

Anti-seismic devices

ICS 91.120.25

National foreword

This British Standard is the UK implementation of EN 15129:2009.

The UK participation in its preparation was entrusted to Technical Committee B/522, Structural bearings.

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

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.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 January 2010
© BSI 2010

ISBN 978 0 580 55084 3

Amendments/corrigenda issued since publication

Date	Comments

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 15129

November 2009

ICS 91.120.25

English Version

Anti-seismic devices

Dispositifs anti-sismiques

Erdbebenvorrichtungen

This European Standard was approved by CEN on 19 September 2009.

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 CEN Management Centre 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 CEN Management Centre has the same status as the official versions.

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



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

Management Centre: Avenue Marnix 17, B-1000 Brussels

Contents

Page

Foreword.....	6
1 Scope	7
2 Normative references	7
3 Terms, definitions, symbols and abbreviations	8
3.1 Terms and definitions	8
3.2 Symbols	14
3.2.1 Latin upper case letters	14
3.2.2 Latin lower case letters	14
3.2.3 Greek letters	14
3.2.4 Subscripts	14
3.3 Abbreviations	15
3.4 List of devices	16
4 General design rules	18
4.1 Performance requirements and compliance criteria.....	18
4.1.1 Fundamental requirements.....	18
4.1.2 Increased reliability of structural system.....	18
4.1.3 Functional requirements	19
4.1.4 Structural and mechanical requirements	19
4.1.5 Compliance criteria.....	19
4.2 Action effects on devices	20
4.2.1 Seismic design situations and seismic combinations of actions	20
4.2.2 Effects of actions	20
4.3 Conceptual design of the devices.....	20
4.3.1 Reliability of the devices' behaviour.....	20
4.3.2 Capacity design	20
4.3.3 Maintenance	20
4.3.4 Modification and replacement of devices	21
4.3.5 Device documentation	21
4.4 General properties	21
4.4.1 Material properties.....	21
4.4.2 Device properties to be used in the analysis.....	21
4.4.3 Re-centring capability	22
4.5 Constitutive laws	23
4.6 Validation of anti-seismic devices	23
5 Rigid connection devices	24
5.1 Permanent Connection Devices.....	24
5.2 Fuse Restraints	24
5.2.1 Performance requirements	24
5.2.2 Material properties.....	24
5.2.3 Design requirements	25
5.2.4 Type Testing.....	25
5.2.5 Factory production control tests	26
5.3 Temporary (dynamic) connection devices.....	26
5.3.1 Functional requirements	26
5.3.2 Material properties.....	27
5.3.3 Design Requirements.....	27
5.3.4 Type Testing.....	28
5.3.5 Factory Production Control Tests.....	30
6 Displacement Dependent Devices	30

6.1	General	30
6.2	Performance Requirements	31
6.3	Materials	33
6.3.1	General	33
6.3.2	Elastomer	33
6.3.3	Steel	34
6.3.4	Other materials (special steel, stainless steel, SMA, visco-elastic polymeric materials).....	34
6.4	Testing	34
6.4.1	General	34
6.4.2	Type tests of materials.....	34
6.4.3	Factory production control tests of materials.....	36
6.4.4	Type tests of devices	37
6.4.5	Factory production control testing of devices	38
7	Velocity Dependent Devices	38
7.1	Functional requirements.....	38
7.2	Material properties	38
7.2.1	General	38
7.2.2	Materials	39
7.2.3	Active Surfaces.....	39
7.2.4	Viscous Fluid	39
7.3	Design requirements.....	39
7.3.1	General	39
7.3.2	Over velocity	40
7.3.3	Buckling	40
7.4	Testing	41
7.4.1	General	41
7.4.2	Type Testing	41
7.4.3	Factory production control	44
8	Isolators.....	44
8.1	General Requirements	44
8.2	Elastomeric Isolators	46
8.2.1	Requirements.....	46
8.2.2	Materials	52
8.2.3	Design.....	59
8.2.4	Testing.....	63
8.2.5	Manufacturing Tolerances.....	72
8.2.6	Marking and Labelling.....	72
8.3	Curved Surface Sliders	73
8.3.1	Requirements.....	73
8.3.2	Materials	77
8.3.3	Design.....	78
8.3.4	Testing	80
8.3.5	Manufacturing, Assembly and Tolerances	87
8.4	Flat Surface Sliders	88
8.4.1	Requirements.....	88
8.4.2	Materials	88
8.4.3	Design.....	88
8.4.4	Testing	88
8.4.5	Manufacturing, Assembly and Tolerances	88
9	Combinations of Devices	89
9.1	Requirements.....	89
9.1.1	General	89
9.1.2	Particular requirements	89
9.2	Materials	89
9.3	Design.....	89
9.4	Testing.....	90
9.4.1	General	90
9.4.2	Type Testing	90

9.4.3	Factory Production Control testing	90
10	Evaluation of conformity.....	90
10.1	General.....	90
10.2	Type testing.....	91
10.2.1	Initial Type Testing	91
10.2.2	Further type-testing	95
10.3	Factory Production Control (FPC)	96
10.3.1	General.....	96
10.3.2	Raw materials and constituents.....	98
10.3.3	Equipment	101
10.3.4	Sampling.....	101
11	Installation	101
12	In-service inspection	102
12.1	General requirements.....	102
12.2	Regular inspection.....	102
12.3	Principal inspection.....	102
Annex A	(informative) Commentary to Clause 1: Scope.....	103
Annex B	(informative) Commentary to Clause 4: General design rules.....	104
B.1	Service life of a device	104
B.2	Basic requirements.....	104
B.3	Reliability differentiation	104
B.4	Increased reliability	104
B.5	Requirements at the ULS	105
B.6	Requirements at the SLS	105
B.7	Structural analysis.....	105
B.8	Material properties.....	105
B.9	Re-centring capability	106
Annex C	(informative) Commentary to Clause 5: Rigid connection devices	107
C.1	Functional requirements.....	107
C.2	Material properties.....	107
C.3	Design Requirements	108
C.4	Testing	108
C.4.1	General.....	108
C.4.2	Low velocity test	109
C.4.3	Seal Wear Test	110
C.4.4	Impulsive Load Test	110
C.4.5	Overload Test.....	111
C.4.6	Cyclic Load Test	111
Annex D	(informative) Commentary to Clause 6: Displacement Dependent Devices.....	112
D.1	Categories of Non Linear Devices (NLD)	112
D.2	Examples of linear devices — Elastomeric shear-strained devices	114
D.3	Examples of non linear devices	114
D.3.1	Buffer	114
D.3.2	Steel hysteretic energy dissipating devices	114
D.3.3	Buckling Restrained Braces	114
D.3.4	SMA Re-centring Devices	115
Annex E	(informative) Commentary to Clause 7: Velocity Dependent Devices	116
E.1	Functional requirements	116
E.2	Design Requirements	118
E.3	Testing	120
E.3.1	General.....	120
E.3.2	Low velocity test for Fluid Viscous Dampers	120
E.3.3	Low velocity test for Fluid Spring Dampers	121
E.3.4	Constitutive law test for Fluid Viscous Dampers	122
E.3.5	Constitutive law test for Fluid Spring Dampers	122

E.3.6	Damping efficiency test	123
Annex F	(informative) Commentary to Clause 8: Isolators.....	125
F.1	Ageing conditions for elastomeric isolators	125
F.2	Low temperature crystallisation	125
F.3	Commentary on Basis of design	126
F.3.1	Shape Factor.....	126
F.3.2	Design shear strain due to compression by vertical loads	127
F.3.3	Isolator stiffnesses.....	127
F.4	Determination of the restoring stiffness by tests for curved and flat surface sliders	128
Annex G	(normative) Equipment for combined compression and shear	130
G.1	General requirements	130
G.2	Data Acquisition	130
G.3	Combined compression and shear equipment.....	130
G.4	Load Platens	131
G.5	Data analysis.....	131
Annex H	(informative) Design of Connections for Devices	133
H.1	Elastomeric Isolators	133
H.2	Sliders.....	133
Annex I	(informative) Method for calculating pressure distributions on spherical surfaces	135
I.1	General	135
I.2	Modelling assumptions.....	135
I.3	Effects of vertical loads	135
I.4	Effects of horizontal loads	137
I.5	Combined loads.....	137
Annex J	(informative) λ-FACTORS FOR COMMON ISOLATOR TYPES.....	139
J.1	$\lambda_{\max}$- values for elastomeric isolators	139
J.2	$\lambda_{\max}$- values for sliding isolator units	140
Annex ZA	(informative) Relationship between this European Standard and the Essential Requirements of EU Directive.....	142
ZA.1	Scope and relevant characteristics	142
ZA.2	Procedure(s) for attestation of conformity of anti-seismic devices	149
ZA.2.1	System(s) of attestation of conformity.....	149
ZA.2.2	EC Certificate and Declaration of conformity.....	151
ZA.3	CE marking and labelling	153
ZA.3.1	Declaration of product properties	154
ZA.3.2	Declaration of compliance with given design specification	155
	Bibliography.....	159

Foreword

This document (EN 15129:2009) has been prepared by Technical Committee CEN/TC 340 “Anti-seismic devices”, the secretariat of which is held by UNI.

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 May 2010, and conflicting national standards shall be withdrawn at the latest by August 2011.

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

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

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

1 Scope

This European Standard covers the design of devices that are provided in structures, with the aim of modifying their response to the seismic action. It specifies functional requirements and general design rules for the seismic situation, material characteristics, manufacturing and testing requirements, as well as evaluation of conformity, installation and maintenance requirements. This European Standard covers the types of devices and combinations thereof as defined in 3.4.

NOTE Additional information concerning the scope of this European Standard is given in Annex A.

2 Normative references

The following referenced documents are indispensable for the application 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.

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

EN 1337 (all parts), *Structural bearings*

EN 1990:2002, *Eurocode – Basis of structural design*

EN 1998 (all parts), *Eurocode 8: Design of structures for earthquake resistance*

EN 10025 (all parts), *Hot rolled products of structural steels*

EN 10083 (all parts), *Steels for quenching and tempering*

EN 10088 (all parts), *Stainless steels*

EN 10204:2004, *Metallic products – Types of inspection documents*

EN ISO 4287, *Geometrical product specifications (GPS) – Surface texture: Profile method – Terms, definitions and surface texture parameters (ISO 4287:1997)*

EN ISO 4526, *Metallic coatings – Electroplated coating of nickel for engineering purposes (ISO 4526:2004)*

EN ISO 6158, *Metallic coatings – Electrodeposited coatings of chromium for engineering purposes (ISO 6158:2004)*

ISO 34 (all parts), *Rubber, vulcanized or thermoplastic – Determination of tear strength*

ISO 37, *Rubber, vulcanized or thermoplastic – Determination of tensile stress-strain properties*

ISO 48, *Rubber, vulcanized or thermoplastic – Determination of hardness (hardness between 10 IRHD and 100 IRHD)*

ISO 188, *Rubber, vulcanized or thermoplastic – Accelerated ageing and heat resistance tests*

ISO 815 (all parts), *Rubber, vulcanized or thermoplastic – Determination of compression set*

ISO 898 (all parts), *Mechanical properties of fasteners*

ISO 1083, *Spheroidal graphite cast irons – Classification*

ISO 3755, *Cast carbon steels for general engineering purposes*

ISO 4664 (all parts), *Rubber, vulcanized or thermoplastic – Determination of dynamic properties*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

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

NOTE In this European Standard, compressive forces, stresses and strains are positive.

3.1.1 activation velocity

velocity at which a Shock Transmission Unit (STU) reacts with its design force

3.1.2 axial force N_{Ed} acting on a device under the design seismic action

maximum value during the action is denoted $N_{Ed,max}$ and the minimum value $N_{Ed,min}$. The minimum value acting on a device may be tensile

3.1.3 core element

component of a Linear Device (LD) or of a Non Linear Device (NLD) on which the mechanism characterising the device's behaviour is based

NOTE Core elements of a LD or of a NLD are the device's components that provide it with the flexibility and, eventually, with the energy dissipation and/or re-centring capacity or any other mechanical characteristic compatible with the requirements of a LD or of a NLD. Examples of core elements are steel plates or bars, shape memory alloy wires or bars, rubber elements.

3.1.4 design displacement d_{bd} (of a device)

total displacement (due to both translation and rotation about the vertical axis of the isolation system) that a device will undergo when the structural system is subjected to the design seismic action alone according to EN 1998-1

3.1.5 design displacement of an isolation system in a principal direction d_{cd}

horizontal displacement at the effective stiffness centre, occurring under the design seismic action alone

3.1.6 (maximum) displacement of a device in a principal direction d_{Ed}

for an anti-seismic device in a bridge d_{Ed} equals d_{max} , the maximum total horizontal displacement at the location of the device including all actions effects and the application of the reliability factor to d_{bd} , according to EN 1998-2:2005, 7.6.2 (2)P

For devices in other structures d_{Ed} equals $\gamma_x d_{bd}$, the design displacement increased by the reliability factor.

