

Eurocode 8 — Design of structures for earthquake resistance —

Part 3: Assessment and retrofitting of buildings

ICS 91.120.25

National foreword

This British Standard is the UK implementation of EN 1998-3:2005, incorporating corrigenda March 2010 and August 2013. It supersedes DD ENV 1998-1-4:1996 which is withdrawn.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by CEN corrigendum March 2010 is indicated in the text by AC₁ AC₁. Text altered by CEN corrigendum August 2013 is indicated in the text by AC₂ AC₂.

The structural Eurocodes are divided into packages by grouping Eurocodes for each of the main materials, concrete, steel, composite concrete and steel, timber, masonry and aluminium. This is to enable a common date of withdrawal (DOW) for all the relevant parts that are needed for a particular design. The conflicting national standards will be withdrawn at the end of the coexistence period, after all the EN Eurocodes of a package are available.

Following publication of the EN, there is a period of two years allowed for the national calibration period during which the national annex is issued, followed by a three year coexistence period. During the coexistence period Member States will be encouraged to adapt their national provisions to withdraw conflicting national rules before the end of the coexistence period. The Commission in consultation with Member States is expected to agree the end of the coexistence period for each package of Eurocodes.

At the end of the coexistence period, the national standards will be withdrawn. In the UK, there is no corresponding national standard.

The UK participation in its preparation was entrusted by Technical Committee B/525, Building and civil engineering structures, to Subcommittee B/525/8, Structures in seismic regions.

A list of organizations represented on this subcommittee can be obtained on request to its secretary.

Where a normative part of this EN allows for a choice to be made at the national level, the range and possible choice will be given in the normative text, and a note will qualify it as a Nationally Determined Parameter (NDP). NDPs can be a specific value for a factor, a specific level or class, a particular method or a particular application rule if several are proposed in the EN.

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To enable EN 1998 to be used in the UK, the NDPs will be published in a National Annex, which will be made available by BSI in due course, after public consultation has taken place.

There are generally no requirements in the UK to consider seismic loading, and the whole of the UK may be considered an area of very low seismicity in which the provisions of EN 1998 need not apply. There is no intention to produce a National Annex to this standard and therefore where it is necessary that seismic assessment and retrofit of a building is performed to the provisions of EN 1998-3, the specifier should confirm the values of the NDPs to be used.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

English version

Eurocode 8: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings

Eurocode 8: Calcul des structures pour leur résistance aux
séismes - Partie 3: Evaluation et renforcement des
bâtiments

Eurocode 8: Auslegung von Bauwerken gegen Erdbeben -
Teil 3: Beurteilung und Ertüchtigung von Gebäuden

This European Standard was approved by CEN on 15 March 2005.

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. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists 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 Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.



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Foreword

This European Standard EN 1998-3, Eurocode 8: Design of structures for earthquake resistance: Assessment and Retrofitting of buildings, 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.

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 December 2005, and conflicting national standards shall be withdrawn at the latest by March 2010.

This document supersedes ENV 1998-1-4:1996.

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

Background of the Eurocode programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonised technical rules for the design of construction works which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980's.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement¹ between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links *de facto* the Eurocodes with the provisions of all the Council's Directives and/or Commission's Decisions dealing with European standards (*e.g.* the Council Directive 89/106/EEC on construction products - CPD - and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

¹ Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

- EN 1990 Eurocode: Basis of structural 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

Eurocode standards recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

Status and field of application of Eurocodes

The Member States of the EU and EFTA recognise that Eurocodes serve as reference documents for the following purposes:

- as a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement N°1 - Mechanical resistance and stability - and Essential Requirement N°2 - Safety in case of fire;
- as a basis for specifying contracts for construction works and related engineering services;
- as a framework for drawing up harmonised technical specifications for construction products (ENs and ETAs)

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents² referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standards³. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by

² According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for hENs and ETAGs/ETAs.

³ According to Art. 12 of the CPD the interpretative documents shall:

- a) give concrete form to the essential requirements by harmonising the terminology and the technical bases and indicating classes or levels for each requirement where necessary ;
- b) indicate methods of correlating these classes or levels of requirement with the technical specifications, e.g. methods of calculation and of proof, technical rules for project design, etc. ;
- c) serve as a reference for the establishment of harmonised standards and guidelines for European technical approvals.

The Eurocodes, *de facto*, play a similar role in the field of the ER 1 and a part of ER 2.

CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving a full compatibility of these technical specifications with the Eurocodes.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

National Standards implementing Eurocodes

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National annex (informative).

The National annex may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e.:

- values and/or classes where alternatives are given in the Eurocode,
- values to be used where a symbol only is given in the Eurocode,
- country specific data (geographical, climatic, etc.), *e.g.* snow map,
- the procedure to be used where alternative procedures are given in the Eurocode.

It may also contain

- decisions on the application of informative annexes,
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

Links between Eurocodes and harmonised technical specifications (ENs and ETAs) for products

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works⁴. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes shall clearly mention which Nationally Determined Parameters have been taken into account.

