CEN/TC 340
Anti-seismic devices

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

CEN/TC 340 DOC. N. 82
June 2006

1 TO DECIDE: X

---

2 SUBJECT/TITLE

prEN 15129 Anti-seismic devices – Clause 4 of the Draft Agenda of the 8th meeting of CEN/TC 340 (AFNOR Paris, 2006-07-19/20) circulated on 2006-06-12.

---

3 SITUATION/BACKGROUND

-

---

4 PROPOSAL

-

SECRETARIAT CEN/TC 340
Via Sannio, 2 ● I 20135 MILANO
TEL. +39 02 70024403●FAX +39 02 70024369
alberto.galeotto@uni.com

CEN/TC 340

Date: 2006-09

TC 340 WI 00340001

CEN/TC 340

Secretariat: UNI

Anti-seismic devices

Erdbebenvorrichtungen

ICS:

Descriptors:

Document type: European Standard
Document subtype:
Document stage: CEN Enquiry
Document language: E

C:\Documents and Settings\fbrusco\Desktop\TC_340_WI_00340001(E).doc STD Version 2.2

Contents

Page

Foreword

This document (TC 340 WI 00340001) has been prepared by Technical Committee CEN/TC 340 “Anti-seismic devices”, the secretariat of which is held by UNI.

This document is currently submitted to the CEN Enquiry.

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, B, C or D, which is an integral part of this document.

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 in the seismic situation, material characteristics, manufacturing and testing requirements, as well as acceptance, installation and maintenance criteria.

This European standard covers the types of devices listed in table 1 (see 3.4).

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

2 Normative references

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

EN 1337-1:2000, *Structural bearings – General design rules.*

EN 1337-2, *Structural bearings – Sliding elements.*

EN 1337-7, *Structural bearings – Spherical and cylindrical PTFE bearings.*

EN 1337-9, *Structural bearings - Protection.*

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

EN 1998-1:2004, *Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings.*

EN 1998-2:2005, *Eurocode 8: Design of structures for earthquake resistance - Part 2: Bridges.*

EN 10025, *Hot rolled products of non-alloy structural steels - Technical delivery conditions.*

EN 10083-1, *Quenched and tempered steels - Part 1: Technical delivery conditions for special steels.*

EN 10083-2, *Quenched and tempered steels - Part 2: Technical delivery conditions for unalloyed quality steels.*

EN 10088-1, *Stainless steels - Part 1: List of stainless steels.*

EN 10088-2, *Stainless steels - Part 2: Technical delivery conditions for sheet/plate and strip for general purposes.*

EN 10088-3, *Stainless steels - Part 3: Technical delivery conditions for semi-finished products, bars, rods and sections for general purposes.*

EN 10113-1, *Hot-rolled products in weldable fine grain structural steels - Part 1: General delivery conditions.*

EN 10137-1, *Plates and wide flats made of high yield strength structural steels in the quenched and tempered or precipitation hardened conditions - Part 1: General delivery conditions.*

EN 10137-2, *Plates and wide flats made of high yield strength structural steels in the quenched and tempered or precipitation hardened conditions - Part 2: Delivery conditions for quenched and tempered steels.*

EN 10137-3, *Plates and wide flats made of high yield strength structural steels in the quenched and tempered or precipitation hardened conditions - Part 3: Delivery conditions for precipitation hardened steels.*

EN 10204, *Metallic products - Types of inspection documents.*

ENV 1090-5, *Execution of steel structures - Part 5: Supplementary rules for bridges.*

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

EN 1337-3, *Structural bearings – Elastomeric bearings.*

EN 1337-5, *Structural bearings – Pot bearings.*

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

EN 1998-2, *Eurocode 8: Design of structures for earthquake resistance - Part 2: Bridges.*

ISO 34, *Rubber, vulcanized or thermoplastic (all parts).*

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, *Rubber, vulcanized or thermoplastic - Determination of compression set at ambient, elevated or low temperatures.*

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

ISO 1083, *Spheroidal graphite cast iron - Classification.*

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

ISO 4664, *Rubber - Guide to the determination of dynamic properties.*

ISO 6158, *Metallic coatings - Electroplated coatings of chromium for engineering purposes.*

ISO 6446, *Rubber products - Bridge bearings -- Specification for rubber materials.*

3 Terms and definitions, symbols and abbreviations

3.1 Definitions

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

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
the maximum value during the action is denoted $N_{Ed,max}$ and the minimum value $N_{Ed,max}$. The minimum value acting on an isolator 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)
displacement (translation or rotation) that a device shall undergo when the structural system is subjected to the design earthquake according to EN 1998-1

3.1.6
(maximum) displacement of a device in a principal direction d_{Ed}
for a bridge isolator d_{Ed} equals d_{max}, the maximum total horizontal displacement at the location of the isolator including all actions effects and the application of the reliability factor to d_{bd}, according to EN1998-2, 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_{Ebd} (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)
the displacement ductility demand referred to the theoretical bilinear cycle, and is evaluated as d_{bd}/d_1 (see 3.1.4 and 3.1.43)

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:

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

$W(d_{bd})$ = 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 it 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 shall be 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 at the total design displacement in the same direction, divided by the absolute value of the total design displacement (secant stiffness)

$$K_{effb} = V_{Ebd} / d_{bd} \tag{2}$$

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

$$K_{in} = (V_{Ebd}/5 - V_{Ebd}/10) / (d(V_{Ebd}/5) - d(V_{Ebd}/10)) \tag{3}$$

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

3.1.19
Fluid Viscous Damper (FVD)
an 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)
an 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/or valve system and at the same time is subjected to progressive compression

3.1.21
Hardening Device (HD)
a 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_{in} of a LD
the stiffness of a LD is defined as the secant stiffness between the points corresponding to the forces $V_{Ebd}/10$ and $V_{Ebd}/5$:

$$K_{in} = (V_{Ebd}/5 - V_{Ebd}/10) /(d(0,2\ V_{Ebd}) - d(0,1\ V_{Ebd})). \qquad (4)$$

NOTE The evaluation of K_{in} 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
the 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
a structural bearing 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 re-centring capability

3.1.27
linear device (LD)
an 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)
an SR whose behaviour is determined by the break-away of sacrificial components.

3.1.29
Non Linear Device (NLD)
an 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)
an 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%

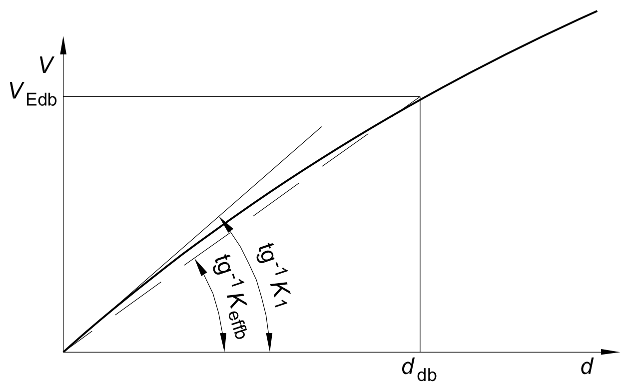


Figure 1 — Initial and effective stiffness of a linear device

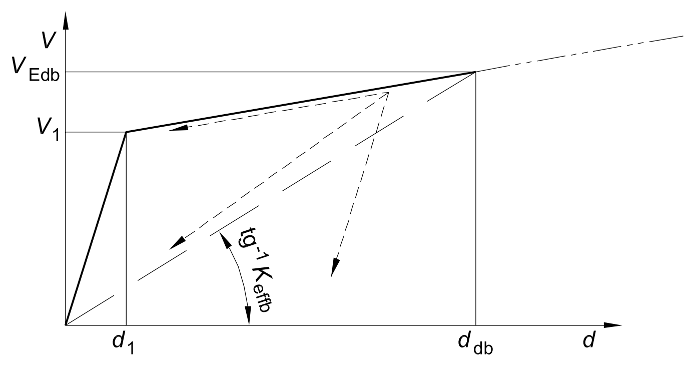


Figure 2 — Effective stiffness of a non linear device.

3.1.31
Permanent Connection Device (PCD)
a 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 event the terms "vertical" and "horizontal" take on the appropriate significance.

3.1.32
Rigid Connection Device (RCD)
a 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
Sacrificial (Fuse) Restraint (SR)
a device that, below a certain pre-established force threshold (break-away force), impedes any relative movements between connected parts, whilst it permits the same 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):

$$K_2 = (V_{\mathrm{Ebd}} - V[d_{\mathrm{bd}}/2]) / [d_{\mathrm{bd}}/2] \quad (5)$$

where:

$V[d_{\mathrm{bd}}/2])$ is the force corresponding to $[d_{\mathrm{bd}}/2]$ 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 $d_{\mathrm{bd}}/2$ 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
a 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
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)
a 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)
a 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)
an 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_{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 (SuRD)
a 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_{bd}], provides a force which is at least 0,1 V_{Ebd}

NOTE The supplemental force > 0,1 V_{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)
an 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 major 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_{bd}, V_{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_{bd}, V_{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.

NOTE 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%.

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, b	Length	m
d	Displacement (translation or rotation) of a device	m
f	Strength, frequency	MPa, Hz
t	Thickness of a layer, tolerance	mm
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 safety factors, over-strength 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

FR Fuse Restraint

FSD Fluid Spring Damper

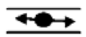
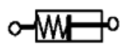
FVD Fluid Viscous Damper

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 Devices
NRD	Non Re-centring Device
PCD	Permanent Connection Device
RCD	Re-Centring Devices
SD	Softening Device
SLS	Serviceability Limit State
SMA	Shape Memory Alloys
SRCD	Supplement Re-Centring Devices
SRs	Sacrificial (Fuse) Restraints
StRD	Statically Re-centring Device
STU	Shock-Transmission Unit
SuRD	Supplemental Re-centring Device
TCD	Temporary Connecting Device
UBDP	Upper Bound Design Properties
ULS	Ultimate Limit State

3.4 List of devices

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

Table 1 — Most common types of Anti-seismic devices

Description of the device			Relevant Clause	Graphic representation: Plan view	Graphic representation: Elevation view, Direction x	Graphic representation: Elevation view, Direction y	Relative movements: Direction x	Relative movements: Direction y	Relative movements: Direction z	Reactions: Direction x	Reactions: Direction y	Reactions: Direction z	Notes All the devices listed in this table accommodate rotations about the three main axes. Y = yes N = no
Rigid Connection Devices (RCDs)	Permanent Connection Devices (PCDs)	Fixed	5.1				N	N	Y	Y	Y	N	This type of device corresponds to type 8.1 of prEN 1337- Part 1
Rigid Connection Devices (RCDs)	Permanent Connection Devices (PCDs)	Movable	5.1				Y	N	Y	N	Y	N	This type of device corresponds to type 8.2 of EN 1337- Part 1
Rigid Connection Devices (RCDs)	Fuse Restraints	Mechanical Fuse Restraints (MFRs)	5.2			–	Y	Y	Y	Y	N	N	
Rigid Connection Devices (RCDs)	Fuse Restraints	Hydraulic Fuse Restraints (HFRs)	5.2			–	Y	Y	Y	Y	N	N	
Rigid Connection Devices (RCDs)	Temporary Connection Devices (TCDs)		5.3			–	Y	Y	Y	Y	N	N	This type of device is usually referred to as Shock Transmission Unit (STU)
Displacement Dependent Devices (DDDs)	Linear Devices (LDs)		6.1			–	Y	Y	Y	Y	N	N	
Displacement Dependent Devices (DDDs)	Non-linear Devices (NLDs)		6.2			–	Y	Y	Y	Y	N	N	
Velocity Dependent Devices (VDDs)	Fluid Viscous Dampers (FVDs)		7.1			–	Y	Y	Y	Y	N	N	This graphic representation applies also to two-shaft dampers
Velocity Dependent Devices (VDDs)	Fluid Spring Dampers (FSDs)		7.1			–	Y	Y	Y	Y	N	N	
Elastomeric Isolators			8.1				Y	Y	N	Y	Y	Y	The isolators are shown in the deformed position to underscore their lateral flexibility

4 General design rules

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

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 design seismic action defined in 2.1(1)P of EN 1998-1 without local or global failure, thus retaining their functional integrity and a residual mechanical resistance, including when applicable a residual load bearing capacity, after the seismic event.

NOTE 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 SRs.

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.

NOTE Non-seismic design situations covered by this European standard should also be considered.

4.1.2 Reliability of the structural system

4.1.2.1 Reliability differentiation

According to the corresponding parts of EN 1998, reliability differentiation for different types of buildings or civil engineering works shall be implemented by classifying structures into different importance categories. To each category, an importance factor γ_I shall be assigned and applied to the seismic action.

NOTE Values of the factor γ_I are recommended in the corresponding parts of EN 1998.

4.1.2.2 Increased reliability

According to EN 1998-1, sub-clause 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}

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 isolators are given in EN 1998-1 and EN 1998-2 (where the factor has the symbol γ_{IS}), and for other devices in the relevant clauses of this European Standard.

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 with 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 importance factor γ_I and 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 sacrificial restraints, for which requirements given in 5.2 apply.

Replacement of the device 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 by 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 Actions

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 Representations of the seismic action

The design seismic action shall be that defined in section 3 of EN 1998 -1, using an elastic response spectrum or related accelerogrammes. Whenever a behaviour factor is applicable, a design spectrum shall be used.

4.2.3 Dynamic analysis

According to the types of devices concerned, the dynamic structural analysis shall be performed either by using a response spectrum or by using a time history analysis.

The use of a response spectrum in connection with an equivalent linear behaviour shall be ruled by conditions given in clause 10.9.2 of EN 1998-1 in particular as concerns limitation of damping. When these conditions are not met, a time-history structural analysis shall be used.

NOTE It is strongly recommended that a time-history analysis is performed when the equivalent damping ratio is higher than 15%.

4.2.4 Effects of actions

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

Effects of actions on devices and their connections to the structure in the seismic situation shall be determined by the application of the structural analysis, as defined in the corresponding parts of EN 1998. Design effects of actions shall take into account additional requirements that are given in the corresponding parts of EN 1998 to fulfil capacity design principles.

Actions applied to the devices and their connections to the structure in the different design situations, including the seismic situations, shall be the basis for the design requirements of the devices and their connections to the structure.

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 4.1.2.2, 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 sections.

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 4.7.

The relevant mechanical and physical properties of the device and its connections to the structure or their components shall be assessed by laboratory tests through appropriate procedures, as required in 4.6 and 4.7 and in the corresponding parts 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} shall be applied to the actions transmitted to the connections between the device and the structure.

NOTE The values of γ_{Rd} are defined in the corresponding sections of this European Standard.

4.3.3 Maintenance

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

NOTE This may be under the responsibility of the designer of the structure.

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 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 him at the time of the replacement.

Inspection and maintenance procedures defined in 4.3.2 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 4.3.2 or in the corresponding parts of this European Standard.

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

NOTE Part of these documents may be provided by the designer of the structure, the remainder being provided by 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 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.

Materials properties shall be represented by representative values.

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.

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 values 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:

- supply — ±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 with due regard to quasi-permanent values of the temperature), as in EN 1990;
- ageing — consistent with the service life considered.

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

NOTE 1 Specific phenomena, such as low temperature crystallisation, have to be considered. 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 7.5.2.4(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).

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_{bd} :

$$E_s \geq 0{,}25\, E_h \tag{6}$$

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, 4.3.3.4.3.

A common position between TC 340 and TC 250-SC 8 has not yet been agreed upon this subject as of the time this document is being completed and disseminated (June 16th, 2006).
In fact, TC 250-SC 8 will meet on June 23rd to examine a proposal tendered by a group of experts from TC 340 during a meeting held in Rome on May 18th 2006. The response to the aforesaid TC 250-SC8 will be discussed during the 8th Meeting in Paris.

NOTE According to EN 1998-1, this rule also applies to the design of the structure. See also B.8 for more details.

4.5 Constitutive laws

The structural analysis shall be based on the appropriate constitutive laws of the devices established by tests as required in 4.6 and 4.7 or in the relevant clauses of this European Standard, so that the behaviour of the structure in the seismic situation may be properly predicted.

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 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 lifetime. 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 lifetime;
- proof of the device's ability to function in a reliable and stable way during its lifetime;
- 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 4.7.1 below, 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 calculation model when attached to a structure, and of the associated detailing. It shall include all information related to geometrical, physical, biological, chemical and mechanical characteristics and tolerances.

4.7 Tests

4.7.1 Type tests

Type tests shall be required:

- for the validation of new devices,
- for the validation of existing devices, when materials are changed,

— for the validation of existing devices in ranges of use outside those previously validated,

— as specified in the relevant clauses of this European Standard.

All mechanical properties of the devices needed in the design for the anticipated service lifetime of the system, together with their ranges of variation due to causes as given in 4.4.1, shall be determined by the type tests. Full-scale devices shall be required for these tests, unless otherwise specified in the relevant clauses of this standard. These tests shall include at least cycling tests, in the conditions of use in the seismic design situation, unless otherwise specified in the relevant clauses of this European Standard. Tests shall be done to establish the representative values of the properties.

The test report shall include at least the following items:

a) Identification of the devices or test specimens (name of manufacturer, origin and number of device manufacturing batch).

b) Dimensions, shape and arrangement of the devices or specimens.

c) Date, type of test, its duration and any other relevant test conditions.

d) Description of test equipment.

e) Complete continuous graphical record of test results, where applicable.

f) Description of the condition of the device or test specimen prior to and after testing.

g) Any operating details not considered in this European Standard and any abnormal incidents occurring during the test.

h) Statement that the test was performed in accordance with this European Standard.

4.7.2 Factory production control tests

Factory production control tests shall be performed, before putting the devices into place, to confirm that their properties conform to the design values, within the accepted tolerance.

Factory production control tests, manufacturing tolerances and installation shall be defined in the validation file.

Detailed description of the factory production control tests according to the type of device considered is given in the corresponding clauses of this European standard.

5 Rigid connection devices

NOTE 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.

5.1 Permanent Connection Devices

Permanent connection devices (PCD) shall allow vertical 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.

The various elements of permanent connection devices shall be designed and manufactured in accordance with the relevant clause of this European Standard and prEN 1337- 8.

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 are devices that, below a certain pre-established force threshold (break-away force), impede any relative movements between connected parts, whereas they freely permit the same after the aforesaid threshold has been exceeded.

FRs can be of the mechanic 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 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 characterized 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 sub-clauses 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 ferrous or non-ferrous 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 shall comply with EN 287, EN 288.

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 1 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.

NOTE 2 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 6.1.1 does not apply to FRs.

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

5.2.4 Prototype Testing

5.2.4.1 Service Load Test

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

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

5.2.4.2 Fatigue Test

This fatigue test shall be performed when requested by the Design Engineer.

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 5.2.4.1 and 5.2.4.3 shall be performed on two samples, one subjected to the fatigue load and one not subjected to fatigue load history.

5.2.4.3 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 design engineer.

NOTE In absence of different tolerance limits provided by the Design Engineer, a typical tolerance limit of ±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 Design Engineer, the Temporary Connection Devices (TCDs), commonly referred to as Shock Transmission Units (STUs), shall provide for an output force in either tension or compression that complies with the design displacement requirements provided by the Design Engineer when the activation velocity is exceeded.

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

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

Thermal and/or time dependent effects velocity shall be estimated by the designer considering for the characteristics of particular structure under design. Anyway, values in the order of 0,01 mm/s are already commonly higher than the most of the real cases.

NOTE 2 Slow movements induced by thermal and/or time dependent effects are characterized by velocities that are some orders of magnitude lesser than those of seismic origin. Thus, the activation velocity value of a TDC 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 Design Engineer without degradation of performance or reduction of useful 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 Design 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 spherical hinges shall be determined by the Design Engineer giving consideration to live load effects, earthquake movements, installation misalignments, etc. The rotation shall in any case be not less than ±2°.

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 Ferrous materials

Shock Transmission Units shall be manufactured from ferrous materials in accordance with one of the following standards:

EN 10025, EN 10083, EN 10113-1, EN 10088, ISO 3755, ISO 1083.

5.3.2.3 Active Surfaces

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

The stainless steel shall be in accordance with EN 10088.

The hard chromium plating process shall comply with the requirements of 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 at least 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_{y5i} in accordance with ISO 4287 of the plated surface shall not exceed 3μm.