3.1.7 design force V_{bd} (of a device)

force (or moment) corresponding to d_{bd}

**3.1.8
devices**

elements which contribute to modify the seismic response of a structure by isolating it, by dissipating energy or by creating permanent or temporary restraints via rigid connections. The devices considered are described in the various clauses of this European Standard

**3.1.9
ductility demand (of a device)**

displacement ductility demand referred to the theoretical bilinear cycle, and is evaluated as d_{bd}/d_1 (see 3.1.4 and 3.1.44)

NOTE The ductility demand is a useful parameter to evaluate the plastic demand of an EDD based on material hysteresis (see 3.1.17).

**3.1.10
effective damping (of a device) ξ_{effb}**

value of the effective viscous damping, corresponding to the energy dissipated by the device during cyclic response at the total design displacement:

$$\xi_{effb} = W(d_{bd}) / (2\pi V_{Ebd} d_{bd}) \quad (1)$$

where

$W(d_{bd})$ = energy actually dissipated by a device during the 3rd load cycle, with maximum displacement equal to d_{bd} .

NOTE ξ_{effb} is introduced for a simple characterisation of the behaviour of any device. It cannot be used in the analytical calculations of the response of the structural system, unless they can be carried out by linear analysis and all the devices have the same damping and stiffness in the given direction. Where different devices are used, reference is made to the overall effective damping of the isolation system.

**3.1.11
effective period T_{eff}**

in the case of seismic isolation, is the period of a single degree of freedom system moving in the direction considered, having the mass of the superstructure and the stiffness equal to the effective stiffness of the isolation system

**3.1.12
effective stiffness of a device in a principal direction K_{effb}**

ratio between the value of the total horizontal force transferred through the device and the component of the total design displacement in the same direction, divided by the absolute value of the total design displacement (secant stiffness)

$$K_{effb} = V_{Ebd} / d_{bd} \quad (2)$$

NOTE K_{effb} is introduced for a simple characterisation of the behaviour of a device. It cannot be used in the analytical calculations of the response of the structural system, unless they can be carried out by linear analysis and all the devices have the same damping and stiffness in the given direction. Where different devices are used, reference is made to the overall effective stiffness of the isolation system.

**3.1.13
effective stiffness of an isolation system in a principal direction K_{eff}**

sum of the effective stiffness of the devices located at the isolation interface

**3.1.14
effective stiffness centre**

stiffness centre of an isolation system, accounting for the effective stiffness of the devices

3.1.15

energy dissipation design

design approach in which mechanical elements are introduced at certain locations of the structure to dissipate the energy which is introduced into the structure by an earthquake

3.1.16

energy dissipation capacity

ability of a device to dissipate energy during the load-displacement cycles

3.1.17

energy dissipating device (EDD)

device which has a large energy dissipation capacity, i.e. which dissipates a large amount of the energy stored during the loading phase. After unloading it normally shows a large residual displacement. A device is classified as EDD if the equivalent viscous damping ξ is greater than 15 %

3.1.18

first branch stiffness K_1 of a NLD

initial stiffness of a NLD is defined as the secant stiffness between the points corresponding to the forces $V_{Ebd}/10$ and $V_{Ebd}/5$:

$$K_1 = (V_{Ebd}/5 - V_{Ebd}/10) / [d(V_{Ebd}/5) - d(V_{Ebd}/10)] \quad (3)$$

NOTE K_1 is referred to as initial or elastic stiffness when dealing with softening devices.

3.1.19

Fluid Viscous Damper (FVD)

anti-seismic device whose output is an axial force that depends on the imposed velocity only; its principle of functioning consists of exploiting the reaction force of a viscous fluid forced to flow through an orifice and/or valve system

3.1.20

Fluid Spring Damper (FSD)

anti-seismic device whose output is an axial force that depends on both imposed velocity and stroke; its principle of functioning consists of exploiting the reaction force of a viscous fluid forced to flow through an orifice and valve system and at the same time is subjected to progressive compression

3.1.21

Hardening Device (HD)

NLD whose effective stiffness K_{effb} and second branch stiffness K_2 are greater than the first branch stiffness K_1

3.1.22

Hydraulic Fuse Restraint (HFR)

Hydraulic Fuse Restraints are SRs whose behaviour is hydraulic in nature and depends upon the opening of relief valves

3.1.23

stiffness K_1 of a LD

stiffness of a LD is defined as the secant stiffness between the points corresponding to the forces $V_{Ebd}/10$ and $V_{Ebd}/5$:

$$K_1 = (0,2 \cdot V_{bd} - 0,1 \cdot V_{bd}) / [d_{(0,2V_{bd})} - d_{(0,1V_{bd})}] \quad (4)$$

NOTE The evaluation of K_1 as secant stiffness is justified by the difficulty of tracing the tangent to a curve at the origin in an experimentally drawn diagram.

3.1.24

isolation system

collection of devices used for providing seismic isolation

3.1.25**isolation interface**

in the case of seismic isolation, the surface which separates the substructure and the superstructure and where the isolation system is located

3.1.26**isolator**

device possessing the characteristics needed for seismic isolation, namely, ability to support gravity load of superstructure, and ability to accommodate lateral displacements. Isolators may also provide energy dissipation, and contribute to the isolation system's recentring capability

NOTE In EN 1998-2, isolator may also designate the devices belonging to an isolation system, whether they support gravity loads or not.

3.1.27**linear device (LD)**

anti-seismic device which is characterised by a linear or almost linear load-displacement relationship up to the displacement d_{bd} , with a stable behaviour under a large number of cycles and substantial independence from velocity. After unloading, it does not show a residual displacement. Even when some energy dissipation occurs in the device, residual displacements shall be negligible, and in any case less than 2 % of the maximum displacement

NOTE For visco-elastic devices, residual displacements can be partially or totally recovered after some hours. In this case, the final residual displacement should be referred to.

3.1.28**Mechanical Fuse Restraint (MFR)**

SR whose behaviour is determined by the break-away of sacrificial components

3.1.29**Non Linear Device (NLD)**

anti-seismic device which is characterised by a non linear load-displacement relationship, with a stable behaviour under the required number of cycles and substantial independence from velocity. A device is classified as non linear if either ξ_{effb} is greater than 15 % or the ratio $|K_{effb} - K_1|/K_1$ is greater than 20 %, where ξ_{effb} and K_{effb} are evaluated at the 3rd cycle with maximum displacement equal to d_{bd}

3.1.30**Non linear Elastic Devices (NLED)**

NLD which normally dissipates a negligible amount of the energy stored during the loading phase. The static residual displacement after unloading shall be negligible. A device is classified as NLED if ξ_{effb} is less than 15 % while the ratio $|K_{effb} - K_1|/K_1$ is greater than 20 %

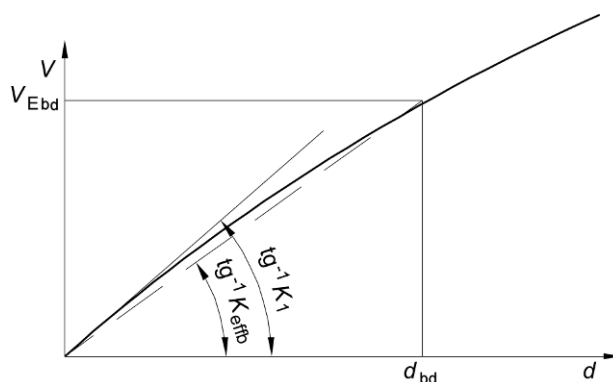


Figure 1 — Initial and effective stiffness of a linear device

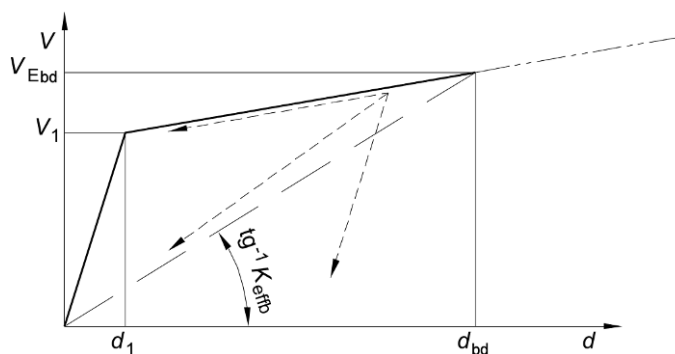


Figure 2 — Effective stiffness of a non linear device

3.1.31

Permanent Connection Device (PCD)

device which provides steady restraint in one or two horizontal directions, accommodates rotations and vertical displacements, i.e. does not transmit bending moments and vertical loads; the device which restrains the movements in one horizontal direction only is referred to as Moveable Connection Device, while the device which restrains the movements in two horizontal directions is defined as Fixed Connection Device

NOTE In certain circumstances, the above devices may be required to operate in a plane inclined to the horizontal. In such case, the terms "vertical" and "horizontal" take on the appropriate significance.

3.1.32

Rigid Connection Device (RCD)

device which links two structural elements without transmitting bending moments and vertical loads; this category of devices includes Permanent Connection Devices (see 5.1), Fuse Restraints (see 5.2) and Temporary Connection Devices (see 5.3)

3.1.33

Fuse Restraint (FR)

device that, below a certain pre-established force threshold (break-away force), prevents any relative movement between connected parts, whilst it permits movement after the aforesaid threshold has been exceeded

3.1.34

second branch stiffness K_2

parameter referred to the theoretical bilinear cycle and defined as (see Figure 2):

$$K_2 = [V_{Ebd} - V_{(0,5 \cdot d_{bd})}] / (0,5 \cdot d_{bd}) \quad (5)$$

where

$V_{(0,5 \cdot d_{bd})}$ is the force corresponding to $(0,5 \cdot d_{bd})$ at the 3rd cycle of the test

NOTE 1 The formula is obtained by evaluating the second branch stiffness as a secant stiffness referred to displacements $0,5 \cdot d_{bd}$ and d_{bd} .

NOTE 2 K_2 is often referred to as post-elastic stiffness when dealing with softening devices.

3.1.35

seismic isolation

design approach in which appropriate mechanisms (isolation systems) are provided at a certain level of the structure to decouple the part of the structure located above this level, therefore modifying the seismic response of the structure and its contents

3.1.36

service life of a device

period over which a device is expected to perform within its specified parameters. The value is taken as that given in Technical Specifications of the Project, based on declarations made by manufacturers

NOTE Additional information concerning the service life is given in informative Annex B.

3.1.37

Shock-Transmission Unit (STU)

device whose output is an axial force that depends on the imposed velocity; its principle of functioning consists of exploiting the reaction force of a viscous fluid forced to flow through an orifice in order to provide a very stiff dynamic connection whilst for low velocity applied loads the reaction is negligible

3.1.38

Softening Device (SD)

NLD whose secant stiffness K_{effb} and second branch stiffness K_2 are smaller than the first branch stiffness K_1

3.1.39

Statically Re-centring Device (StRD)

Energy Dissipating Device whose force-displacement cyclic curve at the 3rd cycle passes through or very near the origin of the axes, at a distance not greater than $0,1 d_{\text{bd}}$

3.1.40

substructure

in the case of seismic isolation, the part of the structure which is located under the isolation interface and is anchored to the foundations

3.1.41

superstructure

in the case of seismic isolation, the part of the structure which is isolated and is located above the isolation interface

3.1.42

Supplemental Re-centring Device (SRCD)

device whose force-displacement cyclic curve at the 3rd cycle passes through or very near the origin of the axes and, for small displacement at unloading ($0,1 d_{\text{bd}}$), provides a force which is at least $0,1 V_{\text{Ebd}}$

NOTE The supplemental force $> 0,1 V_{\text{Ebd}}$ is meant to counteract the effect of parasitic non-conservative forces (e.g. friction in other devices, yielding in structural elements, etc.) or other energy dissipating non re-centring devices, in order to provide the entire structural system with an overall Re-centring capability. The supplemental force is calibrated according to the re-centring requirements of the structural system.

3.1.43

Temporary Connecting Device (TCD)

anti-seismic device whose output is a force that depends on the imposed velocity; its principle of functioning consists of a system providing for the required reaction force when dynamically activated whilst for slow applied movements it does provide a minor reaction

3.1.44

theoretical bilinear cycle of a NLD

it is conventionally defined to identify the main mechanical characteristics of a non linear device through the first and second branch stiffness values and by the following parameters:

d_1 = abscissa of the intersection point of the straight line starting at the origin with stiffness K_1 and the straight line passing through $(d_{\text{bd}}, V_{\text{Ebd}})$ with stiffness K_2 in the experimental 3rd load cycle of a quasi static test;

V_1 = ordinate of the intersection point of the straight line starting at the origin with stiffness K_1 and the straight line passing through $(d_{\text{bd}}, V_{\text{Ebd}})$ with stiffness K_2 in the experimental 3rd load cycle of a quasi static test;

V_{Ebd} = force corresponding to d_{bd} , obtained at the 3rd load cycle during a quasi static test.

