

# **Structural Steel Design to Eurocode 3 and AISC Specifications**

**Claudio Bernuzzi • Benedetto Cordova**

**WILEY** Blackwell

# Structural Steel Design to Eurocode 3 and AISC Specifications

By  
**Claudio Bernuzzi**  
and  
**Benedetto Cordova**

**WILEY** Blackwell

This edition first published 2016  
© 2016 by John Wiley & Sons, Ltd

*Registered Office*

John Wiley & Sons, Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

*Editorial Offices*

9600 Garsington Road, Oxford, OX4 2DQ, United Kingdom  
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at [www.wiley.com/wiley-blackwell](http://www.wiley.com/wiley-blackwell).

The right of the author to be identified as the author of this work has been asserted in accordance with the UK Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book.

**Limit of Liability/Disclaimer of Warranty:** While the publisher and author(s) have used their best efforts in preparing this book, they make no representations or warranties with respect to the accuracy or completeness of the contents of this book and specifically disclaim any implied warranties of merchantability or fitness for a particular purpose. It is sold on the understanding that the publisher is not engaged in rendering professional services and neither the publisher nor the author shall be liable for damages arising herefrom. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Based on *Progetto e verifica delle strutture in acciaio* by Claudio Bernuzzi.  
© Ulrico Hoepli Editore S.p.A., Milano, 2011. Published in the Italian language.

*Library of Congress Cataloging-in-Publication data applied for.*

ISBN: 9781118631287

A catalogue record for this book is available from the British Library.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Cover image: photovideostock/Getty

Set in 10/12pt Minion by SPi Global, Pondicherry, India

Printed in Singapore by C.O.S. Printers Pte Ltd



# Preface

Over the last century, design of steel structures has developed from very simple approaches based on a few elementary properties of steel and essential mathematics to very sophisticated treatments demanding a thorough knowledge of structural and material behaviour. Nowadays, steel design utilizes refined concepts of mechanics of material and of theory of structures combined with probabilistic-based approaches that can be found in design specifications.

This book intends to be a guide to understanding the basic concepts of theory of steel structures as well as to provide practical guidelines for the design of steel structures in accordance with both European (EN 1993) and United States (ANSI/AISC 360-10) specifications. It is primarily intended for use by practicing engineers and engineering students, but it is also relevant to all different parties associated with steel design, fabrication and construction.

The book synthesizes the Authors' experience in teaching Structural Steel Design at the Technical University of Milan-Italy (Claudio Bernuzzi) and in design of steel structures for power plants (Benedetto Cordova), combining their expertise in comparing and contrasting both European and American approaches to the design of steel structures.

The book consists of 16 chapters, each structured independently of the other, in order to facilitate consultation by students and professionals alike. Chapter 1 introduces general aspects such as material properties and products, imperfection and tolerances, also focusing the attention on testing methods and approaches. The fundamentals of steel design are summarized in Chapter 2, where the principles of structural safety are discussed in brief to introduce the different reliability levels of the design. Framed systems and methods of analysis, including simplified methods, are discussed in Chapter 3. Cross-sectional classification is presented in Chapter 4, in which special attention has been paid to components under compression and bending. Design of single members is discussed in depth in Chapter 5 for tension members, in Chapter 6 for compression members, in Chapter 7 for members subjected to bending and shear, in Chapter 8 for members under torsion, and in Chapter 9 for members subjected to bending and compression. Chapter 10 deals with design accounting for the combination of compression, flexure, shear and torsion.

Chapter 11 addresses requirements for the web resistance design and Chapter 12 deals with the design approaches for frame analysis. Chapters 13 and 14 deal with bolted and welded connections, respectively, while the most common type of joints are described in Chapter 15, including a summary of the approach to their design. Finally, built-up members are discussed in Chapter 16. Several design examples provided in this book are directly chosen from real design situations. All examples are presented providing all the input data necessary to develop the design. The different calculations associated with European and United States specifications are provided in two separate text columns in order to allow a direct comparison of the associated procedures.

Last, but not least, the acknowledge of the Authors. A great debt of love and gratitude to our families: their patience was essential to the successful completion of the book.

