



BSI Standards Publication

Eurocode 3 — Design of steel structures

Part 1-14: Design assisted by finite element analysis

National foreword

This British Standard is the UK implementation of EN 1993-1-14:2025.

The UK participation in its preparation was entrusted to Technical Committee CB/203, Design & execution of steel structures.

A list of organizations represented on this committee can be obtained on request to its committee manager.

National choice is allowed in this standard where explicitly stated within notes. The National Annex to this standard contains the national choices to be used for buildings and civil engineering works constructed in the UK.

The first generation of EN Eurocodes was published between 2002 and 2007, with conflicting British Standards withdrawn in 2010. This document forms part of the second generation of EN Eurocodes.

The second generation of EN Eurocodes is expected to be published between 2023 and 2026. These documents are being published as soon as they are available. This is being done to enable users to prepare for the transition from the first generation to second generation of EN Eurocodes.

UK adoptions of the first generation of EN Eurocodes will be withdrawn by BSI on 30 March 2028. Until that date, the first generation documents should be considered as the applicable standards for buildings and civil engineering works constructed in the UK unless otherwise specified by the relevant authority or in the specification for a particular project.

This standard is intended to be used with its National Annex and other referenced documents, including other second generation Eurocodes, as an interdependent suite of documents.

While the use of provisions in this standard in conjunction with first generation Eurocodes is not precluded, it should be undertaken with care and should only be done when users are satisfied that it will not result in a lower level of reliability than the minimum level set in the first generation Eurocodes and associated UK National Annexes.

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Eurocode 3 - Bemessung und Konstruktion von Stahlbauten - Teil 1-14: Bemessung mithilfe von Finite-Element-Berechnung

This European Standard was approved by CEN on 20 July 2025.

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Contents	Page
European foreword	4
0 Introduction.....	5
1 Scope.....	8
1.1 Scope of EN 1993-1-14	8
1.2 Assumptions	8
2 Normative references.....	9
3 Terms, definitions and symbols	9
3.1 Terms and definitions	9
3.2 Symbols and abbreviations	11
3.2.1 Latin upper-case symbols	11
3.2.2 Latin lower-case symbols.....	12
3.2.3 Greek upper-case symbols	12
3.2.4 Greek lower-case symbols.....	13
4 Basis of design.....	14
5 Modelling	16
5.1 Geometrical models	16
5.1.1 General rules for geometrical modelling and discretization	16
5.1.2 Models using beam elements.....	16
5.1.3 Models using plate or shell elements	17
5.1.4 Models using solid elements.....	17
5.1.5 Multi-level and combined models.....	17
5.2 Support and load models	18
5.2.1 Definition of supports	18
5.2.2 Definition of loads	18
5.3 Material models.....	19
5.3.1 General.....	19
5.3.2 Material models for hot-rolled steels with a sharply defined yield point.....	20
5.3.3 Material models for hot-rolled steels with a rounded stress-strain curve, cold-formed steels and stainless steels	22
5.3.4 Advanced material models.....	25
5.4 Imperfections	25
5.4.1 Types of imperfection	25
5.4.2 Geometric imperfections	26
5.4.3 Residual stresses.....	26
5.4.4 Equivalent geometric imperfections	29
5.5 Imperfection combinations.....	33
6 Analysis	33
6.1 Structural analysis.....	33
6.1.1 General.....	33
6.1.2 Types of analysis	34
6.2 Thermal analysis.....	36
7 Verification and validation.....	36

7.1	General	36
7.2	Verification	37
7.3	Validation	38
8	Design methodology	40
8.1	Ultimate limit state (excluding fatigue)	40
8.1.1	General	40
8.1.2	Elastic resistance check – stress check	40
8.1.3	Plastic resistance check.....	41
8.1.4	Buckling resistance check	41
8.1.5	Evaluation method for analysis with material nonlinearity.....	44
8.2	Fatigue	45
8.2.1	General	45
8.2.2	Fatigue checking by the hot spot and effective notch stress method	46
8.2.3	Stress extrapolation for the hot spot stress method in joints	47
8.2.4	FE modelling – hot spot stress.....	52
8.2.5	FE modelling – effective notch stress	53
8.2.6	Additional considerations	54
8.3	Serviceability limit state	55
9	Documentation	55
Annex A (informative) Calculation of model factor (γ_{FE}).....		57
A.1	Use of this annex	57
A.2	Scope and field of application	57
A.3	Calculation of model factor (γ_{FE})	57
Annex B (informative) Stress concentrations		59
B.1	Use of this annex	59
B.2	Scope and field of application	59
B.3	Separation of stress concentration and numerical singularities.....	59
B.4	Consideration of stress concentration in design.....	60
Annex C (normative) Limits on maximum strains for beam finite elements.....		62
C.1	Use of this annex	62
C.2	Scope and field of application	62
C.3	Strain limits	62
Bibliography		66