3.2 Symbols

NOTE The list below covers most of the symbols. Others are defined at their first occurrence in the text.

3.2.1 Latin upper case letters

A	Area	m^2
F	Load, force acting on a device	MN
G	Shear modulus	MPa
M	Moment, bending moment	MN·m
N	Axial force	MN
V	Shear force	MN
R	Resistance	MPa
S	Acting force, acting moment, shape factor	MN, MN·m
T	Temperature, total thickness	°C, mm
E	Modulus, energy	GPa, MJ
K	Stiffness of a device	MN/m

3.2.2 Latin lower case letters

a	Acceleration, length	ms^{-2} , m
b	Length	m
d	Displacement (translation or rotation) of a device	m
f	Strength, frequency	MPa, Hz
t	Thickness of a layer, tolerance, time	mm, s
x, y	Horizontal co-ordinates	
z	Vertical co-ordinates	

3.2.3 Greek letters

α	Coefficient of thermal expansion, angle of rotation	/°C, rad
γ	Partial factor, over-strength factor, reliability factor	
ξ	Equivalent viscous damping factor	
ε	Strain	
μ	Coefficient of friction	

3.2.4 Subscripts

a	actual
b	bearing or device
c	compression
cr	critical
d	design
e	elastomer

eff	effective, equivalent value at design displacement
el	elastic
h	horizontal
i	i-th cycle, i-th element (generic)
in	initial
k	characteristic
max	maximum
min	minimum
res	residual
s	steel
sc	secant
u	ultimate
v	vertical, velocity
x	horizontal co-ordinate, increased reliability
y	horizontal co-ordinate
z	vertical co-ordinate
E	related to seismic situation
I	importance
L	lower limit of service range
M	material
R	resistance value
S	acting value
U	upper limit of service range
1	conventional elastic limit, first branch in the theoretical bilinear cycle of a NLD
2	design displacement and force, second branch in the theoretical bilinear cycle of a NLD
3	3 rd cycle
ϕ	related to bending

3.3 Abbreviations

DP	Design properties
DRD	Dynamically Re-centring Device
DSC	Differential Scanning Calorimeter
EDD	Energy Dissipating Device
FPC	Factory Production Control
FR	Fuse Restraint
FSD	Fluid Spring Damper

FVD	Fluid Viscous Damper
HD	Hardening Device
HDRB	High Damping Rubber Bearing
HFR	Hydraulic Fuse Restraint
LBDP	Lower Bound Design Properties
LD	Linear Device
LDRB	Low Damping Rubber Bearing
LRB	Lead Rubber Bearing
MFR	Mechanic Fuse Restraint
NDP	Nationally Determined Parameters
NLD	Non Linear Device
NLED	Non Linear Elastic Device
NRD	Non Re-centring Device
PCD	Permanent Connection Device
PPRB	Polymer plug rubber bearing
RCD	Re-Centring Device
SD	Softening Device
SLS	Serviceability Limit State
SMA	Shape Memory Alloys
SR	Sacrificial (Fuse) Restraint
SRCD	Supplement Re-Centring Device
StRD	Statically Re-centring Device
STU	Shock-Transmission Unit
TCD	Temporary Connecting Device
UBDP	Upper Bound Design Properties
ULS	Ultimate Limit State

3.4 List of devices

Symbols representing the most common types of devices are given in Table 1.

Table 1 — Most common types of Anti-seismic devices

Description of the Device			Relevant Clause	Graphic Representation			Notes
				Plan view	Elevation view		
					Direction x	Direction y	
Rigid Connection Devices (RGDs)	Permanent Connection Devices (PCDs)	Fixed	5.1				This type of device corresponds to type 8.1 (Restraint bearing) in Table of EN 1337-1:2000 (*)
		Moveable	5.1				This type of device corresponds to type 8.2 (Guide bearing) in Table 1 of EN 1337-1:2000 (°)
	Fuse Restraints	Mechanical Fuse Restraints (MFRs)	5.2			-	
		Hydraulic Fuse Restraints (HFRs)	5.2			-	
	Temporary Connection Devices (TCDs)		5.3			-	This type of device is usually referred to as Shock Transmission Unit (STU)
Displacement Dependent Devices (DDDs)	Linear Devices (LDs)		6.1			-	
	Non linear Devices (NLDs)		6.2			-	
Velocity Dependent Devices	Fluid Viscous Dampers (FVDs)		7.1			-	This graphic representation applies also to two-shaft dampers
	Fluid Spring Dampers (FSDs)		7.1			-	
Seismic Isolators	Elastomeric		8.2				The isolators are shown in the deformed position to underscore their lateral flexibility
	Lead Rubber Bearings		8.2				
	Curved Surface Sliders		8.3				The symbols apply to both Single and Double Curved Surface Sliders
	Flat Surface Sliders		8.4				The symbols apply to both types 2.3 (free sliding pot bearing) and 3.5 (free sliding spherical bearing) in Table 1 of EN 1337-1:2000 (■)
Note 1 (*):	This type of device will correspond to type F.0 (Restraint bearing) in Table 1 of the revised version of EN 1337-1.						
Note 2 (°):	This type of device will correspond to type G.1 (Guide bearing) in Table 1 of the revised version of EN 1337-1.						
Note 3 (■):	This type of device will correspond to types P.2 and S.2, respectively, in Table 1 of the revised version of EN 1337-1.						

4 General design rules

NOTE 1 Additional information concerning the general design rules is given in Annex B.

NOTE 2 The seismic analysis and design of the isolating system of an entire structure is ruled by EN 1998-1, with specific requirements for buildings in EN 1998-1 and EN 1998-2 for bridges. In the seismic analysis of the isolating system of an entire structure, design action effects on individual components, including anti-seismic devices are assessed on the basis of the design seismic action deduced from the structural seismic analysis.

4.1 Performance requirements and compliance criteria

4.1.1 Fundamental requirements

The anti-seismic devices and their connections to the structure shall be designed and constructed in such a way that the following requirements are met, each with an adequate degree of reliability:

a) No failure requirement

The anti-seismic devices and their connections to the structure shall be designed and constructed to withstand the seismic action effects defined by EN 1998-1 for buildings or by EN 1998-2 for bridges without local or global failure, thus retaining a residual mechanical resistance, including when applicable a residual load bearing capacity, after the seismic event.

NOTE 1 The non failure requirement concerns the structure as a whole and, when appropriate, the device and its connection to the structure. It does not concern Fuse Restraints. The device is expected to sustain damage in this event which may necessitate repair or replacement.

b) Damage limitation requirement

The anti-seismic devices and their connections to the structure shall be designed and constructed to withstand a seismic action having a larger probability of occurrence than the design seismic action, without the occurrence of damage and the associated limitations of use, the costs of which would be disproportionately high in comparison with the costs of the structure itself. The seismic action to be considered for the damage limitation requirement is defined in 2.1 (1) P of EN 1998-1:2004.

NOTE 2 The device is expected to sustain no or very minor damage in this event which does not necessitate replacement.

Non-seismic design situations not covered by this European Standard shall also be considered according to relevant European Standards.

NOTE 3 This implies in particular the compliance with Eurocodes.

4.1.2 Increased reliability of structural system

According to EN 1998-1:2004, subclause 10.3 (2) P, in the case of isolation systems, increased reliability shall be required for the isolation devices and their connections to the structure.

NOTE 1 In EN 1998-1, this is implemented by applying a magnification factor γ_x on seismic displacements of each unit. In EN 1998-2, this magnification factor is called γ_{IS} . Recommended minimum values of γ_x or γ_{IS} for isolators are given in EN 1998-1 and EN 1998-2 respectively. Mandatory values may be given in the corresponding National Annexes.

For devices not used in an isolation system, depending on the role they play in the stability of the construction after the earthquake, a reliability factor γ_x equal or greater than 1 shall be applied to the seismic action effects on the devices and their connections to the structure.

NOTE 2 Recommended minimum values of γ_x for devices other than isolators are given in the relevant clauses of this European Standard. The values should be covered by structural Eurocodes at a later stage.

NOTE 3 Higher values of γ_x may be defined by National Authorities or by the owner in the case of a critical structure.

4.1.3 Functional requirements

Devices and their connections to the structure shall be designed and constructed in such a way as to function according to the design requirements and tolerances throughout their projected service life, given the mechanical, physical, chemical, biological and environmental conditions expected.

Devices and their connections to the structure shall be designed, constructed and installed in such a way that their routine inspection and replacement are possible during the service life of the construction.

NOTE For the enforcement of this requirement, it is necessary that the design of the structure takes account of accessibility for both equipment and personnel.

4.1.4 Structural and mechanical requirements

Devices and their connections to the structure shall be designed and constructed in such a way that their performance characteristics conform to the design requirements, as given below:

a) Requirements at the ULS

NOTE 1 The verification of the devices at the Ultimate Limit State (ULS) is associated with the design seismic situation, with due consideration of the reliability of the structural system.

The devices and their connections to the structure shall be verified, with an adequate degree of reliability, to have an appropriate strength and ductility to withstand actions effects in the seismic design situation, taking into account the reliability factor γ_x of the structural system, as defined in 4.1.2, and second order effects.

At the ULS, the devices and their connections to the structure can suffer damage, but shall not reach failure except in the case of fuse restraints, for which requirements given in 5.2 apply.

Replacement of the devices after any damage suffered shall be possible without resorting to major intervention. Where applicable, they shall retain a residual capacity at least equal to the permanent actions to which they are directly subjected or to such combinations of actions corresponding to design situations (including eventually a seismic situation) that may occur after the earthquake, as defined by the structural design.

b) Requirements at the SLS

NOTE 2 The verification of the devices at the Serviceability Limit State (SLS) is associated with the damage limitation requirement and the corresponding seismic action, as defined in 4.1.1.

At the SLS, the devices and their connections to the structure shall remain in a serviceable state, at least as far as their performance under further seismic loads is concerned, and undergo only very minor or superficial damage which should not induce interruption of use, nor require immediate repair.

4.1.5 Compliance criteria

Performance requirements concerning the devices and their connections to the structure shall be satisfied by complying with the procedures set forth in the corresponding clauses of this European Standard, according to the type of devices used.

NOTE The verification of compliance criteria may be obtained by appropriate modelling or testing according to the corresponding clauses of this European Standard.

4.2 Action effects on devices

4.2.1 Seismic design situations and seismic combinations of actions

The seismic design situations defined in 4.1.1 shall be associated with the seismic combinations of actions defined in 6.4.3.4 of EN 1990:2002.

4.2.2 Effects of actions

Combinations of the effects of the components of the seismic action on the devices shall be as defined in the corresponding parts of EN 1998.

4.3 Conceptual design of the devices

4.3.1 Reliability of the devices' behaviour

NOTE 1 An adequate reliability in the behaviour of the devices and their connections to the structure over their service life, as required in 4.1.2, is necessary in order to reduce the uncertainties inherent in seismic design.

Device components shall comply with the relevant European Standards.

NOTE 2 In the cases where European Standards do not exist, national standards may apply.

Choice of the material and construction techniques of the device and its connections to the structure shall be consistent with the design requirements determined for the structure.

A good reproducibility of the mechanical behaviour of the device and of its components shall be obtained, as defined in the relevant clauses of this European Standard.

The description of the mechanical behaviour of the device and its connections to the structure shall be based on adequate modelling and tests, as required in 4.6 and Clause 10.

The relevant mechanical and physical properties of the device and its connections to the structure or their components shall be assessed by tests through appropriate procedures, as required in 4.6 and Clause 10 and in the corresponding clauses of this European Standard.

NOTE 3 Beyond the design seismic action, including reliability factors, there should be no immediate risk of catastrophic failure of the device.

4.3.2 Capacity design

An over-strength factor γ_{Rd} equal to 1,1 shall be applied to the actions transmitted by the device to the connections.

NOTE The actions transmitted by the device to the connections are based on the UBDP (see 4.4.2).

4.3.3 Maintenance

All devices and their connections to the structure shall be accessible for inspection and maintenance.

NOTE This is under the responsibility of the designer of the structure. See 10.5.1 of EN 1998-1:2004, and 7.7.3 of EN 1998-2:2005.

A periodic inspection and maintenance programme for the devices and their connections shall be elaborated during the project implementation.

4.3.4 Modification and replacement of devices

Modification of devices and associated components shall conform to the relevant clauses of this European Standard. Otherwise, such modification shall not be permitted.

Devices used for replacement shall comply with this European Standard and with additional requirements originally defined by the owner, unless otherwise requested by the owner at the time of the replacement.

Inspection and maintenance procedures defined in 4.3.3 shall be updated as necessary.

4.3.5 Device documentation

The documentation shall indicate the type of the device, its performance and the range of temperature and other environmental conditions specified for the project under consideration.

The documentation shall indicate details, sizes and tolerances related to installation of the devices and their connections to the structure, and shall refer to this European Standard.

