Draft for Public Comment

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Interested committees:

Title: Draft BS EN 1993-1-14. Eurocode 3 - Design of steel structures

Part 1-14: Design assisted by finite element analysis

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at **https://standardsdevelopment.bsigroup.com/**. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx

1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex **(e.g. 3.1)**	Paragraph/Figure/ Table/Note	**Type of comment**	**Commend (justification for change) by the MB**	**Proposed change by the MB**	**Secretariat observations on each comment submitted**
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

DRAFT
prEN 1993-1-14

September 2023

ICS 91.010.30; 91.080.13

English Version

Eurocode 3 - Design of steel structures - Part 1-14: Design assisted by finite element analysis

Eurocode 3 - Calcul des structures en acier - Partie 1-14 : Calcul assisté par des analyses par éléments finis

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

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/TC 250.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

This draft European Standard was established by CEN in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

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COMITÉ EUROPÉEN DE NORMALISATION
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European foreword

This document (prEN 1993-1-14:2023) 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 document is currently submitted to the CEN Enquiry.

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.

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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

— New parts are under development, e.g. Eurocode for design of structural glass

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, soft-ware 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 – Basis of structural and geotechnical design.

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, *Design of steel structures – Part 1: General rules and rules for buildings*

— EN 1993-2, *Design of steel structures – Part 2: Bridges*

— EN 1993-3, *Design of steel structures – Part 3: Towers, masts and chimneys*

— EN 1993-4, *Design of steel structures – Part 4: Silos and tanks*

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— EN 1993-5, *Design of steel structures – Part 5: Piling*

— EN 1993-6, *Design of steel structures – Part 6: Crane supporting structures*

— EN 1993-7, *Design of steel structures – Part 7: Sandwich panels* (under preparation).

EN 1993-1 in itself does not exist as a physical document, but comprises the following 14 separate parts, the basic part being EN 1993-1-1:

— EN 1993-1-1, *Design of steel structures – Part 1-1: General rules and rules for buildings*

— EN 1993-1-2, *Design of steel structures – Part 1-2: Structural fire design*

— EN 1993-1-3, *Design of steel structures – Part 1-3: Cold-formed members and sheeting*

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

— EN 1993-1-4, *Design of steel structures – Part 1-4: Stainless steel structures*

— EN 1993-1-5, *Design of steel structures – Part 1-5: Plated structural elements*

— EN 1993-1-6, *Design of steel structures – Part 1-6: Strength and stability of shell structures*

— EN 1993-1-7, *Design of steel structures – Part 1-7: Plate assemblies with elements under transverse loads*

— EN 1993-1-8, *Design of steel structures – Part 1-8: Joints*

— EN 1993-1-9, *Design of steel structures – Part 1-9: Fatigue*

— EN 1993-1-10, *Design of steel structures – Part 1-10: Material toughness and through-thickness properties*

— EN 1993-1-11, *Design of steel structures – Part 1-11: Tension components*

— EN 1993-1-12, *Design of steel structures – Part 1-12: Additional rules for steel grades up to S960*

— EN 1993-1-13, *Design of steel structures – Part 1-13: Beams with large web openings*

— EN 1993-1-14, *Design of steel structures – Part 1-14: Design assisted by finite element analysis*

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 prEN 1993-1-14

prEN 1993-1-14 gives principles and 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 principles and requirements for the application of advanced finite element and similar modelling techniques for research purposes, which may also be used in design processes.

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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 prEN 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 prEN 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 prEN 1993-1-14 through notes to the following clauses:

4(11)	4(15)	5.4.2(1)	7.1(2)
7.2(2)	7.3(1)	7.3(3)	7.3(6)
8.1.2(3)	8.1.2(5)	8.1.5(2)	8.1.5(3)
C.3(1)			

National choice is allowed in prEN 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.

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1 Scope

1.1 Scope of prEN 1993-1-14

(1) This document gives principles and 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 principles and requirements for the application of advanced finite element (FE) and similar modelling techniques for numerical simulation which also covers safety assessment.

(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 standard parts in 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.

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, when a more detailed understanding of structural behaviour is required, the methods described in this document can be useful for the professional 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 prEN 1993-1-14 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.