NOTE Both the 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 by the fluid manufacturer through appropriate technical documentation.

Hydrocarbon-based fluids shall not be used.

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 be designed to withstand a lateral acceleration equal to the maximum acceleration predicted at its location by the seismic analysis. In the absence of the acceleration data, the STU shall be designed to withstand a lateral load equal to at least twice its own weight concomitant to the maximum axial load.

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.

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

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

5.3.4 Testing

5.3.4.1 General

Type testing shall be performed whenever a new product shall be different by more than ±20% in terms of load capacity from a previously tested unit. As a condition to consider valid previous tests, 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 design 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 Low velocity test

NOTE The objective of the impressed 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 impressed 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 design engineer.

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

5.3.4.3 Seal Wear Test

NOTE The objective 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 internal 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 characterized 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 reasonable time. Alternatively, at the discretion of the manufacturer and whenever the TCD normal operation internal pressure is lesser 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 the test, the TCD shall be tested according to 5.2.4.3 to verify the proper functioning of the sealing system and the TCD's break-away load.

5.3.4.4 Impulsive Load Test

NOTE 1 The objective 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 as follows: 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 Design 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.

5.3.4.5 Overload Test

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

The loading history shall be imposed as follows : 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 internal fluid.

5.3.4.6 Cyclic Load Test

NOTE The objective 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 as follows: apply a number of sinusoidal displacement cycles of the type $d(t) = d_o \cdot \sin(2\pi \cdot f_o \cdot t)$, where stroke d_0 and frequency f_0 (Hz) and the duration of the test shall be chosen by the Design 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 then the design value.

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

5.3.4.7 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 20 units having the same design details with the exception of the stroke.

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

All the tests shall be performed at ambient temperature.

Table 2 summarises the tests required for the prototype and the production units.

Table 2 — Tests required for the prototype and the production units

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

(*) Test performed always at ambient temperature

6 Displacement Dependent Devices

This part of the standard deals with the requirements for the design and manufacturing of anti-seismic linear and non-linear 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 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.

6.1 Performance Requirements

Displacement Dependent Devices (DDD) shall be able to sustain a displacement $\gamma_m \gamma_x d_{bd}$.

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

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

NOTE 3 γ_m is an NDP the value of which is given in the National Annex of the relevant part of Eurocode 8. The value of γ_m shall be set after consideration of any safety or reliability factors already applied in determining the value of d_{bd} from the seismic input. It is recommended that the value of γ_m is defined as follows

$$\gamma_m = 1{,}2 \tag{7}$$

Whenever a DDD is used as a component of a seismic isolation system for buildings, bridges or other structures, the γ_m 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.

A linear device shall have both the equivalent damping of the hysteretic energy dissipation ξ_{effbh} less than 15% and the ratio $|K_{effbh}-K_{inh}|/K_{inh}$ less than 0,2.

NOTE 4 The hysteretic properties of a linear device, such as the equivalent damping of the hysteretic energy dissipation ξ_{effbh} and the corresponding stiffness values K_{effbh} and K_{inh}, can be evaluated by making cyclic tests at a very low frequency such as f < 0.001q 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 5 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 1 and 2 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±5) °C.

The differences due to temperature shall be evaluated with reference to the extreme design temperature values.

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

NOTE 6 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 7 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:

$$\left| K_{effb,i} - K_{effb,3} \right| / K_{effb,3} \leq 0.10 \qquad \text{for LD} \qquad (8)$$

$$\left| K_{2,i} - K_{2,3} \right| / K_{2,3} \leq 0,10 \qquad \text{for NLD} \qquad (9)$$

$$\left| \xi_{effb,i} - \xi_{effb,3} \right| / \xi_{effb,3} \leq 0.10 \qquad \text{for LD and NLD} \qquad (10)$$

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≥2).

Table 3 — Tolerance limits for linear devices

	(1) Supply	(2) Ageing	(3) Temperature	(4) Strain Rate
K_{effb}	±15%	±20%	±40%	±10%
ξ_{effb}	±15%	±15%	±15%	±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	±15%	±20%	±20%	±10%
K_{eff}	±15%	±20%	±40%	±10%
ξ_{eff}	±10%	±15%	±15%	±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:

$$| (K_2/K_1) - (K_2/K_1)_d | \leq 0{,}01 \qquad \text{for (1), (2), (3), (4)} \qquad (11)$$

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 extreme design temperatures, 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 displacement value d_1 shall not be exceeded by the displacement produced by the SLS design seismic action.

An over-strength factor γ_{Rd} shall be assumed for safety checking of the design stresses of the structural parts of a device, in order to prevent unexpected failure of the device.

NOTE 8 The values of γ_{Rd} for use in a Country may be found in its National Annex. The recommended value is:

$$\gamma_{Rd} = 1{,}25 \qquad (12)$$

6.2 Materials

6.2.1 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 clause.

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

6.2.2 Rubber

Rubber 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 rubber 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 rubber shall be established by the manufacturer to ensure consistency of the material.

NOTE 2 For low damping rubber based on polychloroprene or natural rubber, the requirements should at least satisfy those given in Table 6 of clause 8; for high damping rubber the requirements should at least satisfy those given in Table 7 of clause 8.

6.2.3 Steel

Steel used in devices shall conform to the requirements given in EN 10025, EN 10083, EN 10088 and EN 10137.

6.2.4 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.

6.3 Testing

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 preferably 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.

6.3.1 Type tests of materials

6.3.1.1 General

Type tests shall be performed to demonstrate conformity with requirements established as specified in 6.2. 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 norm, 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 will be fully responsible, where the relationship between material and device behaviour shall be made clear.

6.3.1.2 Rubber

Tests on rubber shall be performed to establish conformity to the requirements established under 6.2.2 The tests to establish conformity with the requirements of 8.2.2.1(Check numbering) shall be performed according to the methods referred to in 8.2.4.2(Check numbering). Other test methods and procedures shall conform to the appropriate ISO or CEN standard, if any, except that:

— Test pieces may be moulded from the compound cured as far as possible under the same conditions as the rubber in the device, or cut from the device

— dynamic shear testing shall conform to 8.2.4.2.5.2

6.3.1.3 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.

6.3.1.4 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 $\leq 0{,}002\ \mathrm{sec}^{-1}$, at (23 ± 5)°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, 0,2, 0,8 sec^{-1}) and temperatures (as above). The cycle strain amplitudes shall be 3%, 6%, 9%, 12%, up to failure. 10 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 is 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.

6.3.1.5 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.

6.3.2 Factory production control tests of materials

6.3.2.1 General

The uniformity of each production lot must be assessed. Factory production control tests on materials shall be performed to establish conformity to the acceptance requirements established as specified in 6.2.

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.

6.3.2.2 Rubber

Factory production control tests shall be carried out to establish that the rubber conforms to the acceptance requirements specified in 6.2.2.

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 with the appropriate ISO or CEN standard, if any, except that:

— test pieces may be moulded from the compound cured as far as possible under the same conditions as the rubber in the device or cut from the device

— dynamic shear testing shall conform to 8.2.4.2.5.2.

6.3.2.3 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.

6.3.2.4 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 sec^{-1}, at (23 $\pm$5)°C.

c) Loading/unloading tensile tests on super-elastic wire at 0.2 sec^{-1} strain rate, 6% strain amplitude and at (23 $\pm$5)°C temperature (as above). The cycle strain amplitudes shall be 3%, 9%, 12%, up to failure. 10 cycles shall be repeated for each amplitude, each strain rate and each temperature, on separate samples of the same material.

6.3.2.5 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.

6.3.3 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 1 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 have to be qualified together with their connection system.

Testing procedures shall be such that the working and fixings of the device as installed in the structure 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 secs., 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_m and γ_x or a force not less than V_{Ebd} multiplied by γ_m 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 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.

6.3.4 Factory production control testing of devices

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

Test a) described in 6.3.3 shall be carried out on at least [5%] of the supply, with a minimum number of one devices. 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 will not be allowed to 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 term Viscous Damper generally applies to both of them.

Within the tolerances specified by the Design 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 Design 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 Design Engineer shall prescribe the acceptable variation of the output force due to changes in ambient or internal temperature.

The Fluid Spring Damper output force shall depend on velocity and stroke. The Design Engineer shall prescribe the acceptable variation of the output force due to changes in ambient or internal temperature.

The damper design stroke shall take into account for long-term effects, thermally induced and seismic displacement as well as any adjustment length required by the Design 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 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 Design Engineer giving consideration to live load effects, earthquake movements, installation misalignments, etc. The rotation shall in any case be not less than ± 2°.

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 Ferrous materials

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

EN 10025, EN 10083, EN 10113-1, EN 10088, ISO 3755, ISO 1083.

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 guarantee corrosion protection and/or wearing resistance.

The hard chromium plating process shall comply with the requirements of 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 at least 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_{y5i} in accordance with ISO 4287 of the plated surface shall not exceed 3μm.

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.

7.3 Design requirements

7.3.1 General

The Viscous Dampers 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.

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 a_d equal to the maximum predicted at its location by the seismic analysis. Should the acceleration data not be available, the damper shall be designed to withstand a lateral load equal to at least twice its own weight concomitant to 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.

In absence of different tolerance limits provided by the Design Engineer, the maximum differences of the experimental values of the characteristic 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 Table 5. These limits are relevant to variations within the supply (statistical variations), as well as variations due to ageing, temperature, etc.

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

	Supply		Ageing		Temperature (*)	
	VFD	VSD	VFD	VSD	VFD	VSD
F	±15%	±15%	±5%	±5%	±5%	±15%
K_{eff}	N/A	±15%	N/A	±5%	N/A	±15%
EDC	-15%	-15%	-5%	-5%	-5%	-5%

(*) Temperature range –25°C/+50°C

Key
N/A = Not Applicable
EDC= Energy Dissipation per Cycle

7.3.2 Overvelocity

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

$$\gamma_v = (1+t_d)\cdot(1.5)^{\alpha} \tag{13}$$

where:

t_d is the design reaction tolerance guaranteed by the manufacturer

α is the exponent of the constitutive law guaranteed by the manufacturer

NOTE A typical design reaction tolerance guaranteed by the manufacturers at ambient temperature is ±15% (t_d=0,15). Anyway, the t_d value to be considered for design purposes should include temperature effects.

7.3.3 Buckling

The damper piston rod shall be designed to avoid buckling instability when loaded with the factored design load (see 7.2.2) in its fully extended configuration.

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 2 times 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

Type testing shall be performed whenever a new product shall be different by more than ± 20% in terms of load capacity from a previously tested unit and/or its design velocity is greater than what already tested. As a condition to consider valid previous tests, conceptual design and materials shall be the same as used before.

7.4.2.1 General

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 that corresponding to 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 objective 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 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 Design 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 ± 5)°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 objective 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 deflection, from 0 to d_{th}, to d_{th} and back to 0, imposed at constant velocity $v_1 \leq 0{,}1$ mm/s. The value of d_{th} shall be specified by the Deign 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 Design 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 ambient temperature (23 ± 5)°C or at a lower temperature if specified by the Design Engineer.

7.4.2.5 Constitutive law test for Fluid Viscous Dampers

NOTE 1 The scope 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 (in %): 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 temperatures in order to assess the influence of the external 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 scope of this test is to determine the FSD's constitutive law i.e. the parameters F_o (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 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 (in %): 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

$$F_n = \frac{F_n^{(+)} + \left|F_n^{(-)}\right|}{2} \qquad (14)$$

NOTE 3 hysteretic loop cycle with an axis parallel to the force axis at 50% of $+d_{bd}$ and $-d_{bd}$:

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.

7.4.2.6 Damping efficiency test

NOTE 1 The objective 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 $d(t) = d_o \cdot \sin(2\pi \cdot f_o \cdot t)$, where stroke d_0 and frequency f_0 (Hz) shall be specified by the Design 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 7.4.2.4 or 7.4.2.5, shall be within the design tolerance and the energy dissipation shall be greater than the minimum design value.

7.4.2.7 Wind load cycle test

When wind load is deemed to be critical by the Design 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 Design 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.

7.4.2.8 Seal Wear Test

NOTE 1 The objective of the test is to ensure that the seal will withstand 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 7.4.2.6 to verify that the requirements given there are still met.

7.4.2.9 Stroke Verification Test

NOTE The objective 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 1mm.

7.4.3 Factory production control tests

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.

Table 6 — Tests required for type and acceptance 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 ***
Acceptance Tests	**x ***	**x ***	**x ***	**X***			

(*) Test performed at ambient temperature

7.5 Manufacturing Tolerances

The tolerances shall conform with those given in EN 1337-3:2005, Clause 6 except where indicated otherwise in this sub-clause.

For isolators located in a recess the tolerance of the plan dimensions shall be +0,-2mm.

For isolators connected to a flange plate or to the structure by means of bolts, the tolerance on the position of the holes shall be ±0,2% unless an alternative figure is agreed with the structural engineer,

7.6 Marking and Labelling

Isolators shall conform to the marking and labelling requirements (except that related to very low temperature performance) given EN 1337-3:2005, 7.3.

8 Isolators

8.1 General Requirements

Seismic isolators are required to 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.

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 when subject to the anticipated environmental conditions during their projected 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 1 It is recommended that for isolators the value of 1,2, as recommended in EN 1998-1, 10.3 (2), is used for the magnification factor γ_x for all structures, including critical ones, other than bridges.

NOTE 2 The amplification factor, γ_{IS}, applied to the design displacement for bridge isolators in EN1988-2, 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 EN1998-2, is used for bridges.

NOTE 3 The appropriate structural analysis procedures for isolated buildings are specified in EN 1998-1, 10.9, and for bridges in EN 1998-2, 7.5.

For all structures including bridges, the total design horizontal displacement for an isolator, d_{bd}, and the design displacement of the isolation system at the stiffness centre in a particular direction, d_{cd}, shall be taken as those defined in EN 1998-1, 10.2.

For bridges, the maximum displacement, d_{max}, for an isolator is that defined in EN 1998-2, 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 frequently occurring values as defined in EN1990 1.5.1.3.17(see 4.4.2).

8.2 Elastomeric Isolators

8.2.1 Requirements

8.2.1.1 General

The clause 1 applies to elastomeric isolators, both high damping (ξ_b(100%) > 0,06, where the figure in brackets refers to shear strain) and low damping (ξ_b(100%) ≤ 0,06), used with or without complementary devices to extend their range of use. 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 [PPRB]) to achieve the desired level of damping.

Elastomeric isolators shall fulfil the performance requirements given in 1. The materials used in the manufacture of isolators shall conform to the requirements of 1. Each elastomeric isolator shall be designed according to the procedure and rules given in 1.

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 1.

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 ±20% (unless a lower variability has been agreed for the factory production control tests)

— temperature changes reported at T_U and T_L (see 1) and where appropriate the change in horizontal stiffness at 100% rubber shear strain in the low temperature crystallisation test (see 1)

— ageing change reported in test (see 1)

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 (1) and the crystallisation test (1).

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 1 shall apply from this European standard. EN 1337-3:2005 shall apply to such isolators, except the design shall be carried out according to 1. Their fixing to the structure shall not depend only upon friction. The action shall be treated as small when:

a) the design seismic displacement, d_{cd}, is less than the total displacement due to other actions as given in EN1998-2, 7.6.2 (2)

b) the maximum horizontal seismic force is less than the total horizontal force due to other actions as given in EN1998-2, 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 1. 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 1)

— ageing change in conventional shear modulus according to EN1337-3 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: ±5%, ±10%, ±20%, ±50% and ±100% under the test conditions and using the procedures given in the relevant parts of 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 0.5Hz 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 1. If the shear strain, $\varepsilon_{q,E}$, at the design displacement, d_{cd}, is higher than 100%, tests at additional strain amplitudes shall be added as detailed in . γ_b is a partial factor for elastomeric isolators (see 1). 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, $\varepsilon_{q,E}$	**Additional test strains**
100 < $\varepsilon_{q,E}$ ≤150	150 or γ_b $\varepsilon_{q,E}$
150 < $\varepsilon_{q,E}$ ≤ 200	150, 200
200 < $\varepsilon_{q,E}$ ≤ 250	150, 200, 250

NOTE The test strain amplitudes are well spaced so that, if tests are performed on the same isolator, strain history effects are small.

The requirements are that:

- the values of K_b and ξ_b (or K_2 and Q_d) for the third cycle be reported for all the rubber shear strains tested.
- if the design rubber shear strain is not included in the test strains listed, the values of K_b and ξ_b (or K_2 and Q_d) for the third cycle at the design rubber shear strain shall both be determined from the test results by linear interpolation
- the test frequency and reference frequency, if applicable, be reported
- the values of K_b and ξ_b (or K_2 and Q_d) for the third cycle at the design rubber shear strain shall both be within ±20% of the design value.
- the value K_b at 5% shear strain (or Q_d) shall be sufficient to provide adequate restraint, as determined by the structural engineer, against wind loading.

A cyclic test to determine K_b and ξ_b (or K_2 and Q_d), performed at the shear strain amplitude listed in this sub-clause that is closest to the rubber shear strain, $\varepsilon_{q,E}$, at the design displacement, d_{cd}, should be performed as an acceptance test with the requirement that the values of K_b and ξ_b (or K_2 and Q_d) for the third cycle shall both be within ±20% of the design value corrected, if necessary, for the difference between the test and design shear strains.

In the case that measurement of the cyclic horizontal characteristics at the shear strain amplitude listed in this sub-clause that is closest to the rubber shear strain, $\varepsilon_{q,E}$, at the design displacement, d_{cd}, is not to be performed as an acceptance test, the following two tests shall be carried out as acceptance tests:

- measurement of the horizontal secant stiffness under a one-sided ramp loading
- cyclic test to determine K_b and ξ_b (or K_2 and Q_d), performed at a lower shear strain amplitude that is listed in this sub-clause. The shear strain amplitude shall be at least 20%.

The ramp test shall also be performed as a type test in order to establish the requirement for the acceptance test. The isolator used for the cyclic tests shall be deformed up to the rubber shear strain listed in this sub-clause that is closest to the rubber shear strain, $\varepsilon_{q,E}$, at the horizontal design displacement, d_{cd}. The ramp test shall be performed after the cyclic test at that strain and before the cyclic tests at higher strains. The other test conditions and procedures shall conform to the relevant parts of 1. The requirement of the type test is that the secant stiffness at the test shear strain shall be determined. The requirement of the ramp acceptance test is that the secant stiffness shall be within ±20% of the value determined from the type test, adjusted, if necessary, by the procedure given in 6.3.4 to allow for the difference between the design value of the cyclic stiffness K_b at the design displacement, d_{cd}, and the value determined from the type tests. The requirement of the cyclic acceptance test is that the values of K_b and ξ_b (or K_2 and Q_d) for the third cycle shall both be within ±20% of the values obtained in the type test, the value of K_b (or K_2) being adjusted, if necessary, by the procedure given in 6.3.4 to allow for the difference between the design value of the cyclic stiffness K_b (or K_2) at the design displacement, d_{cd}, and the value determined from the type tests.

8.2.1.2.3 Dependence of horizontal characteristics on frequency

The effect of frequency on horizontal characteristics K_b and ξ_b (or K_2 and Q_d) shall be determined by tests performed at a rubber shear strain amplitude of ±100%. The horizontal characteristics shall be measured at three frequencies. The recommended values are:

0,1Hz 0,5Hz 2,0Hz

Other values spaced by the same ratios may be chosen in agreement with the structural engineer. The tests shall be in order of increasing frequency.

The values of K_b and ξ_b (or K_2 and Q_d) for the third cycle shall be reported for each test frequency. The values at the lowest and highest frequencies shall not differ by more than 20% from the value at the middle frequency.

For HDRB and LDRB, the tests may be performed on isolators scaled without restriction, or may be substituted by the tests required in 1 on the elastomer used in its manufacture.

8.2.1.2.4 Dependence of horizontal characteristics on temperature

The changes in horizontal characteristics K_b and ξ_b (or K_2 and Q_d) between the upper and lower service temperatures, T_U and T_L respectively, shall be determined by tests under the conditions and using the procedures given in the relevant parts of 1. The horizontal characteristics shall be measured at a rubber shear strain amplitude of ±100% over a range of temperatures extending from at least T_U to at least T_L. A test at 23°C shall be included. The tests shall be performed in order of decreasing temperature. It is recommended that tests at the following temperatures be included if they are within the range of service conditions:

40°C, 23°C, 0°C, -10°C, -20°C

The values of K_b and ξ_b (or K_2 and Q_d) for the third cycle shall be reported for each test temperature. The values at the lowest temperature shall not differ by more than +80% or –20% from the corresponding values at 23°C, and the values at the highest temperature shall not differ by more than ±20% from those at 23°C.