European foreword

This document (EN 1993-1-14:2025) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical matters by CEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2027, and conflicting national standards shall be withdrawn at the latest by March 2028.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

The first generation of EN Eurocodes was published between 2002 and 2007. This document forms part of the second generation of the Eurocodes, which have been prepared under Mandate M/515 issued to CEN by the European Commission and the European Free Trade Association.

The Eurocodes have been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by the Eurocodes.

The Eurocodes recognize the responsibility of each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level through the use of National Annexes.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and the United Kingdom.

0 Introduction

0.1 Introduction to the Eurocodes

The Structural Eurocodes comprise the following standards generally consisting of a number of parts:

- EN 1990 Eurocode — Basis of structural and geotechnical design
- EN 1991 Eurocode 1 — Actions on structures
- EN 1992 Eurocode 2 — Design of concrete structures
- EN 1993 Eurocode 3 — Design of steel structures
- EN 1994 Eurocode 4 — Design of composite steel and concrete structures
- EN 1995 Eurocode 5 — Design of timber structures
- EN 1996 Eurocode 6 — Design of masonry structures
- EN 1997 Eurocode 7 — Geotechnical design
- EN 1998 Eurocode 8 — Design of structures for earthquake resistance
- EN 1999 Eurocode 9 — Design of aluminium structures
- EN 19100 Eurocode 10 — Design of glass structures
- New parts are under development, e.g. Eurocode for design of fibre-polymer composite structures and design of tensioned membrane structures

The Eurocodes are intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

NOTE Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

0.2 Introduction to EN 1993 (all parts)

EN 1993 (all parts) applies to the design of buildings and civil engineering works in steel. It complies with the principles and requirements for the safety and serviceability of structures, the basis of their design and verification that are given in EN 1990-1 – Basis of structural and geotechnical design – Part 1: New structures.

EN 1993 (all parts) is concerned only with requirements for resistance, serviceability, durability and fire resistance of steel structures. Other requirements, e.g. concerning thermal or sound insulation, are not covered.

EN 1993 is subdivided in various parts:

EN 1993-1-1, *Eurocode 3 — Design of Steel Structures — Part 1-1: General rules and rules for buildings*;

EN 1993-1-2, *Eurocode 3 — Design of Steel Structures — Part 1-2: Structural fire design*;

EN 1993-1-3, *Eurocode 3 — Design of Steel Structures — Part 1-3: Cold-formed members and sheeting*;

NOTE Cold-formed hollow sections supplied according to EN 10219 (all parts) are covered in EN 1993-1-1.

EN 1993-1-4, *Eurocode 3 — Design of Steel Structures — Part 1-4: Stainless steel structures*;

EN 1993-1-5, *Eurocode 3 — Design of Steel Structures — Part 1-5: Plated structural elements*;

EN 1993-1-6, *Eurocode 3 — Design of Steel Structures — Part 1-6: Strength and stability of shell structures*;

EN 1993-1-7, *Eurocode 3 — Design of Steel Structures — Part 1-7: Plate assemblies with elements under transverse loads*;

EN 1993-1-8, *Eurocode 3 — Design of Steel Structures — Part 1-8: Joints*;

EN 1993-1-9, *Eurocode 3 — Design of Steel Structures — Part 1-9: Fatigue*;

EN 1993-1-10, *Eurocode 3 — Design of Steel Structures — Part 1-10: Material toughness and through-thickness properties*;

EN 1993-1-11, *Eurocode 3 — Design of Steel Structures — Part 1-11: Tension components*;

EN 1993-1-12, *Eurocode 3 — Design of Steel Structures — Part 1-12: Additional rules for steel grades up to S960*;

