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# Design of Steel Structures to Eurocodes

 Springer

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# Preface

Buildings characterize urban areas and are related to the personal, social and professional activities of people. The selection of the appropriate materials for its structural elements (reinforced concrete, steel, aluminum, wood, masonry), depends on the characteristics of the building and the design criteria, such as economic, aesthetic, functional, execution time, as well as the conditions of soil quality and seismicity of the construction area. Steel, as a main structural material, is used in all countries, in a different by country extent, depending on the local conditions and the existing tradition in the construction methods. Steel buildings may be distinguished in single and multi storey. Single storey steel buildings are mainly erected for industrial, commercial, warehousing and sports applications. Multi storey constructions are mainly used for residential or office purposes.

The design and fabrication of buildings are performed following rules provided in specifications and Codes. During the last decades, an extended program of common Codes for all European countries was developed, called Eurocodes, covering both design and fabrication issues, in order to facilitate mobility of construction companies, design offices and engineers in the area of the European Community and beyond it. In addition the cooperation between authorities and technical organizations and personnel, coming from different countries, should become easier.

This book presents the rules for the design of steel buildings according to the above Eurocodes, covering the structure as a whole, as well as the design of individual structural members and connections. The presentation is supplemented by many numerical examples. Specific sections of the book are dedicated to the conceptual design, the fabrication and erection phases and the quality requirements. Rules for the seismic design, when required, are also included. The text is organized in 9 chapters. Chapters 1-5 deal with the methods of analysis, the limit states of design and the resistances of cross-sections, members and connections, while chapters 6-8 are related to the conceptual design of single and multi storey buildings as well as to the fabrication methods and the quality control. Chapter 9 includes numerical applications of the design rules in the form of 52 design examples.

Chapter 1 presents the bases of design, in the frame of Eurocodes, the actions applied to building structures, the load combinations for the various limit states of design, as well as the main steel properties and the steel fabrication methods.

Chapter 2 deals with the models and methods of structural analysis, in combination with the structural imperfections and the cross-section classification according to their compactness.

Chapter 3 discusses the cross-sections resistances, when subjected to axial and shear forces, bending or torsion moments and to combinations of the above.

Chapter 4 presents the members design and more specifically the design of members sensitive to instability phenomena, such as flexural, torsional and lateral-torsional buckling. A particular section is devoted to composite beams.

Chapter 5 refers to the design of connections and joints executed by bolting or welding, including beam to column connections in frame structures.

Chapter 6 discusses alternative configurations to be considered during the conceptual design phase of different types of single storey buildings. The design of crane supporting beams is discussed in a special section.

Chapter 7 gives information about the structural elements and systems of multi storey buildings, especially those ensuring their overall stability along the height, as well as about the alternative configurations that could be applied.

Chapter 8 refers to the fabrication and erection procedures, as well as the related quality requirements and the quality control methods. The procedures for bolting, welding and surface protection are included.

Chapter 9 presents fifty two representative numerical examples, based on the design rules for the verification of cross-sections and members, subjected to the usual types of loading, the verification of bolted and welded connections, as well as for specific items such as hollow sections' joints, uniform built-up compression members or column bases. The calculation steps are directly related in the text with the corresponding paragraphs of Eurocodes.

The book is addressed to the structural engineering students, to young engineers working in the field of design or construction of steel buildings, as well as to engineers not familiar with the regulations of Eurocodes.

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# Symbols

Effort was made for the symbols to be in accordance with those used by the Eurocodes. A single symbol is used for those quantities where different symbols are used by different Eurocodes.