Additional information specific to EN 1998-3

Although assessment and retrofitting of existing structures for non-seismic actions is not yet covered by the relevant material-dependent Eurocodes, this Part of Eurocode 8 was specifically developed because:

⁴ See Art.3.3 and Art.12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1.

- For many older structures, seismic resistance was not considered during the original construction, whereas non-seismic actions were catered for, at least by means of traditional construction rules.
- Seismic hazard evaluations in accordance with present knowledge may indicate the need for retrofitting campaigns.
- Damage caused by earthquakes may create the need for major repairs.

Furthermore, since within the philosophy of Eurocode 8 the seismic design of new structures is based on a certain acceptable degree of structural damage in the event of the design earthquake, criteria for seismic assessment (of structures designed in accordance with Eurocode 8 and subsequently damaged) constitute an integral part of the entire process for seismic structural safety.

In seismic retrofitting situations, qualitative verifications for the identification and elimination of major structural defects are very important and should not be discouraged by the quantitative analytical approach proper to this Part of Eurocode 8. Preparation of documents of more qualitative nature is left to the initiative of the National Authorities.

This Standard addresses only the structural aspects of seismic assessment and retrofitting, which may form only one component of a broader strategy for seismic risk mitigation. This Standard will apply once the requirement to assess a particular building has been established. The conditions under which seismic assessment of individual buildings – possibly leading to retrofitting – may be required are beyond the scope of this Standard.

National programmes for seismic risk mitigation through seismic assessment and retrofitting may differentiate between “active” and “passive” seismic assessment and retrofitting programmes. “Active” programmes may require owners of certain categories of buildings to meet specific deadlines for the completion of the seismic assessment and – depending on its outcome – of the retrofitting. The categories of buildings selected to be targeted may depend on seismicity and ground conditions, importance class and occupancy and perceived vulnerability of the building (as influenced by type of material and construction, number of storeys, age of the building with respect to dates of older code enforcement, etc.). “Passive” programmes associate seismic assessment – possibly leading to retrofitting – with other events or activities related to the use of the building and its continuity, such as a change in use that increases occupancy or importance class, remodelling above certain limits (as a percentage of the building area or of the total building value), repair of damage after an earthquake, etc. The choice of the Limit States to be checked, as well as the return periods of the seismic action ascribed to the various Limit States, may depend on the adopted programme for assessment and retrofitting. The relevant requirements may be less stringent in “active” programmes than in “passive” ones; for example, in “passive” programmes triggered by remodelling, the relevant requirements may graduate with the extent and cost of the remodelling work undertaken.

In cases of low seismicity (see EN1998-1, **3.2.1(4)**), this Standard may be adapted to local conditions by appropriate National Annexes.

National annex for EN 1998-3

This standard gives alternative procedures, values and recommendations for classes

with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1998-3: 2005 should have a National annex containing all Nationally Determined Parameters to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

National choice is allowed in EN 1998-3: 2005 through clauses:

Reference	Item
1.1(4)	Informative Annexes A, B and C.
2.1(2)P	Number of Limit States to be considered
2.1(3)P	Return period of seismic actions under which the Limit States should not be exceeded.
2.2.1(7)P	Partial factors for materials
3.3.1(4)	Confidence factors
3.4.4(1)	Levels of inspection and testing
4.4.2(1)P	Maximum value of the ratio $\rho_{\max}/\rho_{\min}$
4.4.4.5(2)	Complementary, non-contradictory information on non-linear static analysis procedures that can capture the effects of higher modes.
AC1 A.4.4.2(5)	Partial factor γ_d for FRP debonding
A.4.4.2(9)	Partial factor γ_d of the FRP

AC1

1 GENERAL

1.1 Scope

(1) The scope of Eurocode 8 is defined in EN 1998-1: 2004, **1.1.1** and the scope of this Standard is defined in **(2)**, **(4)** and **(5)**. Additional parts of Eurocode 8 are indicated in EN 1998-1: 2004, **1.1.3**.

(2) The scope of EN 1998-3 is as follows:

- To provide criteria for the evaluation of the seismic performance of existing individual building structures.
- To describe the approach in selecting necessary corrective measures
- To set forth criteria for the design of retrofitting measures (i.e. conception, structural analysis including intervention measures, final dimensioning of structural parts and their connections to existing structural elements).

NOTE For the purposes of this standard, retrofitting covers both the strengthening of undamaged structures and the repair of earthquake damaged structures.

(3) When designing a structural intervention to provide adequate resistance against seismic actions, structural verifications should also be made with respect to non-seismic load combinations.

(4) Reflecting the basic requirements of EN 1998-1: 2004, this Standard covers the seismic assessment and retrofitting of buildings made of the more commonly used structural materials: concrete, steel, and masonry.

NOTE Informative Annexes A, B and C contain additional information related to the assessment of reinforced concrete, steel and composite, and masonry buildings, respectively, and to their upgrading when necessary.

(5) Although the provisions of this Standard are applicable to all categories of buildings, the seismic assessment and retrofitting of monuments and historical buildings often requires different types of provisions and approaches, depending on the nature of the monuments.

