Sample Chapter

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Eurocode 3: Design of steel structures
Part 1-1: General rules and rules for buildings
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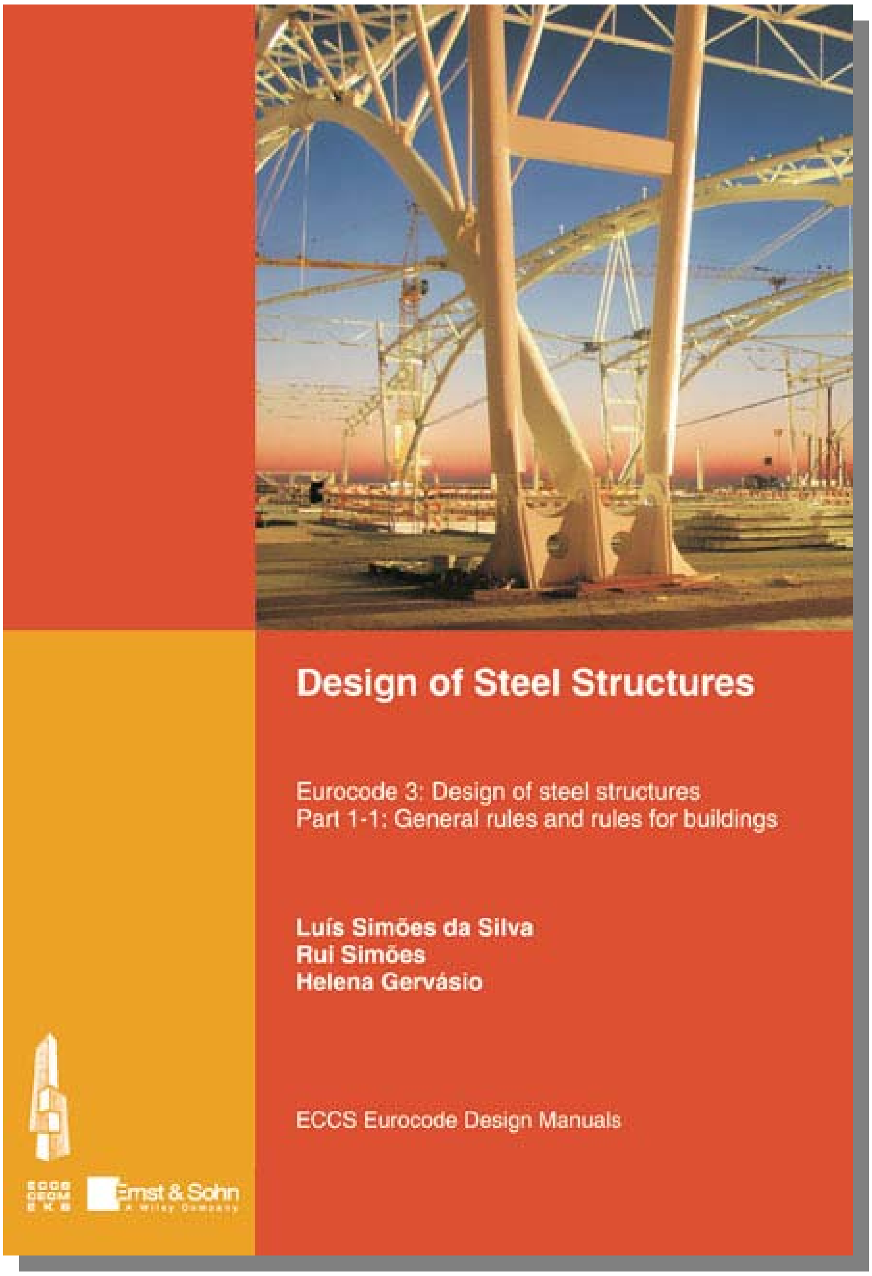

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DESIGN OF STEEL STRUCTURES

ECCS EUROCODE DESIGN MANUALS

DESIGN OF STEEL STRUCTURES
Luís Simões da Silva, Rui Simões and Helena Gervásio

FIRE DESIGN OF STEEL STRUCTURES
Jean-Marc Franssen and Paulo Vila Real

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Eurocode 3: Design of Steel Structures
Part 1-1 – General Rules and Rules for Buildings

Luís Simões da Silva
Rui Simões
Helena Gervásio

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An axial compression force in a cross section in class 4 due to the possible shift, e_N, of the centroid of the effective area, A_{eff}, relative to the centre of gravity of the gross cross section, results in an additional bending moment $\Delta M_{Ed} = N_{Ed}\, e_N$.