We would like to express our deepest thanks to Dr. Giammaria Gabbianelli (University of Pavia-I) and Dr. Marco Simoncelli (Politecnico di Milano-I) for the continuous help in preparing

figures and tables and checking text. We are also thankful to prof. Gian Andrea Rassati (University of Cincinnati-U.S.A.) for the great and precious help in preparation of chapters 1 and 13.

Finally, it should be said that, although every care has been taken to avoid errors, it would be sanguine to hope that none had escape detection. Authors will be grateful for any suggestion that readers may make concerning needed corrections.

*Claudio Bernuzzi and Benedetto Cordova*

# Contents

Preface	x
1 The Steel Material	1
1.1 General Points about the Steel Material	1
1.1.1 Materials in Accordance with European Provisions	4
1.1.2 Materials in Accordance with United States Provisions	7
1.2 Production Processes	10
1.3 Thermal Treatments	13
1.4 Brief Historical Note	14
1.5 The Products	15
1.6 Imperfections	18
1.6.1 Mechanical Imperfections	19
1.6.2 Geometric Imperfections	22
1.7 Mechanical Tests for the Characterization of the Material	24
1.7.1 Tensile Testing	25
1.7.2 Stub Column Test	27
1.7.3 Toughness Test	29
1.7.4 Bending Test	32
1.7.5 Hardness Test	32
2 References for the Design of Steel Structures	34
2.1 Introduction	34
2.1.1 European Provisions for Steel Design	35
2.1.2 United States Provisions for Steel Design	37
2.2 Brief Introduction to Random Variables	37
2.3 Measure of the Structural Reliability and Design Approaches	39
2.4 Design Approaches in Accordance with Current Standard Provisions	44
2.4.1 European Approach for Steel Design	44
2.4.2 United States Approach for Steel Design	47
3 Framed Systems and Methods of Analysis	49
3.1 Introduction	49
3.2 Classification Based on Structural Typology	51
3.3 Classification Based on Lateral Deformability	52
3.3.1 European Procedure	53
3.3.2 AISC Procedure	56

3.4	Classification Based on Beam-to-Column Joint Performance	56
3.4.1	Classification According to the European Approach	57
3.4.2	Classification According to the United States Approach	60
3.4.3	Joint Modelling	61
3.5	Geometric Imperfections	63
3.5.1	The European Approach	63
3.5.2	The United States Approach	67
3.6	The Methods of Analysis	68
3.6.1	Plasticity and Instability	69
3.6.2	Elastic Analysis with Bending Moment Redistribution	76
3.6.3	Methods of Analysis Considering Mechanical Non-Linearity	78
3.6.4	Simplified Analysis Approaches	80
3.7	Simple Frames	84
3.7.1	Bracing System Imperfections in Accordance with EU Provisions	88
3.7.2	System Imperfections in Accordance with AISC Provisions	89
3.7.3	Examples of Braced Frames	92
3.8	Worked Examples	96
4	Cross-Section Classification	107
4.1	Introduction	107
4.2	Classification in Accordance with European Standards	108
4.2.1	Classification for Compression or Bending Moment	110
4.2.2	Classification for Compression and Bending Moment	110
4.2.3	Effective Geometrical Properties for Class 4 Sections	115
4.3	Classification in Accordance with US Standards	118
4.4	Worked Examples	121
5	Tension Members	134
5.1	Introduction	134
5.2	Design According to the European Approach	134
5.3	Design According to the US Approach	137
5.4	Worked Examples	140
6	Members in Compression	147
6.1	Introduction	147
6.2	Strength Design	147
6.2.1	Design According to the European Approach	147
6.2.2	Design According to the US Approach	148
6.3	Stability Design	148
6.3.1	Effect of Shear on the Critical Load	155
6.3.2	Design According to the European Approach	158
6.3.3	Design According to the US Approach	162
6.4	Effective Length of Members in Frames	166
6.4.1	Design According to the EU Approach	166
6.4.2	Design According to the US Approach	169
6.5	Worked Examples	172
7	Beams	176
7.1	Introduction	176
7.1.1	Beam Deformability	176