(6) Since existing structures:

- (i) reflect the state of knowledge at the time of their construction,
- (ii) possibly contain hidden gross errors,
- (iii) may have been submitted to previous earthquakes or other accidental actions with unknown effects,

structural evaluation and possible structural intervention are typically subjected to a different degree of uncertainty (level of knowledge) than the design of new structures. Different sets of material and structural safety factors are therefore required, as well as different analysis procedures, depending on the completeness and reliability of the information available.

1.2 Normative references

(1)P This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

1.2.1 General reference standards

EN 1990 Eurocode - Basis of structural design

EN 1998-1 Eurocode 8 - Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings

1.3 Assumptions

(1) Reference is made to EN 1998-1: 2004, **1.3**.

(2) The provisions of this Standard assume that the data collection and tests is performed by experienced personnel and that the engineer responsible for the assessment, the possible design of the retrofitting and the execution of work has appropriate experience of the type of structures being strengthened or repaired.

(3) Inspection procedures, check-lists and other data-collection procedures should be documented and filed, and should be referred to in the design documents.

1.4 Distinction between principles and application rules

(1) The rules of EN 1990: 2002, **1.4** apply.

1.5 Definitions

(1) Reference is made to EN 1998-1: 2004, **1.5**.

1.6 Symbols

1.6.1 General

(1) Reference is made to EN 1998-1: 2004, **1.6**.

(2) Further symbols used in this Standard are defined in the text where they occur.

1.6.2 Symbols used in Annex A

b width of steel straps in steel jacket

b_o and h_o dimension of confined concrete core to the centreline of the hoop

b_i centreline spacing of longitudinal bars

c concrete cover to reinforcement

d effective depth of section (depth to the tension reinforcement)

d'	depth to the compression reinforcement
d_{bL}	diameter of tension reinforcement
f_c	concrete compressive strength (MPa)
f_{cc}	confined concrete strength
f_{cd}	design value of concrete strength
f_{ctm}	concrete mean tensile strength
$f_{idd,e}$	design value of FRP (fibre-reinforced polymer) effective debonding strength
$f_{fu,w}(R)$	ultimate strength of FRP sheet wrapped around corner with radius R , expression (A.25)
f_y	estimated mean value of steel yield strength
f_{yd}	design value of yield strength of (longitudinal) reinforcement
$f_{yj,d}$	design value of yield strength jacket steel
f_{yw}	yield stress of transverse or confinement reinforcement
h	depth of cross-section
$k_b = \sqrt{1,5 \cdot (2 - w_f / s_f) / (1 + w_f / 100 \text{ mm})}$	covering coefficient of FRP (fibre-reinforced polymer) strips/sheet
n	number of spliced bars along perimeter p
p	length of perimeter line in column section along the inside of longitudinal steel
s	centreline spacing of stirrups
s_f	centreline spacing of FRP (fibre-reinforced polymer) strips ($=w_f$ for FRP sheets)
t_f	thickness of FRP (fibre-reinforced polymer) sheet
t_j	thickness of steel jacket
x	compression zone depth
w_f	width of FRP (fibre-reinforced polymer) strip/sheet
z	length of section internal lever arm
A_c	column cross-section area
A_f	$= t_f w_f \sin \beta$: horizontally projected cross-section area of FRP (fibre-reinforced polymer) strip/sheet with thickness t_f , width w_f and angle β
A_s	cross-sectional area of longitudinal steel reinforcement
A_{sw}	cross-sectional area of stirrup
E_f	FRP (fibre-reinforced polymer) modulus
$L_V = M/V$	shear span at member end
N	axial force (positive for compression)
$V_{R,c}$	shear resistance of member without web reinforcement
$V_{R,max}$	shear resistance as determined by crushing in the diagonal compression strut
V_w	contribution of transverse reinforcement to shear resistance

α	confinement effectiveness factor
γ_{el}	factor, greater than 1,0 for primary seismic and equal to 1,0 for secondary seismic elements
γ_{fd}	partial factor for FRP (fibre-reinforced polymer) debonding
δ	angle between the diagonal and the axis of a column
ε_{cu}	concrete ultimate strain
ε_{ju}	FRP (fibre-reinforced polymer) ultimate strain
$\varepsilon_{su,w}$	ultimate strain of confinement reinforcement
θ	strut inclination angle in shear design
θ_y	chord rotation at yielding of concrete member
θ_u	ultimate chord rotation of concrete member
ν	$= N / bhf_c$ (b width of compression zone)
ρ_d	steel ratio of diagonal reinforcement
ρ_f	volumetric ratio of FRP (fibre-reinforced polymer)
ρ_s	geometric steel ratio
ρ_{sx}	$= A_{sx} / b_w s_h$ = ratio of transverse steel parallel to direction x of loading (s_h = stirrup spacing)
ρ_{tot}	total longitudinal reinforcement ratio
ρ_{sw}	volumetric ratio of confinement reinforcement
ρ_w	transverse reinforcement ratio
φ_u	ultimate curvature at end section
φ_y	yield curvature at end section
ω, ω'	mechanical reinforcement ratio of tension and compression reinforcement

