Revised Indian Code for Structural Steel Design in India

Abstract

The Indian code for structural steel design (IS 800) was revised in 2007 after a gap of 23 years. The paper describes the salient aspects of the revised code. The previous code was following the working stress method (WSM) whereas the revised code is based on the Limit State Method (LSM). The revised code was drafted incorporating the knowledge gained about the behaviour of members and systems over the years. Original research was carried out to arrive at suitable provisions, where required. The new code addresses the phenomena of shear lag in tension members and block shear failure in their connections. It tackles the effect of initial imperfections and residual stresses in compression members by advocating the use of multiple column strength curves. The flexural-torsional buckling of angle struts connected by one leg is taken care of by an equivalent slenderness approach. Provisions for the design of bearing type as well as friction type bolted and welded connections are also given. The use of semi-rigid connections is encouraged by guidelines to calculate the behaviour of standard beam-to-column connections. New sections on durability, fire resistance, fatigue and earthquake resistant design are detailing have been introduced and are briefly reviewed. The response of the industry to the new code is also looked into.

Keywords: Steel Design, Code, Shear Lag, Flexural-torsional Buckling, Industry response

1. Introduction

The fundamental objective of all codes on design and construction of structures is to ensure a basic minimum level of safety and serviceability. To achieve this, codes stipulate design criteria which need to be satisfied unless more rigorous analysis is carried out to ensure the safety and serviceability levels. The design criteria are usually expressed in simple terms to ensure applicability in a wide variety of situations and to facilitate faster design calculations. However, such an approach takes its toll on both reliability and economy of design. To achieve more economical designs without compromising reliability and safety, modern codes have been stipulating more complicated and consequently more cumbersome design criteria taking advantage of the increase in the analysis capabilities of computers and associated software. These criteria reflect the knowledge gained by research and experimentation, which can be utilized to achieve economical designs. However, the code writers' foremost worry is to see how the profession, which has been trained and habituated to carry out designs in a particular manner, will receive the revised criteria and so changes are usually introduced in a gradual fashion. This paper, takes a critical review of the recently revised Indian Code of practice for "General Construction" in Steel (IS 800) in the light of the above discussion.

2. State of Structural Designs Practice in India

The general state of structural design practice in India has lagged behind that in several developed countries due to various reasons. A primary reason for this is extremely infrequent revision of the codes in recent years. Some of the important codes such as the Loading standards (IS 875), Seismic loading Standard (IS 1893), Code for Reinforced Concrete Design (IS 456) and Code for Structural Steel Design (IS 800) have been revised after a period of 20 years. During this period, a lot of changes have taken place in the demand and supply of materials, availability of new materials and structural systems, increased data on loads and performance of structures and the over all economy of the country. Several devastating earthquakes have occurred in India highlighting the inadequacy of structural designs to cater to seismic loads. Several structural failures have occurred due to wind, cyclic loading (fatigue), corrosion and fire, highlighting the importance of these aspects in design.

Although Limit State Method (LSM) was introduced in the Code for the design of reinforced concrete structures (IS 456) way back in 1978, the code for steel design when revised in 1984 retained the working stress method (WSM). This was probably because the option for plastic analysis and design was available for the design of steel frames. The design criteria as per WSM were simple but designers had to refer to other codes for welding, bolt design etc. Also while designing steel-concrete composite structures, there was confusion right from the load calculation as steel was designed by WSM and concrete by LSM. Thus, there was a long-felt and urgent need to revise the code for steel design (IS 800).

3. General Aspects of the Revised Steel Code

In this section, the general aspects of the revised code are highlighted and the deliberations that took place and the consensus reached in the committee meetings on these aspects are described. One of the serious challenges faced by the committee was that it had no control over the other codes, which had a direct and rather profound bearing on the design of steel structures. Some of the codes had just been revised based on the provisions of the current (1984) version of the steel code while the revision of other codes was long pending but uncertain in the near future. So a bold decision was taken to revise and include criteria, which were otherwise outside the purview of a code on steel design.

In limit state design, the foremost criteria in design are the values of partial safety factors for loads and materials. These had a direct bearing on the reliability of the design. Since loads were independent of the material and type of structure, the load factors specified for reinforced concrete should logically be used for steel design also. The only problem was that they did not truly reflect the uncertainties associated with the various types of loads. For example, the load factor for dead load, which can be calculated more reliably, was the same as that for live load. However, after several comparative studies between steel designs by WSM and LSM and taking into account the convenience in hand calculations, it was decided to adopt them for steel design. With these, the only deviation in the WSM and LSM designs were noticed for very high ratios of wind load to live loads, in which case LSM designs turned out to be somewhat heavier. The reason for this was that in WSM there was a relaxation of the allowable stress by $33^1/_3$ % which could not be justified in LSM. The partial safety factors for load specified in the revised code are given in Table 1.