For HDRB and LDRB, the tests may be performed on isolators scaled without restriction, or may be substituted by the tests required in 1 on the elastomer used in its manufacture.

8.2.1.2.5 Dependence of horizontal characteristics on repeated cycling

The horizontal characteristics K_b and ξ_b (or K_2 and Q_d) of the isolator shall be constant under repeated cyclic loading. The stability of the characteristics shall be verified by tests. The rubber shear strain amplitude shall be 100%. Other the test conditions and procedures shall conform to those given in the relevant parts of 1. The requirement for constant characteristics K_b and ξ_b (or K_2 and Q_d) is met when:

- the ratio between the minimum and maximum values of K_b (or K_2) measured in the cycles between the second and the tenth shall not be less than 0,7.

- the ratio between the minimum and maximum values of ξ_b (or Q_d) measured in the cycles between the second and the tenth shall not be less than 0,7.

- the ratio between the minimum and maximum values of K_b (or K_2) measured in the cycles between the first and the tenth shall not be less than 0,6.

For HDRB and LDRB, the tests may be performed on isolators scaled without restriction, or may be substituted by the tests on the elastomer used in its manufacture as required in 1.

The requirements may refer to more than the tenth cycle if requested by the Structural Engineer,

8.2.1.2.6 Capacity in compression under zero lateral displacement

The isolator shall be able to support a vertical load equal to $2N_{Ed,G}$ (where $N_{Ed,G}$ is the dead load plus combination of non-seismic live load(s) according to EN1990 Annex A1(for buildings) or A2 (for bridges) when zero lateral displacement is applied. This requirement shall be checked by applying a vertical load up to $2N_{Ed,G}$ and maintaining that load constant for at least 3 min whilst the isolator is examined for signs of failure. Other test conditions shall conform to the relevant parts of 1.

The requirement is that the load-displacement relation shall be monotonically increasing up to $2N_{Ed,G}$, and that the isolator shall show no visual evidence of manufacturing imperfections or failure. The visual evidence referred to shall include:

- signs of bond failure

- laterally misaligned or vertically misplaced reinforcing plates

- surface cracks or imperfections over 2mm wide or deep

NOTE See EN 1337-3:2005, 4.3.3 and the manufacturing tolerances given in EN 1337-3, Clause 6 for further guidance regarding the requirements.

8.2.1.2.7 Horizontal displacement capacity

The horizontal displacement capacity of an isolator shall be checked up to a displacement of $\gamma_b d_{Ed}$ or a load of $\gamma_b V_{Ed,}$ whichever is reached first (where V_{Ed} is the horizontal load corresponding to d_{bd}) under the following axial loads:

$$N_{zE,max} + 0.2\ N_{Ed,G}$$

$$N_{zE,min} - 0.2\ N_{Ed,G}$$

γ_b is a partial factor for elastomeric isolators.

The value of $N_{zE,min} - 0.2\ N_{Ed,G}$ shall not be a tension force producing a stress greater than 2G, where G is the shear modulus measured at 100% strain (see 1)

NOTE 1 The value ascribed to γ_b for use in a country may be defined in its National Annex. The recommended value of γ_b is 1,15.

The test shall be carried out under a ramp input. The fixings used in the test shall be of the same design as those to be used in fixing the isolator to the protected structure and manufactured from similar materials. The other test conditions shall conform to those stipulated in the relevant parts of 1.

NOTE 2 The rate of loading does not significantly affect the result as the elastomer shear modulus is required not to be very sensitive to frequency. A ramp rate in the range corresponding to a rubber shear rate between 1 and 200%s^{-1} is recommended.

The requirements are that the load shall be monotonically increasing up to the maximum displacement and that the isolator shall not show any significant signs of failure at the end of the test. The visual evidence of failure referred to shall include:

— signs of bond failure

— surface cracks or imperfections over 2 mm wide or deep

The isolator connections to the load platens shall not show any signs of failure or significant yielding.

NOTE 3 See EN 1337-3:2005, 4.3.3 for further guidance regarding visual evidence of failure in the isolator.

If ($N_{zE,max}$ + 0.2 $N_{Ed,G}$) differs from ($N_{zE,min}$ - 0.2 $N_{Ed,G}$) by less than 20% and the minimum load is compressive, only one test at the mean of the two loads need be performed; the same requirements shall be met.

NOTE 4 The value of the minimum vertical load may be tensile. The imposition of tensile stresses above 1MPa on elastomeric isolators should, however, be avoided where possible as cavitation of the rubber occurs at relatively low tensile hydrostatic stresses. A tensile stress of up to 2G is normally sustained without significant cavitation occurring. Special connections between the isolator and structure that remove the possibility of the vertical load on the isolator becoming tensile can be used.

8.2.1.2.8 Compression stiffness

The secant compression stiffness K_v of the isolator shall be determined between (1/3) $N_{Ed,G}$ and $N_{Ed,G}$. The test conditions, equipment and other parts of the procedure shall conform to the relevant parts of 1.

The requirement is that K_v shall be reported.

This test shall also be used as an factory production control test. The requirement is that K_v shall be within ±30% of the value determined in the type test, and the visual inspection at the maximum load shall show no signs of imperfection or failure as given in the requirements in 8.2.1.2.6.

NOTE The force-deflection curve at low loads generally has a low gradient. This phenomenon, termed lead-in or bedding down, is caused by the slight misalignment of the top and bottom bearing surfaces normally present.

8.2.1.2.9 Effect of ageing

The changes in the horizontal characteristics K_b and ξ_b of the isolator (or K_2 only for LRB manufactured using low damping elastomer) shall be estimated to be less than 20% over the expected service life of the isolator. The estimated change shall be determined by accelerated ageing tests on the elastomer material of the isolator (see 1), and by reference to any available directly relevant service life data on devices fabricated from similar materials. For PPRB, ageing tests on the polymer plug material shall also be performed according to 1 so that its contribution to the change in K_b and ξ_b can be estimated. Unless requested otherwise by the Structural Engineer, the requirement in this clause shall be deemed to be met if the elastomer material (and polymer plug material if applicable) satisfies the requirement in 1 under the standard ageing conditions (14 days at 70°C) given there.

NOTE The service life of anti-seismic devices is discussed in Annex B. For elastomeric isolators it can be expected to be 60 years.

8.2.1.2.10 Effect of creep

The short-term creep deformation produced by the design vertical load for non-seismic conditions, $N_{Ed,G}$, may be measured, if requested by the Structural Engineer, in the case of HDRB and PPRB. The conditions and procedures shall conform to those given in the relevant sections of 1.

It is recommended that the percentage creep between 10 min and 10^4 min (approximately one week) should be less than 20% of the deformation after 10 min unless otherwise agreed by the Structural Engineer.

NOTE The recommendation should ensure that deformation of the isolator does not increase excessively over time under the action of the gravity loads supported.

8.2.1.2.11 Low damping bridge isolators subjected to small seismic actions

1) The requirements given in 1, 1 and 1, as modified by this sub-clause, shall apply in addition to the requirements of EN 1337-3:2005.

2) In EN 1337-3:2005 5.3.3.3, the design shear strain due to translatory movements shall be evaluated including the design displacement d_{bd} without the reliability factor γ_x applied.

3) The requirements given in 1 shall be modified so that only the effective horizontal stiffness, K_b, shall be measured at one rubber shear strain agreed with the Structural Engineer. The five requirements listed in 1 are replaced by:

4) the value of K_b for the third cycle be reported

5) the test frequency and reference frequency, if applicable, be reported

6) The rubber shear strain amplitude for requirement 1 shall be agreed with the structural engineer.

7) If the rubber shear strain corresponding to the horizontal displacement $\gamma_b d_{Ed}$ is ≤ 200%, the requirement in 1 shall be deemed to have been met by satisfying EN 1337-3:2005, 4.3.2.1.

8.2.1.3 Structural and mechanical requirements

8.2.1.3.1 Requirements at ULS

The isolator shall be verified to meet the requirements at ULS given in 4.1.4 by its satisfying the lateral capacity test requirement of 1, the maximum total design shear strain of 1, and the stability criterion of 1 (in the case of bolted isolators) or 1 (in the case of recessed or dowelled isolators). A low damping bridge isolators subjected to small seismic actions shall be verified to meet the requirements at ULS given in 4.1.4 by its satisfying the lateral capacity test requirement of 1, the maximum total design shear strain of 1, and the stability criterion of 1 (in the case of bolted isolators) or 1 (in the case of recessed or dowelled isolators).

8.2.1.3.2 Requirements at SLS

Because the requirements at ULS implied by 1 ensure serviceability under that condition, the requirements at SLS given in 4.1.4 are satisfied.

8.2.2 Materials

8.2.2.1 Elastomers

8.2.2.1.1 General

The requirements given in 1 apply to the elastomer used to fabricate the laminated part of the isolator.

The raw elastomers used shall be virgin material; no reclaimed or reground vulcanized rubber shall be used.

The elastomer shall have a shear modulus at a shear strain of 100% within the range 0,35MPa to 1,5MPa.

The vulcanised elastomer shall meet the requirements given in 1.

The tests to determine the quantifiable characteristics to which the requirements refer shall all be performed as type tests. Tests that shall be used as factory production control tests are listed in 1.

The test methods and test pieces shall conform to the relevant sub-clauses in 1.

Low damping elastomers for bridge isolators subjected to small seismic inputs (see 1) need conform only to EN1337-3:2005; they are not subject to the requirements of 1.

NOTE 1 Some of the requirements differ depending on whether samples are moulded from the device compound or taken from a complete finished device.

NOTE 2 The mechanical property requirements (tensile strength, elongation at break and tear resistance) to be met in 1 and 1 are to confirm the general suitability of the elastomer; these properties are not directly related to the performance of the isolator. The compression set test provides a check that the elastomer is adequately vulcanised. The remaining tests (ozone resistance and accelerated ageing in air) provide a check that suitable anti-degradants have been included in the compound.

8.2.2.1.2 General Properties

8.2.2.1.2.1 Low damping elastomers

Low damping elastomers used in isolators for bridges shall conform to EN1337-3:2005 4.4.1. All low damping elastomers, except those for bridge isolators subjected to small seismic inputs (see 1), shall also conform to the material requirements in . The tests are to be carried out as type tests and factory production control tests.

8.2.2.1.2.2 High damping elastomers

High damping elastomers shall meet the requirements given in . The tests are to be carried out as type tests and production control tests.

NOTE Bearings based primarily on natural rubber or polychloroprene rubber have been used as structural bearings for several decades and in most cases have performed to requirements. Isolators fabricated from these two elastomers may therefore be expected to have a long service life. Moreover, natural rubber and polychloroprene rubber crystallise under applied strain, a phenomenon making them resistant to the enlargement of surface cracks under the applied gravity load. For high damping isolators, other elastomers are not excluded by this subclause, but their use necessitates particular consideration of ageing performance and resistance to the growth of surface cracks.

8.2.2.1.3 Dynamic shear modulus and damping

8.2.2.1.3.1 General

The measurement of damping is not required for low damping elastomers (ξ_b(100%) ≤ 0,06), and the damping requirements given in 1 do not apply to them.

Table 8 — Mechanical and physical properties of low damping elastomer

Property	Requirement			Test Method
Shear modulus[a] MPa	0,35≤ G≤ 0,7	0,7< G ≤1,1	1,1<G≤1,5	
Tensile strength MPa,min Moulded testpiece Test piece from bearing[b]	 16 14			ISO 37 Type 2
Elongation at break %,min Moulded testpiece Test piece from bearing[b]	 450 400	 425 375	 350 300	"
Tear resistance[c] kN/m,min	5	8	10	ISO 34[g] Method A
Compression set[d] 70°C, 24h, max	 30	 30	 30	ISO 815 Type A 25% compression
Ozone resistance[e] Elongation 30% - 96h 40°C ±2°C	no cracks	no cracks	no cracks	ISO 1431/1
Accelerated air oven ageing[f] Maximum change from unaged value				ISO 188, Method A
Hardness (IRHD)	-5, +8	± 25	-5, +8	ISO 48
Tensile strength (%)	± 15		± 15	ISO 37 Type2
Elongation at break (%)			± 25	“

a Measured at 100% shear strain

b Test pieces from complete finished isolators shall be taken from the first internal layer and from the layer at the centre of the isolator.

c The values are those for a natural rubber based compound. A polychloroprene based compound shall give values 20% higher.

d The values is that for a natural rubber based compound. A polychloroprene based compound shall give a value 50% lower. For other elastomers, the values shall be agreed between the manufacturer and the structural engineer.

e The ozone concentration shall be appropriate to the elastomer used. For natural rubber based vulcanisates, 25 pphm shall be used and for polychloroprene based vulcanisates 100 pphm. For other elastomers, the values shall be agreed between the manufacturer and the structural engineer. For elastomers with no unsaturated carbon-carbon bonds, an ozone test need not be performed.

f Ageing condition shall be chosen appropriate to elastomers used. For natural rubber based vulcanisates, 7 days at 70°C shall be used and for polychloroprene based vulcanisates, 3 days at 100°C. For other elastomers, the values shall be agreed between the manufacturer and the structural engineer.

g If the legs of the testpiece extend by more than 30%, the method shall be modified to keep the extension below that figure by either increasing the width of the legs or fixing a flexible but relatively inextensible reinforcement to the testpiece; the reinforcement shall leave a gap of 5mm where the tear is expected to grow.

NOTE Because the ozone and ageing tests are checks that appropriate antidegradants have been included, not tests related to service performance, their effectiveness necessitates that the conditions should be appropriate to the elastomer used in fabrication of the devices.

The dynamic testing of the elastomer and the evaluation of the results shall be carried out according to the methods and procedures of 1.

Table 9 — Mechanical and physical properties of high damping elastomers

Property	Requirement		Test Method
	Moulded Sample	Test piece from device[d]	
Tensile strength MPa,min	12	10	ISO 37 Type 2
Elongation at break %,min	400	350	"
Tear resistance kN/m,min	7		ISO 34[c] Method A
Compression set 70°C, 24h, max	60		ISO 815 Type A 25% compression
Ozone resistance[a] Elongation 30% - 96h 40°C ±2°C	no cracks		ISO 1431/1
Accelerated air oven ageing[b] Maximum change from unaged value			ISO 188, Method A
Hardness (IRHD)	-5, +8		ISO 48
Tensile strength (%)	± 15		ISO 37 Type 2
Elongation at break (%)	± 25		"

a The ozone concentration shall be appropriate to the elastomers used. For natural rubber based vulcanisates, 25 pphm shall be used and for polychloroprene based vulcanisates 100 pphm. For other elastomers, the values shall be agreed between the manufacturer and the structural engineer. For elastomers with no unsaturated carbon-carbon bonds, an ozone test need not be performed.

b Ageing condition shall be chosen appropriate to elastomers used. For natural rubber based vulcanisates, 7 days at 70°C shall be used and for polychloroprene based vulcanisates, 3 days at 100°C. . For other elastomers, the values shall be agreed between the manufacturer and the structural engineer.

c If the legs of the testpiece extend by more than 30%, the method shall be modified to keep the extension below that figure by either increasing the width of the legs or fixing a flexible but relatively inextensible reinforcement to the testpiece; the reinforcement shall leave a gap of 5mm where the tear is expected to grow.

d Test pieces from complete finished isolators shall be taken from the first internal layer and from the layer at the centre of the isolator.

NOTE Because the ozone and ageing tests are checks that appropriate antidegradants have been included, not tests related to service performance, their effectiveness necessitates that the conditions should be appropriate to the elastomer used in fabrication of the devices.

8.2.2.1.3.2 Effect of strain amplitude

The elastomer vulcanisate shall be dynamically tested over a range of rubber shear strains. The recommended frequency is 0,5Hz, though another may be requested by the structural engineer. Measurements shall be made at the following shear strain amplitudes:

5%,10%, 20%, 50%,100%, and 150%

If the strain at the design displacement, d_{cd}, is over 100%, tests at additional strain amplitudes shall be added as detailed in .

The tests shall be performed in ascending order of strain amplitude.

The shear modulus and equivalent damping factor shall be reported for the third cycle for each strain amplitude.

Table 10 — Cyclic test strain amplitudes

Design rubber shear strain, $\varepsilon_{q,E}$ (%)	Additional test strain (%)
100 < $\varepsilon_{q,Ed}$ ≤ 150	200
150 < $\varepsilon_{q,Ed}$ ≤ 200	200, 250
200 < $\varepsilon_{qE,d}$ ≤ 250	200, 250, 300

8.2.2.1.3.3 Effect of frequency

The effect of frequency shall be determined by measurements at three frequencies at a shear strain amplitude of ±100%. The tests shall be in order of increasing frequency. The following are the recommended values:

0,1Hz 0,5Hz 2,0Hz

Other values spaced by the same ratios may be chosen in agreement with the structural engineer. The shear modulus and damping for the third cycle shall be reported at each test frequency. The modulus and damping at the lowest and highest frequencies shall not differ by more than 20% from the value at the middle frequency.

If any of the isolators are to be tested at a frequency other than 0,5Hz or the isolation frequency, the isolator test frequency shall be included in the tests of this sub-clause, whilst retaining the pattern of testing in ascending order of frequency.

The ratio between the rubber shear modulus at the reference frequency (0.5Hz or the isolation frequency) mentioned in 1 and the rubber shear modulus at the isolator test frequency shall be applied to the isolator stiffness measurements (for the same rubber shear strain) to correct them for the effect of frequency, and thus determine a value of isolator stiffness at that strain appropriate to the reference frequency. The same procedure shall be used to correct the damping measurement on the isolator for the effect of frequency, and thus determine a value of isolator damping appropriate to the reference frequency.

8.2.2.1.3.4 Effect of temperature

The rubber dynamic shear modulus and damping shall be measured for a shear strain amplitude of ±100% and at the reference frequency (0,5Hz or the isolation frequency) over a range of temperatures extending from at least the upper service temperature, T_U, to at least the lower service temperature T_L. A test at 23°C shall be included. The tests shall be performed in order of decreasing temperature. It is recommended that tests at the following temperatures be included if they are within the range of service conditions:

40°C, 23°C, 0°C, -10°C, -20°C

The values of dynamic shear modulus and damping for the third cycle shall be reported for each test temperature. The values at the lowest temperature shall not differ by more than +80% or –20% from the corresponding values at 23°C, and the values at the highest temperature shall not differ by more than ±20% from those at 23°C.

8.2.2.1.3.5 Shear modulus and damping after accelerated anaerobic ageing

The dynamic shear modulus and damping shall be measured both before ageing and after ageing for 14 days at 70°C. If moulded test pieces are used, the same one shall be tested unaged and aged. The ageing shall be carried out in anaerobic conditions and such that volatile compounding ingredients shall not be lost. The modulus and damping measurements shall be carried out at a shear strain amplitude of ±100%, and the reference frequency (0,5Hz or the isolation frequency).

The shear modulus and equivalent damping factor shall have changed by less than 20% due to the ageing.

The Structural Engineer may request that ageing conditions equivalent to a period of 60 years at the average service temperature be estimated for the elastomer compound and those ageing conditions be substituted for those above; an ageing temperature above 70°C shall not be used.

NOTE See informative Annex **Errore. L'origine riferimento non è stata trovata.** for guidance on the determination of ageing conditions equivalent to a period of 60 years, and recommendations for achieving anaerobic conditions.

8.2.2.1.3.6 Stability of shear properties under repeated cycling

The shear modulus, G, and equivalent damping factor, ξ, of the elastomer shall be stable under repeated cyclic loading. This requirement is met when:

— the ratio between the minimum and maximum values of G measured in the cycles between the second and the tenth shall not be less than 0,7.

— the ratio between the minimum and maximum values of ξ measured in the cycles between the second and the tenth shall not be less than 0,7.

— the ratio between the minimum and maximum values of G measured in the cycles between the first and the tenth shall not be less than 0,6.

The shear strain amplitude shall be 100%. Other the test conditions and procedures shall conform to those given in the relevant parts of 1.

The requirements may refer to more than the tenth cycle if requested by the Structural Engineer.