1.6.3 Symbols used in Annex B

b_{cp}	width of the cover plate
b_f	flange width
d_c	column depth
d_z	panel-zone depth between continuity plates
e	distance between the plastic hinge and the column face
f_c	concrete compressive strength
f_{ct}	tensile strength of the concrete
f_{uw}	tensile strength of the welds
f_{ywh}	yield strength of transverse reinforcement
$f_{y,pl}$	nominal yield strength of each flange

l_{cp}	length of the cover plate
t_{cp}	thickness of the cover plate
t_f	thickness
t_{hw}	web thickness
w_z	panel-zone width between column flanges
A_g	gross area of the section
A_{hf}	area of the haunch flange
A_{pl}	area of each flange
B_S	width of the steel flat-bar brace
B	width of the composite section
E	Young's modulus of the beam
E_B	elastic modulus of the RC (reinforced concrete) panel
F_t	seismic base shear
H	frame height
H_c	storey height of the frame
K_ϕ	connection rotation stiffness
I	moment of inertia
L	beam span
$M_{pb,Rd}$	beam plastic moment
N_d	design axial
N_y	yield strength of the steel brace
S_x	beam elastic (major) modulus;
T_C	thickness of the panel
$V_{pl,Rd,b}$	shear force at a beam plastic hinge
Z_b	plastic modulus of the beam
Z_e	effective plastic modulus of the section at the plastic hinge location
ρ_w	ratio of transverse reinforcement

1.7 S.I. Units

- (1) Reference is made to EN 1998-1: 2004, 1.7.

2 PERFORMANCE REQUIREMENTS AND COMPLIANCE CRITERIA

2.1 Fundamental requirements

(1)P The fundamental requirements refer to the state of damage in the structure, herein defined through three Limit States (LS), namely Near Collapse (NC), Significant Damage (SD), and Damage Limitation (DL). These Limit States shall be characterised as follows:

LS of Near Collapse (NC). The structure is heavily damaged, with low residual lateral strength and stiffness, although vertical elements are still capable of sustaining vertical loads. Most non-structural components have collapsed. Large permanent drifts are present. The structure is near collapse and would probably not survive another earthquake, even of moderate intensity.

LS of Significant Damage (SD). The structure is significantly damaged, with some residual lateral strength and stiffness, and vertical elements are capable of sustaining vertical loads. Non-structural components are damaged, although partitions and infills have not failed out-of-plane. Moderate permanent drifts are present. The structure can sustain after-shocks of moderate intensity. The structure is likely to be uneconomic to repair.

LS of Damage Limitation (DL). The structure is only lightly damaged, with structural elements prevented from significant yielding and retaining their strength and stiffness properties. Non-structural components, such as partitions and infills, may show distributed cracking, but the damage could be economically repaired. Permanent drifts are negligible. The structure does not need any repair measures.

NOTE The definition of the Limit State of Collapse given in this Part 3 of Eurocode 8 is closer to the actual collapse of the building than the one given in EN1998-1: 2004 and corresponds to the fullest exploitation of the deformation capacity of the structural elements. The Limit State associated with the 'no collapse' requirement in EN1998-1: 2004 is roughly equivalent to the one that is here defined as Limit State of Significant Damage.

(2)P The National Authorities decide whether all three Limit States shall be checked, or two of them, or just one of them.

NOTE The choice of $\overline{AC_1}$ the Limit States to be checked in a country $\overline{AC_1}$, among the three Limit States defined in 2.1(1)P, may be found in the National Annex.

(3)P The appropriate levels of protection are achieved by selecting, for each of the Limit States, a return period for the seismic action.

NOTE The return periods ascribed to the various Limit States to be checked in a country may be found in its National Annex. The protection normally considered appropriate for ordinary new buildings is considered to be achieved by selecting the following values for the return periods:

- LS of Near Collapse (NC): 2.475 years, corresponding to a probability of exceedance of 2% in 50 years
- LS of Significant Damage (SD): 475 years, corresponding to a probability of exceedance of 10% in 50 years
- LS of Damage Limitation (DL): 225 years, corresponding to a probability of exceedance of 20% in 50 years.

2.2 Compliance criteria

2.2.1 General

(1)P Compliance with the requirements in 2.1 is achieved by adoption of the seismic action, method of analysis, verification and detailing procedures contained in this part of EN 1998, as appropriate for the different structural materials within its scope (i.e. concrete, steel, masonry).

(2)P Except when using the q -factor approach, compliance is checked by making use of the full (unreduced, elastic) seismic action as defined in 2.1 and 4.2 for the appropriate return period.

(3)P For the verification of the structural elements a distinction is made between ‘ductile’ and ‘brittle’ ones. Except when using the q -factor approach, the former shall be verified by checking that demands do not exceed the corresponding capacities in terms of deformations. The latter shall be verified by checking that demands do not exceed the corresponding capacities in terms of strengths.