## General symbols for geometric properties

b	width
d	depth
h, H	height
t	thickness
l, L	length, span

## General symbols for mechanical properties

A	area
I	second moment of area (moment of inertia)
S	first moment of area (static moment)
W	cross-section modulus

## General symbols for internal forces and moments

$M$	bending moment
$M_T$	torsional moment
$N$	axial force
$V$	shear force

## General symbols for stresses

$\sigma$	direct (normal) stress
$\tau$	shear stress

## Indexes

a	structural steel
add	additional
b	beam
bat	batten
B	buffer

bear	bearing
c	concrete, compression, column, crane
ch	chord
cr	critical value
d	design value, diagonal
dur	durability
E	action effect
eff	effective
el	elastic
eq	equivalent
f	flange
$f_o$	upper flange
$f_u$	lower flange
fat	fatigue
G	permanent
H	horizontal
inf	lower value
k	characteristic value
L	longitudinal, longterm
max	maximum value
min	minimum value
nom	nominal value
o	top, opening
ov	over-strength
p	plate panel zone
pay	payload
pl	plate, plastic
r	rail
R	resistance
s	reinforcement, skewing
S	shrinkage, short
sa	steel + reinforcement
ser	serviceability
sup	upper value
sur	surface
t	tension
T	torsional, transverse
tot	total
u	ultimate, limit value, bottom
V	vertical
w	web, warping, weld
y	yield
I	first order
II	second order

**Axes**

$x$	longitudinal axis of member
$y$	major principal axis of cross-section
$z$	minor principal axis of cross-section

**Operators**

$\Delta$	difference
$\delta$	variation

**Latin small letters**

$a$	length, thickness of a fillet weld, distance between wheels, spacing, clearance, skewing angle
$a_g$	peak ground acceleration
$b$	width, free gap
$b_{eff}$	effective width
$b_{fo}$	width of top flange of steel girder
$b_{fu}$	width of bottom flange of steel girder
$b_o$	half distance between webs
$b_r$	width of a rail, width of a rib
$b_s$	spacing between ribs
$c$	outstand flange width, concrete cover of reinforcement/shear connectors, smeared spring constant, hole clearance
$c_e$	exposure factor
$c_f$	wind coefficient, force coefficient for the structure or elements
$c_{min}$	minimum value of concrete cover
$c_{nom}$	nominal value of concrete cover
$c_{pe}$	pressure coefficients for external pressure
$c_{pi}$	pressure coefficients for internal pressure
$c_s, c_d$	structural factor
$c_\phi, c_\theta$	stiffness of rotational spring
$d$	differential, diameter, shank diameter of shear connector, length of diagonal, grain diameter, thickness of concrete slab, depth of cross-section
$d_{head,sc}$	head diameter of shear connector
$d$	hole diameter
$d_r$	design interstorey drift
$e$	eccentricity, length of a link
$e_D$	edge distance of shear connectors from steel flange
$e_E$	edge distance of shear connectors from concrete slab
$e_L$	spacing of shear connectors in longitudinal direction, length of a long link
$e_s$	length of a short link
$e_T$	spacing of shear connectors in transverse direction
$e$	imperfection, initial, bow
$e_1, e_2$	end/edge distance of bolts
$f$	reduction factor, stress, skewing angle coefficient, source to object distance

$f_{cd}$	design compression strength of concrete
$f_{ck}$	characteristic compression strength of concrete
$f_u$	tensile strength
$f_{ub}$	tensile strength of bolts
$f_{vw}$	shear strength of welds
$f_y$	yield stress of steel
$f_{yd}$	design yield strength of steel
$f_{yk}$	characteristic yield stress of structural steel
$f_{y,w}$	yield stress of web
$g$	permanent load, acceleration of gravity, gap, length of a haunch
$g_a$	self-weight of steel girder
$g_c$	self-weight of concrete
$h$	height, magnitude of weld imperfection
$h_c$	height of concrete slab
$h_p$	height of a trapezoidal sheet
$h_r$	height of rail
$h_w$	height of web
$h_o$	notional size, height of a web opening
$i$	index, radius of gyration
$i_M$	polar radius of gyration in respect to shear center
$i_p$	polar radius of gyration
$k$	spring constant, constant for relationship between yield strength and grain size, floor stiffness
$k_1, k_2$	reduction coefficients for concrete strength
$k_\sigma$	plate buckling coefficient
$k_\tau$	shear buckling coefficient
$l$	length
$l_{eff}$	effective length
$l_k$	buckling length
$l_T$	buckling length in respect to torsion
$l_y$	effective loaded length
$m$	mass, distributed moment
$m_{Ny}$	non-dimensional strong axis bending resistance allowing for axial force
$m_{N,y,w}$	non-dimensional resistance of web for strong axis bending allowing for axial force
$m_{Nz}$	non-dimensional weak axis bending resistance allowing for axial force
$m_u$	non-dimensional bending moment for angles strong axis
$m_v$	non-dimensional bending moment for angles weak axis, number of single wheel drives
$m_y$	non-dimensional bending moment, strong axis
$m_{yf}$	non-dimensional resistance of flanges for strong axis bending
$m_{yw}$	non-dimensional resistance of web(s) for strong axis bending
$m_z$	non-dimensional bending moment, weak axis
$m_{zf}$	non-dimensional resistance of flanges for weak axis bending
$m_{zw}$	non-dimensional resistance of web(s) for weak axis bending