The Gujarat earthquake of January 26, 2001 revealed a lack of integrity between structural members and frames leading to collapse of a portion of a building or total crumbling of multi-storey buildings. This coupled with other threats such as accidents and terrorist attacks underscored the need for robustness of structures. Therefore, a new load called accidental load was defined but its evaluation was left to the collective decision of the owner, architect and structural designers on a case-to-case basis. Also, the requirement to build integrity and redundancy in to the structural system as in other codes such as BS 5950 (2000) was included.

The value for partial safety factor for yield strength of steel γ_{mo} was proposed as 1.15 in the steel-concrete composite construction code (IS 11384). However, in view of the increased quality control procedures adopted by the Indian steel industry in recent year, it was decided to reduce this to 1.10. Further reductions may be possible only if statistical data on steel strengths produced by all the major manufacturers becomes available. However, the partial safety factor for ultimate strength of steel γ_{m1} is kept as 1.25 due to the larger variability of this strength.

The advent and popularity of cold-formed sections and pre-engineered buildings underlined the progress made in design and corrosion protection of thin-walled sections. Therefore, it was decided to lift the limitation on width-to-thickness ratios of hot-rolled sections and allow the full spectrum of sections. To preclude premature local buckling, a section classification based on width-to-thickness ratios was introduced and accordingly four classes of sections namely, plastic, compact, semi-compact and slender were defined.

Table 1 Partial safety factors for loads, γ_f, for limit state design

Combination	***Limit State of Strength***					***Limit state of Serviceability***			
	DL	***LL[b]***		***WL/ EL***	***AL***	***DL***	***LL***		***WL/ EL***
		Leading	*Accom panying*				*Leading*	*Accom panying*	
DL+LL+CL	*1.5*	*1.5*	*1.05*	—	—	*1.0*	*1.0*	*1.0*	—
DL+LL+CL+ WL/EL	*1.2* *1.2*	*1.2* *1.2*	*1.05* *0.53*	*0.6* *1.2*	—	*1.0*	*0.8*	*0.8*	*0.8*
DL+WL/EL	*1.5 (0.9)[a]*	—	—	*1.5*	—	*1.0*	—	—	*1.0*
DL+ER	*1.2[a] (0.9)*	*1.2*	—	—	—	—	—	—	—
DL+LL+AL	*1.0*	*0.35*	*0.35*	—	*1.0*	—	—	—	—

[a] This value is to be considered when the dead load contributes to stability against overturning is critical or the dead load causes reduction in stress due to other loads.

[b] When action of different live loads is simultaneously considered, the leading live load is whichever one causes the higher load effects in the member/section.

Abbreviations: DL= Dead Load, LL= Imposed Load (Live Loads), WL= Wind Load,

SL= Snow Load, CL= Crane Load (Vertical/horizontal), AL=Accidental Load,

ER= Erection Load, EL= Earthquake Load.

To make the code comprehensive and complete, values of design stresses for bolts and welds were also included. New sections on durability, fire protection, fatigue and earthquake resistance were added. These are explained in more detail in the next section.

4. Specific aspects of revised steel code

The design criteria for tension members include yielding of gross section and rupture of net section. Thus, both yield and ultimate stresses will be required for design. In particular, the rupture strength of angles connected by one leg is affected by shear lag. This phenomenon was studied in detail by using the finite element method and based on this study, equations were proposed to calculate the strength. The equations were a bit complicated for design as they try to predict the shear lag effects accurately and so a simplified expression is also provided for preliminary sizing of the angle section. In addition, failure by block shear is possible and the equations specified are based on the AISC (1999) code.

4.1 Design strength of angle members in tension

The rupture strength of an angle connected through one leg is affected by shear lag. The design strength, $T_{dn,}$ as governed by rupture at net section is given by:

$$T_{dn} = 0.9\, A_{nc}\, f_u / \gamma_{m1} + \beta\, A_{go}\, f_y / \gamma_{m0} \qquad (1)$$

where the shear lag coefficient β is given by:

$$\beta = 1.4 - 0.076\ (w/t)\ (f_y/f_u)\ (b_s/L_c) \le (f_u\gamma_{m0}/f_y\gamma_{m1}) \text{ and } \beta \ge 0.7 \qquad (2)$$