EN 1993-1-13, *Eurocode 3 — Design of Steel Structures — Part 1-13: Beams with large web openings*;

EN 1993-1-14, *Eurocode 3 — Design of Steel Structures — Part 1-14: Design assisted by finite element analysis*;

EN 1993-2, *Eurocode 3 — Design of Steel Structures — Part 2: Bridges*;

EN 1993-3, *Eurocode 3 — Design of Steel Structures — Part 3: Towers, masts and chimneys*;

EN 1993-4-1, *Eurocode 3 — Design of Steel Structures — Part 4-1: Silos*;

EN 1993-4-2, *Eurocode 3 — Design of Steel Structures — Part 4-2: Tanks*;

EN 1993-5, *Eurocode 3 — Design of Steel Structures — Part 5: Piling*;

EN 1993-6, *Eurocode 3 — Design of Steel Structures — Part 6: Crane supporting structures*;

EN 1993-7, *Eurocode 3 — Design of Steel Structures — Part 7: Sandwich panels* (under preparation).

All parts numbered EN 1993-1-2 to EN 1993-1-14 treat general topics that are independent from the structural type such as structural fire design, cold-formed members and sheeting, stainless steels, plated structural elements, etc.

All parts numbered EN 1993-2 to EN 1993-7 treat topics relevant for a specific structural type such as steel bridges, towers, masts and chimneys, silos and tanks, piling, crane supporting structures, etc. EN 1993-2 to EN 1993-7 refer to the generic rules in EN 1993-1 and supplement, modify or supersede them.

0.3 Introduction to EN 1993-1-14

EN 1993-1-14 gives requirements for use of numerical methods in the design of steel structures, more specifically for the ultimate limit state (including fatigue) and serviceability limit state verifications. It also gives requirements for the application of advanced finite element and similar modelling techniques, which may also be used in design.

Background information and explanations to the design rules given in this code can be found in the Technical Report - CEN/TR 1993-1-141 [3]. A series of validation and design examples are also included in this document. The validation examples give background and support to the numerical model validation process, while the design examples support the correct application of the EN 1993-1-14 design provisions.

0.4 Verbal forms used in the Eurocodes

The verb “shall” expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may” expresses a course of action permissible within the limits of the Eurocodes.

The verb “can” expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.5 National Annex for EN 1993-1-14

National choice is allowed in this standard where explicitly stated within notes. National choice includes the selection of values for Nationally Determined Parameters (NDPs).

The national standard implementing EN 1993-1-14 can have a National Annex containing all national choices to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

When no national choice is given, the default choice given in this standard is to be used.

When no national choice is made and no default is given in this standard, the choice can be specified by a relevant authority or, where not specified, agreed for a specific project by appropriate parties.

National choice is allowed in EN 1993-1-14 through notes to the following clauses:

4(11)	4(13)	5.4.2(1)	7.1(6)
7.2(3)	7.3(2)	7.3(3)	7.3(6)
7.3(7)	8.1.2(3)	8.1.2(5)	8.1.5(2)
C.3(3)			

National choice is allowed in EN 1993-1-14 on the application of the following informative annexes:

Annex A	Annex B
The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.	

1 Scope

1.1 Scope of EN 1993-1-14

(1) This document gives requirements for the use of numerical methods in the design of steel structures, more specifically for the ultimate limit state (including fatigue) and serviceability limit state verifications. It also gives requirements for the application of advanced finite element (FE) and similar modelling techniques.

(2) This document covers general methodologies such as the finite element method (FEM), finite strip method (FSM) or generalized beam theory (GBT) for modelling, analysis and design of steel structures made of the following members and joint configurations:

- a) hot-rolled profiles,
- b) cold-formed members and sheeting,
- c) welded plated profiles,
- d) stainless steel profiles,
- e) plate assemblies,
- f) shell structures,
- g) welded and bolted joints.

In addition to the general design rules, specific additional rules can also be found in the relevant parts of EN 1993.

(3) This document contains harmonized design rules in terms of the application of the numerical modelling methods, development of the numerical models, application of analysis types, result evaluation methods, and determination of the resistance of steel structures for different limit states.