The documentation shall include design checks and results of the relevant type tests and factory production control tests of the devices used in the project.

The documentation shall indicate aspects of particular importance for the installation of the devices at their location in the structure.

The documentation shall contain a detailed description of inspection and maintenance procedures as required in 4.3.3 or in the corresponding clauses of this European Standard.

The documentation shall contain the description of replacement procedures for the device.

NOTE It is under the responsibility of the designer of the structure to decide which documents are provided by himself or requested from the manufacturer.

4.4 General properties

4.4.1 Material properties

Materials used in the design and construction of the devices and their connections to the structure shall conform to existing European Standards where appropriate.

NOTE 1 In the cases where European Standards do not exist, national standards or other specifications may apply.

Material properties shall be appropriately assessed so as to represent their behaviour adequately under the conditions of strain and strain rate which can be attained during the design seismic situation.

Material properties shall take into account the environmental (physical, biological, chemical and nuclear) conditions with which devices can be faced over their service life. In particular, the effects of temperature variation shall be properly taken into account.

Material properties shall take into account the ageing phenomena that can occur during the service life of the device.

Material properties shall be represented by representative values.

NOTE 2 Representative values are defined in EN 1990.

4.4.2 Device properties to be used in the analysis

Device properties shall take into account the loading history and the accumulated strain cycles.

Device properties shall be appropriately assessed so as to represent their behaviour adequately under the conditions of deformation and deformation rate which can be attained during the design seismic situation.

Device properties shall take into account the environmental (physical, biological, chemical and nuclear) conditions with which devices can be faced over their service life. In particular, the effects of temperature variation shall be properly taken into account.

Device properties shall take into account the ageing phenomena that can occur during the service life of the device.

Design (mean) properties (DP) shall be derived from the type tests.

Two sets of design properties of the system of devices shall be properly established:

- Upper bound design properties (UBDP);
- Lower bound design properties (LBDP).

The overall variations of device properties shall lie between the Lower Bound and the Upper Bound. The lower bound shall correspond to the minimum representative value in the conditions where lower values of properties are obtained. The upper bound shall correspond to the maximum representative value in the conditions where upper values of properties are obtained. Both bounds shall be obtained by considering the quasi permanent values of the variable actions, as defined in the seismic combinations of actions, according to EN 1990, except for temperature for which the frequent value shall be taken into account.

LBDP and UBDP of a given property are representative values obtained from testing procedures defined in the corresponding clauses of this European standard.

The ratio between upper bound and lower bound representative value of any performance related device properties shall not exceed the limits defined in the relevant clauses.

The lower and upper bound representative values shall be determined from the type tests and the following variations:

- FPC test tolerance $\pm 20\%$ (unless a lower variability has been agreed for the acceptance tests);
- temperature varying between T_U and T_L (being the upper and lower values of the temperature considered in the design seismic situations as in EN 1990, with due regard to quasi-permanent values of the temperature);
- ageing consistent with the service life considered.

Combination factors of actions shall be those considered in the seismic combinations of actions.

NOTE 1 Specific phenomena, such as low temperature crystallisation, can be relevant. They are dealt with in the corresponding clauses.

NOTE 2 According to EN 1998-1:2004, 10.8 (1)P and EN 1998-2:2005, 7.5.2.4 (3)P and (4)P, the structural analysis takes into account the extreme situations resulting from the consideration of all upper bound design properties (UBDP) and lower bound design properties (LBDP).

NOTE 3 Values of T_U and T_L are determined according to EN 1991-1-5.

4.4.3 Re-centring capability

In the case of an equivalent linear analysis, to ensure adequate re-centring capability of a seismically isolated structure, it shall be verified that, for a deformation from 0 to d_{Ed} :

$$E_s \geq 0,25 E_h \quad (6)$$

where

E_s is the reversibly stored energy (elastic strain energy and potential energy) of the isolation system, including those elements of the structure influencing its response;

E_h is the energy dissipated by the isolation devices.

In the cases where a time history analysis is performed, the most unfavourable value of the considered effect shall be retained from each time history. Then the design value of the action effect shall be deduced from the results obtained from the different time history analyses, according to EN 1998-1:2004, 4.3.3.4.3.

NOTE According to EN 1998-1, this rule also applies to the design of the structure.

4.5 Constitutive laws

Appropriate constitutive laws of the devices shall be established by tests as required in 4.6 and Clause 10 or in the relevant clauses of this European Standard, so that the behaviour of the structure in the seismic situation may be properly predicted.

NOTE 1 The structural analysis is based on these appropriate constitutive laws. For this structural analysis, the rules given in the corresponding parts of EN 1998 apply.

The behaviour of the devices shall be appropriately modelled to account for non linear effects as well as any other effects, for instance, those due to velocity dependence or restraints.

NOTE 2 For the devices considered, some guidance on modelling constitutive laws is given in the corresponding clauses of this European Standard.

4.6 Validation of anti-seismic devices

Any type of device shall be subjected to a technical validation procedure, which shall include elements proving that the device conforms to its functional requirements. It shall prove that the device will remain operational within its domain of use, including the seismic situation, over its service life. It shall include at least the following:

- a description of the ranges of parameters relevant for the type of device under consideration covered by the validation procedure;
- a method to estimate the expected service life;
- proof of the device's ability to function in a reliable and stable way during its service life;
- values of the mechanical properties of the device, as defined in 4.4;
- range of acceptable environmental conditions;
- description of the behaviour beyond design seismic action to determine the γ_m values;
- description of suitable constitutive laws for analysis;
- a constitutive model describing the behaviour of the device under different conditions of use, including all combinations of actions as defined in EN 1990, representative of the physical phenomena which are expected during the lifetime, notably during the seismic movement;

NOTE The influence of the interaction with adjacent structural elements should be taken into account.

— type tests, as required in Clause 10, covering the anticipated ranges of use of the relevant parameters.

A validation file, including all the elements gathered in the validation procedure, shall be presented for the device. It shall include at least a list of its properties and a description of the device, of its domain of use, of its constitutive laws, of the analytical model when included in a structural model, and of the associated detailing. It shall include all information related to geometrical, physical, biological, chemical and mechanical characteristics and tolerances.

5 Rigid connection devices

NOTE 1 Rigid Connection Devices are used to constrain movements in one or more directions. Therefore, in principle they do not possess any horizontal distortion capability. However, some deformations are unavoidable and are subjected to the requirements specified under this clause.

NOTE 2 Cable restraints are outside the scope of this European Standard.

5.1 Permanent Connection Devices

Permanent Connection Devices (PCD) shall allow vertical axial movements and rotations, i.e. shall not transmit vertical loads and bending moments.

Moveable connection devices shall restrain movements in one direction only. Fixed connection devices shall restrain movements in two directions.

PCD not modifying the natural period of the structure nor dissipating energy can consist of structural bearings governed by EN 1337 and the various elements shall be designed and manufactured in accordance with the relevant part of EN 1337.

Loads, load effects and load combinations shall be determined in accordance with the Eurocode series and shall be specified in accordance with EN 1337-1:2000, Annex B.

5.2 Fuse Restraints

5.2.1 Performance requirements

Fuse Restraints (FRs) or Sacrificial Restraints (SR), below a certain pre-established force threshold (break-away force), shall impede any relative movements between connected parts, whereas they shall freely permit the movements after the aforesaid threshold has been exceeded.

NOTE 1 FRs can be of the mechanical type (MFRs) (when transition is determined by the break-away of sacrificial restraints) or hydraulic in nature (HFRs) (when transition is governed by the opening of an overpressure valve).

NOTE 2 Fuse Restraints are typically used to control the transition between the service and seismic load condition. They connect in a rigid manner two structural components in order to avoid relative displacement for service load condition, but above a preset force threshold they disconnect the above-mentioned structural components. In this way, they are used to bypass the seismic protection system under service conditions, but leave it free to work during the design earthquake. In order not to modify the behaviour of the isolation and/or damping system, FRs are commonly characterised by a sudden transition from service to seismic load condition.

5.2.2 Material properties

5.2.2.1 General

In addition to the requirements in the following subclauses, the materials shall be selected for their compatibility with the expected temperature range of the structure.

5.2.2.2 Materials

Fuse restraints shall be manufactured from materials in accordance with the relevant European Standards.

5.2.2.3 Structural Fasteners

Specification and certification of material shall correspond to the requirements referring to stressing and weldability.

All materials used shall comply with ISO 898.

5.2.2.4 Welding

Welding materials shall comply with EN 1090-2.

5.2.3 Design requirements

FRs shall be designed to withstand service loads with no yielding or failure.

FRs shall be designed so that the maximum design deformation is not exceeded.

NOTE FRs, according to the requirements of a particular application, may have to be designed in order to withstand fatigue loads.

FRs shall be designed to operate within the design load tolerance t_d .

For FRs design purposes, the operating load shall not be factored.

For the design of the MFR's failing component (sacrificial element) and the set-up of the HFR's overpressure valve, any over-strength factor is not applicable (unfactored load). Over-strength factors are applicable to all the other components of the FR units. Clause 4 does not apply to FRs.

After failure, FRs shall not interfere with functioning of anti-seismic devices (if any).

5.2.4 Type Testing

5.2.4.1 General

Type tests of devices shall be performed whenever new devices with an internal or external geometry, materials or kind of constraints different from those already qualified are designed.

If the raw material used for the production does not come from the same batch as used for previous devices, it shall be shown by calculation based on tests on the actual batch of material that the design load tolerance is not exceeded when the actual material batch properties are applied.

5.2.4.2 Service Load Test

The FR shall be subjected three times to a monotonically imposed load up to the maximum service load.

No yielding or failure shall occur. During the three cycles, the maximum measured deformation corresponding to the maximum service load shall be less than or equal to the design load.

5.2.4.3 Fatigue Test

Where required the fatigue test shall be performed.

The FR shall be subjected to 2 million cycles at the expected level of fatigue load.

No yielding or failure shall occur.

In order to verify that the fatigue effect is not influencing the FR strength resistance, the test described in 5.2.4.2 and 5.2.4.4 shall be performed on two samples, one subjected to the fatigue load and one not subjected to fatigue load history.

5.2.4.4 Break-away Test

The FR shall be subjected to a monotonically imposed load up to its break-away load.

The SR shall fail within the design load tolerance t_d to be given by the Structural Engineer.

NOTE In the absence of different tolerance limits provided by the Structural Engineer, a typical tolerance limit of $\pm 15\%$ is recommended.

5.2.5 Factory production control tests

If the raw material used for the production does not come from the same batch as used for manufacture of the prototypes, it shall be shown by calculation that the design load tolerance is not exceeded when the actual material batch properties are applied.

5.3 Temporary (dynamic) connection devices

5.3.1 Functional requirements

Within the tolerances specified by the Structural Engineer, the Temporary Connection Devices (TCDs), commonly referred to as Shock Transmission Units (STUs), shall provide for an output force in tension and/or compression that complies with the design displacement requirements provided by the Structural Engineer when the activation velocity is exceeded.

In the presence of thermally induced or other slowly imposed movements, the TCD shall develop a reaction force less than 10 % of its design force, or a lower value as specified by the Structural Engineer.

NOTE 1 The above requirement is aimed at avoiding fatigue load transmission to the structure.

The velocity associated with thermal and/or time dependent effects may be estimated by the Structural Engineer considering the characteristics of the particular structure under design. Values of the order of 0,01 mm/s are commonly higher than most observed in practice.

NOTE 2 Slow movements induced by thermal and/or time dependent effects are characterised by velocities that are some orders of magnitude lower than those of seismic origin. Thus, the activation velocity value of a TCD is not critical and commonly set in the range from 0,5 mm/s to 5 mm/s.

The TCD's output force shall depend on velocity only and shall not change with its stroke position and temperature.

The TCD shall be capable of operating at the seismic intensity specified by Structural Engineer without degradation of performance or reduction of service life.

The TCD's design stroke shall take into account long-term effects, thermally induced displacements, dynamic deformation and any adjustment length required by the Structural Engineer. The stroke shall in any case be not less than ± 50 mm for bridges or ± 25 mm for buildings.

To maintain the transmitted load aligned along its major axis and avoid undesired bending effects that may be detrimental for the sealing system, the TCD shall be equipped with spherical hinges at both ends. The rotation capacity of the self-lubricating spherical hinges shall be determined by the Structural Engineer giving consideration to live load effects, earthquake movements, installation misalignments, etc. The rotation shall in any case be not less than $\pm 2^\circ$.

Clevis plates or other components shall not geometrically impede the design rotation.

5.3.2 Material properties

5.3.2.1 General

The materials shall be selected for their compatibility with the expected service temperature range, taking account of both the environmental temperature and any changes produced by the functioning of the device.

5.3.2.2 Materials

Temporary Connection Devices shall be manufactured from ferrous materials in accordance with one of the following standards:

EN 10025, EN 10083, EN 10088, ISO 3755 or ISO 1083.

