



**Fourth
Edition**

DESIGN OF
Steel
Structures

**By Limit State Method as Per
IS: 800-2007**

S.S. Bhavikatti



DESIGN OF STEEL STRUCTURES

By Limit State Method as Per IS 800-2007

FOURTH EDITION

S.S. Bhavikatti

Emeritus Professor
Department of Civil Engineering
BVBCET
Hubli-580031
Karnataka



I.K. International Publishing House Pvt. Ltd.

NEW DELHI

Published by

I.K. International Publishing House Pvt. Ltd.
S-25, Green Park Extension
Uphaar Cinema Market
New Delhi-110 016 (India)
E-mail: info@ikinternational.com
Website: www.ikbooks.com

ISBN 978-93-82332-94-7

© 2014 I.K. International Publishing House Pvt. Ltd.

Reprint 2015

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or any means: electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission from the publisher.

Published by Krishan Makhijani for I.K. International Publishing House Pvt. Ltd., S-25, Green Park Extension, Uphaar Cinema Market, New Delhi-110 016 and Printed by Rekha Printers Pvt. Ltd., Okhla Industrial Area, Phase II, New Delhi-110 020.

DESIGN OF STEEL STRUCTURES

By Limit State Method as Per IS 800-2007

PREFACE TO THE FOURTH EDITION

The author thanks the readers, specially Prof. K.V. Pramod of SDMCET, Dharwad and Dr. Ravindra R of R.V. College, Bangalore for their suggestions. Numerical mistakes and print mistakes have been corrected and Fig. 12.5 has been improved.

The author welcomes suggestions for further improvement.

S.S. Bhavikatti

PREFACE TO THE FIRST EDITION

Design of steel structure is an important subject for all civil engineering students. So far working stress method was used for the design. Now-a-days whole world is changing over to limit state method since it is more rational. Hence the Indian code for steel design IS:800 has been revised in the year 2007. With an intention of providing a good textbook for civil engineering students, I have brought out this book. Hope that all universities in India will switch over to limit state method and the students will find this as a good textbook.

A sincere effort has been made in this book to present design procedure using simple language, neat sketches and systematically solved problems. Suggestions for improvements are most welcome.

I thank Bureau of Indian Standard for permitting to use some of the tables and India map showing wind load zones.

I also acknowledge AICTE for giving me an opportunity to associate with BVB College of Engineering and Technology, Hubli.

I am also thankful to the encouragement received from teachers and students from all over India for my earlier books. The keen interest and neat work of the publisher deserves special thanks.

S.S. Bhavikatti

ACKNOWLEDGEMENTS

“**Tables**, 2.1, 2.2, 2.3, 3.1, 5.1, 6.1, 6.2, 6.4(a), 6.4(b), 6.4(c), 6.4(d), 7.1, 7.2, 7.3, 7.4(a), 7.4(b), 7.5, 7.6, 12.1, 12.2, 12.3 on **Pages**: 30, 31, 32, 83, 135, 150, 153, 156, 157, 158, 159, 203, 211, 227, 228, 229, 230, 231, 369, 370, 374, and **Figures**, 12.5, 12.6, 12.7, 12.8 on **Pages**: 368, 371, 372 of this publication have been reproduced, with permission of BIS from IS 800:2007 and IS 875 (Part-3) 1987, to which reference is invited for further details. It is desirable that for more complete details reference be made only to the latest version of this standard which is available from Bureau of Indian Standard, Manak Bhawan, New Delhi.”

CONTENTS

<i>Preface to the fourth edition</i>	v
<i>Preface to the first edition</i>	vi
<i>Acknowledgements</i>	vii
1. Introduction	1
1.1 Common Steel Structures	1
1.2 Advantages and Disadvantages of Steel Structures	1
1.3 Types of Steel	2
1.4 Properties of Structural Steel	3
1.5 Rolled Steel Sections	4
1.6 Special Considerations in Steel Design	9
1.7 Loads	11
1.8 Load Combinations	20
1.9 Structural Analysis	20
1.10 Design Philosophy	21
2. Principles of Limit State Design	27
2.1 Design Requirements	27
2.2 Limit States	28
2.3 Actions (Loads)	29
2.4 Design Strength	30
2.5 Deflection Limits	30
2.6 Other Serviceability Limits	31
2.7 Stability Checks	33
3. Bolted Connections	35
3.1 Riveted Connection	35
3.2 Bolted Connections	36
3.3 Classification of Bolts Based on Type of Load Transfer	38
3.4 Advantages and Disadvantages of Bolted Connections	38
3.5 Terminology	39
3.6 IS 800-2007 Specifications for Spacing and Edge Distances of Bolt Holes	40