8.2.2.1.4 Shear bond test

8.2.2.1.4.1 Unaged

The type of test piece used in the dynamic modulus measurements, but with a length (in the direction of straining) to thickness ratio of at least 10 shall be used to determine the bond shear failure strain. The test piece shall be deformed at a constant rate until a shear strain of at least $\gamma_b \varepsilon_{q,E}$, (where $\varepsilon_{q,E}$ is the rubber shear strain corresponding to the displacement d_{Ed}). The test shall be carried out on three test pieces.

NOTE The rate of loading does not significantly affect the result as the elastomer shear modulus is required not to be very sensitive to frequency. A ramp rate in the range corresponding to a rubber shear rate of 10 – 200%s^{-1} is recommended.

The force-displacement curve shall be monotonically increasing, and the test piece shall show no signs of failure or debonding. The test report shall conform to 1.

8.2.2.1.4.2 Aged

The test described in 1 shall be performed on three test pieces aged 14 days at 70°C. The ageing shall be carried out in anaerobic conditions and such that volatile compounding ingredients shall not be lost. The Structural Engineer may request that ageing conditions equivalent to a period of 60 years at the average service temperature be estimated for the elastomer compound and those ageing conditions be substituted for those above; an ageing temperature above 70°C shall not be used.

The force-displacement curve shall be monotonically increasing, and the test piece shall show no signs of failure or debonding. The test report shall conform to 1.

NOTE See informative Annex **Errore. L'origine riferimento non è stata trovata.** for guidance on the determination of ageing conditions equivalent to a period of 60 years, and recommendations for achieving anaerobic conditions.

8.2.2.1.5 Resistance to low temperature crystallisation

The resistance to low temperature crystallization shall be checked for elastomers susceptible to this phenomenon (eg natural rubber, polychloroprene rubber and certain types of ethylene propylene) if the service temperature falls within the range where crystallization may occur. High damping (ξ(100%) > 0,06) natural rubber shall be checked for minimum service temperatures, T_L<0°C, , low damping natural rubber for minimum service temperatures, T_L<-5°C and polychloroprene for minimum service temperatures, T_L<5°C.

A shear test piece shall be used, and the test procedure given in 1 shall be followed.

The requirement is that the shear stiffness at shear strains of 25% and 100% following the required exposure to low temperature shall both be reported. They shall both be less than 1.5x the respective shear stiffness before exposure.

The test shall be performed as a type test.

8.2.2.1.6 Resistance to slow crack growth

The following test shall be performed on three moulded samples using the geometry of ISO 34 Method A:

— Test: apply load equivalent to 4kN/m

and the following requirement satisfied:

— the initial cut shall not extend in any direction by more than 3mm in <24h of loading.

8.2.2.2 Polymer plug

The plug material used to provide damping in PPRB shall meet the requirements given in 1 and 1, except that regarding 1 there shall be no restriction on the permitted range of shear modulus.

8.2.2.3 Lead plug

The lead shall be of purity ≥ 99.9%.

8.2.2.4 Reinforcing steel plates

The inner reinforcing and end plates used in the fabrication of elastomeric isolators shall meet the requirements given by EN 1337-3:2005, 4.4.3.

8.2.3 Design

8.2.3.1 General

Elastomeric isolators, including low damping isolators shall be designed to meet the relevant provisions of:

- this sub-clause corresponding to load combinations including the seismic action;
- sub-clauses 5.1, 5.2 and 5.3.3 of EN 1337-3:2005 at load combinations not including the seismic action, unless otherwise specified in this sub-clause.

The parameter A_r, the reduced effective plan area due to the horizontal displacement of the top of the bearing relative to the bottom (see EN1337-3 equation(9)), shall only take account of non-seismic horizontal displacements.

8.2.3.2 Types and shapes of isolators

The isolator shall consist of alternate layers of elastomer and steel; in each case the layers shall be nominally identical. It shall be moulded under appropriate conditions of heat and pressure, and the steel plates hot-bonded to the elastomer during vulcanization. Two thick end plates shall be hot bonded to the rest of the isolator. The sides of the isolator, possibly excluding the sides of the end plates in the case of isolators located in a recess, shall be covered with a rubber layer at least 4mm thick. Unless the cover layer provides fire resistance, it shall consist of the same material as that in the bulk of the isolator and be cured at the same time as the main body of the isolator. The two standard fixing methods for bolted elastomeric isolators are shown in Figure 3; recess or dowel fixing methods may be used by agreement of the Structural Engineer. Bearings types shall be only rectangular or circular. It is permissible to include holes of uniform section in the loaded area. The holes may be plugged with lead or other material to provide additional damping.

Table 3 of EN 1337-3:2005 shall not apply to elastomeric isolators.

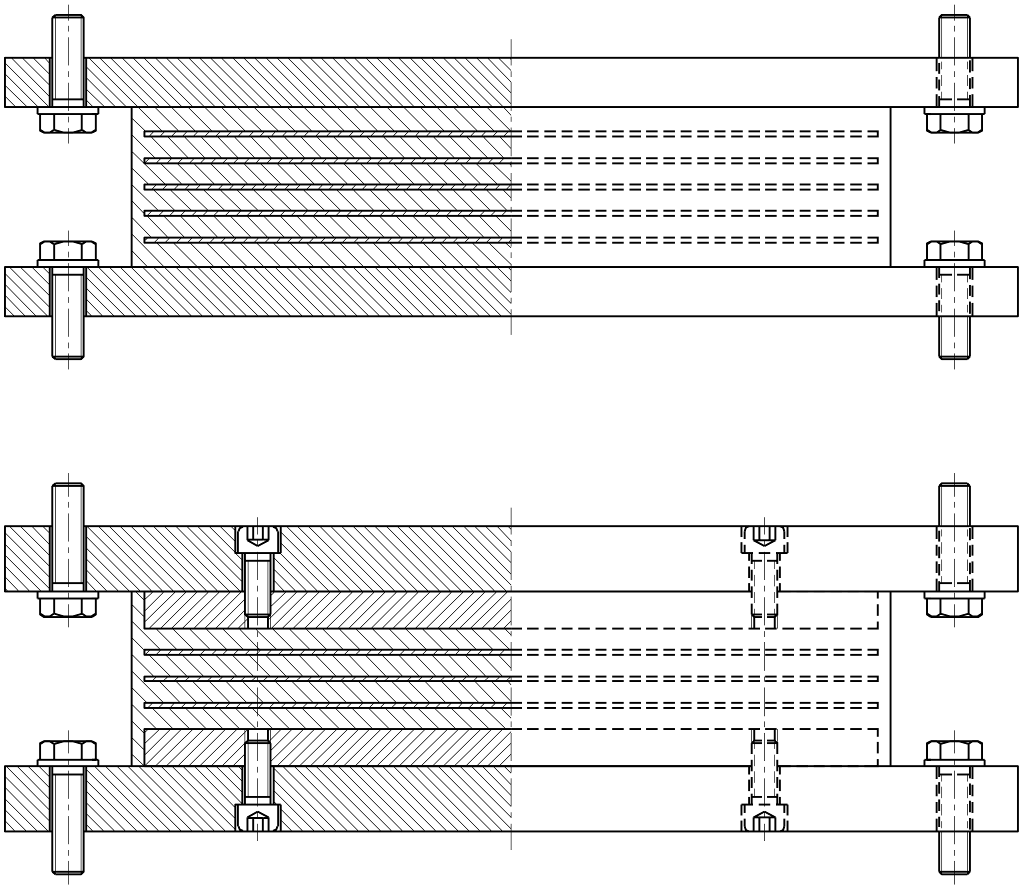


Figure 3 — Standard fixing methods

8.2.3.3 Basis of design

8.2.3.3.1 General

The quantities in the following sub-clauses shall be computed in order to verify the design.

NOTE As an aid to the design process, Annex G.3 gives a commentary to the basis of design clause. In particular, Annex G.3.3 gives expressions for calculating the stiffness of isolators.

The shear modulus at the shear strain due to the earthquake-imposed design horizontal displacement as determined in the type test (see 1) shall be used as the value of shear modulus G in 1 (see Annex G.3.3.1). The required value of shear modulus shall be obtain by interpolation if the design shear strain does not correspond to a test strain.

8.2.3.3.2 Design shear strain due to compression by vertical loads

The design local maximum shear strain due to the compressive strain $\varepsilon_{c,E}$, corresponding to the maximum vertical load , $N_{Ed,max}$, is given by:

$$\varepsilon_{c,E} = \frac{6\ S\ N_{Ed,max}}{A_r\ E'_c} \tag{15}$$

S, the shape factor of the rubber layers, is the ratio between the effective loaded area and the force free area. Thus for circular isolators with internal reinforcing plates of diameter D' and rubber layer thickness t_r :

$$S = \frac{D'}{4t_r} \tag{16}$$

Holes shall be considered in calculating the effective loaded area and the force free area, but holes that are tightly plugged shall be ignored. (See G.3.1 for other examples of formulae for the shape factor.)

A_r is the reduced effective plan area due to non-seismic actions only (e.g. thermally induced actions).

E'_c for rectangular devices, circular devices and annular devices with plugged hole is:

$$E'_c = 3G\left(1 + 2S^2\right) \tag{17}$$

The expression for E'_c for annular devices with unplugged hole is given in Annex G.3.3.4.

NOTE The formula (8.1) can be derived by linear elastic analysis of rubber layers. It is reasonably accurate (it gives an underestimate of up to 10%) for $S \leq 8$; in this context no correction for the effect of bulk compressibility is made. See Annex G.3.2 The factor 1.5 in equation (5.7) of EN 1337-3:2005 for calculation of, $\varepsilon_{c,E}$, is not supported by the analysis.

8.2.3.3.3 Design shear strain due to earthquake-imposed horizontal displacement

The design shear strain, $\varepsilon_{q,E}$, due to the earthquake-imposed design displacement d_{cd}, is given by:

$$\varepsilon_{q,E} = \frac{d_{cd}}{T_q} \tag{18}$$

where T_q is the total thickness of the elastomer active during shear.

8.2.3.3.4 Buckling load

The buckling load for devices with a shape factor, S > 5 is given by the expression:

$$P_{cr} = \frac{\lambda G A_r a' S}{T_q} \tag{19}$$

where, for rectangular devices, a' is the effective width of the device, ie the length of the smaller side of the internal reinforcing plates and λ equals 1.1. For circular devices a' is the effective diameter D' of the device, ie the diameter of the internal reinforcing plates and λ equals 1.3. For bearings with holes, plugged or unplugged, A_r shall exclude the area of the holes.

NOTE See the reference given in Annex G.3.2 for origin of equation (8.5).

8.2.3.4 Design criteria

8.2.3.4.1 Design Shear Strain

The shear strain, $\varepsilon_{q,,E}$, due to the the earthquake-imposed design horizontal displacement, d_{dc}, shall be less than 2.5, ie:

$$\varepsilon_{q,E} \leq 2{,}5 \qquad (20)$$

The requirement in EN 1337-3:2005, 5.3.3.3 shall apply to non-seismic actions.

8.2.3.4.2 Maximum Total Design Shear Strain

The requirement and definitions given here shall replace those in EN 1337-3:2005, 5.3.3 (a) except where stated otherwise.

The maximum total design shear strain $\varepsilon_{t,d}$ is given by the expression:

$$\varepsilon_{t,d} = k_L(\varepsilon_{c,E} + \varepsilon_{q,bd} + \varepsilon_{\alpha,d}) \qquad (21)$$

where $\varepsilon_{c,E}$ is given by equation 8.1,

$\varepsilon_{q,bd}$ is the shear strain corresponding to the total design horizontal displacement, d_{bd},

$\varepsilon_{\alpha,d}$ is given by EN 1337-3:2005, 5.3.3.4. A minimum rotation angle of 0.005radians shall be assumed for each orthogonal direction in calculating $\varepsilon_{\alpha,d.}$

K_L is a type loading factor, which shall be unity except for isolators used to support bridges. In that case the value shall conform with EN 1337-3:2005, Annex C.

The maximum total design shear strain as defined here shall satisfy the requirement:

$$\varepsilon_{t,d} \leq \frac{7{,}0}{\gamma_m} \qquad (22)$$

where γ_m is material safety factor for elastomers. It is recommended that the value of γ_m be taken as 1,0.

NOTE EN1998-2 introduces γ_m as NDP and recommends a value 1,15. EN1337-3:2005 recommends a value of 1,0 for the same parameter.

8.2.3.4.3 Reinforcing plate thickness

The specifications given in EN 1337-3:2005, 5.3.3.5 shall be fulfilled, but with the reduced area A_r calculated taking into account only the non-seismic displacements (i.e. due to thermal variations, shrinkage, etc.) and with K_h = 1 if there is only a central hole. For other holes, whether plugged or unplugged, K_h = 2.

8.2.3.4.4 Buckling stability

For $\frac{P_{cr}}{2} \geq N_{Ed,max} \geq \frac{P_{cr}}{4}$, the following condition shall be satisfied:

$$1 - \frac{2N_{Ed,max}}{P_{cr}} \geq 0{,}7\delta \tag{23}$$

and for $N_{Ed,max} < \frac{P_{cr}}{4}$ the following condition shall be satisfied:

$$\delta \leq 0{,}7 \tag{24}$$

where $\delta = \frac{d_{bd}}{a'}$

NOTE The parameter a' is defined in 1.

8.2.3.4.5 Roll-over stability

If recessed isolators or isolators with dowel connection are used by agreement of the Structural Engineer, instead of the standard fixing methods specified in 8.2.3.2, the roll-over stability shall be checked using equation 8.12.

$$d_{bd} \leq \frac{1}{\gamma_R} \frac{N_{Ed,min} \cdot a'}{\left(K_b T_b + N_{Ed,min}\right)} \tag{25}$$

where:

d_{bd} is the maximum total horizontal displacement of the isolator (in the direction of dimension a' of isolator, if rectangular) ;

$N_{Ed,min}$ is the minimum vertical force at the design seismic situation;

K_b is the horizontal shear stiffness measured at the largest test shear strain;

T_b is the total height of the device;

and γ_R is a partial factor, the recommended value of which is 1,5.

NOTE The parameter a' is defined in 1.

8.2.3.5 Design of connections

The connections between the isolator and the bearing plate fixed to the structure shall be designed to withstand a force equal to $\gamma_{Rd}\,F_{UB}$, where F_{UB} corresponds to the force at γ_b $(d_{Ed})_{UB}$; $(d_{Ed})_{UB}$ is the maximum displacement calculated using the upper values of the device design properties (see). γ_{Rd} is an overstrength factor for elastomeric isolators.

NOTE The value ascribed to γ_{Rd} for use in a country may be defined in its National Annex. The recommended value of γ_{Rd} is 1,1.

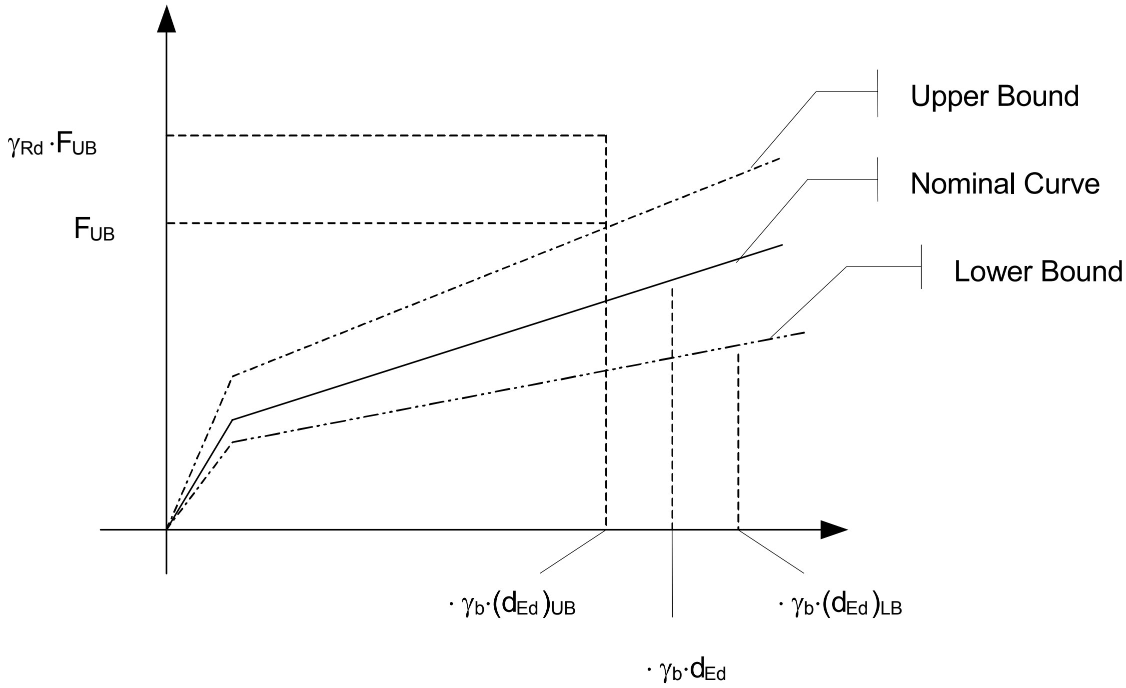


Figure 4 — Schematic diagram indicating determination of F_{UB} for elastomeric isolators

8.2.4 Testing

8.2.4.1 Isolators

8.2.4.1.1 General

The tests in this clause shall be carried out on the elastomeric isolator to demonstrate the satisfaction of the requirements specified in 1.

The test isolators shall be conditioned at the test temperature for at least 24h. Test isolators with a total rubber thickness > 250 mm shall be tested at least 48 h after the completion of moulding. The tests shall be performed on isolators not subjected to any scragging, unless they are to be supplied after scragging. In that case the test isolators shall be subjected to the same scragging procedure as the production isolators. Evidence shall be provided that the change in characteristic values produced by the scragging is permanent. The test isolator shall not have been subjected to any previous tests, except that more than one of the tests in this Clause may be performed on an isolator, provided the order of the tests conforms to 1.

The tests shall be performed at a temperature of $(23\pm5)^{o}C$, unless some other temperature is specified in the following subsections.

Each test report shall include the statement that the test was carried according to this standard.

8.2.4.1.2 Type testing

The type tests listed in shall be performed on the minimum number of samples specified in 1, according to the methods specified in 1. For low damping bridge isolators subjected to small seismic actions, only the tests marked with * in are required as type tests by this European standard; the type tests in EN 1337-3:2005 shall be performed for such isolators.

For those tests required to be performed on an isolator, it shall be full-scale, except the tests on LRB and PPRB to determine the influence of frequency, temperature and repeated cycling on the horizontal characteristics may use isolators scaled according to the following rules:

- isolators of plan dimension ≤ 500mm to be tested full-scale
- for larger isolators, linear dimensions may be reduced by factor up to maximum of 2. All dimensions to be scaled by same factor. Minimum allowed plan dimension for bearing after scaling is 500mm.

The following modifications to an isolator shall require a new set of type tests:

different elastomer compound

a) variation of the shape factor of the elastomer layers of more than 10% with respect to that of a device already tested

b) increase of any external dimension of the isolator or of the plan dimension of the internal reinforcing plates of more than 10%

c) decrease of any external dimension of the isolator or of the plan dimension of the internal reinforcing plates of more than 50%

d) a different type of attachment system is used

e) different moulding conditions are used

NOTE In e) the term ‘different types of attachment system’ refers to bolted, recess or dowelled.

Any smaller differences in the design of the isolator shall require the following type tests to be carried out to provide reference values for the acceptance tests:

a) compression stiffness (1)

b) horizontal stiffness and damping at the two rubber shear strains given in 1 that bracket the design rubber shear strain, $\varepsilon_{q,E}$.

An extension of the ranges of use of a particular isolator type beyond those covered by previous type tests shall require additional type tests to be performed. Extensions of use shall include the following:

a) increase of $\varepsilon_{q,E}$ sufficient to necessitate additional cyclic tests according to

b) increase of upper service temperature by more than 5°C

c) decrease of lower service temperature by more than 3°C

d) increase of design gravity load, N_d, by more than 30%

e) increase of $\gamma_b d_{Ed}$, by more than 5%

f) increase of maximum vertical load including effect of seismic actions, $N_{Ed,max}$, by more than 10%

g) decrease of minimum vertical load including effect of seismic actions, $N_{Ed,min}$, by more than $0,1N_d$ or by amount sufficient to change $N_{Ed,min}$ from compressive to tensile.

