moment (M_p) but with limited rotational capacity i.e. inadequate plastic hinge rotation for formation of plastic mechanism. In class 2 sections, the local buckling prevents the section to undergo required rotation. Class 3 (Semi-compact) sections are those in which the stress in the extreme fibers can reach yield stress; however, the local buckling will prevent the section to reach full-plastic moment capacity (M_p). Such sections can develop merely yield moment (M_y). Class 4 (Slender) sections are those in which local buckling prevents the section from attaining the yield stress, i.e. the section will buckle in the elastic range. However, the AISC-360 and AISC-341 has different nomenclature to these classes, but the explanations are relatively similar. The definition of seismically compact, compact, non-compact and slender-element section is similar to that of class 1, class 2, class 3 and class 4, respectively; however, specific level of rotation capacity limits has been assigned to the first three classes. Seismically compact sections are used for the seismic load resisting system (SLRS) that require high levels of inelasticity. The seismically compact sections shall be capable of achieving a minimum inelastic deformations ductility of 4 (Hamburger *et al.* 2009). Compact sections are expected to achieve the full plastic section capacity. They are capable of developing a fully plastic stress distribution and possessing a rotation capacity of approximately three before local buckling starts. Non-compact section can achieve the yield stress in its compression elements without local buckling, but cannot achieve a rotation capacity of three. In slender-element sections the local buckling will occur in the elastic range.

3. Comparison of Section Classification in Various Codes

Different limits on width to thickness ratios are adopted for cross section classification by different codes. The values of limits on width to thickness ratios are defined in terms of a constant (ε). The ε values in EC3 is $\sqrt{\frac{235}{f_y}}$, in BS5950 is $\sqrt{\frac{275}{p_y}}$ (where p_y is the yield stress of steel defined in MPa), and in IS 800 is $\sqrt{\frac{250}{f_y}}$. In AISC the limits on width to thickness ratios is given in terms of $\sqrt{\frac{E}{f_y}}$. Different codes uses different values of yield stress (f_y), therefore, for comparison purpose the constant (ε) is converted in terms of $\sqrt{\frac{250}{f_y}}$ as per Indian code.

In EC3: $$\sqrt{\frac{235}{f_y}} = 0.97\sqrt{\frac{250}{f_y}} = 0.97\varepsilon \quad (1)$$

In AISC: $$\sqrt{\frac{E}{f_y}} = 28.3\sqrt{\frac{250}{f_y}} = 28.3\varepsilon \quad (2)$$

In BS 5950: $$\sqrt{\frac{275}{f_y}} = 1.04\sqrt{\frac{250}{f_y}} = 1.04\varepsilon \quad (3)$$

Table-1. Modified limits on width to thickness ratio for section classification by different codes

Codes	Classification	Flanges		Web	
		Axial Compression	Flexural Compression	Axial Compression	Flexural Compression
		b/t_f	b/t_f	d/t_w	d/t_w
IS 800	Class 1	9.40 ε		-	84.00 ε
	Class 2	10.50 ε		-	105.00 ε
	Class 3	15.70 ε		42.00 ε	126.00 ε
EC3	Class 1	8.73 ε	8.73 ε	31.99 ε	69.81 ε
	Class 2	9.70 ε	9.70 ε	36.84 ε	80.47 ε
	Class 3	13.57 ε	13.57 ε	40.72 ε	120.22 ε
AISC	Seismically Compact (Class 1)	8.49 ε	8.49 ε	-	69.30 ε
	Compact (Class 2)	-	10.75 ε	-	106.07 ε
	Non-Compact (Class 3)	*15.84 ε	28.28 ε	42.14 ε	161.22 ε
BS 5950	Class 1	9.44 ε		-	83.90 ε
	Class 2	10.49 ε		-	104.88 ε
	Class 3	15.73 ε		41.95 ε	125.86 ε

The modified values of limits on width to thickness ratios based Eqs. (1) -(3) for class 1, class 2 and class 3 sections are shown in Table-1. To have a clear idea of section classification limits in different codes, bar diagrams for four conditions of elements i.e. flange under flexure, web under flexure, flange under axial compression and web under axial compression based on Table-1 has been shown in Fig. 1 to 6. For uniformity, the seismically compact, compact and non-compact sections of AISC have been designated as class 1, class 2 and class 3 sections. The class 4 (slender) section has been excluded from discussion.