$n$	non-dimensional axial force, number, number of, modular ratio of concrete, distribution coefficient
$n_f$	non-dimensional axial resistance of both flanges
$n_L$	modular ratio depending on the type of loading
$n_w$	non-dimensional axial resistance of web(s)
$n_o$	number of openings on beam's web
$n_1, n_2$	non-dimensional resistance of web(s) for weak axis bending, distribution factors
$p$	uniformly distributed load, pitch between bolt holes
$p_R$	probability of exceedance
$p_1, p_2$	spacing of bolts, parallel/perpendicular to force
$q$	uniformly distributed load, behavior factor
$q_b$	basic wind pressure
$q_{fk}$	uniformly distributed imposed load on buildings
$q_p$	peak velocity pressure
$q_{u,kin}$	collapse load of kinematic theorem
$q_{u,stat}$	collapse load of static theorem
$r$	radius
$s$	snow load, length in lattice girders, spacing of staggered bolt holes, spacing
$s_k$	snow load, characteristic value
$s_o$	spacing between web openings
$t$	thickness
$t_f$	thickness of flange
$t_{fo}$	thickness of top flange of steel girder
$t_{fu}$	thickness of bottom flange of steel girder
$t_w$	thickness of web
$u$	perimeter, displacements, cross-section major axis of bending for angles
$v$	loading speed, deformation in y-direction, cross-section minor axis of bending for angles, travelling speed of a crane
$v_b$	basic wind velocity
$v_L$	longitudinal shear flow
$v_{L,Ed}$	longitudinal shear flow, design value
$v_{L,Rd}$	longitudinal shear flow, design resistance
$v_{Mt}$	shear flow due to torsional moments
$w$	width, deformation in z-direction, deflection
$w_M$	deflection due to moments
$w_V$	deflection due to shear forces
$x_{pl}$	depth of plastic neutral axis

### Greek small letters

$\alpha$	aspect ratio of panel, imperfection factor, amplification factor
$\alpha_{crit}, \alpha_{cr}$	critical load multiplier
$\alpha_f$	ratio of the area of both flanges to the total area of the cross-section