7.1.2	Dynamic Effects	178
7.1.3	Resistance	179
7.1.4	Stability	179
7.2	European Design Approach	184
7.2.1	Serviceability Limit States	184
7.2.2	Resistance Verifications	186
7.2.3	Buckling Resistance of Uniform Members in Bending	190
7.3	Design According to the US Approach	199
7.3.1	Serviceability Limit States	199
7.3.2	Shear Strength Verification	200
7.3.3	Flexural Strength Verification	204
7.4	Design Rules for Beams	228
7.5	Worked Examples	233
8	Torsion	243
8.1	Introduction	243
8.2	Basic Concepts of Torsion	245
8.2.1	I- and H-Shaped Profiles with Two Axes of Symmetry	250
8.2.2	Mono-symmetrical Channel Cross-Sections	252
8.2.3	Warping Constant for Most Common Cross-Sections	255
8.3	Member Response to Mixed Torsion	258
8.4	Design in Accordance with the European Procedure	263
8.5	Design in Accordance with the AISC Procedure	265
8.5.1	Round and Rectangular HSS	266
8.5.2	Non-HSS Members (Open Sections Such as W, T, Channels, etc.)	267
9	Members Subjected to Flexure and Axial Force	268
9.1	Introduction	268
9.2	Design According to the European Approach	271
9.2.1	The Resistance Checks	271
9.2.2	The Stability Checks	274
9.2.3	The General Method	280
9.3	Design According to the US Approach	281
9.4	Worked Examples	284
10	Design for Combination of Compression, Flexure, Shear and Torsion	303
10.1	Introduction	303
10.2	Design in Accordance with the European Approach	308
10.3	Design in Accordance with the US Approach	309
10.3.1	Round and Rectangular HSS	310
10.3.2	Non-HSS Members (Open Sections Such as W, T, Channels, etc.)	310
11	Web Resistance to Transverse Forces	311
11.1	Introduction	311
11.2	Design Procedure in Accordance with European Standards	312
11.3	Design Procedure in Accordance with US Standards	316
12	Design Approaches for Frame Analysis	319
12.1	Introduction	319
12.2	The European Approach	319



12.2.1	The EC3-1 Approach	320
12.2.2	The EC3-2a Approach	321
12.2.3	The EC3-2b Approach	321
12.2.4	The EC3-3 Approach	322
12.3	AISC Approach	323
12.3.1	The Direct Analysis Method (DAM)	323
12.3.2	The Effective Length Method (ELM)	327
12.3.3	The First Order Analysis Method (FOM)	329
12.3.4	Method for Approximate Second Order Analysis	330
12.4	Comparison between the EC3 and AISC Analysis Approaches	332
12.5	Worked Example	334
13	The Mechanical Fasteners	345
13.1	Introduction	345
13.2	Resistance of the Bolted Connections	345
13.2.1	Connections in Shear	347
13.2.2	Connections in Tension	354
13.2.3	Connection in Shear and Tension	358
13.3	Design in Accordance with European Practice	358
13.3.1	European Practice for Fastener Assemblages	358
13.3.2	EU Structural Verifications	363
13.4	Bolted Connection Design in Accordance with the US Approach	369
13.4.1	US Practice for Fastener Assemblage	369
13.4.2	US Structural Verifications	376
13.5	Connections with Rivets	382
13.5.1	Design in Accordance with EU Practice	383
13.5.2	Design in Accordance with US Practice	383
13.6	Worked Examples	384
14	Welded Connections	395
14.1	Generalities on Welded Connections	395
14.1.1	European Specifications	397
14.1.2	US Specifications	399
14.1.3	Classification of Welded Joints	400
14.2	Defects and Potential Problems in Welds	401
14.3	Stresses in Welded Joints	403
14.3.1	Tension	404
14.3.2	Shear and Flexure	406
14.3.3	Shear and Torsion	408
14.4	Design of Welded Joints	411
14.4.1	Design According to the European Approach	411
14.4.2	Design According to the US Practice	414
14.5	Joints with Mixed Typologies	420
14.6	Worked Examples	420
15	Connections	424
15.1	Introduction	424
15.2	Articulated Connections	425
15.2.1	Pinned Connections	426
15.2.2	Articulated Bearing Connections	427