TCD may be made out of non ferrous materials but shall be subjected to EOTA procedure.

5.3.2.3 Active Surfaces

Active Surface of the piston rod shall be made of stainless steel or shall be nickel and/or hard chromium plated as appropriate.

The stainless steel shall be in accordance with EN 10088.

The hard chromium plating process shall comply with the requirements of EN ISO 6158.

The nickel plating process shall comply with the requirements of EN ISO 4526.

The minimum total thickness of the hard plating shall be 70 μm , unless the material substrate is made of stainless steel, in which case the minimum plating thickness may be reduced to 40 μm .

The plating shall be free from cracks and pores.

The surface of the base material shall be free from surface porosity, shrinkage cracks and inclusions.

The final surface roughness R_z in accordance with EN ISO 4287 of the plated surface shall not exceed 3 μm .

NOTE Both the base material and hard plating may be polished to achieve the specified surfaced roughness.

5.3.2.4 Viscous Fluid

The viscous fluid used shall be non-toxic, non-flammable and chemically inert. If a fluid other than one that is silicone-based is used, the above-mentioned characteristics shall be demonstrated and certified by the fluid manufacturer.

Hydrocarbon-based fluids shall not be used unless otherwise specified by the Structural Engineer.

5.3.3 Design Requirements

The device shall be so designed that no yielding will result from the application of service loads and no failure will result from application of ultimate loads.

The TCD shall allow for thermal expansion and contraction of the hydraulic fluid to prevent excessive build-up of internal pressure or vacuum pressure.

The TCD shall be designed and constructed to be maintenance free for its expected life under the anticipated service conditions.

The TCD's components (i.e. piston rod) shall be so designed as to avoid buckling instability when loaded with the factored design load in its fully extended configuration and considering 0,10 coefficient of friction for the spherical hinges (unless experimental data are available).

The reliability factor γ_x for the TCD shall be 1,5, unless an overload protection system is incorporated.

Whenever a TCD is equipped with an overload system preventing an excessive pressure build-up, such system shall begin to function at a force threshold 110 % of the design force. In this case, the minimum value of the reliability factor γ_x for the TCD shall be 1,1 and shall be applied to the overload system force threshold.

The device shall be designed to withstand an acceleration (applied to its own mass) perpendicular to the direction of the movement equal to the maximum acceleration predicted at its location by the seismic analysis. In the absence of acceleration data, the device shall be designed to withstand a load perpendicular to the direction of the movement equal to at least twice its own weight in combination with the maximum axial load.

5.3.4 Type Testing

5.3.4.1 General

Type testing shall be performed whenever a new product differs by more than ± 20 % in terms of load capacity and has a stroke more than 20 % larger than a previously tested unit. For previous tests to be valid, conceptual design and materials shall be the same as used before.

The tests listed below need not be performed in the order they are presented, except that the seal wear test shall be carried out before the Impulsive load test and the overload capacity test. Whenever critical, the tests described below shall be repeated at the maximum and minimum expected service temperatures.

5.3.4.2 Pressure Test

Where applicable, an internal pressure shall be applied to each TCD equal to 125 % of that corresponding to the maximum TCD load. This pressure shall be maintained for 120 s.

The requirement is that no visible leakage or signs of physical deterioration or degradation in subsequent performance shall be observed.

5.3.4.3 Low velocity test

NOTE The object of the imposed low velocity test is to evaluate the TCD's axial force resistance under simulated thermal movements.

The loading history shall be the following: One (1) fully reversed cycle of imposed axial displacement from 0 to d_{th} , to $-d_{th}$, to 0 at constant velocity $v_1 \leq 0,1$ mm/s.

The acceptance criterion shall be the following:

- Throughout the displacement cycle the TCD shall develop a reaction force not more than 10 % of its design force, or a lower value as specified by the Structural Engineer.

Both loading history (axial displacement vs. time) and force vs. displacement loop shall be continuously recorded and plotted.

Alternatively the test shall be the following: One (1) fully reversed cycle imposing a constant force equal to 10 % of its design rated force, from 0 to at least d_{th} (d_+) and then to at least $-d_{th}$ (d_-) and back to 0.

The acceptance criterion shall be the following:

- The average recorded constant velocity ($2(|d_+|+|d_-|)/T$ where T is the cycle duration) shall be higher than 0,01 mm/s.

The value of d_{th} shall be specified by the Structural Engineer, but shall not be less than 10 mm.

Both the loading history (axial force vs. time) and the displacement vs. time shall be continuously recorded and plotted.

5.3.4.4 Seal Wear Test

NOTE The object of the test is to assure that the seal will withstand movement due to thermal effects over the assumed design life without leakage of the fluid.

The TCD shall be cyclically tested for 10 000 cycles at an amplitude equal to the expected maximum thermal displacement.

As most TCDs are characterised by a high reaction capacity even at low velocity, the main orifice system may be by-passed in order to reduce the TCD reaction and the pressure build-up so that the test can be performed in a short time. Alternatively, at the discretion of the manufacturer and whenever the TCD normal operation internal pressure is less than 2 MPa, the fluid may be removed, entirely or partially, before the test and refilled into the TCD at the end of the test.

After test, the TCD shall be tested according to 5.3.4.5 and 5.3.4.6 to verify the proper functioning of the sealing system.

5.3.4.5 Impulsive Load Test

NOTE 1 The object of this test is to verify the behaviour of an TCD in terms of displacement and activation velocity when subjected to its design load applied as an impulse.

The loading history shall be imposed in the following manner: apply the design load in less than 0,5 s, maintain it constant for 5 s, reverse it in less than 1 s, and finally maintain it for another 5 s.

NOTE 2 The time of constant load may be increased by the Structural Engineer.

The acceptance criterion shall be the following:

- The displacement after the first 0,5 s shall not exceed the design value at the design force F_d , while reversing from $+F_d$ to $-F_d$ the total deflection shall not exceed twice the design value.
- The velocity measured during the sustained load portion shall not exceed the activation velocity.

5.3.4.6 Overload Test

NOTE The object of this test is to verify the overload capacity of a TCD or the activation of the over-load relief system.

The loading history shall be imposed in the following manner: apply a load equal to 1,5 times the design load in less than 0,5 s, maintain it constant for 5 s, reverse it in less than 1 s, and finally maintain it for another 5 s.

When the device is equipped with an over-load relief system set at a force lower than 1,5 times the design load, the test may be performed to verify the relief system activation.

The acceptance criterion shall be the following:

- The device shall not show any damage to the system or any leakage of fluid.

5.3.4.7 Cyclic Load Test

NOTE The object of the test is to evaluate the TCD's behaviour when subjected to the design load applied cyclically for a time equal to the duration of the expected earthquake.

The loading history shall be imposed in the following manner: apply a number of sinusoidal force cycles of the type $F(t)=F_0 \cdot \sin(2\pi \cdot f_0 \cdot t)$, where force F_0 and frequency f_0 (Hz) and the duration of the test shall be chosen by the Structural Engineer. The test duration shall be equal to that of the intense phase of the expected earthquake, but in any case shall not be less than 15 s.

The acceptance criterion shall be the following:

- The TCD's deflection at the design load shall not be greater than the design value;
- The device shall not show any damage to the system or any leakage of fluid.

5.3.5 Factory Production Control Tests

For Quality Control purposes one unit per production lot shall be subjected to the following tests:

- Pressure Test;
- Low Velocity Test;
- Impulsive Load Test.

A production lot is defined as no more than twenty (20) units having the same design details with the exception of the stroke. The production unit to be tested within the production lot shall be the one with the longest stroke.

Pressure test shall be performed on 100 % of the production units.

All the tests shall be performed at ambient temperature $(23 \pm 3) ^\circ\text{C}$.

Table 2 summarises the required tests for Initial Type Testing and factory production control tests.

Table 2 — Tests for Initial Type Testing and factory production control tests

	Pressure Test	Low Velocity Test	Seal Wear Test	Impulsive Load Test	Overload Test	Cyclic Load Test
Type Tests	x *	x	x *	x	x *	x
FPC Tests	x *	x *		x *		

(*) Test performed always at ambient temperature

6 Displacement Dependent Devices

6.1 General

This part of this European Standard deals with the requirements for the design and manufacturing of linear and non linear anti-seismic devices which do not carry vertical loads, whose behaviour is mainly dependent on displacement rather than on velocity, for use in structures erected in seismic areas in accordance with EN 1998.

NOTE 1 Linear devices (LD) are characterised by a linear or quasi-linear behaviour and are used to change favourably the dynamic characteristics of a structural system. Non-linearity and/or energy dissipation should be compatible with the linear modelling for design analyses of the structural systems including these devices.

NOTE 2 Non Linear Devices (NLD) are characterised by a strongly non linear behaviour and are used to change favourably the dynamic characteristics of a structural system, by introducing significant non-linearity and/or energy dissipation, which should be appropriately taken into account in the non linear modelling for design analyses of the structural systems including these devices.

6.2 Performance Requirements

Displacement Dependent Devices (DDD) shall be able to sustain a displacement $\gamma_x d_{bd}$, taking into account a partial factor γ_b on the maximum force or the displacement of the device and action effects other than seismic, which can affect the initial configuration of the device.

The force-displacement capacity of a device shall be measured up to a displacement of $\gamma_b \gamma_x d_{bd}$ or a load of $\gamma_b \gamma_x V_{Ebd}$, whichever is reached first.

Its force-displacement curve in the loading phase shall not show a decreasing trend while increasing the displacement up to $\gamma_b \gamma_x d_{bd}$ or the force up to $\gamma_b \gamma_x V_{Ebd}$.

The value of γ_b shall be not less than 1,1.

Whenever a DDD is used as a component of a seismic isolation system for buildings, bridges or other structures, the γ_b and γ_x values shall be adjusted in order to comply with the displacement capacity of the isolators (see Clause 8).

The behaviour of a DDD is identified by the effective stiffness K_{effb} and the effective damping ξ_{effb} , as well as by the first branch stiffness K_1 and the second branch stiffness K_2 in the case of a NLD.

NOTE 1 In order to use the theoretical bilinear cycle to model a device's behaviour in non linear simulation analyses of structural systems, the unloading branch of the theoretical cycle should approximate at best the real behaviour of the device. With this aim, the value of ξ_{effb} of the theoretical cycle should not differ from the value of ξ_{effb} of the 3rd cycle of a type test by more than ± 10 %.

A DDD shall comply with the requirements for non seismic conditions as defined by the Structural Engineer, according to the relevant European Standards.

A linear device shall have both the equivalent damping of the hysteretic energy dissipation $\xi_{effb,h}$ less than 15 % and the ratio $|K_{effb,h} - K_{1,h}| / K_{1,h}$ less than 0,2.

NOTE 2 The hysteretic properties of a linear device, such as the equivalent damping of the hysteretic energy dissipation $\xi_{effb,h}$ and the corresponding stiffness values $K_{effb,h}$ and $K_{1,h}$, can be evaluated by making cyclic tests at a very low frequency such as $f < 0,001$ Hz.

The experimental values of the behavioural parameters can differ from the design values because of the manufacturing process or the service conditions of the devices. These variations shall be evaluated experimentally, in order to establish the upper and lower bound values to be considered in the design analyses.

NOTE 3 The stiffness and energy dissipation parameters herein considered identify exhaustively the theoretical behaviour of a device; therefore tolerance limits imposed on stiffness parameters are implicitly applied also to other related parameters, like forces and displacements.

The maximum differences of the experimental values of the behavioural parameters, obtained during initial type tests, with respect to the design values or to the normal condition values, shall be within the tolerance

limits given in Tables 3 and 4 for LD and NLD respectively. These limits are relevant to variations within the supply (statistical variations), as well as variations due to ageing, temperature, displacement rate.

The variations shall be evaluated with reference to the 3rd cycle of the type test.

The maximum differences due to statistical variations within the supply shall be evaluated with respect to the design value.

The maximum differences due to ageing, temperature and strain rate shall be evaluated with respect to the normal condition value, which is referred to the new device tested at $(23 \pm 5) ^\circ\text{C}$.

The differences due to temperature shall be evaluated with reference to the upper and lower design temperature values.

The differences due to strain rate shall be evaluated with reference to a frequency variation of $\pm 50 \%$.

NOTE 4 For devices whose core elements are made of steel, due to its substantial insensitivity to strain rate in the usual range of seismic effects, such differences can be assumed zero.

The overall variation, to be considered when evaluating the upper and lower bound of the design values as specified in EN 1998, is a linear combination of the single differences, where the combination coefficients shall take account of the probability of simultaneous occurrence of such differences.

NOTE 5 If more precise evaluations cannot be made, a coefficient equal to 0,7 can be assumed for all the components of variation.