$\alpha_h, \alpha_m$	reduction factors for sway imperfection
$\alpha_{LT}$	imperfection factor for lateral torsional buckling
$\alpha_{pl}$	shape factor of a cross-section
$\alpha_t$	coefficient of thermal expansion
$\alpha_{ult.k}$	load multiplier to reach the characteristic resistance
$\alpha_w$	ratio of the web area to the total area of the cross-section
$\beta$	buckling length coefficient
$\beta_w$	correlation factor for welds
$\gamma$	safety factor, specific weight, sliding angle
$\gamma_A$	partial safety factor of accidental actions
$\gamma_{AE}$	partial safety factor of seismic actions
$\gamma_c$	partial safety factor for concrete
$\gamma_f, \gamma_F$	partial safety factors for actions
$\gamma_{Ff}$	partial safety factor for fatigue stresses variation
$\gamma_G$	partial safety factor of permanent actions
$\gamma_m$	partial safety factor for a material property
$\gamma_M$	partial safety factor for resistance
$\gamma_{Mf}$	partial safety factor for fatigue resistance
$\gamma_{M0}$	partial safety factor for yield
$\gamma_{M1}$	partial safety factor for stability
$\gamma_{M2}$	partial safety factor for fracture and connections
$\gamma_{M3}$	partial safety factor for slip
$\gamma_Q$	partial safety factor of variable actions
$\gamma_{Rd}$	partial safety factor for resistance
$\gamma_s$	partial safety factor for reinforcement
$\gamma_v$	partial safety factors for shear connectors
$\gamma_I$	importance factor
$\delta$	deflection, Dischinger coefficient
$\delta_{pay}$	deflection due to payload
$\varepsilon$	strain, coefficient depending on $f_y$
$\varepsilon_y$	yield strain
$\varepsilon_u$	ultimate strain
$\theta$	rotation, angle of twist, inter-story sensitivity coefficient
$\theta_p$	rotation of a plastic hinge
$\kappa$	curvature
$\lambda$	slenderness, damage equivalent coefficient, skewing forces coefficient, overlapping percentage
$\lambda_1$	reference slenderness
$\tilde{\lambda}$	relative slenderness for flexural buckling
$\tilde{\lambda}_{LT}$	relative slenderness for lateral torsional buckling
$\tilde{\lambda}_{op}$	relative slenderness for out-of-plane buckling
$\tilde{\lambda}_p$	relative slenderness for plate buckling
$\tilde{\lambda}_w$	relative slenderness for shear buckling
$\tilde{\lambda}_y$	relative slenderness for major axis buckling
$\tilde{\lambda}_z$	relative slenderness for minor axis buckling

$\mu$	slip factor, ductility index, efficiency factor for built-up members
$\mu_i$	snow shape coefficient
$\nu$	Poisson ratio, reduction factor
$\xi$	damping ratio
$\rho$	density, reduction factor for plate buckling, reduction factor for presence of shear, strut index, warping rigidity
$\rho_s$	reinforcement ratio
$\sigma$	direct stress
$\sigma_a$	stress in structural steel
$\sigma_c$	stress in concrete
$\sigma_{cr}$	critical buckling stress
$\sigma_{cr,p}$	critical stress for plate buckling
$\sigma_{cr,FT}$	critical flexural-torsional buckling stress
$\sigma_{cr,T}$	critical torsional buckling stress
$\sigma_s$	stress in reinforcement
$\sigma_{true}$	true stress
$\sigma_w$	stress in web
$\tau$	shear stress
$\tau_{cr}$	critical shear buckling stress
$\tau_{Ed}$	design shear stress
$\tau_f$	flange shear stress
$\tau_w$	web shear stress
$\phi$	angle, dynamic factor
$\phi$	initial sway imperfection
$\chi$	buckling reduction factor
$\chi_c$	reduction factor for column buckling
$\chi_{LT}$	reduction factor for lateral-torsional buckling
$\chi_{op}$	reduction factor for lateral or lateral-torsional buckling
$\chi_w$	reduction factor for shear buckling
$\chi_y$	reduction factor for major axis buckling
$\chi_z$	reduction factor for minor axis buckling
$\psi$	stress ratio, end moments, ratio combination factor of one action with other actions
$\psi_0$	basic value of combination factor
$\psi_1$	frequent value of combination factor
$\psi_2$	quasi permanent value of combination factor
$\omega$	warping function
$\omega_0$	natural circular frequency

### Capital letters

A	cross-section area, gross section area, accidental action
$A_d$	cross-section area of a diagonal
$A_E$	seismic action
$A_{eff}$	effective cross-section area
$A_f$	flange area of cross-section