Where, L_c is the length of the end connection, i.e., distance between the outermost bolts in the end joint measured along the length direction or length of the weld along the length direction; A_{nc} is the net area of the connected leg; A_{go} is gross area of the outstanding leg; t is the thickness of the angle and and w and b_s are as shown in Fig. 1;

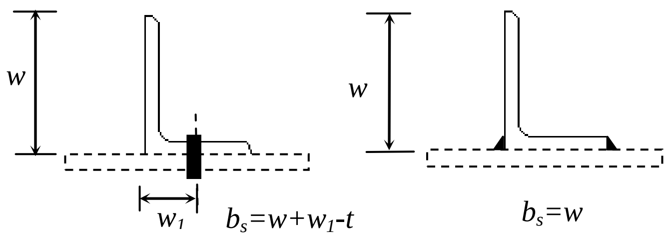


Fig. 1 Angle end connections

Alternatively, the rupture strength of net section may be taken as

$$T_{dn} = \alpha\, A_n\, f_u / \gamma_{m1} \qquad (3)$$

Where, α = 0.6 for one or two bolts, 0.7 for three bolts and 0.8 for four or more bolts along the length in the end connection or equivalent weld length; A_n = net area of the total cross section.

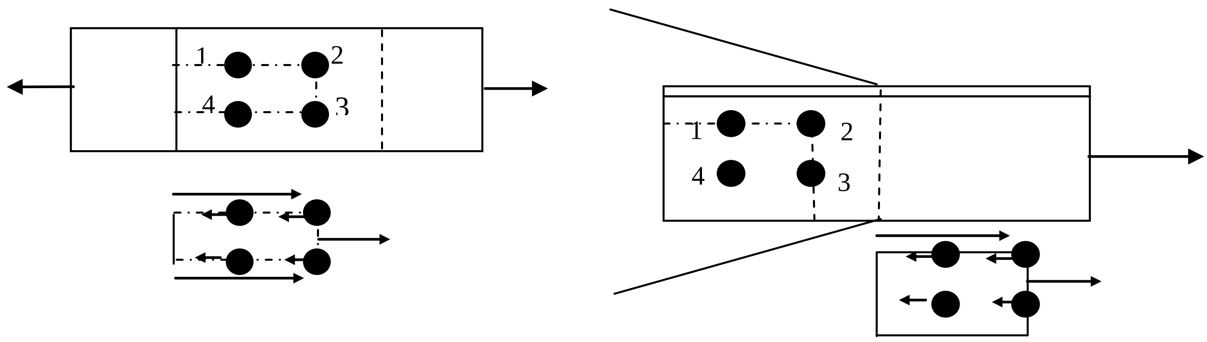
The block shear strength, $T_{db,}$ of a bolted connection is given as the smaller of:

$$T_{db} = (A_{vg}\ f_y / (\sqrt{3}\ \gamma_{m0}) + 0.9 A_{tn}\, f_u / \gamma_{m1}) \qquad (4)$$

or

$$T_{db} = (0.9 A_{vn}\ f_u / (\sqrt{3}\ \gamma_{m1}) + A_{tg}\ f_y / \gamma_{m0}) \qquad (5)$$

Where, $A_{vg,}$ and A_{vn} are the minimum gross and net area in shear along bolt line parallel to external force, respectively (1-2 and 3–4 as shown in Fig. 2(a) and 1-2 as shown in Fig. 2(b); $A_{tg,}$ and A_{tn} are the minimum gross and net area in tension from the bolt hole to the toe of the angle, end bolt line, perpendicular to the line of force, respectively (2-3 as shown in Fig. 2(a) and Fig. 2(b) and $f_{u,}$ and f_y are the ultimate and yield stress of the material, respectively.



(a) (b)

Fig. 2 Block shear failure of (a) Plates and (b) angles

4.2 Design strength of members in compression

The design criteria for compression members are based on multiple column strength curves accounting for initial imperfections and residual stresses. Four curves are specified as in Eurocode 3, which was found to best predict available test results. It was realized that, angle compression members are invariably connected through one leg and so are susceptible to flexural-torsional buckling. Therefore, a detailed finite element analysis study was carried out to establish an equivalent slenderness ratio which can be used to get an accurate estimation of the failure load. Laced and Battened columns are still popular in India owing to the low fabrication costs and so guidelines for their design have been retained.