Table 11 — Isolator testing and requirements

Test	Type test requirements	Factory production control test requirements
Capacity in compression under zero lateral displacement	Support $2N_{Ed,G}$. No defects visible. See 1.	N/A
Compression stiffness	Report value. See 1.	Within ±30% of type test value. No defects visible. See 1
Horizontal characteristics K_b and ξ_b (or K_2 and Q_d) under cyclic deformation	Report strain dependence. At design displacement, d_{cd}, values within ±20% of design value. See 1	Values within ±20% of required values. See 1
*Horizontal stiffness under a one-sided ramp loading (Required if cyclic horizontal stiffness and damping from production control test not measured at shear strain amplitude close to value corresponding to, d_{cd})	Report value at design displacement, d_{cd}. See 1	Within ±20% of adjusted type test value. See 1
Variation of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) with frequency	Report variation. Maximum variation ±20%. See 1	N/A
*Variation of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) with temperature	Report variation. Maximum variation within limits set in 1	N/A
Dependence of horizontal characteristics K_b and ξ_b (or K_2 and Q_d) on repeated cycling	Dependence within limits specified in 1	N/A
*Lateral capacity under maximum and minimum vertical loads, and	Force-displacement curve increasing up to $\gamma_b d_{Ed}$. No defects. See 1.	N/A
Change of horizontal characteristics K_b and ξ_b of the isolator (or K_2 only for LRB manufactured using low damping elastomer) due to ageing	Change ≤ 20%	N/A
Creep test under vertical load[a]	Total Creep rate < 20% per decade. See 1.	N/A
a Optional test	*For low damping bridge isolators subjected to small seismic actions, only the tests marked with * shall apply. See 1 for requirements.	

8.2.4.1.3 Factory production control testing

The factory production control tests listed in shall be carried out by the manufacturer with the sampling frequency specified in 1, according to the methods specified in 1.

The one-sided ramp test of horizontal stiffness shall only be used with the approval of the Structural Engineer and in the absence of suitable test equipment at a reasonable location. In order to obtain the required value of the secant stiffness under ramp loading, the value measured in the type test shall be multiplied by the ratio between the design value of the cyclic stiffness, K_b, and the value of K_b determined at the design shear strain from the type tests.

For low damping bridge isolators subjected to small seismic actions, only the factory production control tests in EN 1337-3:2005 need be performed. The test methods and sampling frequency shall be governed by EN 1337-3:2005.

8.2.4.1.4 Sampling frequency

Each type test shall be carried out at least twice, using a different test isolator in each case. If the double shear test arrangement is used for a type test, only one pair of isolators need be tested.

A test isolator may be subjected to several different type tests provided they are performed in the following order:

a) compression stiffness (1)

dependence of horizontal characteristics on horizontal displacement (1), frequency (1) and temperature(1)

b) effect of creep (1)

c) capacity in compression under zero lateral displacement (1)

and provided the isolator meets the requirement of the preceding test

d) lateral capacity (1)

There shall be a summary test report stating the order of the tests on the isolator and the dates and times of each test.

For each type of isolator, the factory production control compression test and compression and shear test (see) shall be carried out on the first production isolator. Subsequently, at least 20% of the production isolators of each type shall be subjected to both factory production control tests. For projects involving a structure supported by four or fewer isolators, all the production isolators for that structure shall be tested unless otherwise agreed by the Structural Engineer.

8.2.4.1.5 Testing methods and equipment

8.2.4.1.5.1 Compression tests

The equipment shall conform to EN 1337-3:2005, Annex H.4.

The compression stiffness shall be evaluated according to EN 1337-3:2005, Annex H.7.4, using to the procedure in EN1337-3:2005, Annex H.6.2.2 (here the maximum compressive load in the test shall be taken as $N_{Ed,G}$) except that the load shall be applied at a constant displacement rate, and the load and displacement shall be continuously recorded.

The test reports on the compression stiffness test and the test of capacity in compression under zero lateral displacement shall conform to EN 1337-3:2005,Annex H.8 items 1) to 5); they shall also include the vertical displacement rate and the result of the visual inspection.

8.2.4.1.5.2 Combined compression and shear tests of horizontal characteristics

The equipment should allow only one isolator to be tested at a time. The double-shear configuration may be used. The requirements for the testing-machine are given in Annex H.

The cyclic shear displacement should be applied at a frequency 0,5 Hz or the isolation frequency. A lower frequency may be used with the agreement of the Structural Engineer. The test frequency shall be at least 0.01Hz. The input waveform shall be sinusoidal or triangular.

The isolator shall be subjected to a compressive stress of 6MPa.

When isolators are tested at non-ambient temperature without using a temperature controlled enclosure, they shall be lagged with a system capable of maintaining the temperature at the required value. The isolator shall be maintained at the test temperature for sufficient time to ensure the interior has reached that temperature.

NOTE For a large isolator it may take several hours for the interior to reach the test temperature.

The stiffness, K_b, and damping, ξ_b, or second branch (or post-yield) stiffness, K_2, and characteristic strength, Q_d, shall be calculated using the expressions in Annex.H.5.

The test report shall conform with EN 1337-3:2005, Annex H.8, items 1) to 3), and shall also include:

4) configuration of test - single or double shear, location and type of load-cells and displacement transducers, and confirmation (for example regarding any effect of friction on a load-cell reading) that the equipment requirements are satisfied
5) applied compressive load and whether test conducted under constant compressive load or constant compressive displacement
6) test temperature (s)
7) test frequency (ies)
8) list of test shear strain amplitudes in order of test
9) K_b and ξ_b (or K_2 and Q_d) for 3rd cycle at each shear strain amplitude
10) copy of each 3rd cycle shear force-displacement loop and records of variation of compressive load and displacement with time during that cycle
11) date and duration of test

If a test of horizontal stiffness under a ramp loading is carried out, the two test equipment requirements in **Errore. L'origine riferimento non è stata trovata.** relating to the effect of hysteresis in the compressive load train need not apply. The test report items 7) to 11) shall be replaced by:

7) rate of loading

8) secant stiffness at design displacement

9) record of force-displacement curve

10) date and duration of test

8.2.4.1.5.3 Lateral capacity

The equipment should allow only one isolator to be tested at a time. The double-shear configuration may be used; in this case the two isolators under test shall be within 15% of each other in compression stiffness. The requirements for the testing-machine are given in Annex H. The two test equipment requirements in Annex H.3 relating to the effect of hysteresis in the compressive load train need not apply. The test shall be performed under constant compressive load; fixed compressive displacement shall not be used. The maximum applied shear displacement shall be held for at least 2 min during which period checks for visual signs of failure shall be carried out (with due regard to safety precautions). The checks shall also be made after removing the shear displacement, but while the compressive load is maintained.

The test report shall include items 1) to 6) given in 1 and also:

6) compressive load applied

7) shear displacement rate

8) shear force –displacement loading curve

9) results of visual inspection

10) date and duration of test

8.2.4.1.5.4 Creep test

The equipment shall be capable of maintaining the required load constant to within 5% throughout the test.

NOTE Equipment applying a dead load to the test isolator either directly or through an hydraulic arrangement is most suitable.

The creep test shall be carried out on a single isolator subjected to the design vertical static load, N_d , which shall be applied within 2 min. The vertical deflection shall be monitored between 10 min and 10^4 min.

The report on the creep test shall conform with EN 1337-3:2005, Annex H.8 items 1) to 5); the test report shall also include the value of the percentage creep between 10 min and 10^4 min with respect to the deformation after 10 min, the time – deformation diagram on logarithmic axes and a record of any visual changes.

8.2.4.2 Elastomers

8.2.4.2.1 General

The tests in this clause shall be carried out on the elastomer used to fabricate the laminated part of the isolator to demonstrate the satisfaction of the requirements materials in 1. The test pieces shall not have been subjected to any scragging, except in the case that the isolators are supplied after scragging. In that case all shear test pieces shall be subjected to the scragging procedure used for the production isolators.

8.2.4.2.2 Type testing

The type tests listed in shall be performed according to the methods and procedures specified in 1.

For low damping elastomers, the tests specified in and for high damping elastomers, the tests specified in shall be performed as type tests according to the method given in the standard specified in the relevant table; the requirement specified in the table for each test shall be met. The tests shall be carried out at least once.

For low damping elastomers for bridge isolators subjected to small seismic inputs (see 1) the tests in EN1337-3:2005 Table 1 shall be performed according to the sampling frequency and test piece requirements of EN1337-3:2005 Table 8. They are not otherwise subject to the testing requirements of this European standard.

Table 12 — Type testing of Elastomer

Test	Requirement reference
Variation of shear modulus and damping with:	
Strain amplitude	1
Frequency	1
Temperature	1
Ageing	1
Repeated cycling	1
Shear bond test:	
Unaged	1
Aged	1
Low temperature crystallisation	1
Slow crack growth	1

8.2.4.2.3 Factory production control tests

For low damping elastomers, the tests specified in and for high damping elastomers, the tests specified in shall be performed as factory production control tests at the sampling frequency specified in 1 according to the method given in the standard specified in the relevant table; the requirement specified in the table for each test shall be met.

For low damping elastomers for bridge isolators subjected to small seismic inputs (see 1) the tests in EN1337-3:2005 Table 1 shall be performed according to the sampling frequency and test piece requirements of EN1337-3:2005 Table 8.

8.2.4.2.4 Sampling frequency

The factory production control tests, with the exception of the tear test, shall be performed on each batch of compound. The tear test shall be performed on the first batch of compound and subsequently, sampling randomly, at least once for every five batches of compound.

NOTE A batch of compound is an individual mix or blend of mixes of the same composition.

8.2.4.2.5 Testing methods and equipment

8.2.4.2.5.1 General

The tests shall be performed either on samples moulded at the same temperature as the bulk of the device and for a comparable time, or on samples taken from a complete finished device (the device need not be fully bonded to aid fabrication of the test pieces). In the latter case, samples both from the top or bottom internal rubber layer and from the middle of the device shall be tested, except that for the ozone resistance test the samples shall be from the side cover layer.

The tests shall be performed at (23±2)°C, unless otherwise stated.

When performing tests at non-ambient temperature, precautions shall be taken to ensure that the whole rubber test piece is at the required temperature, ±1°C. The temperature of the test piece shall be recorded.

NOTE For rubber test pieces bonded to metal plates, a time (in minutes) numerically at least equal to the square of the rubber thickness (in mm) is recommended to ensure the whole rubber test piece reaches factory production control the test temperature.

The tests to satisfy the general property requirements given in 1 shall be carried out according to the standard specified in in the case of low damping rubber and that specified in in the case of high damping rubber.

The test report shall state whether moulded samples or samples taken from a complete finished device were used; for the latter the results for the samples from both an outer internal rubber layer and from the middle of the device shall be reported. The report shall state that the test is conducted according to the requirements of this standard.

8.2.4.2.5.2 Dynamic shear modulus and damping

The test pieces shall conform with ISO 4664 except that the quadruple shear arrangement, and rectangular rubber elements may be used. The dimension of the rectangular rubber elements in the direction of shear shall be at least four times the thickness.

The test machine should be capable of recording the force and displacement for a particular cycle. The test frequency, except where the test requires a range of frequencies, shall be 0,5Hz unless agreed otherwise by the structural engineer Four complete sinusoidal cycles shall be applied for each amplitude, except that 11 cycles shall be applied in the test to assess stability of properties under repeated cycling. Except for that test, the shear modulus and damping values shall be evaluated for the third deformation cycle. The test piece stiffness and damping shall be calculated using the expressions in Annex H.5. The shear modulus, G, of the rubber shall be determined from the observed stiffness, k_h, for one rubber element and its area and thickness:

$$G = k_h \text{ X (thickness/area)} \tag{26}$$

The test report shall state:

1) type of testpiece geometry used, curing conditions, and whether specially moulded or cut from device

2) details of testing-machine, load cell and displacement transducer

3) test temperature(s)

4) strain amplitude(s)

5) values of shear modulus and damping for third cycle

In the test to assess stability of shear properties under repeated cycling the report shall replace item 5) by values of shear modulus and damping for second to tenth cycles and shear modulus for first cycle, and include additional items:

6) ratio between the minimum and maximum values of G measured in the cycles between the second and the tenth

7) ratio between the minimum and maximum values of ξ measured in the cycles between the second and the tenth

8) ratio between the minimum and maximum values of G measured in the cycles between the first and the tenth

8.2.4.2.5.3 Shear bond test

The test report shall include:

1) type and geometry of test pieces, curing conditions, and whether specially moulded or cut from device
2) rate of deformation
3) force-displacement curve
4) report of visual inspection
5) ageing conditions
6) the results from all test pieces.

8.2.4.2.5.4 Resistance to low temperature crystallisation

Immediately prior to testing, the test piece shall be conditioned at 70°C for 45 min followed by 3 h at 23°C. The force-displacement relation shall first be recorded at 23°C up to a shear strain of 100%, using a ramp loading at a rate not below 100%/min.

A shear strain of 40% shall be applied during the exposure to low temperatures; the time and temperature of exposure shall be set by the Structural Engineer according to the service conditions, except that the test temperature for natural rubber shall not be below -25°C and for polychloroprene not below -10°C. The time of exposure shall relate to the period over which the minimum daily service temperature may be at or below the test temperature.

NOTE The temperatures specified in the preceding paragraph are those at which the rate of crystallization is highest. Annex G.2 gives background information about low temperature crystallisation and recommendations on the test duration.

At the end of the required exposure period, the force-displacement relation shall be recorded up to a shear strain of 100%, using the same ramp loading rate as for the initial test, at the same temperature as that specified for the exposure. . Any transfer of the test piece to equipment different from that used during the exposure to the low temperature shall ensure that the test piece temperature during the transfer does not rise by more than 2°C. The shear stiffness of the test piece shall be measured.

The test report shall include:

1) details of the test equipment
2) test piece geometry, curing conditions, and whether specially moulded or cut from device
3) rate of loading and shear displacement
4) low temperature and time of exposure
5) secant shear stiffness at 23°C, and at low test temperature at end of exposure period

8.2.4.2.5.5 Resistance to slow crack growth

Test report shall include:

1) testpiece geometry, curing conditions, and whether specially moulded or cut from device

2) load applied

3) crack extension under load within 24h

8.2.4.3 Polymer plug

The tests in this clause shall be carried out on the plug material used to provide damping in PPRB to demonstrate the satisfaction of the requirements in 1.

8.2.4.3.1 Type testing

The type tests, with the exception of the shear bond tests and crack growth test, listed in shall be performed according to the methods and procedures specified in 1.

8.2.4.3.2 Factory production control tests

Measurement of the shear modulus and damping at a shear strain amplitude corresponding to the design displacement, d_{cd}, shall be performed on each batch of material. The test methods and procedures shall conform to those used in the type test. The requirement shall be that the

shear modulus and damping values shall be within ±15% of the corresponding value from the type test.

8.2.5 Manufacturing Tolerances

The tolerances shall conform with those given in EN 1337-3:2005, Clause 6 except where indicated otherwise in this sub-clause.

For isolators located in a recess the tolerance of the plan dimensions shall be +0,-2mm.

For isolators connected to a flange plate or to the structure by means of bolts, the tolerance on the position of the holes shall be ±0,2% unless an alternative figure is agreed with the structural engineer.

8.2.6 Marking and Labelling

Isolators shall conform to the marking and labelling requirements (except that related to very low temperature performance) given EN 1337-3:2005, 7.3.

8.3 Curved Surface Sliders

8.3.1 Requirements

8.3.1.1 General

This sub-clause applies to seismic isolators that provide the four main functions (see 3.1.26) through an appropriate arrangement of curved sliding surfaces and use the characteristics of a pendulum to lengthen the natural period of the isolated structure.

This sub-clause also applies to the Double Concave Curved Surface Slider that comprises two facing primary sliding surfaces with the same radius of curvature, both contributing to the accommodation of horizontal displacement.

NOTE: A Curved Surface Slider is characterised by a marked non-linear behaviour; thus it induces significant non-linearity and energy dissipation into the dynamic characteristics of a structural system, features which should be appropriately taken into account in the modelling of the structure (see 4.2.3 of this European Standard and 10.9.7(5) of EN 1998-1)

Curved Surface Sliders shall fulfil the performance requirements given in 1. The materials used in the manufacture shall conform to the requirements of 1.

Except where indicated in this sub-clause, Curved Surface Sliders shall conform to the general, functional and performance requirements given in EN 1337-2:2004 and EN 1337-7:2004 or equivalent European Technical Approvals for structural bearings.

The load bearing capacity, as well as deformation and damping characteristics used in the design and seismic analysis of the isolation system shall be verified by testing in accordance with 1.

The fundamental properties of Curved Surface Sliders shall be evaluated and its seismic performance verified by the initial type test programme given in section 1 prior to its use. This type tests shall be performed separately on a minimum of two (2) full-size specimens of each type equal to that used in the design.

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 ± 20%

— temperature and ageing changes reported at T_u and T_L (see 1)

In combining the two a factor of 0,7 shall be used.

The ratio between the upper and lower bound design property values shall be less than 1.8.

8.3.1.2 Performance requirements for Curved Surface Sliders

8.3.1.2.1 General

The performance requirements define quantifiable characteristics that shall be determined for curved surface sliders by type tests. Any required limiting values are indicated. Those tests that shall be also used as factory production control tests are listed in 1.

When the task of the Curved Surface Sliders is that of only guaranteeing three functions, i.e. vertical loads transmission, lateral flexibility and restoring force, and not the dissipation of energy, materials, design requirements and testing procedures shall be fully in accordance with EN 1337-2:2004 or equivalent ETA's for structural bearings. In this case the sliding isolation tests of other than test run S and P1 shall not be carried out.

8.3.1.2.2 Load bearing capacity

Curved Surface Sliders shall be capable of supporting a vertical load in its laterally undeformed state equal to $2N_{Ed,G}$, where $N_{Ed,G}$ is the dead load plus combination of non-seismic live load(s) according to EN1990 Annex A1(for buildings) or A2 (for bridges)

The device shall not show any damage and the liner of both primary and secondary sliding surfaces shall not show any sign of progressive flow or deterioration due to inadequate mechanical resistance, bonding and/or confinement in tests in accordance with 1.

The load bearing capacity of the Sliding Pendulum isolator shall remain unaltered after the tests specified in1.

NOTE The liner of the primary sliding surface acts as conventional bearing material under service conditions and thus it is essential to verify the stability of its mechanical properties after a major earthquake.

8.3.1.2.3 Horizontal displacement capacity

The Isolators shall be capable of accommodating a horizontal displacement equal to $\gamma_b \cdot d_{E,d}$.

NOTE The value ascribed to γ_b for the use of curved surface sliders in a country may be defined in its National Annex. The recommended value of γ_b is 1,0.

The isolators shall not include any mechanical elements that serve as end-stroke devices, such as containment rings, so as to avoid the eventuality of any impact between rigid mechanical elements causing damage to the same in the event displacements larger than γ_b d_{Ed} take place.

8.3.1.2.4 Maximum frictional resistance to service movements

NOTE 1 Static friction resistance is the maximum force to produce macroscopic motion occurring during the first movement (see 3.2.3 of EN 1337-2: 2000) and is considered in the design of the isolator, its anchoring system and the adjacent structural members.

During the movements developed under service conditions, the Isolators shall develop a frictional force lesser or equal than the value specified by the Structural Engineer.

Friction shall not be used to relieve the effects of externally applied horizontal loads other than earthquake induced (see also 6.7 of EN 1337-2:2000).

NOTE 2 The isolators may incorporate restraint devices that eliminate wind or other external loads induced motions in one or all directions and that release the device for full motion in case of earthquake (see section 5.2 Fuse Restraints).

Benchmark values of the frictional resistance force are to be proven through tests in accordance with 1. The measured breakaway frictional force developed by the isolator shall be lesser than the admissible value specified by the Structural Engineer.

A liner specimen shall be subjected to a long-term friction test in accordance with 1. The total slide path s_t shall be declared by the manufacturer and shall not be less than 10.000m for bridges and 1.000m for buildings or equivalent type of structures thereof.

8.3.1.2.5 Isolation characteristics

NOTE 1 Dynamic friction is the mechanism through which energy dissipation is produced by the Sliding Pendulum isolator. Therefore, this parameter is of vital importance in determining the response of the seismic isolation system.