(4) This document provides rules for numerical modelling and design of steel structures using all steel grades from S235 up to and including S700, unless otherwise stated in individual clauses.

1.2 Assumptions

(1) This document gives rules intended for engineers who are experienced in the use of FE.

(2) It is recognized that structural analysis, based upon the laws of physics, has been successfully researched, developed, historically or currently used for the design and verification of elements or whole structural frames. This remains appropriate for many structural solutions. However, as an alternative, the methods described in this document can be also applied for design.

(3) Unless specifically stated, EN 1990, EN 1991 (all parts) and the other relevant parts of EN 1993-1 apply.

(4) The design methods given in this document are applicable if

- the execution quality is as specified in EN 1090-2 and/or EN 1090-4, and
- the construction materials and products used are as specified in the relevant parts of EN 1993, or in the relevant material and product specifications.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. through 'should' clauses) and permissions (i.e. through 'may' clauses).

EN 1090-2, *Execution of steel structures and aluminium structures - Part 2: Technical requirements for steel structures*

EN 1090-4, *Execution of steel structures and aluminium structures - Part 4: Technical requirements for cold-formed structural steel elements and cold-formed structures for roof, ceiling, floor and wall applications*

EN 1990:2023, *Eurocode - Basis of structural and geotechnical design*

EN 1991 (all parts), *Eurocode 1 — Actions on structures*

EN 1993 (all parts), *Eurocode 3 — Design of steel structures*

3 Terms, definitions and symbols

For the purposes of this document, the following terms, definitions and symbols apply.

3.1 Terms and definitions

3.1.1

analysis requiring subsequent design check

analysis which results in different system response quantities to be used in the design check of the analysed structure

Note 1 to entry: Analysis types to be applied: LA, LBA, GNA, GNIA, MNA

3.1.2

benchmark case

list of input and output data of the analytical or numerical solutions to verify the results by comparison with simplified model, or experimental tests

3.1.3

degree of freedom

DOF

independent motion that is allowed to the structure

Note 1 to entry: DOF can be defined as DOF per node (1 to 7 – maximum 3 translational, 3 rotational and warping) and total number of DOFs for the whole structure as sum of all node's DOFs.

3.1.4

direct resistance check

analysis performed for design checks, which results in the ultimate resistance of the analysed structure

Note 1 to entry: Analysis types to be applied: MNA, GMNA, GMNIA.

3.1.5

follower load

load changing direction as a function of the deformation of the analysed structure in a non-linear analysis

3.1.6

global analysis

structural analysis of the complete structure or part of the structure under investigation, rather than individual structural members or components treated separately

3.1.7

numerical model

numerical idealization to simulate and predict aspects of behaviour of a system used to represent the structural behaviour of the analysed structure or a part of it

3.1.8

multi-level or combined model

modelling of the entire structure using different types of elements within one model, making the DOFs compatible at the intersection regions

3.1.9

numerical design calculation

numerical model and analysis type used for the static design check of a structure or a part of it

Note 1 to entry: Results of the numerical model can be (i) different system response quantities (SRQs) to be used for further evaluation or (ii) resistances to be used for direct resistance check.

3.1.10

numerical simulation

complementation or extension of physical experiments to determine the direct resistance of a structure

3.1.11

second order analysis

geometrically non-linear analysis based on second order approximations (geometric stiffness or stress stiffening approach)

3.1.12

standard design case

numerical model-based design check of failure modes for which Eurocode based design resistance model also exists

3.1.13

sub-model

part of the entire structure modelled using equivalent support and load conditions representing the neglected part of the structure

3.1.14

system response quantity

SRQ

relevant output value resulting from a certain analysis

Note 1 to entry: SRQ reflects the main objective of the analysis by selecting the important parameters and the limitation of their errors in both verification and validation. Examples for SQR are internal forces or deformations

3.1.15**validation**

comparison of the numerical results to experimental data or known accurate solutions