NOTE Information for classifying components/mechanisms as “ductile” or “brittle” may be found in the relevant material-related Annexes.

(4)P Alternatively, a q -factor approach may be used, where use is made of a seismic action reduced by a q -factor, as indicated in 4.2(3)P. In safety verifications all structural elements shall be verified by checking that demands due to the reduced seismic action do not exceed the corresponding capacities in terms of strengths evaluated in accordance with (5)P.

(5)P For the calculation of the capacities of ductile or brittle elements, where these will be compared with demands for safety verifications in accordance with (3)P and (4)P, mean value properties of the existing materials shall be used as directly obtained from *in-situ* tests and from the additional sources of information, appropriately divided by the confidence factors defined in 3.5, accounting for the level of knowledge attained. Nominal properties shall be used for new or added materials.

(6)P Some of the existing structural elements may be designated as “secondary seismic”, in accordance with the definitions in EN 1998-1: 2004, 4.2.2 (1)P, (2) and (3). “Secondary seismic” elements shall be verified with the same compliance criteria as primary seismic ones, but using less conservative estimates of their capacity than for the elements considered as “primary seismic”.

(7)P In the calculation of strength capacities of brittle “primary seismic” elements, material strengths shall be divided by the partial factor of the material.

NOTE: The values ascribed to the partial factors for steel, concrete, structural steel, masonry and other materials for use in a country can be found in the National Annex to this standard. Notes to clauses 5.2.4(3), 6.1.3(1), 7.1.3(1) and 9.6(3) in EN1998-1: 2004 refer to the values of partial factors for steel, concrete, structural steel and masonry to be used for the design of new buildings in different countries.

2.2.2 Limit State of Near Collapse (NC)

(1)P Demands shall be based on the design seismic action relevant to this Limit State. For ductile and brittle elements demands shall be evaluated based on the results

of the analysis. If a linear method of analysis is used, demands on brittle elements shall be modified in accordance to **4.5.1(1)P**.

(2)P Capacities shall be based on appropriately defined ultimate deformations for ductile elements and on ultimate strengths for brittle ones.

(3) The q -factor approach (see **2.2.1(4)P**, **4.2(3)P**) is generally not suitable for checking this Limit State.

NOTE The values of $q = 1,5$ and $2,0$ quoted in **4.2(3)P** for reinforced concrete and steel structures, respectively, as well as the higher values of q possibly justified with reference to the local and global available ductility in accordance with the relevant provisions of EN 1998-1: 2004, correspond to fulfilment of the Significant Damage Limit State. If it is chosen to use this approach to check the Near Collapse Limit State, then **2.2.3(3)P** may be applied, with a value of the q -factor exceeding those in **4.2(3)P** by about one-third.

2.2.3 Limit State of Significant Damage (SD)

(1)P Demands shall be based on the design seismic action relevant to this Limit State. For ductile and brittle elements demands shall be evaluated based on the results of the analysis. In case a linear method of analysis is used, demands on brittle elements shall be modified in accordance to **4.5.1(1)P**.

(2)P Except when using the q -factor approach, capacities shall be based on damage-related deformations for ductile elements and on conservatively estimated strengths for brittle ones.

(3)P In the q -factor approach (see **2.2.1(4)P**, **4.2(3)P**), demands shall be based on the reduced seismic action and capacities shall be evaluated as for non-seismic design situations.

2.2.4 Limit State of Damage Limitation (DL)

(1)P Demands shall be based on the design seismic action relevant to this Limit State.

(2)P Except when using the q -factor approach, capacities shall be based on yield strengths for all structural elements, both ductile and brittle. Capacities of infills shall be based on mean interstorey drift capacity for the infills.

(3)P In the q -factor approach (see **2.2.1(4)P**, **4.2(3)P**), demands and capacities shall be compared in terms of mean interstorey drift.

3 INFORMATION FOR STRUCTURAL ASSESSMENT

3.1 General information and history

(1)P In assessing the earthquake resistance of existing structures, the input data shall be collected from a variety of sources, including:

- available documentation specific to the building in question,
- relevant generic data sources (e.g. contemporary codes and standards),
- field investigations and,
- in most cases, in-situ and/or laboratory measurements and tests, as described in more detail in **3.2** and **3.4**.

(2) Cross-checks should be made between the data collected from different sources to minimise uncertainties.

3.2 Required input data

(1) In general, the information for structural evaluation should cover the following points from a) to i).

a) Identification of the structural system and of its compliance with the regularity criteria in EN 1998-1: 2004, **4.2.3**. The information should be collected either from on site investigation or from original design drawings, if available. In this latter case, information on possible structural changes since construction should also be collected.

b) Identification of the type of building foundations.

c) Identification of the ground conditions as categorised in EN 1998-1: 2004, **3.1**.

d) Information about the overall dimensions and cross-sectional properties of the building elements and the mechanical properties and condition of constituent materials.

e) Information about identifiable material defects and inadequate detailing.

f) Information on the seismic design criteria used for the initial design, including the value of the force reduction factor (q -factor), if applicable.

g) Description of the present and/or the planned use of the building (with identification of its importance class, as described in EN 1998-1: 2004, **4.2.5**).

h) Re-assessment of imposed actions taking into account the use of the building.

i) Information about the type and extent of previous and present structural damage, if any, including earlier repair measures.