Tests in accordance with 1 shall be carried out.

Test 0 thereof shall be requested only if the austenitic steel overlay is manufactured with seams. Three cycles shall be completed as specified in in a direction of motion perpendicular to the seams.

The force-deflection plots for all tests specified in shall have a positive incremental lateral stiffness.

The austenitic steel mating spherical sheet shall not show evident signs of buckling, permanent deformation or dislocation.

The following acceptance criteria for tests specified in shall be considered:

Test S – Service Conditions:

The maximum recorded horizontal force shall not exceed the value specified by the Structural Engineer.

Tests D1, D2, D3 – Dynamic Conditions :

1) There is no more than +/- 10% change in the restoring stiffness between successive cycles.
2) For each cycle, the restoring stiffness of the upper portion of the cycle is within 5% of the value obtained for the lower portion.
3) The average of the restoring stiffness for the three cycles is within +/- 15% of the design value, as specified by the Structural Engineer.
4) The maximum lateral force for each of the three cycles is within +/- 15% of the design value, as specified by the Structural Engineer.
5) The energy dissipated per cycle (EDC) for each cycle is no less than 85% of the design EDC, adjusted for maximum target displacements.
6) The restoring stiffness of each cycle and the average restoring stiffness of one specimen is within +/- 15% of the same stiffness of the other specimen.

Test O – Integrity of overlay:

The same acceptance criteria indicated for Dynamic Conditions tests shall apply. The test specimen shall be free of cracks and any sign of damage.

Test E – Seismic Condition:

The same acceptance criteria indicated for Dynamic Conditions tests shall apply.

Test B – Bi-directional:

No sign of buckling, permanent deformation or dislocation of the austenitic steel surface shall appear.

Test P1 – Benchmark for factory production control test

Test P2 – Property Verification:

The same acceptance criteria indicated for Service Conditions tests shall apply.

Under all loading conditions, the movement in the sliding surfaces shall be smooth and without producing any type of vibrations such as those induced by the stick-slip phenomenon.

The force oscillation shall be contained inside a variation range of +/- 5% of the average restoring force, at any level of bearing displacement. The average restoring force shall be obtained from the best-fit straight line determined by the least square interpolation of the response between +/- 95% of the peak displacement.

NOTE 2 The magnitude of the force fluctuation due to stick-slip will depend on the compliance of the testing-machine and connections to the device

The coefficient of friction and all the related performance parameters must fall within the limits specified by the Structural Engineer under the testing conditions specified in 1 hereinafter.

The temperature and ageing dependent upper and lower bound design values referred to in 4.4.2 shall be based on the results of the long term friction tests as per 1. It shall be assumed, that the ratio between this values is equal to the ratio between the dynamic friction values $\mu_{dyn,max}$ and $\mu_{dyn,min}$ at the end of phase B taking into account the upper and lower bound service temperatures, T_U and T_L respectively, determined on the basis of frequently occurring values as defined in EN1990 1.5.1.3.17(see 4.4.2).

NOTE 3 Ageing in this context is understood as the long term friction behaviour altered by the accumulated slide path under service condition.

8.3.1.2.6 Wear resistance

NOTE 1: The sliding elements are the critical components of the Sliding Pendulum isolator and their survivability after a major earthquake serves to avoid the need for immediate maintenance interventions or, worse yet, a rehabilitation intervention.

NOTE 2: The objective of this verification is that of showing the isolator’s capacity to survive protracted actions during its service lifespan, as well at the occurrence of a seismic attack.

NOTE 3: The creep deformation is significant and therefore its effect is deducted from the observed thickness reduction to correctly evaluate the wear. In the absence of more precise measurements the settlement of the sliding material after 48 hours of constant loading without sliding movement can be considered as creep deformation.

The wear of the sliding surfaces during their useful service life and at the occurrence of a design-level earthquake, shall be so limited as to ensure an adequate safety margin for the correct functioning of the isolator in accordance with the tests per 1 and 1 and the following acceptance criteria:

a) the reduction in thickness of the bearing liner, measured as the difference between the liner thickness at each of the eight (8) symmetrically placed locations prior to and following the prototype bearing testing, shall not exceed 20% of the initial thickness
b) the depth of any scratch produced by scoring of the austenitic steel surface shall be lesser than 0,05 mm

c) the deformation of the backing plates shall be such that the maximum deviation Δz from theoretical curved surface within the area of the mating sliding sheet shall not exceed 0,0003 $\times$ L or 0,2 mm, whichever is greater

8.3.2 Materials

8.3.2.1 Liner

Only materials suitable for curved surfaces of structural sliding bearings as per EN 1337-2:2004 or equivalent ETA's shall be used.

NOTE: For primary sliding surfaces, undimpled sheets without lubrication may be used.

8.3.2.2 Mating surfaces

Austenitic steel in accordance with EN 10088-2 1.4401 + 2B or 1.4404 +2B or backing plates with at least 100 µm hard chromium plating acc. ISO 6158 shall be used as mating surface. The thickness of austenitic steel sheets shall be at least 2,5 mm.

The surface characteristics of the primary sliding surface shall be defined by the manufacturer and considered in the sliding behaviour tests as per 1and1.

The surface characteristics of the secondary sliding surface shall be in accordance with clause 5.4 and 5.5 of EN 1337-2:2004.

8.3.2.3 Lubricants

If the sliding surface is lubricated, the lubricant shall be in accordance with clause 5.8 of EN 1337-2:2004.

8.3.2.4 Backing plates

Steel plates in accordance with EN 10025 or EN 10137-1, cast iron in accordance with ISO 1083, cast carbon steel in accordance with ISO 3755 or stainless steel in accordance with EN 10088 shall be used for the backing plates, as appropriate.

The substrate for hard chromium plated sliding surfaces shall be steel in accordance with EN 10025 grade S 355 J2G3 or fine grain steel of the same or higher grade in accordance with EN 10113-1.

8.3.3 Design

8.3.3.1 Load bearing capacity

The load bearing capacity shall be verified in accordance with 6.2.1 and 6.2.3 of EN 1337–7 : 2004.

NOTE 1: For spherical sliding surfaces with an included angle $2\ \theta \leq 60°$, the method of stress verification shall be in accordance with the method given in EN 1337-7:2004. For spherical sliding surfaces with an included angle $2\ \theta > 60°$, compressive stress verification shall be conducted using appropriate calculation methods, such as Finite Elements Modelling.

NOTE 2: A valid simplified method for calculating stress distribution in spherical bearing surfaces within the linear-elastic range is shown in Annex L.

8.3.3.2 Horizontal displacement capacity

The mating surface dimensions of the primary sliding surface shall be so proportioned that in all conditions they completely cover the primary bearing liner.

8.3.3.3 Rotation capacity

The mating surface dimensions of the secondary sliding surface shall be so proportioned that in all conditions they completely cover the secondary bearing liner.

8.3.3.4 Friction resistance

NOTE : During movements of Curved Surface Sliders, friction develops in both the primary and secondary sliding surfaces. Notwithstanding, the requirements for the two surfaces are different, inasmuch as friction in the primary sliding surface serves to dissipate energy, whilst in the secondary sliding surface friction needs to be minimized so as to ensure proper distribution of pressure in the bearing's liner materials.

8.3.3.4.1 Maximum frictional resistance force

The static coefficient of friction μ_{max} shall be used for verification of the isolator and the structure in which it is incorporated. The design value of the maximum frictional resistance force is given by the equation:

$$F_{xy,d} = \mu_{\max} N_{Ed,G} sign(\dot{d}_b) \qquad (27)$$

where:

$N_{Ed,G}$ is the normal force through the device under non-seismic design conditions

sign$(\dot{d}_b)$ is the sign of the velocity vector $(\dot{d}_b)$, and

d_b is the relative displacement of the two sliding surfaces

a) primary sliding surface

The values are obtained from long term friction tests as per 1. The design values for different pressure levels are the maximum values measured in the phases A, C and D at the end of the test at various pressures. Intermediate values shall be obtained by linear interpolation or through equation 8.13 .

For pressures below 0,08 f_k or above 0,33 f_k, where f_k is the characteristic compressive strength of the sliding material, the coefficient of friction shall be assumed equal to the threshold values.

The design temperature is the frequently occurring low temperature as defined in EN1990 1.5.1.3.17and to be specified by the Structural Engineer. In the absence of more precise values, T_L = -10 °C for bridges and 0 °C for buildings shall be used.

b) secondary sliding surface

When lubricated PTFE is used as sliding material, its friction coefficient shall comply with sub-clause 4.1 of EN 1337-2:2000. In the event other sliding materials are used, provided the same have secured a European

Technical Approval (ETA) for their use in structural devices, said friction coefficient shall comply with the values specified in said ETA.

8.3.3.4.2 Sliding Isolation

NOTE The behaviour of the isolator during a seismic attack is governed by the frictional and geometrical characteristics of the primary sliding surface. See also A.2.1 of Annex A of EN 1337-7:2004.

The maximum and minimum values of the dynamic coefficient of friction specified by the Structural Engineer shall be used for the design and verification of the isolator as well as the dynamic analysis of the structure.

8.3.3.5 Backing plates

Backing plates shall be designed and verified in accordance to sub-clause 6.9 of EN 1337-2:2004 adapting formula (6) to the used sliding material.

They shall be made out of solid elements, without lightening hollows and ribs.

8.3.3.6 Separation of sliding surfaces

NOTE 1 Separation of the sliding surfaces may lead to wear due to contamination and increased deformation of the bearing liner secondary to faulty confinement of the latter. As this could jeopardize long term fitness for use, the condition $\sigma_p = 0$ is considered as the serviceability limit state.

It shall be verified that $\sigma_p \geq 0$ under all load combinations at serviceability limit state. By doing so, the sliding material shall be assumed to be linear elastic and the backing plates deemed to be rigid.

For spherical sliding surfaces with an included angle $2\theta \leq 60°$, the condition $\sigma_p \geq 0$ is satisfied at the serviceability limit state when the total eccentricity e_t falls within the kernel of the project area.

NOTE 2 The method for calculating the eccentricities in spherical surfaces is given in Annex A of EN 1337-7:2004.

For spherical sliding surfaces with an included angle $2\theta > 60°$, the verification of the condition $\sigma_p \geq 0$ shall be conducted using suitable calculation methods, such as Finite Elements Modelling.

NOTE 3 The simplified method shown in Annex L may also be used to this purpose.

8.3.3.7 Rotation capacity

NOTE: In the Sliding Pendulum isolator, translation movements induce rotational movements in the articulated slider, which are accommodated by the Secondary Sliding Surface .

The Secondary Sliding Surface shall be capable of accommodating the rotation of the articulated slider consequent to a horizontal displacement equal to $\gamma_b \cdot d_{E,d}$. In accordance with 5.4 of EN 1337-1:2000 this design movement shall be increased by ±0,005 [rad] or ±10mm/R_2 [rad] - whichever is greater - where R_2 [mm] is the radius of curvature of the Secondary Sliding Surface. This addition only applies for the design of rotation capacity. It shall not be used to calculate stresses.

8.3.3.8 Design of connections

The connections between the slider and the plate fixed to the structure shall be designed to withstand a force equal to $\gamma_{Rd}\, F_{UB}$, where F_{UB} corresponds to the force at γ_b $(d_{Ed})_{UB}$; $(d_{Ed})_{UB}$ is the maximum displacement calculated using the upper values of the device design properties (see for an example of a slider with approximately linear characteristics). γ_{Rd} is an overstrength factor for elastomeric isolators.

NOTE The value ascribed to γ_{Rd} for use in a country may be defined in its National Annex. The recommended value of γ_{Rd} is 1,1.

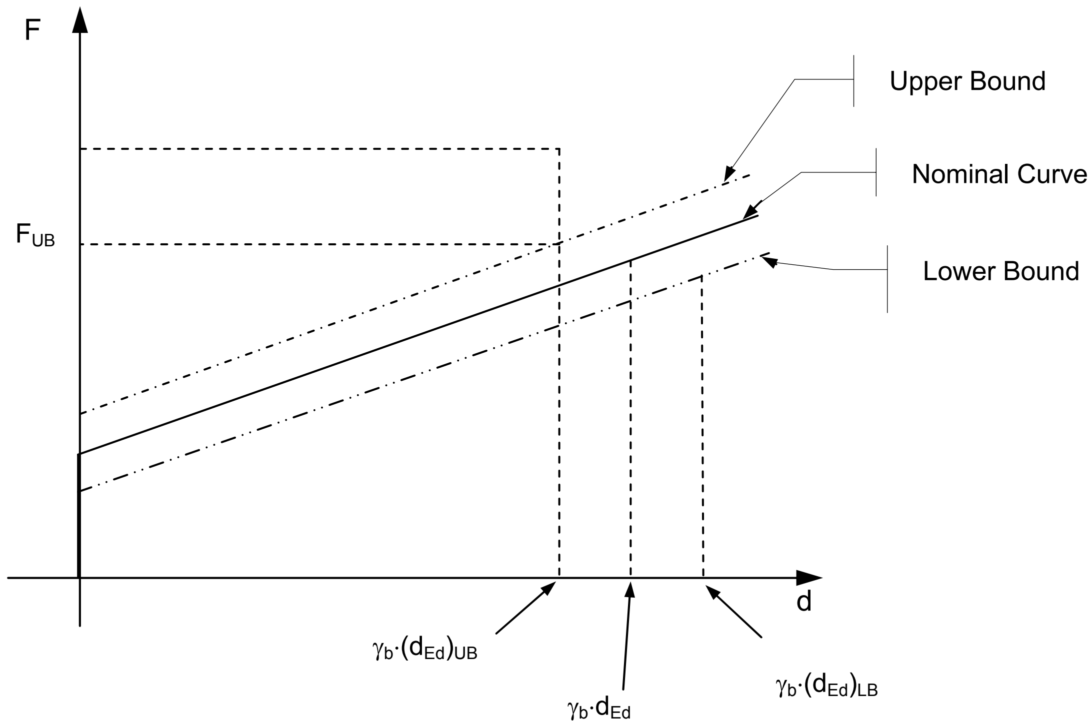


Figure 5 – Schematic diagram indicating determination of F_{UB} for sliding isolators

8.3.4 Testing

8.3.4.1 Type Testing

8.3.4.1.1 General

Tests shall be carried out on the Sliding Pendulum Isolator and samples of sliding elements to demonstrate the satisfaction of the general performance characteristics specified in 1.

NOTE 1 The test programme involves a substantial total energy input to the Sliding Pendulum isolator. 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 isolator. To hold the latter in check, the temperature at the centre of the primary bearing liner needs to be monitored and reported. It is advisable to divide the test programme into groups of tests. After performing one group, the isolator is allowed to cool to a temperature specified by the manufacturer before performing the subsequent test group.

NOTE 2 The tests listed in this clause may be performed in an order different from that presented.

The tests shall be arranged into groups in accordance with the criterion that the total energy input to the Sliding Pendulum isolator in each test group does not exceed 1,5 times the energy dissipated by the isolator during a design level earthquake.

If entrance and exit cycles are required for the correct execution of the test, the related energy input shall be taken into account.

The tests shall be performed at a temperature of 23 °C ± 5 °C, unless some other temperature is specified in 1 or by the Structural Engineer.

Experimental results obtained from tests on similar bearings (reference devices) that satisfy all the requirements of this sub-clause may be used for new devices provided:

1) design displacements of the new device is within +/- 20% of the reference design value
2) the bearing capacity of the new device is within +/- 20% of the reference design value
3) design friction coefficients are the same for new and reference device.
4) Basic materials for sliding elements are the same for new and reference device.
5) The radius of curvature of both primary and secondary curved surfaces is within ±20 % the reference design value

Prior to performing these tests, the isolator shall be subjected to a 10-minute pre-loading with an axial load equal to the non-seismic design load $N_{Ed,G}$. At the end of the pre-loading time, the thickness of the liner shall be measured at eight (8) symmetrically spaced locations in both the primary and secondary sliding elements by using a thickness gauge accurate to 0,05 mm. This set of values shall represent the benchmark values for further verifications.

NOTE 1 For safety reasons the thickness measurement may be carried out by electronic sensors or replaced by measurements on unloaded devices, if appropriate conversion rules for the loaded condition are available.

NOTE 2 If the liner is recessed in its backing plate, “liner thickness” is the protrusion of the liner sheet from its recess.

8.3.4.1.2 Load bearing capacity

NOTE: The objective of this test is to verify the overload capacity of Sliding Pendulum isolators.

The loading history of the test shall be the following: at zero displacement, apply a load equal to 2· $N_{Ed,G}$ (see 1) and maintain it constant for 1 minute. A continuous plot of the vertical force vs. displacement shall be recorded.

8.3.4.1.3 Frictional resistance force under service conditions

NOTE: The objective of these tests is to verify the maximum lateral force developed by the isolator under service conditions.

Loading history: At zero displacement, apply a vertical load equal to the non-seismic design load $N_{Ed,G}$ and keep it constant for 30 minutes, then impose a sliding velocity $v \leq 0{,}1$ mm/s for one (1) minute. A continuous plot of the horizontal force vs. displacement shall be recorded.

8.3.4.1.4 Static coefficient of friction

NOTE: This section describes the method for determining the static coefficient of friction of material samples, as well as the wear resistance of the primary curved sliding surface where no lubricant is used. The principles of verification, the terms and definitions as well as the test equipment and specimens are shown in Annex D of EN 1337-2:2004.

A long-term friction test with the programme in accordance with shall be carried out under the following conditions:

Table 13 – Long term friction test programme

Phase Number	1	2	3	4	5
Type	A	B	A	C	D
Distance	22 m	s_t	22 m	22 m	22 m

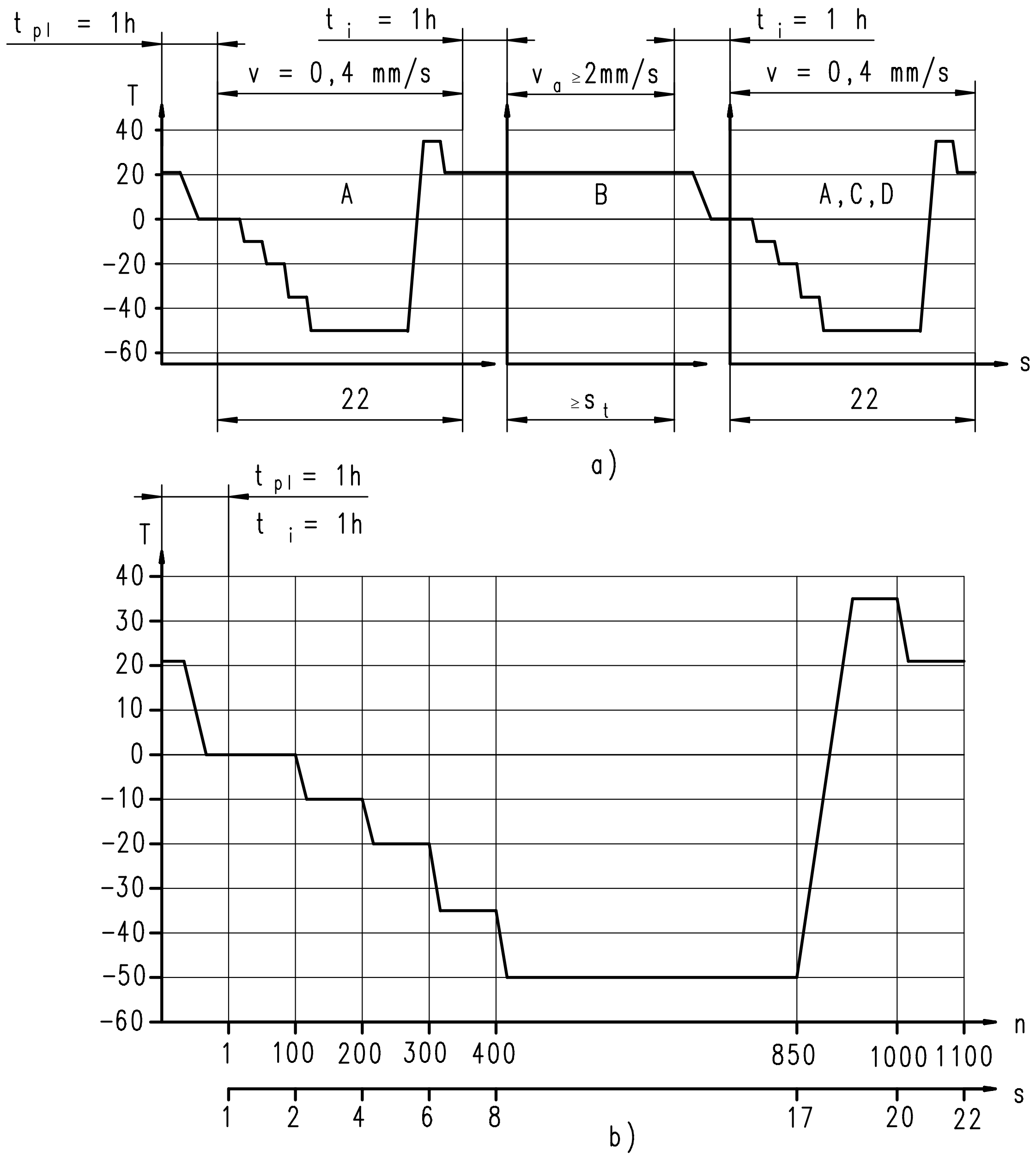
Specimen: Mating surface and liner material according to EN 1337-2:2004 or equivalent ETA

Diameter of liner specimen L = 75 mm

In the phases A, C and D the static coefficients of friction shall be measured at the different temperature levels.