15.3	Splices	429
15.3.1	Beam Splices	430
15.3.2	Column Splices	431
15.4	End Joints	434
15.4.1	Beam-to-Column Connections	434
15.4.2	Beam-to-Beam Connections	434
15.4.3	Bracing Connections	437
15.4.4	Column Bases	438
15.4.5	Beam-to-Concrete Wall Connection	441
15.5	Joint Modelling	444
15.5.1	Simple Connections	450
15.5.2	Rigid Joints	454
15.5.3	Semi-Rigid Joints	458
15.6	Joint Standardization	462
16	Built-Up Compression Members	466
16.1	Introduction	466
16.2	Behaviour of Compound Struts	466
16.2.1	Laced Compound Struts	471
16.2.2	Battened Compound Struts	473
16.3	Design in Accordance with the European Approach	475
16.3.1	Laced Compression Members	477
16.3.2	Battened Compression Members	477
16.3.3	Closely Spaced Built-Up Members	478
16.4	Design in Accordance with the US Approach	480
16.5	Worked Examples	482
	Appendix A: Conversion Factors	491
	Appendix B: References and Standards	492
	Index	502

# CHAPTER 1

## The Steel Material

### 1.1 General Points about the Steel Material

The term *steel* refers to a family of iron–carbon alloys characterized by well-defined percentage ratios of main individual components. Specifically, iron–carbon alloys are identified by the carbon (C) content, as follows:

- *wrought iron*, if the carbon content (i.e. the percentage content in terms of weight) is higher than 1.7% (some literature references have reported a value of 2%);
- *steel*, when the carbon content is lower than the previously mentioned limit. Furthermore, steel can be classified into extra-mild ( $C < 0.15\%$ ), mild ( $C = 0.15 \div 0.25\%$ ), semi-hard ( $C = 0.25 \div 0.50\%$ ), hard ( $C = 0.50 \div 0.75\%$ ) and extra-hard ( $C > 0.75\%$ ) materials.

Structural steel, also called *constructional steel* or sometimes *carpentry steel*, is characterized by a carbon content of between 0.1 and 0.25%. The presence of carbon increases the strength of the material, but at the same time reduces its ductility and weldability; for this reason structural steel is usually characterized by a low carbon content. Besides *iron* and *carbon*, structural steel usually contains small quantities of other elements. Some of them are already present in the iron ore and cannot be entirely eliminated during the production process, and others are purposely added to the alloy in order to obtain certain desired physical or mechanical properties.

Among the elements that cannot be completely eliminated during the production process, it is worth mentioning both *sulfur* (S) and *phosphorous* (P), which are undesirable because they decrease the material ductility and its weldability (their overall content should be limited to approximately 0.06%). Other undesirable elements that can reduce ductility are *nitrogen* (N), *oxygen* (O) and *hydrogen* (H). The first two also affect the strain-ageing properties of the material, increasing its fragility in regions in which permanent deformations have taken place.

The most important alloying elements that may be added to the materials are *manganese* (Mn) and *silica* (Si), which contribute significantly to the improvement of the weldability characteristics of the material, at the same time increasing its strength. In some instances, *chromium* (Cr) and *nickel* (Ni) can also be added to the alloy; the former increases the material strength and, if is present in sufficient quantity, improves the corrosion resistance (it is used for stainless steel), whereas the latter increases the strength while reduces the deformability of the material.

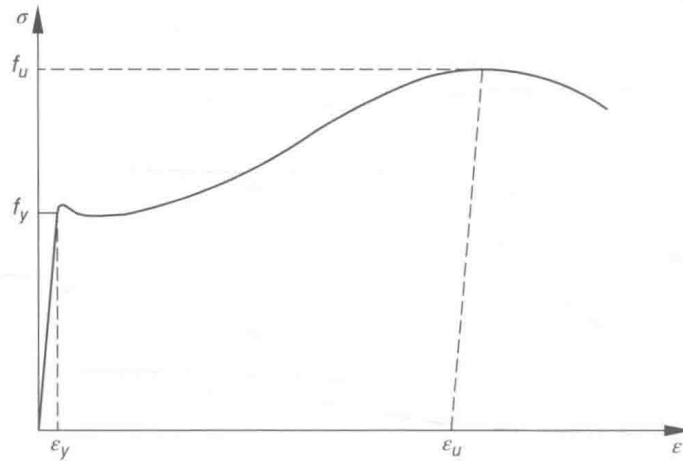


Figure 1.1 Typical constitutive law for structural steel.