The analysis of cross sections with class 4 is not included in the scope of this book. The analysis may be performed according to EC3-1-3, for cold formed sections; according to EC3-1-5, for hot rolled sections and welded sections; and according to EC3-1-6, for circular hollow sections.

3.1.3. Buckling resistance of members

In addition to verification of the cross section resistance, the buckling resistance of members must also be checked, according to clauses 6.3 and 6.4. The buckling phenomenon depends on the presence of compressive stresses and therefore it must be checked for all members subjected to axial compression, bending moment or a combination of both. Shear buckling effects should also be considered according to EC3-1-5.

For a member under pure compression the buckling modes to take into account are: i) flexural buckling; ii) torsional buckling and iii) torsional-flexural buckling. A member under bending moment must be checked against lateral-torsional buckling. A member under a combination of compression force and bending moment must be checked against all the buckling modes mentioned above. The theoretical background, the design rules and several applications relating to the buckling resistance of steel members are presented in the sub-chapters 3.5, 3.6 and 3.7.

3.2. TENSION

3.2.1. Behaviour in tension

Figure 3.6 illustrates various examples of structures with some members that are commonly assumed to be loaded only in tension. Figure 3.7 shows typical cross sections of tension members. Simple or built-up rolled sections are commonly used in trusses, lattice girders and as bracing members. Cables, flats or bars are used in bracing systems. Cables, flats or bars are some times used in bridges or long-span roofs; such member types are discussed in detail in EC3-1-11 (2006c).

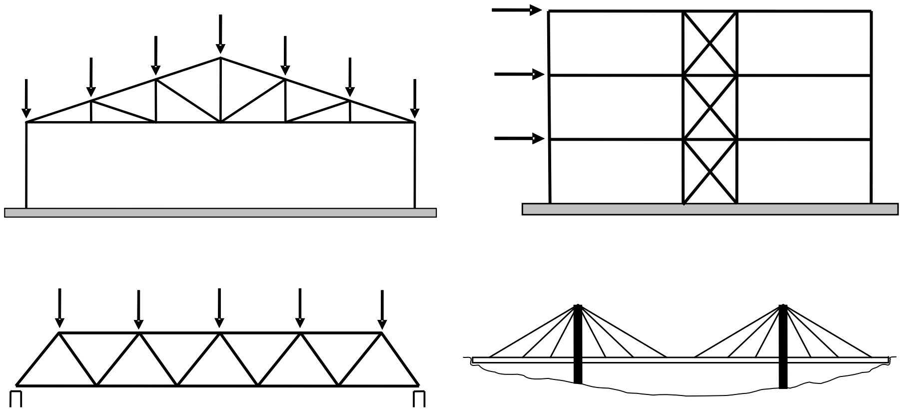

Figure 3.6 – Structures with some members in tension

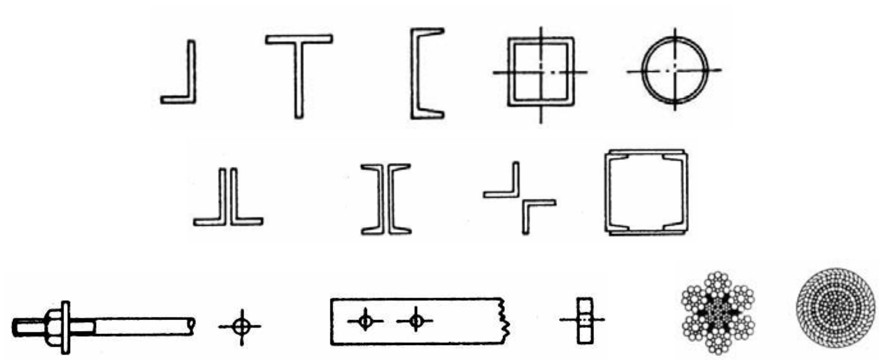

Figure 3.7 – Typical cross sections of members in tension

The behaviour of members in tension is closely related to the stress-strain behaviour of steel subjected to uniaxial tensile forces. Recalling the stress-strain relationship shown in Figure 1.7, the ultimate cross section resistance corresponds to the tensile strength R_m, although the plastic resistance is also often considered as the ultimate tensile resistance of the member, especially when ductility is of concern.