(2)P Depending on the amount and quality of the information collected on the points above, different types of analysis and different values of the confidence factors shall be adopted, as indicated in **3.3**.

3.3 Knowledge levels

3.3.1 Definition of knowledge levels

(1) For the purpose of choosing the admissible type of analysis and the appropriate confidence factor values, the following three knowledge levels are defined:

KL1 : Limited knowledge

KL2 : Normal knowledge

KL3 : Full knowledge

(2) The factors determining the appropriate knowledge level (i.e. KL1, KL2 or KL3) are:

i) *geometry*: the geometrical properties of the structural system, and of such non-structural elements (e.g. masonry infill panels) as may affect structural response.

ii) *details*: these include the amount and detailing of reinforcement in reinforced concrete, connections between steel members, the connection of floor diaphragms to lateral resisting structure, the bond and mortar jointing of masonry and the nature of any reinforcing elements in masonry,

iii) *materials*: the mechanical properties of the constituent materials.

(3) The knowledge level achieved determines the allowable method of analysis (see 4.4), as well as the values to be adopted for the confidence factors (CF). The procedures for obtaining the required data are given in 3.4.

(4) The relationship between knowledge levels and applicable methods of analysis and confidence factors is illustrated in Table 3.1. The definitions of the terms ‘visual’, ‘full’, ‘limited’, ‘extended’ and ‘comprehensive’ in the Table are given in 3.4.

Table 3.1: Knowledge levels and corresponding methods of analysis (LF: Lateral Force procedure, MRS: Modal Response Spectrum analysis) and confidence factors (CF).

Knowledge Level	Geometry	Details	Materials	Analysis	CF
KL1	From original outline construction drawings with sample visual survey <i>or</i> from full survey	Simulated design in accordance with relevant practice <i>and</i> from limited in-situ inspection	Default values in accordance with standards of the time of construction <i>and</i> from limited in-situ testing	LF- MRS	CF_{KL1}
KL2		From incomplete original detailed construction drawings with limited in-situ inspection <i>or</i> from extended in-situ inspection	From original design specifications with limited in-situ testing <i>or</i> from extended in-situ testing	All	CF_{KL2}
KL3		From original detailed construction drawings with limited in-situ inspection <i>or</i> from comprehensive in-situ inspection	From original test reports with limited in-situ testing <i>or</i> from comprehensive in-situ testing	All	CF_{KL3}

NOTE The values ascribed to the confidence factors to be used in a country may be found in its National Annex. The recommended values are $CF_{KL1} = 1,35$, $CF_{KL2} = 1,20$ and $CF_{KL3} = 1,00$.

3.3.2 KL1: Limited knowledge

(1) KL1 corresponds to the following state of knowledge:

i) *geometry*: the overall structural geometry and member sizes are known either (a) from survey; or (b) from original outline construction drawings used for both the

original construction and any subsequent modifications. In case (b), a sufficient sample of dimensions of both overall geometry and member sizes should be checked on site; if there are significant discrepancies from the outline construction drawings, a fuller dimensional survey should be performed.

ii) *details*: the structural details are not known from detailed construction drawings and may be assumed based on simulated design in accordance with usual practice at the time of construction; in this case, limited inspections in the most critical elements should be performed to check that the assumptions correspond to the actual situation. Otherwise, more extensive *in-situ* inspection is required.

iii) *materials*: no direct information on the mechanical properties of the construction materials is available, either from original design specifications or from original test reports. Default values should be assumed in accordance with standards at the time of construction, accompanied by limited *in-situ* testing in the most critical elements.

(2) The information collected should be sufficient for performing local verifications of element capacity and for setting up a linear structural analysis model.

(3) Structural evaluation based on a state of limited knowledge should be performed through linear analysis methods, either static or dynamic (see 4.4).

3.3.3 KL2: Normal knowledge

(1) KL2 corresponds to the following state of knowledge:

i) *geometry*: the overall structural geometry and member sizes are known either (a) from an extended survey or (b) from outline construction drawings used for both the original construction and any subsequent modifications. In case (b), a sufficient sample of dimensions of both overall geometry and member sizes should be checked on site; if there are significant discrepancies from the outline construction drawings, a fuller dimensional survey is required.

ii) *details*: the structural details are known either from extended *in-situ* inspection or from incomplete detailed construction drawings. In the latter case, limited *in-situ* inspections in the most critical elements should be performed to check that the available information corresponds to the actual situation.

iii) *materials*: information on the mechanical properties of the construction materials is available either from extended *in-situ* testing or from original design specifications. In this latter case, limited *in-situ* testing should be performed.

(2) The information collected should be sufficient for performing local verifications of element capacity and for setting up a linear or nonlinear structural model.

(3) Structural evaluation based on this state of knowledge may be performed through either linear or nonlinear analysis methods, either static or dynamic (see 4.4).