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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 (e.g. LA, LBA, GNA, GNIA, MNA) performed for design checks, which results are different system response quantities to be further used in the static check of the analysed structure

3.1.2
benchmark case
offers the inputs and outputs of the analytical or numerical solutions to verify the results by comparison on simplified model, or experimental tests used to check the quality of the numerical model to be validated

3.1.3
degree of freedom
DOF
number of independent motions that are 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 (e.g. MNA, GMNA, GMNIA) performed for design checks, which result is the ultimate resistance of the analysed structure

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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 (e.g. coupling of beam, plate, shell or solid 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 conditions representing the neglected part of the structure

3.1.14
system response quantity
SRQ
relevant output value resulting from a certain analysis; it reflects the main objective of the analysis by selecting the major parameters and the limitation of their errors in both validation and verification

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3.1.15
validation
comparison of the numerical solution and the experimental behaviour (or known accurate solutions)

3.1.16
verification
comparison of the numerical solutions and accurate analytical or numerical results

3.2 Symbols and abbreviations

3.2.1 Latin upper-case symbols

A	elongation after fracture defined in the relevant material specification
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 prEN 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
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 bifurcation load of the examined structure
R_{GMNA}	calculated plastic resistances based on GMNA analysis
R_{GMNIA}	calculated buckling resistances based on GMNIA analysis
$R_{k,known}$	calculated or known characteristic structural resistance
$R_{test,known}$	known test result
R_{MNA}	calculated plastic resistance based on MNA analysis
R_{pl}	plastic resistance of the examined structure or cross-section
$R_{pl,d}$	design plastic resistance of the examined structure
$R_{pl,k}$	characteristic plastic resistance of the examined structure
V_X	coefficient of variation of the ratio of the measured (or known) and computed results

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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
a_{rs}, b_{rs}, c_{rs}, d_{rs}, e_{rs}, f_{rs}, g_{rs}, h_{rs}	geometrical parameters of the residual stress patterns
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 stress
f_{yb}	basic yield strength of cold-formed steel
h_w	web depth
k_n	characteristic fractile factor
m	second strain hardening exponent for the Ramberg-Osgood type material model cold-formed steel and stainless steels
m_X	mean value of the ratio of the measured (or known) and computed results
n	material coefficient for the Ramberg-Osgood type material model for cold-formed steel 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

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3.2.4 Greek lower-case symbols

α	imperfection factor
$\alpha_{ult,k}$	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 cold-formed steel and stainless steels
$\varepsilon_{1,0}$	total strain at 1 % proof stress for the Ramberg-Osgood type material model cold-formed steel 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
ε_{mpb}	maximum allowed plastic strain for bolts
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
σ	stress
$\sigma_{0,05}$	0,05 % proof stress for the Ramberg-Osgood type material model cold-formed steel and stainless steels
$\sigma_{1,0}$	1 % proof stress for the Ramberg-Osgood type material model cold-formed steel and stainless steels
$\sigma_{0,4t}$	calculated stress change in a distance of 0,4·t from the weld toe in fatigue design situation
$\sigma_{0,5t}$	calculated stress change in a distance of 0,5·t from the weld toe in fatigue design situation
$\sigma_{0,9t}$	calculated stress change in a distance of 0,9·t from the weld toe in fatigue design situation
$\sigma_{1,0t}$	calculated stress change in a distance of 1,0·t from the weld toe in fatigue design situation
$\sigma_{1,5t}$	calculated stress change in a distance of 1,5·t from the weld toe in fatigue design situation
σ_{4mm}	calculated stress change in a distance of 4 mm from the weld toe in fatigue design situation
σ_{5mm}	calculated stress change in a distance of 5 mm from the weld toe in fatigue design situation
σ_{8mm}	calculated stress change in a distance of 8 mm from the weld toe in fatigue design situation
σ_{12mm}	calculated stress change in a distance of 12 mm from the weld toe in fatigue design situation

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σ_{15mm}	calculated stress change 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 bifurcation stress of the full cross-section
$\sigma_{cr,d}$	elastic critical distortional bifurcation 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 and modelling

(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 1993-1 (all parts).

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

(4) This document gives design rules for the

a) ultimate limit state design (excluding fatigue),

b) fatigue design situation,

c) serviceability limit state design.

(5) Finite element analysis-based design may be executed by one of the following two methods, which should be recognised as different and treated differently in the design process:

a) numerical design calculation,

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b) numerical simulation.

(6) The design methods differ regarding the (i) applied geometrical and material properties, (ii) results of the analysis, (iii) validation and verification process, (iv) further 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 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 methods should be used: LA, LBA, GNA, GNIA, MNA. 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 methods should be used: MNA, GMNA, GMNIA. 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 geometrical and stiffness parameters, e.g. Young's modulus. Strength parameters, e.g. material properties, are taken as nominal values from the product standards, which represent fractile values.

(11) Numerical simulations may be applied to complement or extend laboratory tests used in test-based design.

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 resistance of the analysed structure.

(13) Application of finite element analysis-based design methods should not bring significant resistance increases compared to well-established traditional design methods, unless shown to be reasonable through validation and verification of the employed finite element model according to Clause 7 covering all relevant failure modes.

(14) The rules of prEN 1993-1-14 are independent of the software used. However, the capabilities of the chosen software should be checked by the designer and it should be confirmed that the software is applicable for the limit state check being used (see Clause 8).

(15) To ensure design quality, the applicability of the design using numerical methods should be linked to design qualification and experience levels (DQLs).

NOTE Minimum appropriate qualifications and experience of personnel designing structures using numerical models can be defined in the National Annex based on EN 1990:2023, Table B.1.