3.1.16**verification**

comparison of the numerical solution and the exact mathematical solution

3.2 Symbols and abbreviations**3.2.1 Latin upper-case symbols**

A	elongation after fracture defined in the relevant product standard
C_1, C_2	material coefficient for hot-rolled steels
E	modulus of elasticity
E_1, E_2, E_3	strain hardening modulus of the stress-strain curve for cold-formed structures covered by EN 1993-1-3
$E_{0.2}$	tangent modulus of the stress-strain curve at the yield strength for cold-formed steel and stainless steels
E_{sh}	strain hardening modulus for hot-rolled steels
F	force
H	total section depth of welded box sections
L	member length
$L_{r,min}, L_{r,max}$	limits of the extrapolation region for tubular joints in fatigue design situation
R_{comp}	structural resistance computed by the numerical model
$R_{b,d}$	design buckling resistance
$R_{b,k}$	characteristic buckling resistance
R_{check}	computed resistance for the check structural resistance case
R_{cr}	lowest elastic critical buckling load of the examined structure
R_{GMNA}	calculated plastic resistance based on GMNA
R_{GMNIA}	calculated buckling resistance based on GMNIA
$R_{k,known}$	calculated or known characteristic structural resistance
$R_{test,known}$	known test result
R_{MNA}	calculated plastic resistance based on MNA
$R_{pl,d}$	design plastic resistance of the examined structure or cross-section
$R_{pl,k}$	characteristic plastic resistance of the examined structure or cross-section
V_X	coefficient of variation of the ratio of the measured (or known) and computed results

V_{Ed}	design value of the shear force
$V_{pl,Rd}$	design value of the plastic resistance to shear force

3.2.2 Latin lower-case symbols

a	length of a panel or sub-panel
b	width of a panel or sub-panel
b_f	flange width
b_{num}	correction factor
$a_{rs}, b_{rs}, c_{rs}, d_{rs}, e_{rs}, f_{rs}, g_{rs}, h_{rs}$	geometrical parameters of the residual stress patterns
e	displacement
e_0	amplitude of the equivalent geometric imperfection
$e_{0,dist}$	imperfection magnitude for distortional buckling mode
f_u	ultimate tensile strength
f_y	yield strength
f_{yb}	basic yield strength of cold-formed steel
h	total depth of I-sections
h_w	web depth
k_n	characteristic fractile factor
m	second strain hardening exponent for the Ramberg-Osgood type material model for cold-formed steels and stainless steels
m_X	mean value of the ratio of the measured (or known) and computed results
n	first strain hardening exponent for the Ramberg-Osgood type material model for cold-formed steels and stainless steels
r	radius of notch in fatigue design situation
t	plate thickness
t_w	web thickness
t_0	chord member wall thickness in tubular joints
t_1	brace member wall thickness in tubular joints

3.2.3 Greek upper-case symbols

Θ	flank angle of the weld model in fatigue design situation
Ω	project specific parameter that defines the maximum permissible level of plastic strain in the structure

3.2.4 Greek lower-case symbols

α	imperfection factor
α_δ	weighting factor for Q_δ
$\alpha_{ult,k}$	minimum load amplifier of the design loads to reach the characteristic resistance of the most critical cross-section
β_{LT}	reference relative bow imperfection for lateral torsional buckling
ε	strain
$\varepsilon_{0,2}$	total strain at 0,2 % proof stress for the Ramberg-Osgood type material model for cold-formed steels and stainless steels
$\varepsilon_{1,0}$	total strain at 1 % proof stress for the Ramberg-Osgood type material model for cold-formed steels and stainless steels
ε_{csm}	maximum allowed plastic strain based on continuous strength method
ε_{Ed}	design value of the maximum longitudinal compressive strain
ε_{mb}	maximum plastic strain for bolts determined from the bolt elongation after fracture
ε_{mpb}	maximum allowed plastic strain for bolts in the numerical model
ε_{sh}	strain hardening strain for hot-rolled steels
ε_{true}	true-strain
ε_u	ultimate strain
ε_y	yield strain
$\bar{\lambda}$	relative slenderness
ν	Poisson's ratio
ν_{pl}	Poisson's ratio in the plastic range
σ	stress
$\sigma_{0,05}$	0,05 % proof stress for the Ramberg-Osgood type material model for cold-formed steels and stainless steels
$\sigma_{1,0}$	1 % proof stress for the Ramberg-Osgood type material model for cold-formed steels and stainless steels
$\sigma_{0,4t}$	calculated change in stress in a distance of 0,4·t from the weld toe in fatigue design situation
$\sigma_{0,5t}$	calculated change in stress in a distance of 0,5·t from the weld toe in fatigue design situation
$\sigma_{0,9t}$	calculated change in stress in a distance of 0,9·t from the weld toe in fatigue design situation
$\sigma_{1,0t}$	calculated change in stress in a distance of 1,0·t from the weld toe in fatigue design situation