3.3.4 KL3: Full knowledge

(1) KL3 corresponds to the following state of knowledge:

i) *geometry*: the overall structural geometry and member sizes are known either (a)

from a comprehensive survey or (b) from the complete set of outline construction drawings used for both the original construction and any subsequent modifications. In case (b), a sufficient sample of both overall geometry and member sizes should be checked on site; if there are significant discrepancies from the outline construction drawings, a fuller dimensional survey is required.

ii) *details*: the structural details are known either from comprehensive *in-situ* inspection or from a complete set of detailed construction drawings. In the latter case, limited *in-situ* inspections in the most critical elements should be performed to check that the available information corresponds to the actual situation.

iii) *materials*: information on the mechanical properties of the construction materials is available either from comprehensive *in-situ* testing or from original test reports. In this latter case, limited *in-situ* testing should be performed.

(2) **3.3.3(2)** applies.

(3) **3.3.3(3)** applies.

3.4 Identification of the Knowledge Level

3.4.1 Geometry

3.4.1.1 Outline construction drawings

(1) The outline construction drawings are those documents that describe the geometry of the structure, allowing for identification of structural components and their dimensions, as well as the structural system to resist both vertical and lateral actions.

3.4.1.2 Detailed construction drawings

(1) The detailed drawings are those documents that describe the geometry of the structure, allowing for identification of structural components and their dimensions, as well as the structural system to resist both vertical and lateral actions. In addition, they contain information about details (as specified in **3.3.1(2)**).

3.4.1.3 Visual survey

(1) A visual survey is a procedure for checking correspondence between the actual geometry of the structure with the available outline construction drawings. Sample geometry measurements on selected elements should be carried out. Possible structural changes which may have occurred during or after construction should be subjected to a survey as in **3.4.1.4**.

3.4.1.4 Full survey

(1) A full survey is a procedure resulting in the production of structural drawings that describe the geometry of the structure, allowing for identification of structural components and their dimensions, as well as the structural system to resist both vertical and lateral actions.

3.4.2 Details

(1) Reliable non-destructive methods may be adopted in the inspections specified as follows:

3.4.2.1 Simulated design

(1) A simulated design is a procedure resulting in the definition of the amount and layout of reinforcement, both longitudinal and transverse, in all elements participating in the vertical and lateral resistance of the building. The design should be carried out based on regulatory documents and state of the practice used at the time of construction.

3.4.2.2 Limited in-situ inspection

(1) A limited *in-situ* inspection is a procedure for checking correspondence between the actual details of the structure with either the available detailed construction drawings or the results of the simulated design in 3.4.2.1. This entails performing inspections as indicated in 3.4.4(1)P.

3.4.2.3 Extended in-situ inspection

(1) An extended *in-situ* inspection is a procedure used when the original detailed construction drawings are not available. This entails performing inspections as indicated in 3.4.4(1)P.

3.4.2.4 Comprehensive in-situ inspection

(1) A comprehensive *in-situ* inspection is a procedure used when the original detailed construction drawings are not available and when a higher knowledge level is pursued. This entails performing inspections as indicated in 3.4.4(1)P.

3.4.3 Materials

3.4.3.1 Destructive and non-destructive testing

(1) Use of non-destructive test methods (e.g., Schmidt hammer test, etc.) should be considered; however such tests should not be used in isolation, but only in conjunction with destructive tests.

3.4.3.2 Limited in-situ testing

(1) A limited programme of *in-situ* testing is a procedure for complementing the information on material properties derived either from standards at the time of construction, or from original design specifications, or from original test reports. This entails performing tests as indicated in 3.4.4(1)P. However, if values from tests are lower than default values in accordance with standards of the time of construction, an extended *in-situ* testing is required.

3.4.3.3 Extended in-situ testing

(1) An extended programme of *in-situ* testing is a procedure for obtaining information when neither the original design specification nor the test reports are

available. This entails performing tests as indicated in **3.4.4(1)P**.

3.4.3.4 Comprehensive in-situ testing

(1) A comprehensive programme of *in-situ* testing is a procedure for obtaining information when neither the original design specification nor the test reports are available and when a higher knowledge level is pursued. This entails performing tests as indicated in **3.4.4(1)P**.

3.4.4 Definition of the levels of inspection and testing

(1)P The classification of the levels of inspection and testing depend on the percentage of structural elements that have to be checked for details, as well as on the number of material samples per floor that have to taken for testing.

NOTE The amount of inspection and testing to be used in a country may be found in its National Annex. For ordinary situations the recommended minimum values are given in Table 3.2. There might be cases requiring modifications to increase some of them. These cases will be indicated in the National Annex.

Table 3.2: Recommended minimum requirements for different levels of inspection and testing.

Level of inspection and testing	Inspection (of details)	Testing (of materials)
	For each type of primary element (beam, column, wall):	
	Percentage of elements that are checked for details	Material samples per floor
Limited	20	1
Extended	50	2
Comprehensive	80	3

3.5 Confidence factors

(1)P To determine the properties of existing materials to be used in the calculation of the capacity, when capacity is to be compared with demand for safety verification, the mean values obtained from *in-situ* tests and from the additional sources of information, shall be divided by the confidence factor, CF, given in Table 3.1 for the appropriate knowledge level (see **2.2.1(5)P**).