Typically, the governing design situation for members subject to tension corresponds to the location of the joints (either the connection to other parts of the structure or splices within the tension member). In these cross sections, either because of bolting or because of a change of cross-sectional shape, the net area of the cross section must be taken into account. The calculation of the net area in tension was described in section

3.1.2.2. In addition, it is noted that stress concentrations occur in the neighbourhood of holes or discontinuities, as shown in Figure 3.8.

Bolted or welded connections often induce second-order moments because of small eccentricities, as shown in Figure 3.9. These second-order effects should be taken into account. Alternatively, careful detailing should be specified to eliminate these eccentricities, as illustrated in Figure 3.10.

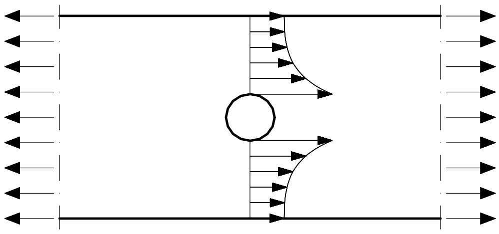

Figure 3.8 – Concentration of tension next to a hole

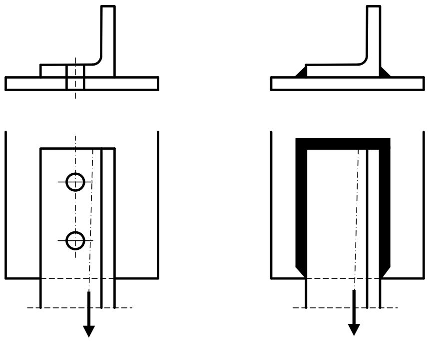

Figure 3.9 – Eccentric connections

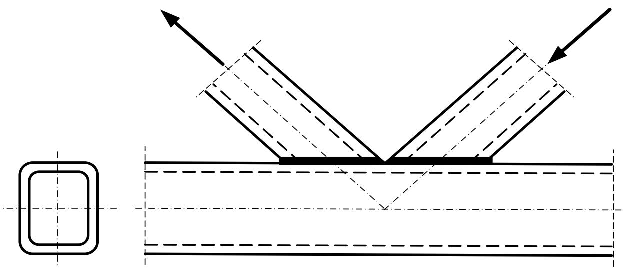

Figure 3.10 – Welded connections between hollow sections

3.2.2. Design for tensile force

A member exclusively subject to a tension force is under a uniaxial stress state. According to clause 6.2.3(1), the design value of the tension force N_{Ed} at each cross section, including cross sections in the vicinity of the connections, should satisfy:

$$\frac{N_{Ed}}{N_{t,Rd}} \leq 1.0 , \tag{3.5}$$

where $N_{t,Rd}$ is the design tension resistance. For sections with holes the design tension resistance $N_{t,Rd}$ should be taken as the smallest of:

- design plastic resistance of the gross cross section,

  $$N_{pl,Rd} = A f_y / \gamma_{M0} , \tag{3.6}$$

  where A is the gross cross section area, f_y is the yield strength of steel and γ_{M0} is the partial safety factor.

- design ultimate resistance of the net cross section at holes for fasteners,

  $$N_{u,Rd} = 0.9 A_{net} f_u / \gamma_{M2} , \tag{3.7}$$

  where A_{net} is the net cross section area, f_u is the ultimate strength of steel and γ_{M2} is the partial safety factor.

Whenever dissipative behaviour is required under cyclic loading, such as in the case of capacity design (CEN, 2004a), the design plastic resistance $N_{pl,Rd}$ should be less than the design ultimate resistance of the net section at fasteners holes $N_{u,Rd}$ (clause 6.2.3(3)), that is,

$$N_{u,Rd} > N_{pl,Rd} \Leftrightarrow \frac{A_{net}}{A} > \frac{f_y}{0.9 f_u} \frac{\gamma_{M2}}{\gamma_{M0}} . \tag{3.8}$$