Steel is characterized by a symmetric constitutive stress-strain law ( $\sigma$ - $\epsilon$ ). Usually, this law is determined experimentally by means of a tensile test performed on coupons (samples) machined from plate material obtained from the sections of interest (Section 1.7). Figure 1.1 shows a typical stress-strain response to a uniaxial tensile force for a structural steel coupon. In particular, it is possible to distinguish the following regions:

- an initial branch that is mostly linear (*elastic phase*), in which the material shows a linear elastic behaviour approximately up to the yielding stress ( $f_y$ ). The strain corresponding to  $f_y$  is usually indicated with  $\epsilon_y$  (yielding strain). The slope of this initial branch corresponds to the modulus of elasticity of the material (also known as longitudinal modulus of elasticity or Young's modulus), usually indicated by  $E$ , with a value between 190 000 and 210 000 N/mm<sup>2</sup> (from 27 560 to 30 460 ksi, approximately);
- a *plastic phase*, which is characterized by a small or even zero slope in the  $\sigma$ - $\epsilon$  reference system;
- the ensuing branch is the *hardening phase*, in which the slope is considerably smaller when compared to the elastic phase, but still sufficient enough to cause an increase in stress when strain increases, up to the ultimate strength  $f_u$ . The hardening modulus has values between 4000 and 6000 N/mm<sup>2</sup> (from 580 to 870 ksi, approximately).

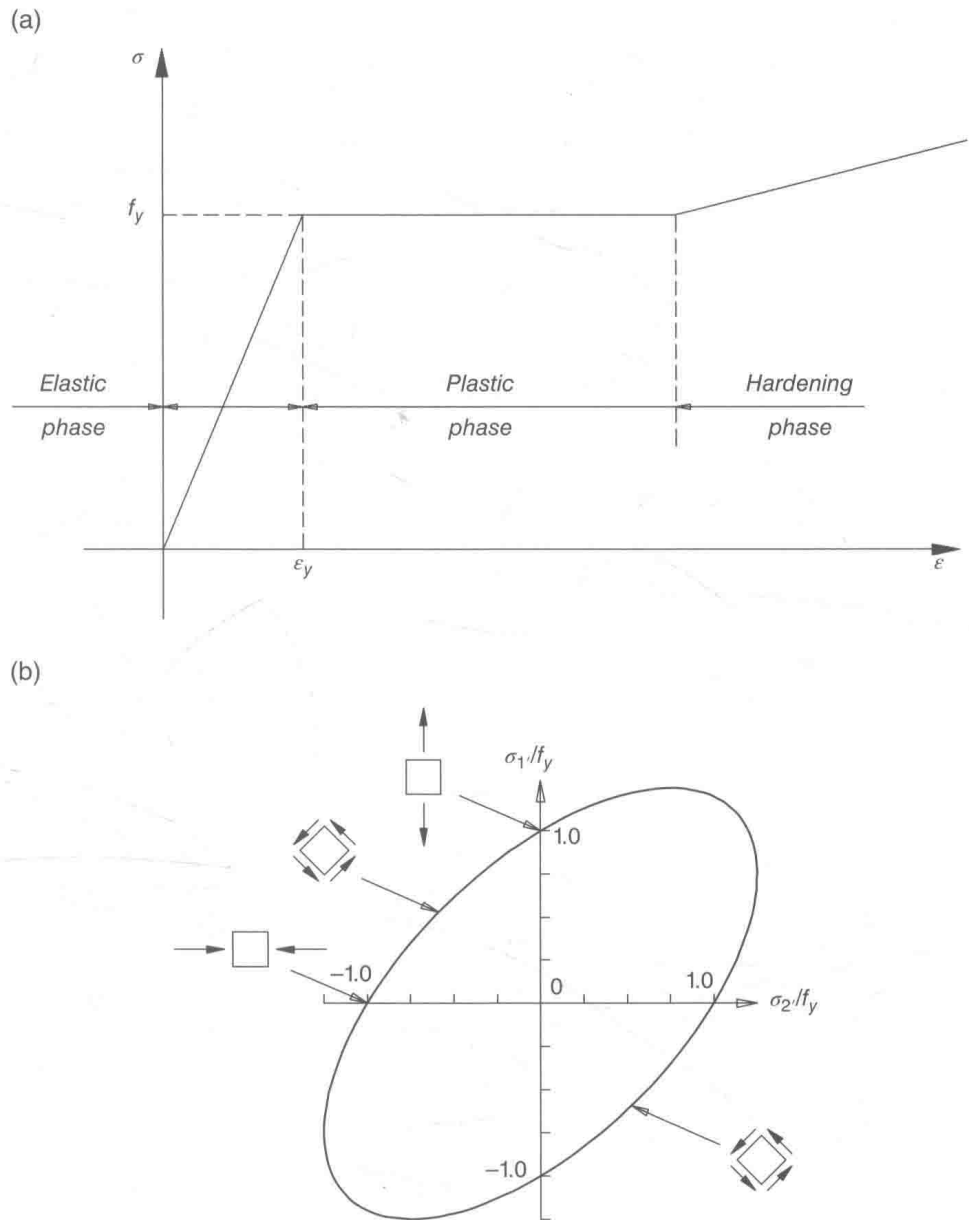
Usually, the uniaxial constitutive law for steel is schematized as a multi-linear relationship, as shown in Figure 1.2a, and for design purposes an elastic-perfectly plastic approximation is generally used; that is the hardening branch is considered to be horizontal, limiting the maximum strength to the yielding strength.