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, geometry complexity (curvature) and the solution method to ensure that the results meet both the validation and verification requirements.

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(2) The discretization of the chosen model should be adequate and it should follow the geometrical properties of the structure. A finer mesh may be used in zones where large gradients of stresses, strains or temperatures are expected. Element shape properties should be of suitable quality to ensure accuracy (element aspect ratio, jacobian ratio, warping factor, etc.).

(3) At locations with high stress or strain concentrations or at the location where failure of the structure is anticipated, mesh refinement should be used to ensure the required accuracy, except for fatigue verification which applies predefined mesh refinements according to 8.2.

(4) The accuracy of the chosen FE mesh (density, chosen element types) should be proven by model verification according to Clause 7.

(5) Cold-formed steel cross-sections should be modelled with rounded corners, unless their effect is not relevant according to prEN 1993-1-3.

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

(7) Element types (such as truss or cable elements, etc.) not covered by the following clauses may also be applied in the numerical model taking special care on their modelling specialties.

(8) A geometrically non-linear global analysis of beam structures (see 6.1.2) may normally be based on second order theory.

NOTE As a general rule, the accuracy of calculations according to second order theory is sufficient for global analysis of frame structures. In exceptional cases, more accurate geometrically non-linear calculations are required, if the displacements are large enough to significantly change the stress resultants in the structure.

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

5.1.2 Models using beam elements

(1) The system axis of the beam model should be identical to that of the centroid of the cross-sections, or it should be chosen such that the effects of its displacement 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 by the numerical analysis.

(3) When using a beam model, the behaviour of the joints between the beam structural members should be considered. The assumed stiffness (hinged joint, continuous joint, semi-rigid joint) should be determined according to EN 1993-1-8.

(4) If torsion and/or stability problems involving torsion (e.g. lateral torsional buckling, torsional buckling, torsional-flexural buckling, etc.) are being studied using beam models, the used elements should be capable of capturing torsion-related warping effects (for example elements using 7 DOFs - 3 translational, 3 rotational and warping).

(5) Beam elements should include shear effects if relevant.

(6) Strain limits to determine the point at which cross-section failure occurs are given in Annex C.

NOTE The calculation of elastic critical loads (for lateral torsional buckling) for members of varying height can require the use of specific beam elements.

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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. Care should be taken that the effects of eccentricities and offsets from mid-surfaces are properly included in the model and 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 should be used having 5 or 6 DOFs at each node. 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 prEN 1993-1-6.

(5) Care should be taken at zones where higher through thickness shear stresses occur.

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. Special care is needed to the application of loads and supports defined in a compatible way with these three DOFs (i.e. bending moments and rotational loads cannot be applied).

(2) The chosen mesh should be continuous at the intersection points, in the joint regions and at the location of thickness changes.

(3) In solid models, bolts can be modelled by using the shank area with their nominal cross-section for sufficiently accurate consideration of the stiffness of the bolt. 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, continuous load, displacement and rotation transfer should be provided at the interfaces between the different modelled parts.

(2) If different levels of modelling are used and different structural elements are connected, their eccentricities should be included within the model.

(3) In multi-level or combined models, contact elements or other interface elements 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 the sub-model should be identical to the effects 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 chosen supports should be in compliance with the supporting effect of the adjacent components of the global model. The chosen supports should consider the stiffness properties and the deformation capacity of the adjacent structural components.

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(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 investigated. Recommendations are given in Annex B.

(4) Special care should be given to the definition of supports in non-linear analyses (specially in case of plate, shell and solid elements) to avoid undesired clamping effects.

NOTE Supports that act as pinned supports in a linear analysis can produce undesired stiffening effects in a non-linear analysis.

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

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

(7) Care 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 may be effective. However, care should be taken to ensure that unsymmetrical buckling modes crossing the symmetry plane are not critical. For further information, see prEN 1993-1-6.

5.2.2 Definition of loads

(1) Loading applied in the numerical model should be related to the chosen solution technique (load or displacement controlled analysis).

(2) Where a non-linear 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 non-linear 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.

5.3 Material models

5.3.1 General

(1) Material properties should be taken as nominal values where the analysis is used in support of numerical design calculations.

(2) In the case of analysis used for model validation, the chosen material properties should be based on relevant material tests (measured values).

(3) The stress-strain relationship of steel in compression may be assumed to be identical to that in tension.

(4) The material properties given in this standard apply to temperatures below 100 °C. In the case of fire, the mechanical properties of carbon steel and stainless steels may be taken from prEN 1993-1-2. These defined properties are only valid for heating rates in fire situations (as defined in prEN 1993-1-2) and are not applicable to other heating rates, especially where enduring high temperature condition occur.

(5) Under elevated temperatures, the effects of basic creep need not be given explicit consideration provided that the stress-strain relationships given in prEN 1993-1-2 are used.

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