In the case of members with Category C preloaded bolted connections loaded in shear[2], the design tension resistance $N_{t,Rd}$ at the cross section with holes for fasteners should be taken as $N_{net,Rd}$ (clause 6.2.3(4)):

$$N_{net,Rd} = A_{net} f_y / \gamma_{M0} . \tag{3.9}$$

For angles connected by one leg and other unsymmetrically connected members in tension (such as T sections or channel sections), the eccentricity

[2] Connections slip-resistant at ultimate limit state (clause 3.4.1(1)c of EC3-1-8).

in joints and the effects of the spacing and edge distances of the bolts should be taken into account in determining the design resistance (clause 3.10.3(1) of EC3-1-8). According to clause 3.10.3(2) of EC3-1-8, a single angle in tension connected by a single row of bolts, see Figure 3.11, may be treated as concentrically loaded over an effective net section for which the design ultimate resistance should be determined as follows:

$$N_{u,Rd} = \frac{2.0(e_2 - 0.5\,d_0)\,t\,f_u}{\gamma_{M2}}; \qquad \text{(1 bolt)} \qquad (3.10)$$

$$N_{u,Rd} = \frac{\beta_2\,A_{net}\,f_u}{\gamma_{M2}}; \qquad \text{(2 bolts)} \qquad (3.11)$$

$$N_{u,Rd} = \frac{\beta_3\,A_{net}\,f_u}{\gamma_{M2}}. \qquad \text{(3 bolts or more)} \qquad (3.12)$$

In these expressions,

t is the thickness of the leg of an angle;
f_u is the ultimate strength of steel;
d_0 is the hole diameter ;
e_2 is the distance of the centre of the fastener holes to the adjacent edge of the angle, perpendicular to the direction of load transfer (as illustrated in Figure 3.11);
γ_{M2} is a partial safety factor, defined according to EC3-1-8.

The net area, A_{net}, is calculated according to sub-section 3.1.2.2 (clause 6.2.2); in angles of unequal legs, connected by the smaller leg, A_{net} should be taken as equal to the net section area of an equivalent equal-leg angle of leg size equal to that of the smaller leg. Parameters β_2 and β_3 are reduction factors which are defined depending on the distance between holes (pitch p_1), according to Table 3.1; for values of $2.5d_0 < p_1 < 5d_0$, these parameters can be determined by linear interpolation.

Table 3.1 – Reduction factors β_2 and β_3

Distance	p_1	$\leq 2.5\,d_0$	$\geq 5.0\,d_0$
2 bolts	β_2	0.4	0.7
3 bolts or more	β_3	0.5	0.7

It is reminded that no matter what value is given by (3.10) to (3.12), the resistance is limited by (3.6).

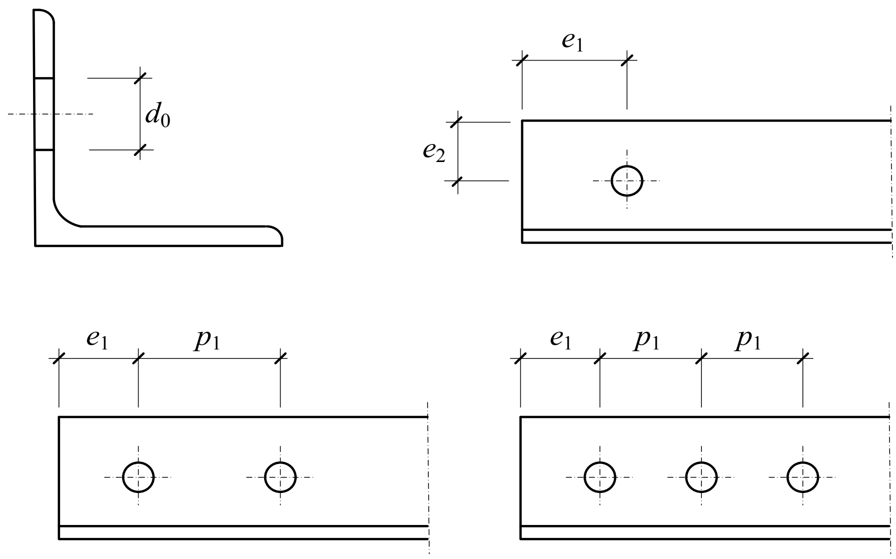

Figure 3.11 – Angles connected by one leg

Members that comprise angles connected by welding only in one leg can be treated as being concentrically loaded. Resistance is determined using expression (3.6), but based on an effective cross section area. The area of the effective cross section, according to clause 4.13 of EC3-1-8, must be evaluated as follows: i) for angles of equal legs or unequal legs that are connected by the larger leg, the area of the effective section may be considered as equal to the gross area; ii) for angles of unequal legs, connected by the smaller leg, the area of the effective section should be taken as equal to the gross area of an equivalent angle, with legs that are equal to the smaller of the legs.