The limits on width to depth ratios for flanges under flexure is same as the limits for flange under axial compression in IS 800, EC3, BS 5950 and seismically compact section of AISC, however, the limiting values are different among these codes. For flange under axial compression AISC distinguishes the sections in two groups i.e. non-slender and slender sections, therefore, the same limit on width to thickness ratio for non-slender sections has been used for compact and non-compact sections as shown in Table-1. For flange of class 1 section, AISC provide most stringent criteria followed by EC3, IS 800 and BS 5950. The limit in BS 5950 is approximately 11% higher than AISC. For flange of class 2 section EC3 provides most stringent criteria. As discussed above for flange under compression, AISC provide limit of 15.84ε for non-slender section which seems to be significantly higher for class 2 sections and therefore, this limit has been considered in class 3 sections for comparison with other codes. For flanges under flexure,

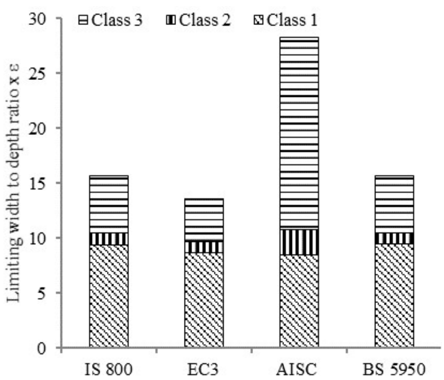

Fig. 1. Classification of flange under flexure

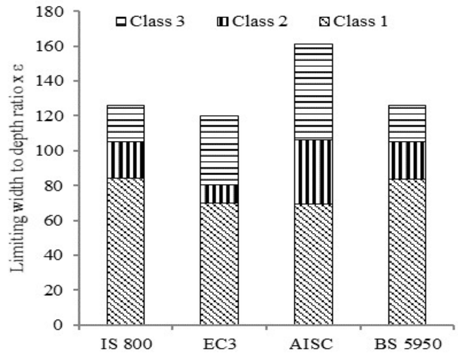

Fig. 2. Classification of web under flexure

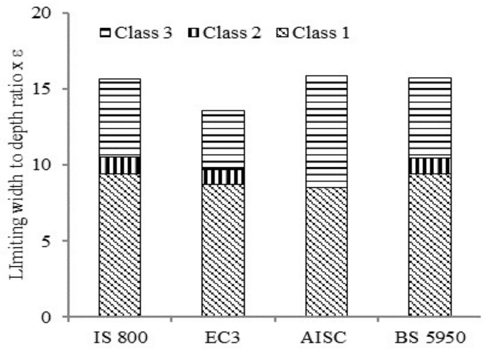

Fig. 3. Classification of flange under axial compression

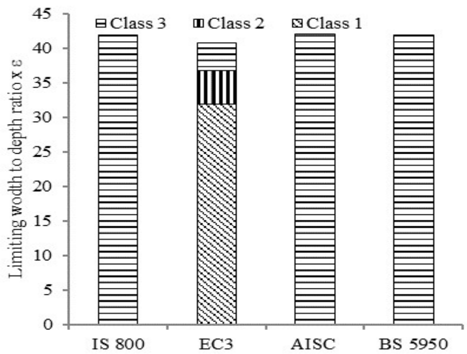

Fig. 4. Classification of web under axial compression

AISC provides less conservative values compared to other codes. Furthermore, for class 3 sections EC3 limits are more stringent. For flange under flexure the limit of AISC class 3 section is 2.1 times higher than EC3. Similar observation has also been reported by Topkaya and Sahin [18].

For web under axial compression, only EC3 provides the limit for class 1, class 2 and class 3 sections, whereas, IS 800, AISC and BS 5950 provide limit for class 3 sections only. Moreover, in all codes the limits of class 3 sections for web under axial compression are similar. For web under flexural compression the limits for class 1 section is similar in EC3 and AISC, whereas, the limits given by IS 800 and BS 5950 is similar.

However, the limits of IS 800 is 21% higher than EC3. The much intriguing fact is the difference in limiting value given for class 2 sections in EC3 and the other codes. The limiting value, EC3 for class 2 section is lesser than the limit of class 1 section of IS 800 and BS 5950. This means that, the section which is considered as class 1 by IS 800 or BS

5950 shall have the chances to be a class 3 section by limits given in EC3. For example, if the section's width to thickness ratio is from 80.5-83.9; it'll be class 1 section by IS 800 and BS 5950, a class 2 section by AISC but a class 3 section by EC3.

In this way, the considered moment capacity of the section will be lesser in case of EC3 since only yielding in extreme fiber is expected from class 3 sections but plastic moment capacity is expected from class 1 and class 2 sections. AISC provides significantly higher limit than the other three codes for class 3 sections.

As discussed above, different codes provide different limits for section classification. To highlight the difference among the considered four codes, standard rolled I-sections provided in the Handbook for Structural Engineers SP 6(1):1964 have been examined for flexural compression.

A total of 65 sections have been considered for classification as shown in Fig. 5. The classification is done only under consideration of flexural action. Total of 65 standard sections are available which are classified by four different codes.