$A_{net}$	net section area at holes
$A_p$	gross area of plate
$A_{ref}$	reference area for wind force
$A_s$	stress area of bolts
$A_u$	minimum cross-section area after fracture
$A_v$	shear area
$A_w$	web area of cross-section, throat area of weld
$A_0$	initial cross-section area, area enclosed by the middle line of a hollow section
$B$	warping bimoment
$B_{Ed}$	design warping moment
$B_{el.Rd}$	elastic bimoment resistance
$B_{p.Rd}$	punching resistance of bolts
$B_{pl.Rd}$	plastic bimoment resistance
$C$	concrete, creep of concrete, wind load factor, spring constant
$C_d$	rotational spring, limiting design value of the effects of actions in SLS
$C_e$	exposure coefficient
$C_m$	equivalent uniform moment factors
$C_t$	thermal coefficient
$D$	maximum acceptable relative displacement, diameter, compressive force
$\Delta h$	height variation
$\Delta l$	elongation, contraction
$\Delta T_M$	linear temperature difference
$\Delta T_p$	temperature difference between structural parts
$\Delta T_u$	uniform temperature difference
$E$	modulus of elasticity
$E_a$	modulus of elasticity of structural steel
$E_c$	modulus of elasticity of concrete
$E_{c,28}$	modulus of elasticity of concrete at 28 days
$E_{cm}$	modulus of elasticity of concrete – mean value
$E_d$	design value for effect of actions
$E_{d,dst}$	design value for effects of destabilizing actions
$E_{d,stab}$	design value for effects of stabilizing actions
$E_D$	absorbed hysteretic energy
$E_s$	modulus of elasticity of reinforcement
$E_t$	tangent modulus of steel
$F$	force
$F_{b,Rd}$	bearing resistance of bolts
$F_{cr}, F_{crit}$	critical concentrated load, buckling load
$F_d$	design value of an action, force of a diagonal
$F_{Ed}$	imposed design load
$F_{f,Rd}$	bottom flange strength under concentrated load
$F_k$	characteristic value of an action
$F_{p,C}$	preloading force of bolts, design shear force of bolts
$F_{s,Rd}$	slip resistance of bolts
$F_T$	force on a T-stub

$F_{t,Rd}$	tension resistance of bolts
$F_{v,Rd}$	shear resistance of bolts
$F_W$	wind force, force on weld
$G$	weight, shear modulus, permanent action
$G_1$	self-weight of the structure
$G_2$	self-weight of non-structural elements
$G_{inf}$	permanent actions with favorable effects
$G_{sup}$	permanent actions with unfavorable effects
$H$	horizontal force, lateral force, altitude
$HB$	Brinell hardness
$H_{Ed}$	design horizontal loading
$I$	second moment of area (moment of inertia),
$I_{eff}$	second moment of area of effective part
$I_{net}$	second moment of area of net section
$I_p$	second moment of area of plate, polar second moment of area of a stiffener
$I_t$	torsion constant
$I_w$	warping constant
$I_y$	second moment of area around strong axis
$I_z$	second moment of area around weak axis
$J$	creep function, impact energy, torsion constant
$K$	stiffness , drive force
$K_G$	geometric stiffness matrix
$L$	length, span, longitudinal force
$L_e$	distance between zero moments
$L_{eff}$	effective length for resistance to concentrated forces
$L_f$	influence length
$L_\Phi$	determinant length
$M$	bending moment, mass
$M_{a,el,Rd}$	elastic design moment resistance of steel girder
$M_{c,Rd}$	design bending resistance
$M_{Ed}$	design moment
$M_{el}$	elastic moment of a cross-section
$M_{el,Rd}$	elastic design moment resistance
$M_{f,Rd}$	design bending resistance of cross-section consisting of the flanges only
$M_{N,pl,Rd}$	design bending resistance of cross-section allowing for axial forces
$M_{N,y,Rd}$	design strong axis bending resistance allowing for axial forces
$M_{N,z,Rd}$	design weak axis bending resistance allowing for axial forces
$M_{pl}, M_p$	plastic moment of a cross-section
$M_{pN}$	plastic moment allowing for axial forces
$M_{pl,Rd}$	design plastic bending resistance
$M_{pl,u,Rd}$	strong axis plastic design bending resistance for angles
$M_{pl,v,Rd}$	weak axis plastic design bending resistance for angles
$M_{pl,V,Rd}$	design plastic bending resistance allowing for shear forces
$M_{p,link}$	bending plastic resistance of a link
$M_{pl,y,Rd}$	plastic design bending resistance, strong axis
$M_{pl,z,Rd}$	plastic design bending resistance, weak axis