$\sigma_{1,5t}$	calculated change in stress in a distance of $1,5 \cdot t$ from the weld toe in fatigue design situation
σ_{4mm}	calculated change in stress in a distance of 4 mm from the weld toe in fatigue design situation
σ_{5mm}	calculated change in stress in a distance of 5 mm from the weld toe in fatigue design situation
σ_{8mm}	calculated change in stress in a distance of 8 mm from the weld toe in fatigue design situation
σ_{12mm}	calculated change in stress in a distance of 12 mm from the weld toe in fatigue design situation
σ_{15mm}	calculated change in stress in a distance of 15 mm from the weld toe in fatigue design situation
σ_{rt}	tensile residual stress
σ_{rc}	compressive residual stress
σ_{ft}, σ_{wt}	tensile residual stress of stainless steel welded or laser welded I-sections and welded box sections
σ_{fc}, σ_{wc}	compressive residual stress of stainless steel welded or laser welded I-sections and welded box sections
$\sigma_{cr,cs}$	elastic local critical buckling stress of the full cross-section
$\sigma_{cr,d}$	elastic critical distortional buckling stress
σ_{nom}	nominal stress in fatigue design situation
σ_{HS}	geometric (hot spot) stress in fatigue design situation
σ_{EN}	effective notch stress in fatigue design situation
σ_{true}	true-stress
ρ	reduction factor to determine the design value of the reduced plastic resistance to bending moment making allowance for the presence of shear forces
ρ_{csm}	reduction factor for the maximum allowed strain limit in beam elements considering interaction between bending and shear
γ_{FE}	model factor covering the uncertainties of the numerical model and the executed analysis type

4 Basis of design

(1) The basis of design with numerical methods shall be in accordance with the general rules given in EN 1990 and EN 1991 (all parts) and the specific design provisions for steel structures given in the relevant parts of EN 1993.

(2) Steel structures designed according to this document shall be executed according to EN 1090-2 and/or EN 1090-4 with construction materials and products used as specified in the relevant parts of EN 1993, or in the relevant material and product specifications.

(3) Dynamic effects should be taken into account according to the relevant application part of EN 1993. This document does not contain rules for dynamic analysis.

(4) This document gives design rules for the

- a) ultimate limit state (excluding fatigue),
- b) fatigue,
- c) serviceability limit state.

(5) Finite element analysis-based design may be carried out by one of the following two methods, which should be treated differently in the design process:

- a) numerical design calculation,
- b) numerical simulation.

(6) The design methods differ regarding the (i) applied geometrical and material properties, (ii) results of the analysis, (iii) verification and validation process, (iv) evaluation method of output data and (v) reliability assessment of the calculation results.

(7) Numerical design calculations may be different based on the analysis type and its results; design rules are given based on the following two categories:

- a) analysis requiring subsequent design check,
- b) direct resistance check.

(8) In the case of analysis requiring subsequent design check one of the following analysis types should be used: LA, LBA, GNA, GNIA, MNA (see 6.1.2 and Table 6.1). The results of the analysis are different system response quantities which are to be further used in the design check of the analysed structure.

(9) In the case of direct resistance check one of the following analysis types should be used: MNA, GMNA, GMNIA (see 6.1.2 and Table 6.1). The result of the analysis is the ultimate resistance of the analysed structure, determined according to 8.1.5.

(10) In the case of numerical design calculations, nominal values should be used for the geometry, and characteristic values should be applied for the material properties obtained from the relevant parts of EN 1993.

(11) Numerical simulations may be applied to complement or extend laboratory tests used in design assisted by testing.

NOTE The National Annex can give further rules and limitation on the application of numerical simulation.

(12) In the case of numerical simulations, measured (or mean) values should be used for geometrical and material properties. The result of the analysis is the prediction of the measured (or mean) resistance of the analysed structure.