The flexural-torsional buckling strength of single angle loaded in compression through one of its legs may be evaluated using the equivalent slenderness ratio, $\lambda_{e,}$ as given below

$$\lambda_e = \sqrt{k_1 + k_2\lambda_{vv}^2 + k_3\lambda_\phi^2} \tag{6}$$

Where, k_1, k_2, k_3 are constants depending upon the end condition, as given in Table 2 and,

$$\lambda_{vv} = \frac{\left(\dfrac{l}{r_{vv}}\right)}{\varepsilon\sqrt{\dfrac{\pi^2 E}{250}}} \quad \text{and} \quad \lambda_\phi = \frac{(b_1 + b_2)}{\varepsilon\sqrt{\dfrac{\pi^2 E}{250}} \times 2t} \tag{7}$$

where, l is the centre to centre length of the supporting member; r_{vv} is the least radius of gyration about the minor axis; b_1, b_2 are the width of the two legs of the angle; t is the thickness of the angle and ε is the yield stress ratio $\sqrt{(250/f_y)}$.

4.3 Design strength of members in bending

The design criteria for beams and plate girders are concerned with the possibility of using slender webs to achieve economy. Thus, checks to verify web buckling and web crippling at the supports have been introduced. In the case of plate girders, the possibility of using tension-field action as well as an overhang at the support to anchor it, are highlighted. Equations are given to calculate the post-buckling strength of webs and the anchor forces. Laterally unsupported beams are dealt in a manner analogous to the compression member design.

The design criteria for beam-columns subjected to axial compression and bending consists of two separate checks for strength and stability. A reduction in the bending capacity in beams subjected to high shear is also proposed.

Table 2 Constants k_1, k_2 and k_3

No. of bolts at the each end connection	*Gusset/Connecting member Fixity*[†]	k_1	k_2	k_3
≥ 2	*Fixed*	*0.20*	*0.35*	*20*
	Hinged	*0.70*	*0.60*	*5*
1	*Fixed*	*0.75*	*0.35*	*20*
	Hinged	*1.25*	*0.50*	*60*

[†] *Stiffeness of in-plane rotational restraint provided to the gusset/connecting member. For partial restraint, the λ_e can be interpolated between the λ_e results for fixed and hinged cases.*

4.4 Design strength of connections

Connections form part-and-parcel of a structure and also play a role in member design. Connections consist of rivets, bolts or welds and associated elements such as gusset plates. However, rivets are not being used anymore in India and so the code gives guidelines only for bolted and welded connections. Both bearing and friction grip types bolts are considered. Effects of long joints, large grip lengths and prying forces in end-plate connections can be accounted for using the proposed guidelines. The possibility of using semi-rigid connections has been emphasized and guidelines for classification and modeling of such connections are given in an appendix.

4.5 Other new considerations in Design

Although the serviceability limit states of durability and fire resistance have long been recognized, it has been a general practice not to design for these limit states. However, the revised code requires that the structure be designed for these limit states explicitly. Some guidelines are given in the code to carry out the design. It is hoped that these will kindle interest among designers to pay attention to these aspects and learn more about the topics. With reference to durability, five levels of exposure are defined and for each level, the details of the coating system to be adopted are specified for a desired life in years.

Fire engineering is also a specialized topic and there are other codes dealing with various aspects of fire protection. Therefore the revised code gives only some definitions and describes the variation of yield strength and Young's modulus with temperature. The design criterion is that the period of structural adequacy should be greater than or equal to the fire resistance level. Methods of satisfying this criterion either by test or calculation are explained.

Structural members in industrial structures and severe wind zones may experience fatigue under cyclic loading. An entire section in the code is devoted to this topic. Starting with basic definitions, various detail categories are described and the S-N curves are given to enable design for fatigue.

The Northridge earthquake of 1994 and the Kobe earthquake of 1995 underscored the need for designing and detailing steel structures to prevent failure by local buckling and brittle crack propagation. To ensure good performance under earthquake loading, an entire section has been added in the revised code. The provisions are based on capacity design principles and consist of general guidelines for members and connections as well as specific guidelines for frame topologies. Only concentric diagonal or cross braced frames and moment resisting frames are covered.

5. Summary and Conclusions

An overview of the revised code of practice for steel construction was given. The code is based on the limit state method and incorporates significant changes compared to its previous version. Considerable comparative studies on provisions in other codes were carried out and where required, original research was done as in the case of angles in tension and compression, to arrive at suitable provisions. New topics have been introduced on durability, fire resistance, fatigue and earthquake resistant design. These have been kept concise and simple and can be expanded in future versions.

Although the code is giving equations to accurately predict member strengths under complex stress and instability conditions, the equations are difficult to use in routine design. Hence, the industry has not received the code favourably. However, with the availability of design handbooks and spread sheets is likely to offset this attitude to a certain extent. More importantly, it is hoped that the understanding of the concepts and their implications in design can better impress the importance of evaluating them.

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