4. Sections with elements of different classes

Each code gives distinct explanation when elements in same section fall under different cross section classification. According to IS 800, if different elements of a cross-section fall under different classes, the section shall be classified considering the most critical element. According to EC3, a cross-section is normally classified according to the lowest class of elements; however, it allows considering a higher section class for some exceptions. For example, if the cross-sections have a Class 3 web and Class 1 or 2 flanges, then the section may be classified as class 2 by considering an effective web area. Similarly, if the web is considered to resist shear forces only and is assumed not to contribute to the bending and normal force resistance of the cross section, the section may be designed as Class 2, 3 or 4 sections, depending only on the class of the flange. AISC gives different sets of formulas for different cases such as, doubly symmetric I-shaped members with compact webs and non-compact or slender flanges bent about their major axis, other I-shaped members with compact or non-compact webs bent about their major axis, doubly symmetric and singly symmetric I-shaped members with slender webs bent about their major axis. Thus in each case, limit states are set according to the yielding and buckling criteria.

For instance, if the case of the compact flange and non-compact web is taken, the limit states are as 1) compression flange yielding, 2) lateral torsional buckling, 3) compression flange buckling, and 4) tension flange yielding. BS 5950 indicates that if elements of a section lie in different classes, the section shall be classified based on least favourable section, however, it provides formula to calculate effective plastic moduli if compression flange and web are of different class.

In order to indicate the difference in design moment capacity calculated using different codes (with respective safety factors), sections with elements of same class and sections with elements of different classes has been considered. First section, designated as section 1, with elements of class 1 (total depth 400 mm, flange width 140 mm, flange thickness 16 mm and web thickness 8.9 mm)

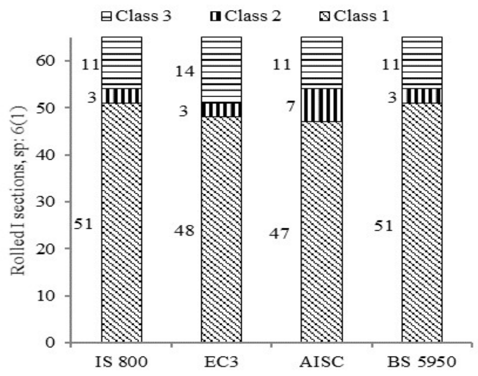

Fig. 5. Section classification of standard rolled I sections of SP: 6(1) by different codes

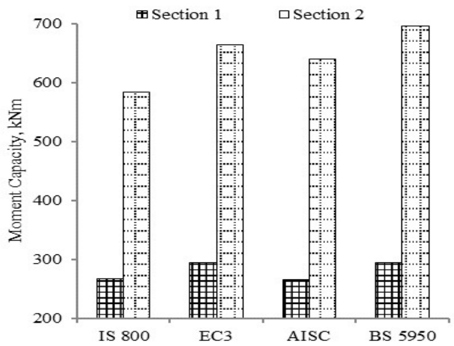

Fig. 6. Comparison of design moment capacity by different codes.

provides minimum design moment capacity of 264 kNm by AISC and maximum design moment capacity of 294 kNm by EC3 and BS 5950, with difference of 11% as shown in Fig. 6. Second section, designated section 2, with flange of class 1 and web of class 3 (total depth 700 mm, flange width 200 mm, flange thickness 16 mm, and web thickness 6 mm) provides minimum design moment capacity of 582 kNm by IS 800 and maximum of design moment capacity of 695 kNm by BS 5950, with a difference of approximatly 20%. By comparing the difference in design moment capacities for the section 1 and 2, it can be said that variation is significant for the section with elements of different classes.

5. Conclusion

Amongst the four codes compared in this paper, it has been observed that seismically compact section (class 1) of AISC provides the most stringent limits on width to thickness ratio. For other classes i.e. class 2 and class 3 limits provided by EC3 are the most stringent. For class 3 sections (non-compact) the limits provided by AISC are significantly higher than other three codes. For web under axial compression, EC3 provide limits for all the three classes, whereas, other three codes provide limit for only class 3 sections. Since, different codes provide different range of limits for section classification, there are possibilities that a section can be designated as class 1 in one code and class 3 in other code. Consensus on the classification procedure for sections having elements of different classes amongst different code has not been observed. In IS 800 the section class is defined based on the lowest class of elements, whereas, in other codes different approaches are suggested to design sections with element of different classes. This leads to significant variation in design moment capacities calculated by different codes.

Disclosures

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List of Notations

b	: Width of the flange
b/t_f	: Width to thickness ratio of flange
d	: Web depth
d/t_w	: Width to thickness ratio of web
E	: Modulus of elasticity of steel
f_y	: Yield strength of the material
M_p	: Plastic bending moment
M_y	: Yield moment
t_f	: Thickness of the flange
t_w	: Thickness of the web.