$M_r$	torque for tightening of bolts
$M_R$	bending resistance
$M_{Rd}$	design bending resistance
$M_{sh}$	primary shrinkage moment
$M_{T,Ed}$	design torsional moment
$M_w$	bi-moment
$M_x, M_t$	torsional moment
$M_{xp}$	primary torsional moment
$M_{xs}$	secondary torsional moment
$M_{y,Ed}$	design strong axis moment
$M_{z,Ed}$	design weak axis moment
$M_I$	moment from first order theory
$M_{II}$	moment from second order theory
$N$	axial force
$N_{b,Rd}$	design buckling resistance
$N_c$	axial force in concrete
$N_{c,el}$	force in concrete at elastic resistance of steel girder
$N_{c,f}$	force in concrete for full shear connection
$N_{cr}$	Euler buckling load, axial force at cracking of concrete
$N_{cr,y}$	critical buckling forces for major axis
$N_{cr,z}$	critical buckling forces for minor axis
$N_{c,Rd}$	design resistance to compression
$N_E$	critical Euler buckling load
$N_{Ed}$	design axial force
$N_{Ed,G}$	design axial force due to the non-seismic loads
$N_{net,Rd}$	design yielding resistance at net section
$N_{pl}, N_p$	plastic axial force
$N_{pl,Rd}$	plastic design resistance force
$N_R$	resistance to axial force
$N_s$	axial force in reinforcement
$N_{sh}$	primary shrinkage axial force
$N_{t,Rd}$	design resistance to tension
$N_{u,Rd}$	design ultimate resistance to tension for sections with holes
$P$	load, force, prestressing
$P_e$	limit elastic force
$P_p$	limit plastic force
$P_{Rd}$	shear resistance of shear connectors
$P_u$	ultimate force
$Q$	variable action, imposed load on buildings
$Q_k$	variable load, concentrated load, characteristic value
$Q_{max}$	maximum value of the characteristic vertical wheel load
$Q_{r,min}$	minimum load per wheel of the unloaded crane
$R$	resistance
$R_d$	design resistance
$R_{fy}$	resistance of a dissipative member
$RH$	relative humidity

$S$	static moment (first moment of area), snow load, fatigue class of a crane, force applied by the guidance means of a crane wheel
$S_a$	blast cleaning class
$S_{a,d}$	design response spectrum, design spectral acceleration
$S_B$	spring constant of a buffer
$S_e$	elastic response spectrum, elastic spectral acceleration
$S_j$	rotation stiffness of a joint
$S_v$	shear stiffness
$T$	temperature, vibration period, transverse force, total torsional moment
$T_{Ed}$	design torsion moment
$T_L$	design life
$T_R$	return period of an event
$T_t$	St Venant torsion moment
$T_{t,pl,Rd}$	plastic Saint Venant torsion resistance
$T_w$	warping torsion moment
$U$	class of crane related to the total number of cycles
$V$	shear force, vertical load, total potential
$V_{b,Rd}$	shear buckling resistance
$V_{bf,Rd}$	design shear resistance-contribution of the flange
$V_{bw,Rd}$	design shear resistance-contribution of the web
$V_L$	force due to longitudinal shear
$V_{p,link}$	plastic shear resistance of a link
$V_{Ed}$	design shear force, design vertical loading
$V_{pl,Rd}$	plastic shear resistance
$V_{Rd}$	design shear resistance
$W$	section modulus, wind load
$W_{eff}$	elastic section modulus of effective cross-section
$W_{el}$	elastic section modulus
$W_{pl}$	plastic section modulus
$W_{pl,u}$	strong axis plastic section modulus for angles
$W_{pl,v}$	weak axis plastic section modulus for angles
$X$	material property
$Z$	through thickness property
$\Delta$	erection or manufacturing tolerance
$\Delta \delta$	deflection variation
$\Delta \sigma$	normal stress variation
$\Delta \sigma_c$	fatigue resistance against normal stress variation
$\Delta \tau$	shear stress variation
$\Delta \tau_c$	fatigue resistance against shear stress variation
$\Sigma Q_r$	sum of all wheel vertical loads of a loaded crane
$\Phi$	Coefficient to determine the reduction factor $\chi$ , diameter of bars
$\Omega$	ratio $N_{Rd}/N_{Ed}$ or $M_{Rd}/M_{Ed}$