Table 14 – Friction test conditions

Type A (phases 1 and 3), C (phase 4), D (phase 5) …. Temperature - Programme – Test)			
Contact Pressure of lubricated special sliding material	σ_p	Type A : $0{,}33\ f_k\ {}^{+3}_{0}$ Type C : $0{,}17\ f_k\ {}^{+3}_{0}$ Type D : $0{,}08\ f_k\ {}^{+3}_{0}$	MPa
Temperature	T	0/-10/-20/-35/-50/+35/+21 (±1)	°C
Temperature gradient		0,5 ± 1,0	°C / min
Preload time	t_{pl}	1	h
Stroke	s_A	$10\ {}^{+0{,}5}_{0}$	mm
Dwell time at the end of the strokes	t_0	12±1	s
Number of cycles (two strokes)	n	1 100	
Sliding speed	v	$0{,}4\ {}^{+0{,}1}_{0}$	mm / s
Dwell between phases	t_i	1	h
Type B (phase 2)			
Contact Pressure of lubricated special sliding material	σ_p	$0{,}33\ f_k\ {}^{+3}_{0}$	MPa
Temperature	T	21 ± 1	°C
Temperature gradient		0,5 ± 1,0	°C / min
Stroke	s_B	$8\ {}^{+0{,}5}_{0}$	mm
Number of cycles (two strokes)	n	$n = \frac{s_t}{2s_B}$	
Sliding speed	v_a	≥ 2	mm/s



Key

Figure 5 — Temperature profile of the long term sliding test

If the minimum temperature, T_{min}, for the intended use is higher than the temperature of some sections of the Temperature Program Test, during said sections the temperature shall be kept constant and equal to T_{min}.

NOTE T_{min} is the lowest likely service temperature and is not the same as T_L.

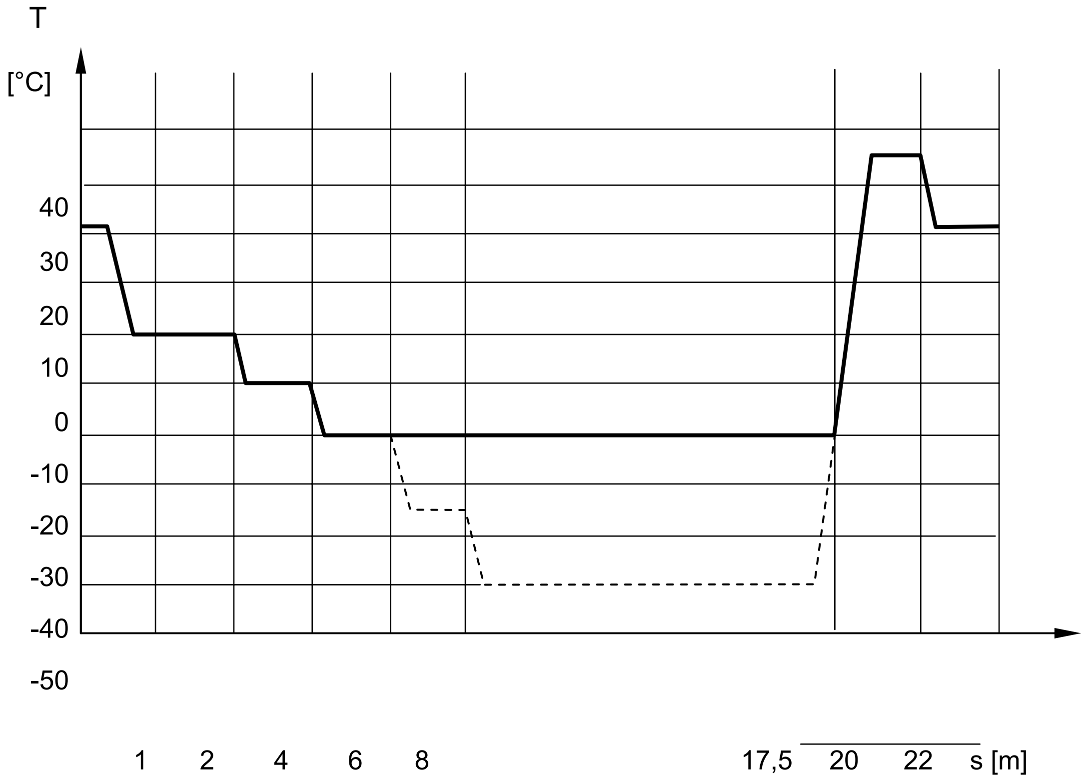


Figure 6 — Example of Temperature programme of the long term sliding test for T_{min} = –20 °C

8.3.4.1.5 Sliding isolation tests

NOTE 1: The objective of these tests is to verify the dynamic behaviour of Curved Surface Sliders in terms of frictional resistance (or coefficient of friction), the damping capacity, as well as stability under repeated cycling.

The sliding isolation tests shall be conducted in accordance with the test matrix provided in below.

NOTE 2: For the materials used in the bearing liners, the relationship between the friction coefficient μ and the pressure σ_p is given by the expression:

$$\mu = f(\sigma_p) \qquad (28)$$

As an example for thermoplastic materials the following expression

$$\mu = \frac{C}{\sqrt{\sigma_p}} \qquad (29)$$

where C is a constant may be used.

This function depends on the type of sliding material used, roughness of mating surfaces, temperature, velocity etc. The Structural Engineer should take into account the above when specifying the values for the friction coefficient under different loading conditions.

A continuous plot of the horizontal force-displacement hysteresis loop shall be recorded for each run.

The displacement input waveform shall be sinusoidal of the type $d(t) = d_{Ecd} \cdot \sin(2\pi \cdot f_o \cdot t)$.

Frequency f_o [Hz] shall be properly chosen in relation to stroke $d_{c,d}$ [mm] so as – for each type of test – the peak velocity $v_o = 2\pi \cdot f_o \cdot d_{c,d}$ [mm/s] equals the specified value $v_{E,d}$.

The dynamic coefficient of friction μ_{dyn} shall be evaluated as follows:

when measured for the first cycle:

$$\mu_{dyn,1} = \frac{A_{h,1}}{4 \cdot N_S \cdot d_X} \tag{30}$$

when computed for the 3-cycles:

$$\mu_{dyn,3} = \frac{1}{3} \cdot \sum_{i=1}^{3} \frac{A_{h,i}}{4 \cdot N_S \cdot d_X} \tag{31}$$

where:

$A_{h,i}$ is the area enclosed within the hysteresis loop in the i- cycle [kJ]

N_s is the value of vertical axial load under which the isolator is to be tested [kN]

d_x is the value of the peak horizontal displacement achieved during the test [m]

Table 11 — Test Matrix to verify the sliding isolation behaviour

Type of Test	Test run	Compression Load N_S [kN]	Displacement d_X [m]	Peak velocity v_o [mm/s]	Number of cycles
Service	S	$N_{Ed,G}$	maximum non seismic movement	5	20
Benchmark	P1	$N_{Ed,G}$	$1,0 \cdot d_{c,d}$	50	3
Dynamic 1	D1	$N_{Ed,G}$	$0,25 \cdot d_{c,d}$	v_{Ed}	3
Dynamic 2	D2		$0,5 \cdot d_{c,d}$	v_{Ed}	3
Dynamic 3	D3		$1,0 \cdot d_{c,d}$	v_{Ed}	3
Integrity of overlay	O	$N_{Ed,G}$	$1,0 \cdot d_{c,d}$	v_{Ed}	3
Seismic	E	$N_{Ed,max}$ and $N_{Ed,min}$	$d_{c,d}$	v_{Ed}	3
Bi-directional	B	$N_{Ed,G}$	$1,0 \cdot d_{c,d}$	v_{Ed}	3
Property verification	P2	$N_{Ed,G}$	$1,0 \cdot d_{c,d}$	v_{Ed}	3

Test B shall be performed with the simultaneous application of a sinusoidal displacement input waveformin two perpendicular directions.

NOTE 3: The equation to obtain a “clover leaf” path of maximum amplitude d_x is the following:

$$(x^2 + y^2)^3 = x^2 * y^2$$

If testing equipment is unable to perform test B, the test can be completed after a rotation of 90 degree of the bearing in order to involve a displacement path perpendicular to the one verified with previous tests.

Restoring stiffness shall be measured from the best-fit straight line determined by the “least-squares” method as measured from 0.95 times the cycle displacement range.

One value shall be obtained respectively for the upper and the lower portion of the force-displacement curve.

An average of the two measurements shall also be calculated.

NOTE 4: Unless otherwise specified, restoring stiffness for one cycle is intended as the average between upper and lower stiffness.

8.3.4.1.6

At the conclusion of the test programme shown in the liner thickness shall be measured in the presence of an axial force equal to the permanent load G_d by using a thickness gauge accurate to 0,05 mm at the same 8 symmetrically spaced locations used for assessing the benchmark values (see 1).

Subsequently, the isolator shall be disassembled for visual and instrumental examination.

8.3.4.2 Factory production control tests

8.3.4.2.1 Property verification test

One full-size unit per production lot shall be subjected to factory production control tests comprising the following:

a) Vertical load bearing capacity (see 1 and 1)

b) Frictional resistance force under service conditions (see 1 and1)

c) Test run P1 (see 1 and 1)

For the purpose of the factory production control tests, a production lot shall be a set of no more than 20 identical units. Curved Surface Sliders with different design movements due to non seismic inputs are considered to be identical for this purpose, if all the other design parameters are equal.

If the load bearing capacity of a unit exceeds 20% of the overall weight of the supported structure the number of production units subjected to production tests, for that set, shall be doubled.

The same requirement as indicated for type testing shall apply.

8.3.4.2.2 Material testing

The testing of raw materials and constituents shall be carried out in accordance with Table 16 of EN 1337-2:2004 or in the presence of other sliding materials the equivalent regulations in the respective ETA.

NOTE: The respective short term friction test is also valid to judge the conformity of non lubricated material in primary sliding surfaces.

8.3.5 Manufacturing, Assembly and Tolerances

NOTE This clause deals with workmanship, assembly and fitting tolerances.

8.3.5.1 Sliding elements

The liner shall be attached in accordance with EN 1337-2:2004, clause 7.1.1 or the methods specified in the equivalent ETA’s.

The maximum deviation Δz from theoretical plane or curved surface within the area of the mating sliding sheet shall not exceed $0{,}0003 \times L$ or 0,2 mm, whichever is greater. Care shall be taken to ensure that the austenitic steel sheet is fully in contact with the backing plate over the area, which will be in contact with the sliding sheet.

8.3.5.2 Lubricating

After cleaning and prior to assembly, the sliding sheet of the secondary sliding surface shall be lubricated with lubricant according to EN 1337-2:2004 in a way which ensures that all the dimples are filled.

For the primary sliding surface any contamination of the sliding material with lubricant shall be prevented.

8.3.5.3 Backing Plates

Surfaces of backing plates in contact with sliding materials or anchor and shimming plates shall be treated in such a way that the maximum deviation Δz from theoretical curved surface shall not exceed $0{,}0003 \times d$ or 0,2 mm, whichever is greater.

8.3.5.4 Assembly

All devices shall be assembled at the supplier's factory. Suitable, temporary assembly ties shall be provided, so that the entire assembly is shipped, in protective packaging, as a unit and remains intact when uncrated and installed. Packaging shall be adequate to prevent damage from impact as well as from dust and moisture contamination during shipping and storage. All devices shall be delivered ready for installation and appropriately marked with their identification codes a specified in the Specification document. The devices are marked by the designation plate and in addition on the upper surface for clear identification of the installation location and its orientation. No disassembly on side shall occur without assistance of the manufacturer.

8.3.5.5 Protection against contamination and corrosion

NOTE 1 General requirements for corrosion protection are given in EN 1337-9. This sub-clause gives additional requirements for sliding elements.

Where the austenitic steel sheet is attached by full area bonding or by continuous fillet weld, provided the area covered by the austenitic steel sheet is free from rust and rust inducing contaminants, no further treatment of the backing plate behind the austenitic steel sheet is required.

A positive means shall be provided to avoid any possible moisture contamination in case of cracking weld fillets.

The areas of the backing plate behind the liner and austenitic steel sheets attached by confinement, screwing, counterpunched screwing or riveting shall be protected by one coat of primer (dry film thickness 20 μm to 100 μm).

Provision against contamination of the sliding surface shall be made by suitable devices. Such protection devices shall be easily removable for the purpose of inspection. Since hard chromium plating is not resistant to chlorides in acid solution or to fluorides and can be damaged by air borne particles, such that occur in industrial environments, special provision shall be made to protect the surfaces in these conditions.

Prior to assembly the sliding surfaces shall be cleaned.

During assembly process, provisions shall be taken against contamination of sliding surfaces.

8.3.5.6 Reference surface for installation

In order to ensure bearing alignment in accordance with EN 1337-11 a reference surface or other suitable device shall be installed on the sliding element. The deviation from parallel of the reference surface with respect to the plane projection of the primary sliding surface shall not exceed 0,1%.

The installation of the device shall be executed in accordance with EN 1337-11.

8.4 Flat Surface Sliders

8.4.1 Requirements

The sliding elements of Flat Surface Sliders shall conform to EN 1337-2 or be covered by an ETA (European Technical Approval).

The sliding elements shall be combined with a rotating element in accordance with EN 1337-1.

NOTE 1 Flat Surface Sliders can be considered as the limit case for Surface Sliders when $R = \infty$.

When Flat Surface Sliders are used to dissipate energy, in addition to transmit vertical loads and provide lateral flexibility, their sliding elements shall conform to 8.3.1 of this European Standard.

NOTE In Curved Surface Sliders restoring force is provided by gravity due to its geometry, while sliding devices with flat sliding surface do not possess any re-centring capability.

Flat Surface Sliders shall be used in combination with appropriate devices that provide adequate restoring capability to the seismic isolation system.

8.4.2 Materials

Materials shall conform to section 8.3.2 of this European Standard.

8.4.3 Design

Design shall conform to section 8.3.3 of this European Standard.

8.4.4 Testing

Testing shall conform to section 8.3.4 of this European Standard.

8.4.5 Manufacturing, Assembly and Tolerances

Manufacturing, Assembly and Tolerances shall conform to section 8.3.5 of this European Standard.

9 Combination of Devices

9.1 Requirements

9.1.1 General

Anti-seismic devices comprising a combination of components shall meet the requirements given in Clause 4 except where indicated otherwise in this clause. The connection between the individual components shall allow all relative displacements, translations and rotations, as appropriate.

NOTE 1 Sliders are examples of combined devices. They consist of the combination of a structural bearing allowing sliding movement in one or more directions in accordance with the relevant Parts of EN 1337 and one or more anti-seismic devices in accordance with the relevant clauses of this standard. The anti-seismic devices are connected to the components of the structural bearing so that in case of earthquake the consequent relative displacement will activate them. Most frequently the structural bearings utilized for that purpose are pot bearings or spherical bearings with sliding elements conforming with EN 1337-5, EN 1337-7 and EN 1337-2 combined with rigid connection devices, linear devices, non-linear devices, viscous dampers or rubber bearings conforming with the relevant clauses of this Standard. Also a combination with more than one type of anti-seismic device is possible.

NOTE 2 For the combination of bearing and rigid connection device see clause 5.

9.1.2 Particular requirements

The combined devices shall meet the performance requirements specified by the Structural Engineer.

9.2 Materials

The materials used in the manufacture of the combined device shall meet the requirements given in the appropriate clauses of this Standard for the individual components.

9.3 Design

The individual components of the combined device shall be designed according to the rules given in the appropriate clauses of this Standard.

In determining the loads and displacements imposed on the individual components, account shall be taken of any interactive effects between the components.

The connections between the movable and fixed components of the device shall allow all relative movement foreseen amplified by a reliability factor γ_x, and shall be designed to transmit the design forces amplified by the same factor γ_x. The recommended minimum value of γ_x is 1,3.

9.4 Testing

9.4.1 General

Tests shall be carried out on the device to demonstrate that the requirements specified in clause 9.1.2 are satisfied.

The tests shall be performed at a temperature of (23±5)^{o}C, unless some other temperature is specified in the following subsections.

9.4.2 Type testing

The type testing shall be carried out prior to commencing the manufacture by an approved testing laboratory, or other facility approved by the structural engineer.

A type test of each design of device shall be performed at full-scale, unless with the agreement of the Structural Engineer this is deemed impractical. If full-scale type tests of the complete device are not performed, tests of each element at full-scale and the complete device at a scale not less than 1:4 shall be carried out. Tests on the individual components shall be in accordance with the relevant clauses of this Standard.

9.4.3 Routine testing

Routine tests shall be performed either on a complete device or on the individual components in accordance with the relevant clauses of this Standard.

10 Evaluation of conformity

10.1 General

The tests and inspections specified in this clause shall be carried out to demonstrate conformity of the construction product (anti-seismic device) with this European Standard.

The given system of evaluation of conformity is also valid for non-series production.

10.2 Control of the construction product and its manufacture

10.2.1 Factory production control

The extent and frequency of factory production control by the manufacturer and by a third party (if required) shall be conducted in accordance with Tables 12 to Table 15. In addition, it shall be checked by controlling the inspection certificates as listed in Tables 16 to 19 that the incoming raw material and components comply with this European standard.

10.2.2 Initial type testing

The extent of type-testing shall be conducted in accordance with Tables 12 to 15.

Type testing shall be performed prior to commencing manufacture. It shall be repeated if changes in the construction product or manufacturing processes occur.

Certificates containing material properties established in 5.2.3, 5.3.3, 6.1.2, 6.1.3.1, 6.2.2, 6.2.3.1, 7.3, 8.2, 8.4.2.2, 9.2 shall be individually examined during type-testing and shall be retained by the manufacturer of the anti-seismic device and by the third party (if required).

Type testing shall be supplemented with the relevant calculations from design requirement clauses of the individual type of device for the evaluation of the final performance of the anti-seismic device.