In order to assure a stable behaviour under cyclic loading, variations in a series of load cycles relevant to the same displacement shall be limited as follows:

$$|K_{\text{effb},i} - K_{\text{effb},3}| / K_{\text{effb},3} \leq 0,10 \text{ for LD} \quad (7)$$

$$|K_{2,i} - K_{2,3}| / K_{2,3} \leq 0,10 \text{ for NLD} \quad (8)$$

$$|\xi_{\text{effb},i} - \xi_{\text{effb},3}| / \xi_{\text{effb},3} \leq 0,10 \text{ for LD and NLD} \quad (9)$$

where subscript 3 is relevant to quantities at the 3rd load cycle and subscript i is relevant to quantities at the i-th load cycle of an experimental test, excluding the 1st cycle ($i \geq 2$).

Table 3 — Tolerance limits for linear devices

	(1) Supply	(2) Ageing	(3) Temperature	(4) Strain Rate
K_{effb}	$\pm 15 \%$	$\pm 20 \%$	$\pm 40 \%$	$\pm 10 \%$
ξ_{effb}	$\pm 15 \%$	$\pm 15 \%$	$\pm 15 \%$	$\pm 10 \%$

The ratio between upper bound and lower bound characteristic values of any performance related material properties shall not exceed 1,4 for metallic components and 1,8 for non-metallic components.

Table 4 — Tolerance limits for non linear devices

	(1) Supply	(2) Ageing	(3) Temperature	(4) Strain Rate
K_2	$\pm 15 \%$	$\pm 20 \%$	$\pm 20 \%$	$\pm 10 \%$
K_{eff}	$\pm 15 \%$	$\pm 20 \%$	$\pm 40 \%$	$\pm 10 \%$
ξ_{eff}	$\pm 10 \%$	$\pm 15 \%$	$\pm 15 \%$	$\pm 10 \%$

When the design hardening ratio $(K_2/K_1)_d$ is not greater than 0,05, the tolerance limit on K_2 given in Table 2 is no more valid and shall be substituted by the following limits:

$$|(K_2/K_1) - (K_2/K_1)_d| \leq 0,01 \text{ for (1), (2), (3), (4)} \quad (10)$$

The performance characteristics of a device under the design earthquake shall be defined by the Structural Engineer through the assignment of d_{bd} , K_{effb} and ξ_{effb} , besides K_1 , K_2 for NLD, or equivalent parameters defining the force-displacement cycle, as well as of the expected number of cycles under the design earthquake, the displacement rate, the design temperature range, the environmental conditions for ageing.

The design values of the parameters characterising the force displacement cycle of a NLD shall be established according to the results of the design non linear analyses on the entire structural system including devices, under seismic actions.

The analyses shall take account of the non linear behaviour of the NLD's which are part of it. The following conditions shall be satisfied:

- The displacement value d_{bd} shall not be exceeded by the displacement produced by the ULS design seismic action;
- The offset displacement (i.e. the residual displacement at zero force at the end of earthquake) produced by the SLS design seismic action shall not exceed the value d^* where d^* is a NDP (the recommended value is 5 % of d_{bd} but not less than 10 mm).

6.3 Materials

6.3.1 General

Materials can be used in a device in parts playing different functions. Two main functions can be distinguished: “core” function, characterising the cyclic seismic behaviour of the device, and structural function.

Core materials shall satisfy the requirements specified in the following subclauses.

Structural materials shall satisfy the appropriate EN, if any, or other existing standards.

6.3.2 Elastomer

Elastomer type test requirements for a specific device shall be established by the manufacturer to ensure that the material is adequate to achieve the performance requirements of the device. The adhesion strength to the appropriate substrate shall be a requirement when the elastomer is bonded to an element for fixing or reinforcement.

NOTE 1 The requirements in 8.2.2.1 may be used as a guide.

Requirements of factory production control tests of elastomer shall be established by the manufacturer to ensure consistency of the material.

NOTE 2 For low damping elastomer based on polychloroprene or natural elastomer, the requirements should at least satisfy those given in Table 8 of Clause 8; for high damping elastomer the requirements should at least satisfy those given in Table 9 of Clause 8.

6.3.3 Steel

Steel used in devices shall conform to the requirements given in EN 10025, EN 10083, and EN 10088.

6.3.4 Other materials (special steel, stainless steel, SMA, visco-elastic polymeric materials)

Other materials shall conform to existing European Standards. Additional tests shall be specified according to the required behaviour of the material in the device.

6.4 Testing

6.4.1 General

The conformity, within specified tolerances, of the actual mechanical characteristics of seismic devices to the performance requirements shall be verified by the outcome of specific experimental tests.

The experimental tests shall be carried out by imposing cyclic deformations according to the schedule and the procedures indicated below. During the tests, the values of forces and displacements shall be continuously recorded, thus characterising the entire course of the successive cycles.

Tests should be performed on complete devices. However, if no important interactions among the functions of the various elements occur, separate tests on single core elements can be made. In such case, the actual behaviour of the device shall be verified by means of calculations and data on the connections and interactions among the various elements.

Mechanical tests include:

- Type tests of materials;
- Factory production control tests of materials;
- Type tests of devices;
- Factory production control tests of devices.

6.4.2 Type tests of materials

6.4.2.1 General

Type tests shall be performed to demonstrate conformity with requirements established as specified in 6.3. If a test procedure in an existing standard cannot be cited, a procedure shall be established by the manufacturer to ensure that the material is adequate to achieve the performance requirements of the device.

For a material having only a structural purpose, testing procedures shall conform to the relevant standard, if any, in force for that material; otherwise they shall be established by the manufacturer.

For the materials which are part of the device mechanism, the kind and the method of testing shall conform to current standards, if any; otherwise they shall be established case by case by the manufacturer, unless specified below, bearing in mind the following needs:

- relating the measured material behaviour to its behaviour in the device;
- evaluating the variation of material behaviour with respect to changes of environmental conditions, material temperature, ageing, strain rate;
- evaluating the interactions between material behaviour and device performance.

They shall be justified in a report, for which the manufacturer is fully responsible, where the relationship between material and device behaviour shall be made clear.

6.4.2.2 Elastomer

Tests on elastomer shall be performed to establish conformity to the requirements established under 6.3.2. The tests to establish conformity with the requirements of 8.2.2.1 shall be performed according to the methods referred to in 8.2.4.2. Other test methods and procedures shall conform to the appropriate ISO or EN standard, if any, except that:

- test pieces may be moulded from the compound cured as far as possible under the same conditions as the elastomer in the device, or cut from the device;
- dynamic shear testing shall conform to 8.2.4.2.5.2.

6.4.2.3 Steel

Certifications based on existing standards are required. Other tests may be specified as appropriate according to the function of the material in the device.

6.4.2.4 Shape Memory Alloys (SMA)

Shape memory alloys shall be tested in martensitic state (no super-elasticity) or in austenitic state (super-elasticity) according to their use in the device.

The following tests shall be carried out:

- a) DSC (Differential Scanning Calorimeter) measurements: to determine the transformation characteristics of alloys, particularly the transition temperatures, especially those relevant to the transformations of phase martensite - austenite and vice versa.
- b) Monotonic tensile failure tests at strain rate $\leq 0,002 \text{ s}^{-1}$, at $(23 \pm 5) ^\circ\text{C}$ and at the limits of the service temperature range.
- c) Loading/unloading tensile tests on super-elastic wire: to determine the behaviour of the sample and its failure load at different strain rates ($0,05 \text{ s}^{-1}$, $0,2 \text{ s}^{-1}$, $0,8 \text{ s}^{-1}$) and temperatures (as above). The cycle strain amplitudes shall be 3 %, 6 %, 9 %, 12 %, up to failure. Ten cycles shall be repeated for each amplitude, each strain rate and each temperature, on separate samples of the same material.
- d) Cyclic tests of the SMA components, stressing them under the conditions to which they are subjected in the devices during the structure's response to the design earthquake (e.g. in loading/unloading tension for super-elastic wires, in bending or torsion for bars, etc.), that means at least to the same levels of maximum deformation, and with the same average frequencies. At least ten cycles shall be sustained by the component without failure.

6.4.2.5 Other materials

Certifications based on existing standards are required. Other tests may be specified as appropriate according to the function of the material in the device.

6.4.3 Factory production control tests of materials

6.4.3.1 General

The uniformity of each production lot shall be assessed. Factory production control tests on materials shall be performed to establish conformity to the acceptance requirements established as specified in 6.3.

If a test procedure in an existing standard is not cited, the sampling frequency shall be at least 2 specimens for each lot of production.

NOTE This prescription is meant to allow the use of newly conceived devices, possibly made of new materials, for which qualified procedures to test the requested behaviour are not standardised yet.

6.4.3.2 Elastomer

Factory production control tests shall be carried out to establish that the elastomer conforms to the acceptance requirements specified in 6.3.2.

The tests to establish conformity with the requirements of 8.2.2.1 shall be performed according to the methods referred to in 8.2.4.2.

Tests to establish conformity with other acceptance requirements shall conform to the appropriate ISO or EN standards, if any, except that:

- test pieces may be moulded from the compound cured as far as possible under the same conditions as the elastomer in the device or cut from the device;
- dynamic shear testing shall conform to 8.2.4.2.5.2.

6.4.3.3 Steel

Certifications based on existing standards are required. Other tests may be specified as appropriate according to the function of the material in the device.

6.4.3.4 Shape Memory Alloys

Shape memory alloys shall be tested in martensitic state (no super-elasticity) or in austenitic state (super-elasticity) according to their use in the device.

The following tests shall be carried out:

- a) DSC (Differential Scanner Calorimeter) measures: to determine the transformation characteristics of alloys, particularly the transition temperatures, especially those relevant to the transformations of phase martensite - austenite and *vice versa*.
- b) Monotonic tensile failure tests at strain rate $\leq 0,002 \text{ s}^{-1}$, at $(23 \pm 5) ^\circ\text{C}$.
- c) Loading/unloading tensile tests on super-elastic wire at $0,2 \text{ s}^{-1}$ strain rate and at $(23 \pm 5) ^\circ\text{C}$ temperature. The cycle strain amplitudes shall be 3 %, 6 %, 9 %, 12 %, up to failure. Ten cycles shall be applied for each amplitude.

6.4.3.5 Other materials

Certifications based on existing standards are required. Other tests may be specified as appropriate according to the function of the material in the device.

6.4.4 Type tests of devices

Type tests of devices are to be performed whenever new devices with an internal or external geometry, materials or kind of constraints different from those already qualified are designed.

If the geometrical linear differences are less than 20 % and the results can be suitably extrapolated to the new device, new type tests need not be performed.

At least one prototype device shall be tested. Devices used for prototype tests shall not be installed in the structure, unless the mechanical characteristics of the device are not affected by the test or are fully recovered, e.g. by substitution of the core elements.

Devices shall be qualified together with their connection system.

Testing procedures shall be such that the working conditions and fixings of the device are reproduced.

In general, type tests shall be carried out on full-scale specimens.

If device capacities exceed the feasible range of performance of existing facilities in the EU, they can be carried out on reduced scale specimens, whose geometrical scale ratio is not less than 0,5, provided that the pertinent mechanical similitude conditions are fulfilled. The manufacturer shall provide a report in which the extension of the results to full-scale devices is justified through calculations and, possibly, tests carried out on full-scale core elements. The specimens shall be loaded so as to produce the same stresses and strains as those experienced during the response of the device to the design earthquake.

NOTE 1 If no important interactions among the functions of the various elements occur, separate tests on single full-scale core elements can be made. In such cases, the actual behaviour of the device should be evaluated by means of calculations on the connections and interactions among the various elements.

In general, dynamic tests shall be carried out to reproduce the actual working conditions of the devices. If it can be demonstrated that velocity has negligible influence, quasi-static tests can be carried out. Unless the Structural Engineer prescribes a different program, related to some special working conditions, the test procedure shall include the steps listed below.

- a) Evaluation of the force-displacement cycle. Increasing amplitude cycles shall be imposed, at 25 %, 50 % and 100 % of the maximum displacement, which shall be at least equal to $\pm d_{bd}$. Five cycles for each intermediate amplitude and at least ten cycles for the maximum amplitude shall be applied. If scaled specimens are used, test displacements and cycling frequency shall be consistently scaled. The device shall not break and shall keep its characteristics unchanged during test. If the fundamental period of the structural system in which the device has to be used is considerably less than 2 s, a corresponding increase of the number of test cycles at $\pm d_{bd}$ shall be prescribed by the Structural Engineer. In case of linear devices for which the hysteretic component of energy dissipation shall be evaluated, the previous test sequence shall be repeated also at a frequency not greater than 0,001 Hz, with at least 3 cycles for each amplitude.

NOTE 2 One important parameter that the Structural Engineer should carefully consider is the number of cycles to be imposed to the specimens, as it is related to both the duration of the earthquake and to the vibration frequencies of the structural systems. The number of ten cycles is related to the use of devices in seismic isolation systems, producing fundamental periods of the order of 2 s.

- b) Ramp test for the static evaluation of the failure displacement. Deformations shall be applied at low speed. A displacement not less than d_{bd} multiplied by γ_b and γ_x or a force not less than V_{Ebd} multiplied by γ_b and γ_x , whichever is reached first, shall be imposed. If scaled specimens are used, test displacements shall be consistently scaled. The force in the device shall not decrease while increasing the displacement.