3.2.3. Worked examples

Example 3.1: Calculate the net area A_{net} of the bolted section of the plate represented in Figure 3.12. Assume a plate with thickness t and the remaining dimensions (in *mm*), as indicated in Figure 3.12.

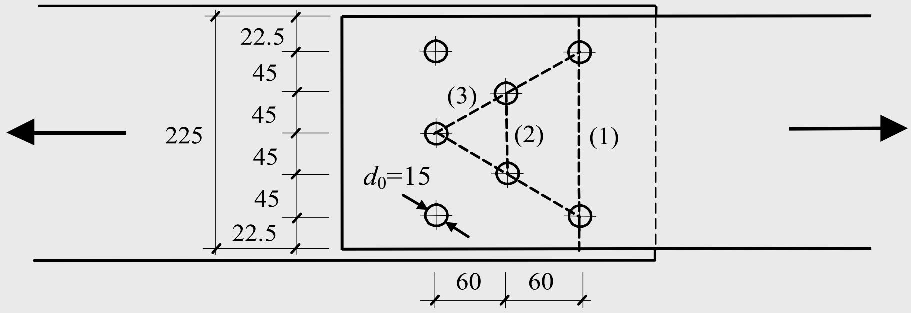

Figure 3.12 – Net area of a plate

The connection is loaded by a concentric axial force, therefore the load may be assumed to be uniformly distributed amongst the fasteners. Due to the position of the fasteners, the net area is evaluated considering fracture sections 1, 2 and 3, as illustrated in Figure 3.12. Fracture section 1 is perpendicular to the direction of the force, whereas fracture sections 2 and 3 include staggered pitches. However, all of these sections correspond to net sections subjected to the totality of the applied axial force. Hence, from expressions (3.3) and (3.4):

Fracture section 1 $\rightarrow A_{net}^{(1)} = 225 \times t - 2 \times t \times 15 = 195\,t$.

Fracture section 2 $\rightarrow A_{net}^{(2)} = 225 \times t - 4 \times t \times 15 + 2 \times t \times \dfrac{60^2}{4 \times 45} = 205\,t$.

Fracture section 3 $\rightarrow A_{net}^{(3)} = 225 \times t - 5 \times t \times 15 + 4 \times t \times \dfrac{60^2}{4 \times 45} = 230\,t$.

The net area of the plate is given by the minimum value, $A_{net} = 195\,t$.

Example 3.2: Consider the chord AB of the steel truss, indicated in Figure 3.13, assuming it is submitted to a design tensile axial force of N_{Ed} = 220 *kN*. The cross section consists of two angles of equal legs, in steel grade S 235. Design chord AB assuming two distinct possibilities for the connections:

a) welded connections;

b) bolted connections.