The yielding strength is the most influential parameter for design. Its value is obtained by means of a laboratory uniaxial tensile test, usually performed on coupons cut from the members of interest in suitable locations (see Section 1.7).

In many design situations though, the state of stress is biaxial. In this case, reference is made to the well-known Huber-Hencky-Von Mises criterion (Figure 1.2b) to relate the mono-axial yielding stress ( $f_y$ ) to the state of plane stress with the following expression:

$$\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 + 3\sigma_{12}^2 = f_y^2 \quad (1.1)$$

where  $\sigma_1$ ,  $\sigma_2$  are the normal stresses and  $\sigma_{12}$  is the shear stress.



**Figure 1.2** Structural steel: (a) schematization of the uniaxial constitutive law and (b) yield surface for biaxial stress states.

In the case of pure shear, the previous equation is reduced to:

$$\sigma_{12} = \tau_{12} = \frac{f_y}{\sqrt{3}} = \tau_y \quad (1.2)$$

With reference to the principal stress directions  $1'$  and  $2'$ , the yield surface is represented by an ellipse and Eq. (1.1) becomes:

$$(\sigma_{1'})^2 + (\sigma_{2'})^2 - (\sigma_{1'}) \cdot (\sigma_{2'}) = f_y^2 \quad (1.3)$$

### 1.1.1 Materials in Accordance with European Provisions

The European provisions prescribe the following values for material properties concerning structural steel design:

Density:	$\rho = 7850 \text{ kg/m}^3 (= 490 \text{ lb/ft}^3)$
Poisson's coefficient:	$\nu = 0.3$
Longitudinal (Young's) modulus of elasticity:	$E = 210\,000 \text{ N/mm}^2 (= 30\,460 \text{ ksi})$
Shear modulus:	$G = \frac{E}{2(1 + \nu)}$
Coefficient of linear thermal expansion:	$\alpha = 12 \times 10^{-6} \text{ per } ^\circ\text{C} (= 6.7 \times 10^{-6} \text{ per } ^\circ\text{F})$

The mechanical properties of the steel grades most used for construction are summarized in Tables 1.1a and 1.1b, for hot-rolled and hollow profiles, respectively, in terms of yield strength ( $f_y$ ) and ultimate strength ( $f_u$ ). Similarly, Table 1.2 refers to steel used for mechanical fasteners. With respect to the European nomenclature system for steel used in high strength fasteners, the generic tag ( $j.k$ ) can be immediately associated to the mechanical characteristics of the material expressed in International System of units (I.S.), considering that:

- $j.k.10$  represents the yielding strength expressed in  $\text{N/mm}^2$ ;
- $j.100$  represents the failure strength expressed in  $\text{N/mm}^2$ .