3.7	Types of Bolted Connections	42
3.8	Types of Actions on Fasteners	43
3.9	Assumptions in Design of Bearing Bolts	43
3.10	Principles Observed in the Design	45
3.11	Design Tensile strength of Plates in a Joint	45
3.12	Design Strength of Bearing Bolts	47
3.13	Design Procedure with Bearing Type Bolts Subject to Shearing Forces	50
3.14	Efficiency of a Joint	50
3.15	Eccentric Connection with Bearing Bolts when Load is in the Plane of Group of Bolts	66
3.16	Design of Bearing Bolts Subjected to Eccentric Loading in the Plane of Bolts	71
3.17	Tension Capacity of Bolts	75
3.18	Design Criteria for Bolt Subjected to Combined Shear and Tension	76
3.19	Design of Bearing Bolts Subjected to Eccentric Loading Causing Moment in the Plane Perpendicular to the Plane of Group of Bolts	77
3.20	Shear Capacity of HSFG Bolts	82
3.21	Tension Resistance of HSFG Bolts	85
3.22	Interaction Formula for Combined Shear and Tension	85
3.23	Prying Forces	86
4.	Welded Connections	95
4.1	Advantages and Disadvantages of Welded Connections	95
4.2	Types of Welded Joints	96
4.3	Important Specifications for Welding	98
4.4	Design Stresses in Welds	100
4.5	Reduction in Design Stresses for Long Joints	101
4.6	Eccentric Connection – Plane of Moment and the Plane of Welds is the Same	108
4.7	Combined Axial and Shear Stress	115
4.8	Eccentric Connection–Moment at Right Angles to the Plane of Weld	115
5.	Design of Tension Members	121
5.1	Design Strength of a Tension Member	122
5.2	Design Procedure	134
5.3	Tension Member Splice	140
5.4	Lug Angles	143
6.	Design of Compression Members	149
6.1	Buckling Class of Cross-Section	149
6.2	Slenderness Ratio	151
6.3	Design Compressive Stress and Strength	152
6.4	IS Tables for Design Stress	155
6.5	Shapes of Compression Members	160

6.6	Design of Compression Members	165
6.7	Laced and Battened Columns	168
6.8	Design of Laced Columns	169
6.9	Design of Battened Columns	174
6.10	Column Splice	177
6.11	Design of Column Splices	178
6.12	Column Bases	184
6.13	Design of Slab Base	185
6.14	Design of Gusseted Base	189
7.	Design of Beams	195
7.1	Plastic Moment Carrying Capacity of a Section	195
7.2	Classification of Cross-Sections	202
7.3	Design Procedure	204
7.4	Bending Strength of a Laterally Supported Beam	204
7.5	Shear Strength of a Laterally Supported Beam	205
7.6	Deflection Limits	206
7.7	Web Buckling Strength	214
7.8	Web Crippling	215
7.9	Design of Built up Section	220
7.10	Design Strength of Laterally Unsupported Beams	224
7.11	Effective Length for Lateral Torsional Buckling	229
7.12	Design of Laterally Unsupported Beams	233
7.13	Design of Purlins	233
7.14	Design Procedure	235
7.15	Simplified Method for the Design of Angle Purlins	245
7.16	Design of Grillage Beams	247
8.	Design of Bolted Beam Connections	257
8.1	Types of Beam Connections	257
8.2	Design of Framed Connections Using Bolt	260
8.3	Design of Unstiffened Seated Connections	263
8.4	Design of Stiffened Seated Connection	268
8.5	Design of Small Moment Resistant Connections	272
8.6	Design of Large Moment Connections	277
9.	Design of Welded Beam Connections	287
9.1	Framed Connections	287
9.2	Welded Unstiffened Seat Connection	295
9.3	Stiffened Welded Seat Connections	298
9.4	Moment Resistant Welded Connections	301