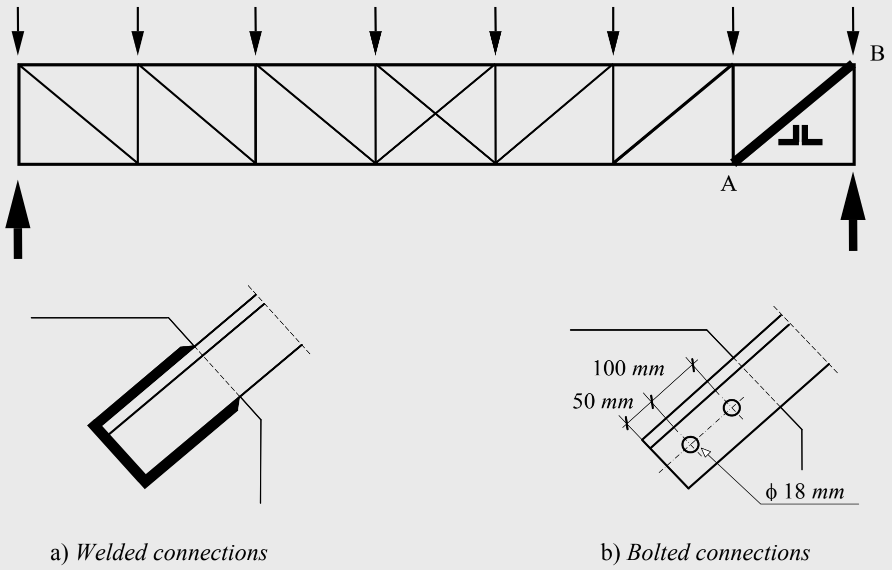

Figure 3.13 – Steel truss

a) *Welded connections*

The chord is made up by two angles of equal legs, but the connection is made only in one leg of the angle. Thus, according to clause 4.13 of EC3-1-8, the effective area can be considered equal to the gross area. Therefore, the following conditions must be satisfied:

$$N_{Ed} \leq N_{t,Rd} = \frac{A\, f_y}{\gamma_{M0}},$$

where $\gamma_{M0} = 1.0$, $f_y = 235\ MPa$ and A is the gross area of the section. Considering the design axial force, $N_{Ed} = 220\ kN$, then:

$$220\ kN \leq \frac{A \times 235 \times 10^3}{1.0} \Rightarrow A \geq 9.36 \times 10^{-4}\ \mathrm{m}^2 = 9.36\ cm^2.$$

From a table of commercial profiles, a solution with two angles 50x50x5*mm*, with a total area of $2 \times 4.8 = 9.6\,cm^2$, satisfies the above safety requirement.

b) *Bolted connections*

In this case, the chord, made up by angles of equal legs, is connected by 2 bolts only in one leg. According to clause 3.10.3 of EC3-1-8, the following design conditions must be ensured:

$$N_{Ed} \leq N_{t,Rd}\text{ , with } N_{t,Rd} = \min\left[N_{pl,Rd} = \frac{A\,f_y}{\gamma_{M0}} ; N_{u,Rd} = \frac{\beta_2\,A_{net}\,f_u}{\gamma_{M2}} \right],$$

where, γ_{M0} = 1.0, γ_{M2} = 1.25, f_y = 235 *MPa*, f_u = 360 *MPa*, A is the gross area of the cross section, A_{net} is the net area of the bolted section, and β_2 is a factor obtained from Table 3.1 (or Table 3.8 of EC3-1-8). A first check based on the plastic design of the gross cross section leads to:

$$220\,kN \leq \frac{A \times 235 \times 10^3}{1.0} \quad \Rightarrow \quad A \geq 9.36 \times 10^{-4}\,m^2 = 9.36\,cm^2.$$

Hence, the section obtained in the previous design, two angles 50x50x5 *mm* ($A = 9.6\,cm^2$), also satisfies this safety requirement.

The second condition (expression (3.11), reproduced above) requires the evaluation of the net area A_{net}, (illustrated in Figure 3.14) and the factor β_2, both evaluated according to clause 3.10.3 of EC3-1-8.

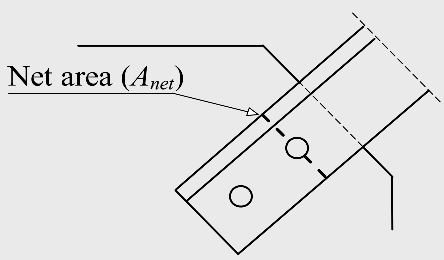

Figure 3.14 – A_{net} in the bolted connection

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This book introduces the fundamental design concept of Eurocode 3 for current steel structures in building construction, and their practical application.
Following a discussion of the basis of design, including the principles of reliability management and the limit state approach, the material standards and their use are detailed. The fundamentals of structural analysis and modeling are presented, followed by the design criteria and approaches for various types of structural members. The theoretical basis and checking procedures are closely tied to the Eurocode requirements. The following chapters expand on the principles and applications of elastic and plastic design, each exemplified by the step-by-step design calculation of a braced steel-framed building and an industrial building, respectively.
Besides providing the necessary theoretical concepts for a good understanding, this manual intends to be a supporting tool for the use of practicing engineers. In order of this purpose, throughout the book, numerous worked examples are provided, concerning the analysis of steel structures and the design of elements under several types of actions. These examples will facilitate the acceptance of the code and provide for a smooth transition from earlier national codes to the Eurocode.

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