Effects of ageing, temperature and cycling frequency shall be evaluated either on the prototype by repeating step a) in the different conditions specified by the Structural Engineer, or on the core mechanism, elements or materials. In the latter case, the effects on the overall behaviour of the device shall be quantitatively evaluated. The core components shall be replaced in a prototype if a test produces an irreversible change in the

component. If the core mechanism is based on steel or lead and adequate protection of the core elements is provided against environmental actions, ageing effects may be ignored.

6.4.5 Factory production control testing of devices

Factory production control tests shall be always carried out on the devices prior to their installation. It shall be possible to identify each device, and associate it with the production lot it belongs to.

Test a) described in 6.4.4 shall be carried out on at least 2 % of the supply, with a minimum number of one device. The tested devices may be installed into the structure, if it is demonstrated that the fatigue resistance of their core elements is one order of magnitude greater than the number of cycles undergone during test. In any other case, they shall not be installed into the structure, unless their mechanical characteristics are fully recovered, e.g. by substitution of the non linear mechanism or of the core elements.

7 Velocity Dependent Devices

7.1 Functional requirements

NOTE This clause considers two types of Viscous Damper namely Fluid Viscous Damper (FVD) and Fluid Spring Damper (FSD). The general term Viscous Damper applies to both of them.

Within the tolerances specified by the Structural Engineer, the Viscous Damper shall provide an output force in either tension or compression that complies with the constitutive law declared by the manufacturer over a velocity range extending at least two decades down from the maximum design level.

The Viscous Damper shall be capable of operating at the energy levels specified by the Structural Engineer without degradation of performance or reduction of service.

The Fluid Viscous Damper output force shall depend on velocity only and shall not change with damper stroke position. The Structural Engineer shall prescribe the acceptable variation of the output force due to changes in ambient or internal temperature, or due to causes such as ageing, wearing, etc.

The Fluid Spring Damper output force shall depend on velocity and stroke. The Structural Engineer shall prescribe the acceptable variation of the output force due to changes in ambient or internal temperature, or due to such causes as ageing, wearing, etc.

The damper design stroke shall take into account long-term effects, thermally induced and seismic displacement as well as any adjustment length required by the Structural Engineer. The stroke shall in any case be not less than ± 50 mm for bridges or ± 25 mm for buildings.

The damper shall be equipped with self-lubricating spherical hinges at each end in order to maintain the transmitted load aligned along its major axis and avoid undesired bending effects that may be detrimental to the sealing system.

The rotation capacity of the spherical hinges shall be determined by the Structural Engineer giving consideration to live load effects, earthquake movements, installation misalignments, etc. The rotation shall in any case be not less than $\pm 2^\circ$.

Clevis plates or other components shall not physically impede the design rotation.

7.2 Material properties

7.2.1 General

The materials shall be selected for their compatibility with the expected service temperature range, taking account of both the environmental temperature and any changes produced by the functioning of the device.

7.2.2 Materials

Viscous Dampers shall be manufactured from ferrous materials in accordance with one of the following standards:

EN 10025, EN 10083, EN 10088, ISO 3755 or ISO 1083.

Dampers may be made out of non ferrous materials but shall be subjected to EOTA procedure.

7.2.3 Active Surfaces

The entire Active Surface of the piston rod shall either be made of stainless steel or be nickel and/or hard chromium plated as appropriate to ensure corrosion protection and/or wearing resistance.

The hard chromium plating process shall comply with the requirements of EN ISO 6158.

The nickel plating process shall comply with the requirements of EN ISO 4526.

The stainless steel shall be in accordance with EN 10088.

The minimum total thickness of the hard plating shall be 70 μm , unless the material substrate is made of stainless steel, in which case the minimum plating thickness may be reduced to 40 μm .

The plating shall be free from cracks and pores.

The surface of the base material shall be free from porosity, shrinkage cracks and inclusions.

The final surface roughness R_z in accordance with EN ISO 4287 of the plated surface shall not exceed 3 μm .

NOTE Both the material and hard plating may be polished to achieve the specified surfaced roughness.

7.2.4 Viscous Fluid

The operating viscous fluid shall be non-toxic, non-flammable and chemically inert. If a fluid other than one that is silicone-based is used, the above-mentioned characteristics shall be demonstrated.

Hydrocarbon-based fluids shall not be used unless otherwise specified by the Structural Engineer.

7.3 Design requirements

7.3.1 General

The Viscous Dampers shall be so designed that no yielding results from the application of service loads and no failure results from application of ultimate loads.

Viscous Dampers in general shall be designed to withstand the maximum internal pressure resulting from the most adverse combination of design input data.

The Viscous Damper shall be designed to withstand a lateral acceleration in accordance with 5.3.3.

The device shall be designed to withstand an acceleration (applied to its own mass) perpendicular to the direction of the movement equal to the maximum acceleration predicted at its location by the seismic analysis. In the absence of acceleration data, the device shall be designed to withstand a load perpendicular to the direction of the movement equal to at least twice its own weight in combination with the maximum axial load.

The Viscous Damper shall contain provisions to allow for thermal expansion of the viscous fluid to prevent excessive build-up of internal pressure.

The Viscous Damper shall be designed and constructed to be maintenance free for its expected life under the anticipated service conditions.

The maximum differences between the experimental values of the characteristic parameters, obtained during initial type tests, and the design values or the normal condition values shall be within the tolerance limits given in Table 5. These limits are relevant to variations within the supply (statistical variations), as well as variations due to temperature, etc.

The overall variation, to be considered when evaluating the upper and lower bound of the design values as specified in EN 1998, is a linear combination of the single differences, where the combination coefficients shall take account of the probability of simultaneous occurrence of such differences.

NOTE 1 If more precise evaluation cannot be made, a coefficient equal to 0,7 can be assumed for all the components of variation. The ratio between upper bound and lower bound characteristic values of any characteristic parameter will not exceed 1,4.

Table 5 — Tolerance limits (t_d) for velocity dependent devices

	(1) Supply		(2) Temperature (*)	
	<i>FVD</i>	<i>FSD</i>	<i>FVD</i>	<i>FSD</i>
<i>F</i>	± 15 %	± 15 %	± 5 %	± 15 %
<i>K_{eff}</i>	N/A	± 15 %	N/A	± 15 %
<i>EDC</i>	- 15 %	- 15 %	- 5 %	- 5 %

(*) Temperature range – 25 °C/+ 50 °C

N/A = Not Applicable

EDC= Energy Dissipation per Cycle

NOTE 2 Ageing is not relevant to this kind of device as the fluid is not in contact with air.

7.3.2 Over velocity

The design force shall be amplified by a reliability factor γ_r equal to the following:

$$\gamma_r = (1+t_d) \cdot (1,5)^\alpha \quad (11)$$

where

t_d is the design reaction tolerance given by the manufacturer;

α is the exponent of the constitutive law ensured by the manufacturer.

7.3.3 Buckling

The damper piston rod shall be designed to avoid buckling instability when loaded with the factored design load (see 7.3.2) in its fully extended configuration and considering 10 % coefficient of friction for the spherical hinges (unless experimental data are available).

7.4 Testing

7.4.1 General

NOTE 1 The test programme involves an enormous total energy input to the damper. Therefore, care is required in the execution of the test programme to ensure that any tests performed in quick succession will not excessively overheat the damper. To achieve this, the damper temperature at critical locations (indicated by the manufacturer) needs to be monitored and reported, and it is advisable to divide the test programme into groups of tests. After performing one, the damper is allowed to cool to a specified temperature before performing the subsequent test group.

NOTE 2 The tests listed in this clause need not be performed in the order they are presented.

The tests shall be arranged into groups in accordance with the criterion that the total energy input to the damper in each test group does not exceed twice the energy dissipated by the damper during a design level earthquake.

NOTE 3 Testing should not proceed while the damper temperature exceeds a level specified by the manufacturer.

7.4.2 Type Testing

7.4.2.1 General

Type testing shall be performed whenever a new product has a load capacity differing by more than $\pm 20\%$ from that of a previously tested unit and/or its design velocity is greater. For previous tests to be valid, the conceptual design and materials shall be the same as used before.

The test specimen temperature shall be monitored at two locations, indicated as critical by the manufacturer, on the damper body. Recording shall start 5 min prior to test and continue for 15 min after testing.

7.4.2.2 Pressure test for Fluid Viscous and Fluid Spring Dampers

Where applicable, an internal pressure shall be applied to each FVD or FSD that shall be equivalent to 125 % of the maximum damper load. This pressure shall be maintained for 120 s.

The requirement is that no visible leakage or signs of physical deterioration or degradation in performance shall be observed.

7.4.2.3 Low velocity test for Fluid Viscous Dampers

NOTE 1 The object of the low velocity test is to evaluate the damper's axial force resistance under simulated thermal movements.

The loading history shall be the following: One (1) fully reversed cycle of axial displacement, from 0 to d_{th} , to $-d_{th}$ and back to 0, imposed at a constant absolute velocity $v_1 \leq 0,1$ mm/s. The value of d_{th} shall be specified by the Structural Engineer, but shall not be less than 10 mm.

NOTE 2 The value of d_{th} is intended to correspond to the typical maximum displacement due to thermal effects.

The requirement is that throughout the full displacement cycle the damper shall develop a reaction force less than the 10 % of its design rated force, or a lower value if specified by the Structural Engineer. Both the loading history (axial displacement vs. time) and the force vs. displacement loop shall be continuously recorded and plotted.

Alternatively the test shall be the following: One (1) fully reversed cycle imposing a constant force equal to 10 % of its design rated force, from 0 to at least d_{th} (d_+) and then to at least $-d_{th}$ (d_-) and back to 0.

The average recorded constant velocity " $(2(|d_+|+|d_-|)/T)$ where T is the cycle duration) shall be higher than 0,01 mm/s. The value of d_{th} shall be specified by the Structural Engineer, but shall not be less than 10 mm.

Both the loading history (axial force vs. time) and the displacement vs. time shall be continuously recorded and plotted.

The test shall be performed at temperature $(23 \pm 5) ^\circ\text{C}$, or at a lower temperature if specified by the Design Engineer.

7.4.2.4 Low velocity test for Fluid Spring Damper

NOTE 1 The object of the low velocity test is to evaluate the damper's axial force resistance under simulated thermal movements or quasi-static loads.

The loading history shall be the following: One (1) fully reversed cycle of axial displacement, from 0 to d_{th} , to $-d_{th}$ and back to 0, imposed at constant velocity $v_1 \leq 0,1 \text{ mm/s}$. The value of d_{th} shall be specified by the Design Engineer, but shall not be less than 10 mm.

NOTE 2 The value of d_{th} is intended to correspond to the typical maximum displacement due to thermal and other quasi-static effects such as braking, wind, etc.

The requirement is that throughout the full displacement cycle the damper shall develop a reaction force less than a factor $(1 + t_d)$ of its design reaction, or a value as specified by the Structural Engineer.

Both the loading history (axial displacement vs. time) and the force vs. displacement loop shall be continuously recorded and plotted.

The test shall be performed at temperature $(23 \pm 5) ^\circ\text{C}$ or at a lower temperature if specified by the Structural Engineer.

7.4.2.5 Constitutive law test for Fluid Viscous Dampers

NOTE 1 The purpose of this test is to determine the damper's characteristic force vs. velocity curve, i.e. the parameters C and α , which define the constitutive law $F = C \times v^\alpha$.

The loading history shall consist of the following: at each velocity, impose three (3) fully reversed cycles of axial deflection from 0 to $+d_{bd}$, to $-d_{bd}$ and back to 0, where d_{bd} is the seismic design displacement.

The applied velocity shall include at least the following increments of the maximum rated velocity: 1 %, 25 %, 50 %, 75 % and 100 %.

The requirement is that all experimental points of the reaction force characteristic curve shall fall within the tolerance envelope.

NOTE 2 The damper's reaction force F_n at a velocity v_n is defined as the average of the positive and negative intercepts with the force axis of the second hysteretic loop cycle.

The test shall be repeated at the maximum and minimum design temperature in order to assess the influence of the ambient temperature on the reaction force produced by the units. These repeat tests may be omitted if results of tests certified by an independent laboratory and performed on similar units over the same or a wider temperature range are already available.

7.4.2.6 Constitutive law test for Fluid Spring Damper

NOTE 1 The purpose of this test is to determine the FSD's constitutive law i.e. the parameters F_0 (Pre-load), K (Stiffness), C and α (Damping), which define part of its constitutive law.

The loading history shall consist of the following: at each velocity, impose three (3) fully reversed cycles of axial displacement from 0 to $+d_{bd}$, to $-d_{bd}$ and back to 0, where d_{bd} is the seismic design displacement.

The applied velocity shall include at least the following increments of the maximum rated velocity: 1 %, 25 %, 50 %, 75 % and 100 %.