**Table 1.1a** Mechanical characteristics of steels used for hot-rolled profiles.

EN norm and steel grade	Nominal thickness $t$			
	$t \leq 40 \text{ mm}$		$40 \text{ mm} < t \leq 80 \text{ mm}$	
	$f_y \text{ (N/mm}^2\text{)}$	$f_u \text{ (N/mm}^2\text{)}$	$f_y \text{ (N/mm}^2\text{)}$	$f_u \text{ (N/mm}^2\text{)}$
EN 10025-2				
S 235	235	360	215	360
S 275	275	430	255	410
S 355	355	510	335	470
S 450	440	550	410	550
EN 10025-3				
S 275 N/NL	275	390	255	370
S 355 N/NL	355	490	335	470
S 420 N/NL	420	520	390	520
S 460 N/NL	460	540	430	540
EN 10025-3				
S 275 M/ML	275	370	255	360
S 355 M/ML	355	470	335	450
S 420 M/ML	420	520	390	500
S 460 M/ML	460	540	430	530
EN 10025-5				
S 235 W	235	360	215	340
S 355 W	355	510	335	490
EN 10025-6				
S 460 Q/QL/QL1	460	570	440	550



**Table 1.1b** Mechanical characteristics of steels used for hollow profiles.

EN norm and steel grade	Nominal thickness $t$			
	$t \leq 40$ mm		$40 \text{ mm} < t \leq 65$ mm	
	$f_y$ (N/mm <sup>2</sup> )	$f_u$ (N/mm <sup>2</sup> )	$f_y$ (N/mm <sup>2</sup> )	$f_u$ (N/mm <sup>2</sup> )
EN 10210-1				
S 235 H	235	360	215	340
S 275 H	275	430	255	410
S 355 H	355	510	335	490
S 275 NH/NLH	275	390	255	370
S 355 NH/NLH	355	490	335	470
S 420 NH/NLH	420	540	390	520
S 460 NH/NLH	460	560	430	550
EN 10219-1				
S 235 H	235	360		
S 275 H	275	430		
S 355 H	355	510		
S 275 NH/NLH	275	370		
S 355 NH/NLH	355	470		
S 460 NH/NLH	460	550		
S 275 MH/MLH	275	360		
S 355 MH/MLH	355	470		
S 420 MH/MLH	420	500		
S 460 NH/NLH	460	530		

**Table 1.2** Nominal yielding strength values ( $f_{yb}$ ) and nominal failure strength ( $f_{ub}$ ) for bolts.

Bolt class	4.6	4.8	5.6	5.8	6.8	8.8	10.9
$f_{yb}$ (N/mm <sup>2</sup> )	240	320	300	400	480	640	900
$f_{ub}$ (N/mm <sup>2</sup> )	400	400	500	500	600	800	1000

The details concerning the designation of steels are covered in EN 10027 Part 1 (*Designation systems for steels – Steel names*) and Part 2 (*Numerical system*), which distinguish the following groups:

- *group 1*, in which the designation is based on the usage and on the mechanical or physical characteristics of the material;
- *group 2*, in which the designation is based on the chemical content: the first symbol may be a letter (e.g. C for non-alloy carbon steels or X for alloy steel, including stainless steel) or a number.

With reference to the group 1 designations, the first symbol is always a letter. For example:

- *B* for steels to be used in reinforced concrete;
- *D* for steel sheets for cold forming;
- *E* for mechanical construction steels;
- *H* for high strength steels;
- *S* for structural steels;
- *Y* for steels to be used in prestressing applications.

Focusing attention on the structural steels (starting with an S), there are then three digits XXX that provide the value of the minimum yielding strength. The following term is related to the technical conditions of delivery, defined in EN 10025 ('Hot rolled products of structural steel') that proposes the following five abbreviations, each associated to a different production process:

- the AR (*As Rolled*) term identifies rolled and otherwise unfinished steels;
- the N (*Normalized*) term identifies steels obtained through normalized rolling, that is a rolling process in which the final rolling pass is performed within a well-controlled temperature range, developing a material with mechanical characteristics similar to those obtained through a normalization heat treatment process (see Section 1.2);
- the M (*Mechanical*) term identifies steels obtained through a thermo-mechanical rolling process, that is a process in which the final rolling pass is performed within a well-controlled temperature range resulting in final material characteristics that cannot be obtained through heat treating alone;
- the Q (*Quenched and tempered*) term identifies high yield strength steels that are quenched and tempered after rolling;
- the W (*Weathering*) term identifies weathering steels that are characterized by a considerably improved resistance to atmospheric corrosion.