(2)P To determine the properties to be used in the calculation of the force capacity (strength) of ductile components delivering action effects to brittle components/mechanisms, for use in **4.5.1(1)P(b)**, the mean value properties of existing materials obtained from *in-situ* tests and from the additional sources of information, shall be multiplied by the confidence factor, CF, given in Table 3.1 for the appropriate knowledge level.

4 ASSESSMENT

4.1 General

(1) Assessment is a quantitative procedure for checking whether an existing undamaged or damaged building will satisfy the required limit state appropriate to the seismic action under consideration, as specified in **2.1**.

(2)P This Standard is intended for the assessment of individual buildings, to decide on the need for structural intervention and to design the retrofitting measures that may be necessary. It is not intended for the vulnerability assessment of populations or groups of buildings for seismic risk evaluation for various purposes (e.g. for determining insurance risk, for setting risk mitigation priorities, etc.).

(3)P The assessment procedure shall be carried out by means of the general analysis methods specified in EN 1998-1: 2004, **4.3**, as modified in this Standard to suit the specific problems encountered in the assessment.

(4) Whenever possible, the method used should incorporate information of the observed behaviour of the same type of building or similar buildings during previous earthquakes.

4.2 Seismic action and seismic load combination

(1)P The basic models for the definition of the seismic motion are those presented in EN 1998-1: 2004, **3.2.2** and **3.2.3**.

(2)P Reference is made in particular to the elastic response spectrum specified in EN 1998-1: 2004, **3.2.2.2**, scaled to the values of the design ground acceleration established for the verification of the different Limit States. The alternative representations allowed in EN 1998-1: 2004, **3.2.3** in terms of either artificial or recorded accelerograms are also applicable.

(3)P In the q -factor approach (see **2.2.1(4)P**), the design spectrum for linear analysis is obtained from EN 1998-1: 2004, **3.2.2.5**. A value of $q = 1,5$ and $2,0$ for reinforced concrete and steel structures, respectively, may be adopted regardless of the structural type. Higher values of q may be adopted if suitably justified with reference to the local and global available ductility, evaluated in accordance with the relevant provisions of EN 1998-1: 2004.

(4)P The design seismic action shall be combined with the other appropriate permanent and variable actions in accordance with EN 1998-1: 2004, **3.2.4**.

4.3 Structural modelling

(1)P Based on information collected as indicated in **3.2**, a model of the structure shall be set up. The model shall be such that the action effects in all structural elements can be determined under the seismic load combination given in **4.2**.

(2)P All provisions of EN 1998-1: 2004 regarding modelling (EN 1998-1: 2004, **4.3.1**) and accidental torsional effects (EN 1998-1: 2004, **4.3.2**) shall be applied without

modifications.

(3) The strength and the stiffness of secondary seismic elements, (see **2.2.1(6)P**) against lateral actions may in general be neglected in the analysis.

(4) Taking into account secondary seismic elements in the overall structural model, however, is advisable if nonlinear analysis is applied. The choice of the elements to be considered as secondary seismic may be varied after the results of a preliminary analysis. In no case the selection of these elements should be such as to change the classification of the structure from non regular to regular, in accordance with the definitions in EN 1998-1: 2004, **4.2.3**.

(5)P Mean values of material properties shall be used in the structural model.

4.4 Methods of analysis

4.4.1 General

(1) The seismic action effects, to be combined with the effects of the other permanent and variable loads in accordance with the seismic load combination in **4.2(4)P**, may be evaluated using one of the following methods:

- lateral force analysis (linear),
- modal response spectrum analysis (linear),
- non-linear static (pushover) analysis,
- non-linear time history dynamic analysis.
- q -factor approach.

(2)P Except in the q -factor approach of **2.2.1(4)P** and **4.2(3)P**, the seismic action to be used shall be the one corresponding to the elastic (*i.e.*, un-reduced by the behaviour factor q) response spectrum in EN 1998-1: 2004, **3.2.2.2**, or its equivalent alternative representations in EN 1998-1: 2004, **3.2.3**.

(3)P In the q -factor approach of **2.2.1(4)P** the seismic action is defined in **4.2(3)P**.

(4) Clause **4.3.3.1(5)** of EN1998-1: 2004 applies.

(5) The above-listed methods of analysis are applicable subject to the conditions specified in **4.4.2** to **4.4.5**, with the exception of masonry structures for which procedures accounting for the peculiarities of this construction typology need to be used.

NOTE Complementary information on these procedures may be found in the relevant material-related Informative Annex.

4.4.2 Lateral force analysis

(1)P The conditions for this method to be applicable are given in EN 1998-1: 2004, **4.3.3.2.1**, with the addition of the following:

Denoting by $\rho_i = D_i/C_i$ the ratio between the demand D_i obtained from the analysis