The acceptance criterion is that the reaction force characteristic curve shall fall within the tolerance envelope.

NOTE 2 The damper's reaction force F_n at a velocity v_n is defined as the average of the intercepts of the second hysteretic loop cycle with an axis parallel to the force axis at 50 % of $+d_{bd}$ and $-d_{bd}$:

$$F_n = \frac{F_n^{(+)} + |F_n^{(-)}|}{2} \quad (12)$$

The test shall be repeated at the maximum and minimum design temperature in order to assess the influence of the external temperature on the reaction of the units. These repeat tests may be omitted if results of tests certified by an independent laboratory and performed on similar units over the same or a wider temperature range are already available.

7.4.2.7 Damping efficiency test

NOTE 1 The object of the Damping efficiency test is to evaluate the energy dissipating capability of the device and the reaction stability.

The loading history shall be the following: impose five (5) harmonic full displacement cycles of the type $d(t) = d_0 \cdot \sin(2\pi \cdot f_0 \cdot t)$, where stroke d_0 and frequency f_0 (Hz) shall be specified by the Structural Engineer taking care not to exceed the energy dissipation corresponding to two design level earthquakes.

NOTE 2 If 5 cycles are above the capability of the testing facility, the test may be carried out in groups of cycles, but with a minimum of 3 continuous cycles maintained.

Cooling between each group of cycles shall not be applied.

The requirement is that for each cycle the damper reaction, determined as described in 7.4.2.5 or 7.4.2.6, shall be within the design tolerance and the energy dissipation shall be greater than the minimum design value.

7.4.2.8 Wind load cycle test

When wind load is deemed to be critical by the Structural Engineer, prototype dampers shall be tested in order to verify their capacity to resist wind-induced vibrations.

The prototype damper shall be cycled at a frequency and displacement specified by the Structural Engineer, for 200 cycles (e.g. 0,4 Hz at +/- 12 mm). Continuous temperature measurement shall be carried out.

The requirements are that at any time during the test the unit shall not bind, seize or break, and that after the test the unit shall show no evidence of leakage.

7.4.2.9 Seal Wear Test

NOTE 1 The object of the test is to ensure that the seal withstands movements due to thermal effects over the assumed design life of the device without leakage of the internal fluid.

The damper shall be tested for 10 000 cycles at an amplitude equal to the expected maximum thermal displacement d_{th} .

NOTE 2 Dampers generally have a high energy dissipation capacity, even at low velocity, therefore, in order to perform the test in a reasonable time without excessive heat build-up within the device, the main orifice system may be by-passed so as to reduce the damper reaction and any pressure build-up. Alternatively, the damper fluid may be removed, entirely or partially, for the cycling test.

After cycling, the damper shall be tested according to 7.4.2.7 to verify that the requirements given there are still fulfilled.

7.4.2.10 Stroke Verification Test

NOTE The purpose of the test is to ensure that the damper is able to accommodate the design stroke.

One full-stroke cycle shall be applied to the damper. The damper need not be filled with fluid.

The requirement is that the damper shall be able to accommodate a stroke at least equal to the design value within a tolerance of 1 mm.

7.4.3 Factory production control

For Quality Control purposes one unit per production lot shall be subjected to the following tests:

- Low Velocity Test;
- Constitutive Law Test;
- Damping Efficiency Test.

A production lot is defined as no more than twenty (20) units having the same constitutive law and the same design details with the exception of the stroke. The constitutive law test shall be performed at ambient temperature.

The pressure test shall be performed on 100 % of the production units.

Table 6 summarises the tests required for the prototype and the production units. The production unit to be tested within the production lot shall be the one with the longest stroke.

Table 6 — Tests required for type and FPC testing

	Pressure Test	Low Velocity Test	Constitutive Law Test	Damping Efficiency Test	Wind Load Test	Seal Wear Test	Stroke Verification Test
Type Tests	x *	x	x	x	x *	x *	x *
Factory Production Control	x *	x *	x *	x*			

(*) Test performed at ambient temperature

8 Isolators

8.1 General Requirements

Seismic isolators shall support the gravity load of a structure without excessive creep and resist non-seismic actions such as wind loadings and thermally induced displacements. They shall provide by a low horizontal stiffness or other means the desired low horizontal natural frequency for the isolated structure. They shall be able to accommodate the large horizontal displacements produced by seismic actions whilst still safely supporting the gravity load of the structure and resisting the vertical forces produced by the seismic actions. They shall provide a level of damping sufficient adequately to control the horizontal displacements produced by the seismic actions unless supplementary devices are used to provide the damping.

The types of isolators covered by this clause are:

- a) Elastomeric isolators, including those with a plug of lead or high damping polymeric material to enhance the damping;
- b) sliders, both curved and flat surface.

NOTE 1 Steel spring isolators are not covered, though it is intended to include them in future versions of this European Standard.

Isolators shall be designed and manufactured to accommodate the translation and rotation movements imposed by seismic and other actions whilst supporting the vertical load imposed by gravity, seismic actions and other live loads. They shall function correctly if subjected to the anticipated environmental conditions during their design service life. When isolators are likely to be subjected to exceptional environmental and application conditions, such as immersion in water, exposure to oils or chemicals, or installation in an area constituting a significant fire risk, additional precautions shall be taken (see EN 1337-9) in the light of a precise definition of the conditions.

Isolators shall fulfil the general rules given in Clause 4.

All the anti-seismic devices of an isolation system shall not impair the performance of the structural system under non-seismic service conditions.

NOTE 2 It is recommended that for isolators the value of 1,2, as recommended in EN 1998-1:2004, 10.3 (2), is used for the magnification factor γ_x for all structures, including critical ones, other than bridges.

All types of isolators shall be attached to the structure by mechanical fixing only, unless the minimum vertical load on the isolators during the seismic action has been determined by dynamic analysis. Then at least 75 % of the horizontal load shall be supported by mechanical anchorages.

NOTE 3 The amplification factor, γ_{is} , applied to the design displacement for bridge isolators in EN 1998-2:2005, 7.6.2 (1)P, is here represented by the symbol γ_x . It is recommended that the value of 1,5 as recommended in EN 1998-2, is used for bridges.

NOTE 4 The appropriate structural analysis procedures for isolated buildings are specified in EN 1998-1:2004, 10.9, and for bridges in EN 1998-2:2005, 7.5.

NOTE 5 The isolators considered in this European standard provide isolation against only horizontal seismic actions. They can be designed additionally to provide isolation against vertical vibrations. Vertical stiffness tests additional to that in 8.2.1.2.8 would be required.

For all structures including bridges, the total design horizontal displacement for an isolator under the design seismic action is denoted by d_{bd} .

For bridges, the maximum displacement, d_{max} , for an isolator is that defined in EN 1998-2:2005, 7.6.2 (2). It shall be obtained by adding to the amplified design seismic displacement $\gamma_x d_{bd}$, the potential offset displacements due to:

- a) the permanent actions;
- b) the long-term deformations (post-tensioning, shrinkage and creep for concrete decks) of the superstructure;

and

- c) 50 % of the thermal action.

For other structures, the maximum displacement is $\gamma_x d_{bd}$. The symbol d_{Ed} denotes the appropriate maximum displacement of an isolator for any type of structure.

The vertical loads, $N_{Ed,max}$ and $N_{Ed,min}$, are respectively the maximum and minimum values obtained in the design seismic situation.

The values of upper and lower bound service temperatures, T_U and T_L respectively, shall be determined on the basis of values determined according EN 1991-1-5 and Annex J of EN 1998-2:2005.

NOTE 6 If no results on the variation of the device properties are available, estimates for preliminary analysis are given in Annex J.

8.2 Elastomeric Isolators

8.2.1 Requirements

8.2.1.1 General

Subclause 8.2 applies to elastomeric isolators, both high damping ($\xi_b(100\%) > 0,06$, where the figure in brackets refers to shear strain) and low damping ($\xi_b(100\%) \leq 0,06$), used with or without complementary devices to extend their range of use.

NOTE High damping rubber bearings are here designated HDRB, and low damping rubber bearings LDRB. The elastomeric isolators may contain holes plugged with lead (such isolators are termed lead rubber bearings [LRB]) or high damping polymeric material (such isolators are here termed polymer plugged rubber bearings to 3.3 [PPRB]) to achieve the desired level of damping.

Elastomeric isolators shall fulfil the general requirements given in 8.1 and the performance requirements given in 8.2.1.2. The materials used in the manufacture of isolators shall conform to the requirements of 8.2.2. Each elastomeric isolator shall be designed according to the procedure and rules given in 8.2.3.

Elastomeric isolators shall conform to the general and functional requirements respectively given in EN 1337-3:2005, 4.1 and 4.2.

The elastomeric isolator design properties to use in the structural analysis shall be the data reported from the tests 8.2.4.1.2.

The upper and lower bound values of the design properties referred to in 4.4.2 shall be determined from the type tests and the following variations:

- production variability $\pm 20\%$ (unless a lower variability has been agreed for the factory production control tests);
- temperature changes reported at T_U and T_L (see 8.2.1.2.4) and where appropriate the change in horizontal stiffness at 100 % rubber shear strain in the low temperature crystallisation test (see 8.2.2.1.5);
- ageing change reported in test (see 8.2.1.2.9).

In combining the three a factor of 0,7 shall be used for the production variability and temperature variation, and a factor of 1,0 for the ageing variation. When low temperature crystallisation has to be considered, the change in the stiffness at low temperature shall be the larger of those reported for the cyclic test (8.2.1.2.4) and the crystallisation test (8.2.2.1.5).

The ratio between the upper and lower bound design property values for all elastomeric isolators shall be less than 1,8.

For low damping elastomeric bridge isolators to be used in instances where the design seismic action is small, only the particular requirements given in 8.2.1.2.11 shall apply from this European standard. EN 1337-3 shall apply to such isolators, except the design shall be carried out according to 8.2.3.

The action shall be treated as small when:

- a) the design seismic displacement, d_{bd} , is less than the total displacement due to other actions as given in EN 1998-2:2005, 7.6.2 (2);
- b) the maximum horizontal seismic force is less than the total horizontal force due to other actions as given in EN 1998-2:2005, 7.6.2 (2).

For such isolators, the effective horizontal stiffness K_b , used in the structural analysis, shall be determined from the value reported under 8.2.1.2.11. The upper and lower bound values referred to in 4.4.2 shall be determined from that and the following variations:

- production variability tolerance value for the apparent conventional shear modulus according to EN 1337-3:2005, 4.3.1.1;
- temperature changes reported at T_U and T_L (see 8.2.1.2.4);
- ageing change in conventional shear modulus according to EN 1337-3:2005, 4.3.1.4.

8.2.1.2 Performance requirements for isolators

8.2.1.2.1 General

The performance requirements define quantifiable characteristics that shall be determined for elastomeric isolators by type tests. Any required limiting values are indicated. Those tests that shall be also used as factory production control tests are listed in 8.2.4.1.3.

The measurement of damping is not required for low damping isolators, and the damping requirements given in 8.2.1.2.2 need not apply to them.

The requirements in EN 1337-3:2005, 4.3.4 and 4.3.6 shall apply to isolators for bridges.

8.2.1.2.2 Dependence of horizontal characteristics on rubber shear strain

The horizontal characteristics under cyclic loading shall be measured at the following rubber shear strains: $\pm 5\%$, $\pm 10\%$, $\pm 20\%$, $\pm 50\%$ and $\pm 100\%$ under the test conditions and using the procedures given in the relevant subclauses of 8.2.4.1. The horizontal characteristics shall be expressed in terms of effective horizontal stiffness, K_b , and equivalent damping factor, ξ_b , except that LRB and PPRB may be characterised in terms of second branch (or post-yield) stiffness, K_2 , and characteristic strength, Q_d (this is defined as the force at which the force-displacement loop intersects the force axis). If the tests are carried out at a frequency other than 0,5 Hz or the isolation frequency, the horizontal characteristics reported shall be referred to one of those frequencies by correcting for the effect of test frequency according to the procedure given in 8.2.2.1.3.3. If the shear strain, $\epsilon_{q,E}$, at the design displacement, d_{bd} , is higher than 100 %, tests at additional strain amplitudes shall be added as detailed in Table 7. γ_6 is a partial factor for elastomeric isolators (see 8.2.1.2.7). The tests may all be performed on the same isolator, in which case they shall be conducted in order of increasing strain amplitude and only at the strains specified in this subclause. The cyclic displacement shall be applied about zero shear displacement; no offset displacement shall be applied.

Table 7— Cyclic test rubber strain amplitudes

Strains in %

Design rubber shear strain, $\epsilon_{q,E}$	Additional test strains
$100 < \epsilon_{q,E} \leq 150$	150 or $\gamma_6 \times \epsilon_{q,E}$
$150 < \epsilon_{q,E} \leq 200$	150, 200
$200 < \epsilon_{q,E} \leq 250$	150, 200, 250