The YY code identifies various classes concerning material toughness as discussed in the following. Non-alloyed steels for structural use (EN 10025-2) are identified with a code after the yielding strength (XXX), for example:

- YY: alphanumeric code concerning toughness: S235 and S275 steels are provided in groups JR, J0 and J2. S355 steels are provided in groups JR, J0, J2 and K2. S450 steels are provided in group J0 only. The first part of the code is a letter, J or K, indicating a minimum value of toughness provided (27 and 40 J, respectively). The next symbol identifies the temperature at which such toughness must be guaranteed. Specifically, R indicates ambient temperature, 0 indicates a temperature not higher than 0°C and 2 indicates a temperature not higher than -20°C;
- C: an additional symbol indicating special uses for the steel;
- N, AR or M: indicates the production process.

Weldable fine grain structural steels that are normalized or subject to normalized rolling (EN 10025-3); that is, steels characterized by a granular structure with an equivalent ferriting grain size index greater than 6, determined in accordance with EN ISO 643 ('Micrographic determination of the apparent grain size'), are defined by the following codes:

- N: for the production process;
- YY: for the toughness class. The L letter identifies toughness temperatures not lower than -50°C; in the absence of the letter L, the reference temperature must be taken as -20°C.

Fine grain steels obtained through thermo-mechanical rolling processes (EN 10025-4) are identified by the following code:

- M: for the production process;
- YY: for the toughness class. The letter L, as discussed previously, identifies toughness temperatures no lower than -50°C; in the absence of the letter L, the reference temperature must be taken to be -20°C.

Weathering steels for structural use (EN 10025-5) are identified by the following code:

- the YY code indicates the toughness class: these steels are provided in classes J0, J2 and K2, indicating different toughness requirements at different temperatures.
- the W code indicates the weathering properties of the steel;
- P indicates an increased content of phosphorous;
- N or AR indicates the production process.

Quenched and tempered high-yield strength plate materials for structural use (EN 10025-6) are identified by the following codes:

- Q code indicates the production process;
- YY: identifies the toughness class. The letter L indicates a specified minimum toughness temperature of  $-40^{\circ}\text{C}$ , while code L1 refers to temperatures not lower than  $-60^{\circ}\text{C}$ . In the absence of these codes, the minimum toughness values refer to temperatures no lower than  $-20^{\circ}\text{C}$ .

In Europe, it is mandatory to use steels bearing the CE marks, in accordance with the requirements reported in the Construction Products Regulation (CPR) No. 305/2011 of the European Community. The usage of different steels is allowed as long as the degree of safety (not lower than the one provided by the current specifications) can be guaranteed, accompanied by adequate theoretical and experimental documentation.

## 1.1.2 Materials in Accordance with United States Provisions

The properties of structural steel materials are standardized by ASTM International (formerly known as the *American Society for Testing and Materials*). Numerous standards are available for structural applications, generally dedicated to the most common product families. In the following, some details are reported.

### 1.1.2.1 General Standards

ASTM A6 (*Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes and Sheet Piling*) is the standard that covers the general requirements for rolled structural steel bars, plates, shapes and sheet piling.

### 1.1.2.2 Hot-Rolled Structural Steel Shapes

Table 1.3 summarizes key data for the most commonly used hot-rolled structural shapes.

#### • W-Shapes

ASTM A992 is the most commonly used steel grade for all hot-rolled W-Shape members. This material has a minimum yield stress of 50 ksi (356 MPa) and a minimum tensile strength of 65 ksi (463 MPa). Higher values of the yield and tensile strength can be guaranteed by ASTM A572 Grades 60 or 65 (Grades 42 and 50 are also available) or ASTM A913 Grades 60, 65 or 70 (Grade 50 is also available). If W-Shapes with atmospheric corrosion resistance characteristics are required, reference can be made to ASTM A588 or ASTM A242 selecting 42, 46 or 50 steel Grades. Finally, W-Shapes according to ASTM A36 are also available.

#### • M-Shapes and S-Shapes

These shapes have been produced up to now in ASTM A36 steel grade. From some steel producers they are now available in ASTM A572 Grade 50. M-Shapes with atmospheric corrosion resistance characteristics can be obtained by using ASTM A588 or ASTM A242 Grade 50.