SLOVENSKI STANDARD
SIST EN 1998-3:2005
01-oktober-2005

Nadomeġļ a:
SIST ENV 1998-1-4:2000+D1:2001
SIST ENV 1998-3:2001

Evrokod 8: Projektiranje potresnoodpornih konstrukcij – 3. del: Ocena in prenova stavb

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

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

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

Ta slovenski standard je istoveten z: **EN 1998-3:2005**

ICS:

91.010.30	Tehniļ ni vidiki	Technical aspects
91.120.25	Zaġļ ita pred potresi in vibracijami	Seismic and vibration protection

SIST EN 1998-3:2005 **en**

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 1998-3

June 2005

ICS 91.120.25

Supersedes ENV 1998-1-4:1996

English version

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

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

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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.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 1998-3:2005: E

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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of an identical text or by endorsement, at the latest by December 2005, and conflicting national standards shall be withdrawn at the latest by March 2010.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 agreement[1] 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 Documents[2] referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standards[3]. 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 works[4]. 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:

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[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 gradate 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 ρ_{max}/ρ_{min}
4.4.4.5(2)	Complementary, non-contradictory information on non-linear static analysis procedures that can capture the effects of higher modes.

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

$f_{fdd,e}$ 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 $= t_f \cdot w_f \cdot \sin\beta$: 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**.