10. Design of Plate Girders	305
10.1 Elements of Plate Girders	306
10.2 Self Weight of Plate Girder	307
10.3 Economical Depth	307
10.4 Size of Flanges	311
10.5 Shear Buckling Resistance of Web	311
10.6 End Panel Design	313
10.7 Anchor Forces	315
10.8 Design of Connection Between Flange and Web Plates	316
10.9 Design of Bearing Stiffeners	316
10.10 Weld for End Stiffeners	319
10.11 Design of Intermediate Stiffeners	319
10.12 Connection of Intermediate Stiffeners to Web	320
10.13 Procedure of Design of Plate Girder	321
10.14 Summary	341
11. Design of Gantry Girders	343
11.1 Loads	343
11.2 Position of Moving Load for Maximum Effects	343
11.3 Profile of Gantry Girder	346
11.4 Limitation on Vertical Deflection	346
11.5 Design Procedure	347
12. Design of Roof Trusses	361
12.1 Bracings	362
12.2 Types of Roof Trusses	362
12.3 Nomenclature of Members of Trusses	363
12.4 Pitch of Trusses	364
12.5 Spacing of Trusses	364
12.6 Purlins	365
12.7 Sheetings	365
12.8 Loads	366
12.9 Load Combinations	375
12.10 Loads on Trusses	380
12.11 Analysis of Trusses	380
12.12 Grouping of Members	381
12.13 Design of Members	381
12.14 Design of Joints	381
12.15 End Bearing	382
Appendix	391
Index	405

1

INTRODUCTION

Design of a building consists of two parts viz. (i) functional design and (ii) structural design. The first part consists in planning the building to serve its requirements taking into account ventilation, lighting, aesthetic view etc. The structural design consists in proportioning various elements of the building such that loads acting on it are transferred safely to the ground and at the same time unnecessarily excess material is not used.

For transferring the loads to the ground various materials, like asbestos sheets, tiles, bricks, cement concrete, reinforced concrete, steel, aluminium are used. However, main body of the present-day structures consists of R.C.C or steel. In tall structures composite construction of steel and concrete is also commonly used.

1.1 COMMON STEEL STRUCTURES

Steel has high strength per unit mass. Hence it is used in constructing large column-free structures. The following are the common steel structures in use:

1. Roof trusses for factories, cinema halls, auditoriums etc.
2. Trussed bents, crane girders, columns etc., in industrial structures.
3. Roof trusses and columns to cover platforms in railway stations and bus stands.
4. Single layer or double layer domes for auditoriums, exhibition halls, indoor stadiums etc.
5. Plate girder and truss bridges for railways and roads.
6. Transmission towers for microwave and electric power.
7. Water tanks.
8. Chimneys etc.

1.2 ADVANTAGES AND DISADVANTAGES OF STEEL STRUCTURES

The advantages of steel over other materials for construction are:

1. It has high strength per unit mass. Hence even for large structures, the size of steel structural element is small, saving space in construction and improving aesthetic view.

2. It has assured quality and high durability.
3. Speed of construction is another important advantage of steel structure. Since standard sections of steel are available which can be prefabricated in the workshop/site, they may be kept ready by the time the site is ready and the structure erected as soon as the site is ready. Hence there is lot of saving in construction time.
4. Steel structures can be strengthened at any later time, if necessary. It needs just welding additional sections.
5. By using bolted connections, steel structures can be easily dismantled and transported to other sites quickly.
6. If joints are taken care, it is the best water and gas resistant structure. Hence can be used for making water tanks also.
7. Material is reusable.

The disadvantages of steel structures are:

1. It is susceptible to corrosion.
2. Maintenance cost is high, since it needs painting to prevent corrosion.
3. Steel members are costly.

1.3 TYPES OF STEEL

Steel is an alloy of iron and carbon. Apart from carbon by adding small percentage of manganese, sulphur, phosphorus, chrome nickel and copper special properties can be imparted to iron and a variety of steels can be produced. The effect of different chemical constituents on steel are generally as follows:

- (i) Increased quantity of carbon and manganese imparts higher tensile strength and yields properties but lower ductility, which is more difficult to weld.
- (ii) Increased sulphur and phosphorus beyond 0.06 percent imparts brittleness, affects weldability and fatigue strength.
- (iii) Chrome and nickel impart corrosion resistance property to steel. It improves resistance to high temperature also.
- (iv) Addition of a small quantity of copper also increases the resistance to corrosion.