(13) Verification and validation, according to Clause 7, of the employed finite element model covering all relevant failure modes should be performed in cases where the application of finite element analysis-based design methods provides significant resistance increases compared to well-established traditional design methods.

NOTE 1 In cases of significant resistance increases the structural resistance can be reduced accordingly.

NOTE 2 The National Annex can specify acceptance limits of the numerical model results for specific cases.

(14) The rules given in this document are independent of the software used. The capabilities of the software should be checked by the designer, and it should be confirmed that the software is applicable to the limit state being checked, see Clause 8.

(15) Analysis shall be based upon numerical models that are appropriate for the limit state under consideration. The analysis type applied shall be consistent with the design assumptions.

5 Modelling

5.1 Geometrical models

5.1.1 General rules for geometrical modelling and discretization

(1) The chosen finite element (linear or higher order element) shall be related to the chosen mesh density, geometric complexity (curvature) and the solution method to ensure that the results meet both the verification and validation requirements, see Clause 7.

(2) The discretization of the chosen model should be adequate and it should follow the geometrical properties of the structure.

(3) The accuracy of the FE mesh (density, element type, element shape properties such as aspect ratio, jacobian ratio, warping factor, etc.) should be of suitable quality and be proven by model verification according to Clause 7.

(4) At locations with high stress, strain or temperature concentrations/gradients or at the location where failure of the structure is anticipated, mesh refinement can improve accuracy, except for fatigue design checking which applies predefined mesh refinements according to 8.2.

(5) Cold-formed steel cross-sections should be modelled with rounded corners, if their effect is relevant according to EN 1993-1-3, otherwise modelling of rounded corners may be omitted from the model.

(6) Where FE analysis is used in support of design calculations for joints in cold-formed structures in the scope of EN 1993-1-3, the joint FE model should be validated by test results or verified against appropriate design rules.

(7) Element types (such as cable elements, nonlinear bars, etc.) not covered by the following clauses may also be applied in the numerical model taking account of their particular modelling requirements.

(8) A geometrically nonlinear global analysis of beam structures (see 6.1.2) may normally be based on second order theory (see 3.1.11), because in general, the accuracy of calculations according to second order theory is sufficient for global analysis of frame structures. If in exceptional cases, the displacements are large enough to significantly change the stress resultants in the structure, more accurate geometrically nonlinear calculations should be applied.

(9) The degrees of freedom (DOFs) of the chosen element should be made compatible within the modelled structure and with the chosen boundary conditions.

(10) Where the geometry of the structure varies with time (for instance in a Construction Stage Analysis), careful consideration should be given to the strain state of new elements or groups of elements at the point of instantiation. Where uncertainty exists in regard to appropriate strain state, sensitivity studies should be undertaken to identify the critical situation for design purposes.

(11) The structural detailing with respect to strength and ductility requirements shall conform to the assumption made for the analysis.

5.1.2 Models using beam elements

(1) The system axis of the beam model should usually be identical to that of the centroid of the cross-sections, or it should be chosen such that the effects of its offset from the centroid of the cross-sections are sufficiently small to ignore.

- (2) If the system axis differs from the centroid line (or if shear and gravity centres differ and are relevant in the calculation), either eccentricities should be included in the interpretation, or internal force adjustment should be made in the numerical analysis.
- (3) When using beam finite element models, the behaviour of the joints between structural members should be considered.
- (4) The structural properties of the joints should be determined according to EN 1993-1-8 unless a conservative choice for the stiffness of the joints is made for the analysis.
- (5) If torsion and/or stability problems involving torsion (e.g. lateral torsional buckling, torsional buckling, torsional-flexural buckling, etc.) are analysed using beam models, the elements used should be capable of capturing torsion-related warping effects (for example elements using 7 DOFs - 3 translational, 3 rotational and warping).
- (6) The formulation of beam elements should account for shear deformation when relevant.
- (7) For strain limits to determine the point at which cross-section failure occurs use Annex C (normative).