By slightly varying chemical composition various types of steels are manufactured to be used as structural member, tubes, pipes, sheets, strips, reinforcements for R.C.C, rivets, bolts, nuts and for welding.

In this chapter mainly structural steels are discussed and their properties presented. The structural steel is the steel used for the manufacture of rolled steel sections. These rolled steel sections are used to form steel frameworks required in the structures.

Structural steel may be mainly classified as mild steel and high tensile steel.

Structural steel is also known as standard quality steel. Its requirements have been specified in IS 226-1975. This steel is also available in copper bearing quality in which case it is designated as Fe 410-Cu-S, where 410 refers to ultimate tensile strength of 410 Mpa ($= 410 \text{ N/mm}^2$).

This is also known as grade E250 steel in which 250 refers to 250 Mpa yield strength. E300 (Fe-440) and E-350 (Fe 490) steels are also manufactured.

In high tensile steel mechanical properties and resistance to corrosion are enhanced by alloying with small proportions of some other alloys or increasing the carbon content. Standards of high tensile steel are covered in IS 961-1975. Weldable quality steels which are recommended by IS 2007 are designated as E410 (Fe 540), E450 (Fe 570)D and E450 (Fe 590)E. As per IS 800-2007, the structural steel used in general construction, coming under the purview shall conform to IS 2062 i.e., to weldable quality steel.

Structural steel other than those specified under mild steel and high tensile steel conforming to weldable quality may also be used provided that the permissible stresses and other design provisions are suitably modified and the steel is also suitable for the type of fabrication adopted.

Steel (ordinary quality) that is not supported by mill test result may be permitted to be used for unimportant members, where their properties such as ductility and weldability do not affect the performance requirements of the structure as a whole.

In this book mild steel (structural steel-standard quality) and high tensile steel of weldable quality (conforming to IS 2062) are considered for the design.

1.4 PROPERTIES OF STRUCTURAL STEEL

The properties of steel required for engineering design may be classified as

- (i) Physical Properties
- (ii) Mechanical Properties.

(i) *Physical Properties:* Irrespective of its grade physical properties of steel may be taken as given below (clause 2.2.4 of IS 800-2007):

- (a) Unit mass of steel, $\rho = 7850 \text{ kg/m}^3$.
- (b) Modulus of elasticity, $E = 2.0 \times 10^5 \text{ N/mm}^2$.
- (c) Poisson's ratio, $\mu = 0.3$.
- (d) Modulus of rigidity, $G = 0.769 \times 10^5 \text{ N/mm}^2$.
- (e) Coefficient of thermal expansion, $\alpha_t = 12 \times 10^{-6}/^\circ\text{C}$.

(ii) *Mechanical Properties:* The following are the important mechanical properties in the design:

- (a) Yield stress f_y .
- (b) The tensile or ultimate stress f_u .

- (c) The maximum percentage elongation on a standard gauge length and
- (d) Notch toughness.

Except for notch toughness, the other properties are determined by conducting tensile tests on samples cut from the plates, sections etc. IS 800-2007 gives mechanical properties of different types of structural steel products in its Table 1.1. Table 1.1 gives mechanical properties of structural steel conforming to IS 2062, which are used for the design in this book.

Table 1.1 Mechanical properties of structural steel conforming to IS Code 2062

Sl. No.	Grade/ Classification	Yield Stress in N/mm ²			Ultimate Tensile Stress in N/mm ²	Percentage Elongation
		$t < 20$ mm	$t = 20-40$ mm	$t > 40$ mm		
1	E250 (Fe 410W)A	250	240	230	410	23
2	E250 (Fe 410W)B	250	240	230	410	23
3	E250 (Fe 410W)C	250	240	230	410	23
4	E300 (Fe 440)	300	290	280	440	22
5	E350 (Fe 490)	350	330	320	490	22
6	E410 (Fe 540)	410	390	380	540	20
7	E450 (Fe 570)D	450	430	420	570	20
8	E450 (Fe 590)E	450	430	420	590	20

Notes:

1. Percentage elongation shall be taken over the gauge length $5.65 \sqrt{S_u}$ where, S_u is original cross-sectional area of the specimen.
2. If elongation is non-proportional, 0.2 percent proof stress is taken as yield stress.

1.5 ROLLED STEEL SECTIONS

Like concrete, steel section of any shape and size cannot be cast on site, since steel needs very high temperature to melt it and roll into required shape. Steel sections of standard shapes, sizes and length are rolled in steel mills and marketed. User has to cut them to the required length and use required sections for the steel framework. Many steel sections are readily available in the market and are in frequent demand such steel sections are known as *Regular Steel Sections*. Some steel sections are not in use commonly, but the steel mills can roll them if orders are placed. Such steel sections are known as *Special Sections*.

Various types of rolled steel sections manufactured are listed below:

- (i) Rolled steel I-sections (Beam sections)
- (ii) Rolled steel Channel sections
- (iii) Rolled steel Angle sections
- (iv) Rolled steel Tee sections
- (v) Rolled steel Bars
- (vi) Rolled steel Tubes

- (vii) Rolled steel Plates
- (viii) Rolled steel Flats
- (ix) Rolled steel Sheets and Strips.

Steel tables give nominal dimensions, weight per metre length and geometric properties of various rolled steel sections.

1.5.1 Rolled Steel I-section

The following five series of rolled steel I-sections are manufactured in India:

- (a) Indian Standard Junior beams – ISJB
- (b) Indian Standard Light Beams – ISLB
- (c) Indian Standard Medium Beams – ISMB
- (d) Indian Standard Wide-flange Beams – ISWB
- (e) Indian Standard Heavy Beams – ISHB.

Figure 1.1 shows a typical I-section beam.

These sections are designated by the series to which they belong, followed by depth (in mm) and weight per metre run e.g. ISMB 500 @ 0.852 kN/m. It may not matter much if weight per metre length is not written in case of ISJB, ISLB and ISMB sections, since there is only one standard section for a specified depth. But in case of ISWB and ISHB sections weight per unit length should always be specified since for the same depth in these series more than one sections are available with different weight and properties e.g.

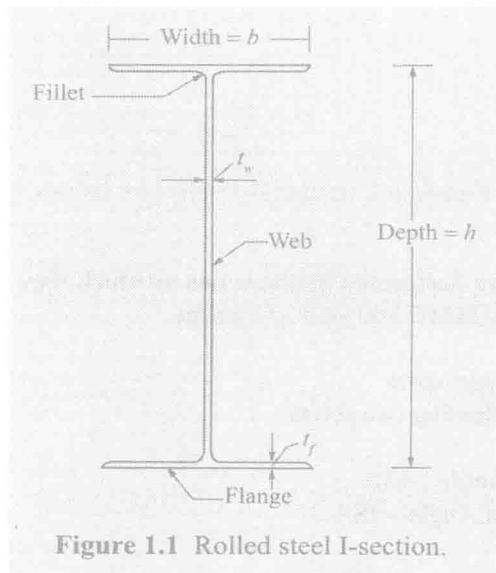


Figure 1.1 Rolled steel I-section.

ISWB 600 @ 1.423 kN/m

ISWB 600 @ 1.312 kN/m

ISHB 450 @ 0.855 kN/m

ISHB 450 @ 0.907 kN/m.

1.5.2 Rolled Steel Channel Sections

These sections are classified into the following four series:

- (a) Indian Standard Junior Channel – ISJC
- (b) Indian Standard Light Channel – ISLC
- (c) Indian Standard Medium weight Channel – ISMC
- (d) Indian Standard Special Channel – ISSC.

Figure 1.2 shows a typical channel section.

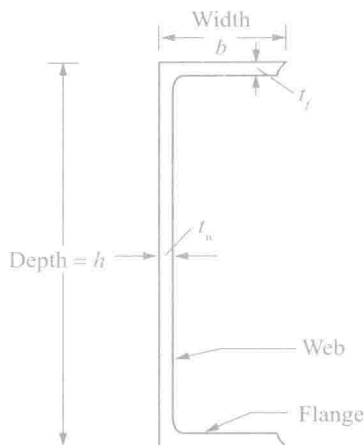


Figure 1.2 Rolled steel channel section.

Rolled steel channel sections are designated by the series to which they belong, followed by depth (in mm) and weight (in kN/m). e.g. ISMC 300 @ 0.351 kN/m.

1.5.3 Rolled Steel Angle Sections

These are classified into the following two series:

- (a) Indian Standard Equal Angle – ISA
- (b) Indian Standard Unequal Angle – ISA.

Figure 1.3 shows typical sections.