5.1.3 Models using plate or shell elements

- (1) The middle surface of a plate or shell may be taken as the reference surface for modelling. The effects of eccentricities and offsets from mid-surfaces should be properly included in the model such that they realistically represent the structural behaviour of the modelled structure.
- (2) Eccentricities and steps in the middle surface should be included in the model, if they induce significant bending effects caused by the membrane stress resultants following an eccentric path.
- (3) For the modelling of 3D surface bodies (plated, cold-formed and shell structures) shell elements with 5 or 6 DOFs at each node should be used. The chosen elements should be able to model thin or moderately-thick shells. Special shell elements with different DOFs may be used in specific shell problems (e.g. shells of revolution, cylindrical, conical or spherical shells, etc.).
- (4) Additional requirements modelling shell structures are given in EN 1993-1-6.

5.1.4 Models using solid elements

- (1) For the modelling of solid bodies loaded by either in-plane loads or loads perpendicular to their plane, plane elements with 2 or 3 DOFs (only translational) at each node may be used for meshing (e.g. plane stress/strain or axisymmetric problems).

NOTE Solid elements usually have 3 DOFs (only translational) at each node. Loads and supports are to be defined in a compatible way with these three DOFs (i.e. bending moments and rotational loads cannot be applied).

- (2) In solid models, bolts may be modelled by using the shank area with their nominal cross-section for sufficiently accurate consideration of the stiffness of the bolt.
- (3) Where stress checks on the shank or the threaded area of the bolt are to be made, appropriate modifications should be made (e.g. the bolt diameter corresponding to the stress area of the bolt may be used).

5.1.5 Multi-level and combined models

- (1) In multi-level or combined models, load, displacement and rotation transfer should be provided at the interfaces between the different parts modelled.
- (2) If different levels of modelling are used and different structural elements are connected, a plan on how to postprocess shall be made to account for the eccentricity between beam and plate.

NOTE In several cases the preferred solution is to model the beam element in the neutral axis of the plate member. Assumptions made during modelling has impact on the post-processing.

(3) In multi-level or combined models, contact elements or other interface elements (representing appropriate interaction properties between the different parts such as friction etc.) may be used to couple the different model parts. The different DOFs of the different elements should be made compatible as well as the discretization of different parts.

(4) Effects acting on and the boundary conditions of the sub-model should replicate those of the relevant modelled part within the entire structure.

5.2 Support and load models

5.2.1 Definition of supports

(1) The support conditions in the numerical model should be chosen to reflect in a realistic or conservative manner the behaviour of the physical supports in the real structure.

(2) Where sub-modelling is used, the support conditions should be in compliance with the supporting effect of the adjacent components of the global model. The supports should consider the stiffness properties and the deformation capacity of the adjacent structural components.

(3) If concentrated or point supports are used in plate, shell or solid models, numerical stress concentrations may occur near the supports, which should be considered. Recommendations are given in Annex B. Concentrated nodal restraints in solid 3D meshes are not recommended. The local restraints should be implemented over an appropriate surface.

(4) Attention should be given to the definition of supports in nonlinear analyses (specially in case of plate, shell and solid elements) to avoid inappropriate clamping effects.

(5) Specific boundary conditions for shell structures are given in EN 1993-1-6.

(6) If an open section member is subject to torsional rotations resulting from instability or applied loads (e.g. cold-formed structures covered by EN 1993-1-3), special attention should be taken with the warping conditions of the supports and joints.

(7) Attention should be taken if symmetry conditions are applied and symmetry plane passes through supports or loads.

NOTE Symmetry can only be used where the expected structural behaviour (failure mode, buckling mode, deformed shape, loading and supporting conditions, etc.) has been verified to be symmetrical.

(8) In axisymmetric shells, the use of symmetry in one segment (cake slice) of the structure can be effective. However, attention should be taken to ensure that unsymmetrical buckling modes crossing the symmetry plane are not critical. For further information, see EN 1993-1-6.

(9) Where boundary conditions can vary with time (for instance due to construction activity), consideration should be given to the appropriate numerical means of introducing these changes so as to capture physical conditions.

5.2.2 Definition of loads

(1) Loads applied to the numerical model should be consistent with the solution technique (load or displacement controlled analysis).

(2) Where a nonlinear analysis is used, the appropriateness of the load definition mode should be checked and verified according to Clause 7.

NOTE Load and displacement-controlled analyses can lead to different results, arising from the different load transfer and load distribution modes in the numerical model.

(3) Where geometrically nonlinear analysis is performed, and follower load effects are possible, either they should be incorporated into the analysis, or it should be verified that their influence is negligible.