Table 16 — Rigid Connection Devices

Type of Devices		Subject of control	Control in accordance with	Frequency
Permanent Connection Devices	Type	See prEN 1337-8		
	Factory Production Control	See prEN 1337-8		
Fuse Restraints	Type	Service Load Test	5.2.4.1	1 prototype
		Fatigue Test	5.2.4.2	1 prototype
		Break-away Test	5.2.4.3	1 prototype
	Factory Production Control	Acceptance Testing	5.2.5	100%
Temporary (Dynamic) Connection Devices	Type	Low Velocity Test	5.3.4.1	1 prototype
		Seal Wear Test	5.3.4.2	1 prototype
		Impulsive Load Test	5.3.4.3	1 prototype
		Overload Test	5.3.4.4	1 prototype
		Cyclic Load Test	5.3.4.5	1 prototype
	Factory Production Control	Low Velocity Test	5.3.4.1	5%
		Impulsive Load Test	5.3.4.3	5%
		Cyclic Load Test	5.3.4.5	5%

Table 17 —Displacement Dependent Devices

Type of Devices		Subject of control	Control in accordance with	Frequency
Linear	Type	Evaluation of Force Vs Displacement Cycle	6.1.3.3 (a)	1 prototype
		Ramp Test	6.1.3.3 (b)	1 prototype
	Factory Production Control	Evaluation of Force Vs Displacement Cycle	6.1.3.3 (a)	5%
		Ramp Test	6.1.3.3 (b)	5%
Non-linear	Type	Evaluation of Force Vs Displacement Cycle	6.2.3.3 (a)	1 prototype
		Ramp Test	6.2.3.3 (b)	1 prototype
	Factory Production Control	Evaluation of Force Vs Displacement Cycle	6.2.3.3 (a)	5%
		Ramp Test	6.2.3.3 (b)	5%

Table 18 — Velocity Dependent Devices

Type of Devices		Subject of control	Control in accordance with	Frequency
Fluid Viscous Dampers	Type	Pressure Test	7.4.1.1	1 prototype
		Low Velocity Test	7.4.1.2	1 prototype
		Constitutive Law Test	7.4.1.4	1 prototype
		Damping Efficiency Test	7.4.1.6	1 prototype
		Wind Load Cyclic Test	7.4.1.7	1 prototype
		Seal Wear Test	7.4.1.8	1 prototype
		Stroke Verification Test	7.4.1.9	1 prototype
	Factory Production Control	Pressure Test	7.4.1.1	100%
		Low Velocity Test	7.4.1.2	5%
		Constitutive Law Test	7.4.1.4	5%
		Damping Efficiency Test	7.4.1.6	5%
Fluid Spring Dampers	Type	Pressure Test	7.4.1.1	1 prototype
		Low Velocity Test	7.4.1.3	1 prototype
		Constitutive Law Test	7.4.1.5	1 prototype
		Damping Efficiency Test	7.4.1.6	1 prototype
		Wind Load Cyclic Test	7.4.1.7	1 prototype
		Seal Wear Test	7.4.1.8	1 prototype
		Stroke Verification Test	7.4.1.9	1 prototype
	Factory Production Control	Pressure Test	7.4.1.1	100%
		Low Velocity Test	7.4.1.3	5%
		Constitutive Law Test	7.4.1.5	5%
		Damping Efficiency Test	7.4.1.6	5%

Table 19 — Control and testing of Elastomeric Isolators

	Subject of control	Control in accordance with	Frequency
Type	Capacity in compression under zero lateral displacement	8.4.1.5.1	Two prototypes
	Compression Stiffness	8.4.1.5.1	Two prototypes
	Horizontal stiffness and damping under cyclic deformation or horizontal stiffness under a one-sided ramp loading	8.4.1.5.2	Two (or four if tested in pairs) prototypes
	Lateral capacity under maximum and minimum vertical loads	8.4.1.5.2	Two (or four if tested in pairs) prototypes
Factory Production Control	Compression Stiffness	8.4.1.5.1	One test per 350dm^3 of elastomer used in production
	Horizontal stiffness and damping under cyclic deformation or horizontal stiffness under a one-sided ramp loading	8.4.1.5.2	One test per 1750dm^3 of elastomer used in production

10.2.3 Raw materials and constituents

Compliance with the product requirements specified in 5.2.3, 5.3.3, 6.1.2, 6.2.2, 7.3, 8.2, 9.2 shall be verified by means of inspection certificates in accordance with EN 10204 to the level stated in Tables 16 to 19.

Table 20 — Specific testing of raw materials and constituents for Rigid Connection Devices

Type of inspection certificate in accordance with EN 10204	Subject of control	Control in accordance with	Frequency
3.1.B	Ferrous materials	Certifications based on existing standards	Every batch
	Viscous Fluid	Certifications based on existing standards	
	Plating	Certifications based on existing standards	
	Other materials	Certifications based on existing standards	

Table 21 — Specific testing of raw materials and constituents for Displacement Dependent Devices

Type of inspection certificate in accordance with EN 10204	Subject of control	Control in accordance with	Frequency
3.1.B	Rubber	ISO 6446 Table 3 Test as per 8.2.2 performed according to 8.4.2	Every batch
	Ferrous materials	Certifications based on existing standards	
	Shape Memory Alloys	Test as per 6.2.3.2.4	
	Other materials	Certifications based on existing standards	

Table 22 — Specific testing of raw materials and constituents for Velocity Dependent Devices

Type of inspection certificate in accordance with EN 10204	Subject of control	Control in accordance with	Frequency
3.1.B	Ferrous materials	Certifications based on existing standards	Every batch
	Viscous Fluid	Certifications based on existing standards	
	Plating	Certifications based on existing standards	
	Other materials	Certifications based on existing standards	

Table 23— Specific testing of raw materials and constituents for Elastomeric Isolators

Type of inspection certificate in accordance with EN 10204	Subject of control	Control in accordance with	Frequency
3.1.B	High damping elastomers	Table 7 (except tear resistance)	Type test (once) Routine test every batch
		Tear resistance (Table 7)	Type test (once) Routine test every 5 batches
		Table 13	Type test (once)
	Low damping elastomers	EN 1337-3:2005, Table 1 (except tear resistance)	Type test (once) Routine test every batch
		Tear resistance (EEN 1337-3:2005), Table 1)	Type test (once) Routine test every 5 batches
	Steel plates	EN 1337-3:2005, 4.4.3	

10.3 Sampling

Random samples shall be taken from the running production.

11 Installation

11.1 General requirements

All the relevant requirements given in EN 1337-11 for the structural bearings shall be applied also to the anti-seismic devices.

NOTE It is recommended the installation be performed by duly trained personnel, preferably supplied from the manufacturer or working under its supervision.

In particular the manufacturer of the device shall supply the following information:

a) A detailed installation drawing showing all the data and the procedures required for the installation (data shall include dimensions, levels, inclinations, tolerances, quality of the setting material, pre-setting in function of the temperature)

b) Installation tolerances. For sliders and elastomeric bearings the tolerances shall meet at least the tolerances given in the relevant parts of EN 1337

c) Records to be made at the installation. Records shall be based on similar concepts of the records required for structural bearings as given in EN 1337-11

12 In-service inspection

12.1 General requirements

All the relevant requirements given in EN 1337-10 for the structural bearings shall be applied also to the anti-seismic devices.

12.2 Regular inspection

In the regular inspection all the properties listed in Clause 5 of EN 1337-10 shall be checked with the following addition:

g) Oil leakage (for Temporary Dynamic Connection Devices, Velocity Dependant Devices and all devices utilising fluids)

If an oil leakage is detected a Principal Inspection shall be performed.

12.3 Principal inspection

The principal inspection shall be carried out at less frequent intervals than the regular inspection and will normally replace one of these.

The first principal inspection shall be carried out within one year of the structure being put into service.

The principal inspection shall be repeated after any earthquake reaching the level of no failure requirement as defined in 4.1.1 a).

The specific checks for the different types of anti-seismic devices shall be defined by the manufacturer. For sliders and elastomeric bearings the specific checks shall meet at least the requirements given in EN 1337-10.

The Principal inspection after any earthquake reaching the level of no failure requirement as defined at Clause 4.1.1 a) shall foresee the replacement of at least two anti-seismic devices with spare units and the repetition of the prototype tests. The same requirements given in the relevant part of this standard for the acceptance shall be met.

The records to be made at the Principal Inspection shall be defined by the manufacturer and shall be based on similar concepts of the records required for structural bearings as given in EN 1337-10

Annex A
(informative)

Commentaries to Clause 1: Scope

The modification of the seismic response of the structure may be obtained by increasing the fundamental period of the structure, by modifying the shape of the fundamental mode, by increasing the damping, by limiting the forces transmitted to the structure and/or introducing temporary connections that improve the overall seismic response. Other ways of modification may be envisaged.

There are several types of devices that can be used to that aim, each with different possibilities of location within the structure.

A popular way to modify the structural response is to provide seismic isolation. In that case, the isolation units are usually located below the main mass of the structure and are arranged over the isolation interface. They can have a quasi-elastic behaviour, to increase the fundamental period of the structure, or a non-linear softening behaviour, to limit the force transmitted to the structure.

A reduction of the structural response can also be obtained by damping devices, installed at different levels of the structure to dissipate energy.

The introduction of temporary constraints, activated only by the fast movements due to seismic actions, can also contribute to a considerable improvement in the seismic response of a structure.

Combinations of devices of the types described above may also be used.

Isolators used for anti-seismic purposes often play the role of bearings in non-seismic situations. Therefore, they may also be ruled by EN 1337-1, EN 1337-3, EN 1337-5 and EN 1337-7.

The design of structures whose response is modified by anti-seismic devices is ruled by the structural Eurocodes. In the case of base-isolated structures, section 10 of EN 1998-1 applies, with additional requirements in EN 1998-2, for bridges.

This European standard sets rules for the design of anti-seismic devices, specific to the seismic situation. These devices have in general to sustain non-seismic situations; in these situations, they are ruled by Eurocodes and other European standards.

Annex B
(informative)

Commentaries to Clause 4: General design rules

B.1 Service life of a device

The service life of a device, as stated in 3.1, is defined by the Owner in the Technical Specifications of the Project. The figure is based on declarations made by the device manufacturer as part of the validation procedure (see 4.6) or on the specific conditions of the project when the conditions given in the validation procedure do not apply. This service life can also be related when necessary to the lifetime of the structure, as given in the design specifications of the project or, in the absence of such specification, on general indications given in EN 1990. The service life of the devices may be less than the lifetime of the construction.

B.2 Basic requirements

Basic requirements concern both the structure and the devices, as their dynamic behaviour and their limit states cannot be completely dissociated. They have to be fully consistent with those set forth in EN 1998. Requirements and specific rules for the design of structures are given in EN 1998, while this European Standard covers additional requirements and specific rules for the design of devices.

Basic requirements for the structure are deemed to be satisfied when compliance criteria of section 2.2 of EN 1998 - 1 are met.

B.3 Increased reliability

The γ_x factor is required by EN 1998-1 for isolation systems and its recommended value is 1,2. National Authorities should specify the corresponding values for use in their territory. This value can differ according to the type of device considered. The present standard gives additional recommendations for the values of γ_x according to the different types of device, to help the National Authorities in their choice, or the Owner or the Design Engineer when no requirements exist.

In cases where no isolation system is used, but aseismic devices are present, it can still be justified to increase the reliability of the system by introducing a γ_x factor greater than 1, the value depending upon the function the devices play in the overall stability of the structure, the types of device used and the future use of the structure. The present standard gives recommendations on how to choose a suitable value of γ_x.

B.4 Requirements at the ULS

The device and its connections to the structure should be designed so that, for a seismic action beyond the design seismic action, there is no immediate catastrophic failure or immediate change in the properties sufficient to be detrimental to the dynamic behaviour of the structure.

After a seismic action corresponding to the design seismic situation, the replacement of the device should be possible, without either demolition and replacement of the structure or addition of parts to the structure. However, a very limited demolition in the vicinity of the anchorage (meaning approximately of the same size) is permitted. The replacement procedure should be described in the design documents as required in 4.3.4. Major interventions including larger demolitions and/or replacement of parts of the structure or the addition of new structural elements may be envisaged after a seismic action beyond the design level.

B.5 Requirements at the SLS

It is undesirable to have a construction that responds perceptibly under frequently occurring loads, such as time-dependent loads or wind. Therefore, additional measures shall be taken, where isolation systems are used, to provide an adequate lateral stiffness against frequently occurring loads.

B.6 Structural analysis

Structural analysis in a seismic situation is, in principle, dealt with in EN 1998-1 and EN 1998-2. However, due to the presence of specific types of devices, additional requirements consistent with those in the Eurocodes may be necessary to cover instances not considered in those standards.

The main characteristics of an anti-seismic device that should be carefully assessed for the use in the design of the structure are its flexibility, its damping capacity and its self-centring capability.

B.7 Material properties to be used in the analysis

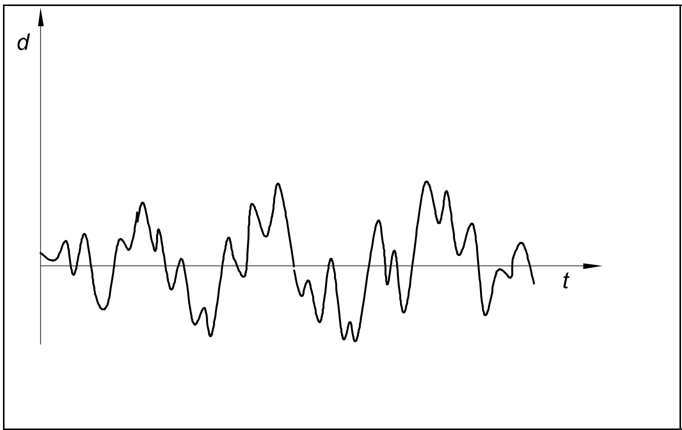
A suitable choice in the sets of properties (UBDP and LBDP) may result in only two enveloping analyses.

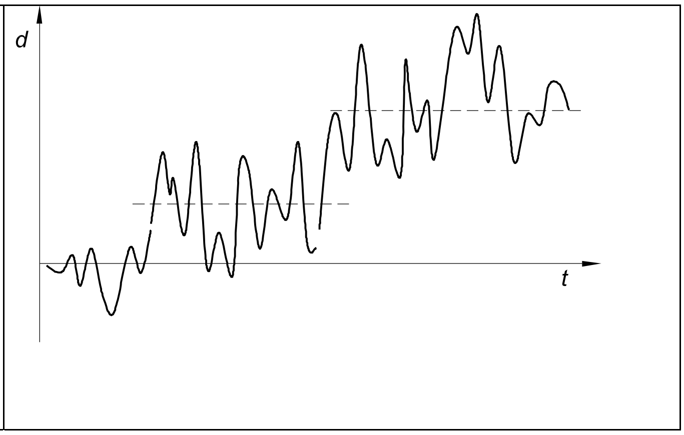
B.8 Re-centring capability

The purpose of the re-centring capability requirement is not so much that of limiting residual displacement at the end of a seismic event, but instead that of preventing cumulative displacements during the event, as indicated in Figures B1 and B2.

A requirement for re-centring capability is necessary to take into account unpredictable adverse factors, such as sliding bearings' out of level.

Re-centring assumes particular relevance in structures located in close proximity to a fault, where earthquakes characterised by highly asymmetric time histories are expected (Near Field or Fling effect).





Among the four fundamental functions of a seismic isolation system, energy dissipation and re-centring capability are two opposing functions and their relative importance depends primarily on the case under examination.

The criterion given in 4.4.3 is based on energy concepts and thus couples very well with the intrinsic nature of the phenomenon in question (the earthquake).The suggested verification requirement can be easily translated in formulae or design criteria for each type of isolator or isolation system.

It should be noted that re-centring capability is a characteristic of the **entire isolation system**, not necessarily of each of its components (e.g. the single isolator).The calculation of reversibly stored energy E_S must take into account also those elements of the structure that influence its response, such as a slender pier solidly connected to the bridge deck that undergoes flexural deformation during a seismic event. In this case the pier acts as a spring and thus it may be considered for all practical purposes like a supplemental re-centring device. A second example of structural elements that influence the response of the structure are the hangers of suspended bridges. In this case the stored energy is of the potential type.

Annex C
(informative)

Commentary to Clause 5: Rigid connection devices

C.1 Functional requirements

An STU is fully defined when the Design Engineer specifies the following design magnitudes:

- design force (kN)
- activation (lock-up) velocity (mm/s)
- drag force (kN)
- drag velocity (mm/s)
- maximum stroke (± mm)
- thermal stroke (± mm)
- tolerances
- rotation angle (± degrees)
- service temperature range

where the maximum stroke includes displacement due to both any slowly occurring effect (thermal, creep and shrinkage effects) and dynamic effects, and additional adjusting length (whenever required).

The activation velocity should be estimated as about 1% of the maximum relative velocity experienced at its ends.

The first requirement ensures that the force developed by the unit at a velocity equal to or less than the activation velocity shall be at least equal to the design force in the entire range of environmental temperature.

The second requirement ensures that, when the device is subjected to slowly applied relative movements at its ends, such as thermal expansion/contraction, its reaction does not exceed the design drag force in the entire range of environmental temperature.

This requirement aims to avoid fatigue loads acting on structural members.

The third requirement aims to verify that whenever the STUs should be subjected to impulsive loads of other nature than the seismic, such as braking forces for devices installed on bridges, an additional evaluation of the performance should be made in terms of force, velocity, stiffness and number of load cycles.

C.2 Design Requirements

The proposed partial factors shall be correlated with the earthquake period of return.

Whenever the STU should be equipped with an over-load relief system such as relief valves acting to limit the excess of pressure into the device when the design condition is exceeded, lower safety factor can be used.

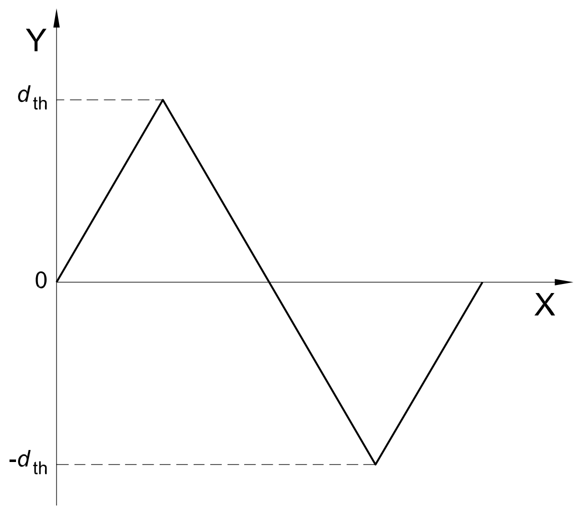
The most detrimental acceleration acting on the device, with the exception of the axial one, is vertical . In fact, the sealing system and the device itself should be designed to withstand the effect of the STU's self-weight plus the vertical acceleration.

C.3 Testing

STUs shall provide the expected behaviour over the full service temperature range.

Considering the available technologies, the most critical issues are related to the drag force produced by the STU at the lowest expected temperature (because the fluid viscosity increases with decrease of temperature), and the design stiffness at the highest expected temperature (at which the fluid viscosity will be least).

C.3.1 Impressed low velocity test



Key

Y Displacement (mm)

X Time (s)

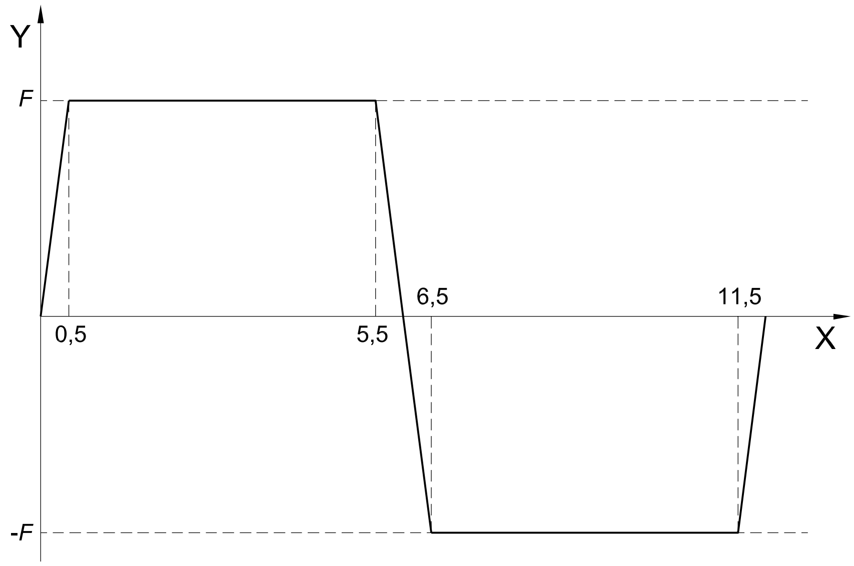
Figure C.1 — Loading history for Impressed low velocity test

C.3.2 Seal Wear Test

STUs are typically required to function during the earthquake, having for years experienced only thermally induced movements. At the time of the earthquake the sealing system must guarantee a proper functioning even after a long "resting" period. Seal wear must not compromise the behaviour of the entire structure.

C.3.3 Impulsive Load Test

The 0,5 s time required to reach the maximum force aims just to provide a shock-like effect on the STU. From the testing point of view, this loading time can generally be easily achieved. STUs characterized by exceptional loads and strokes may be tested with a longer loading time.

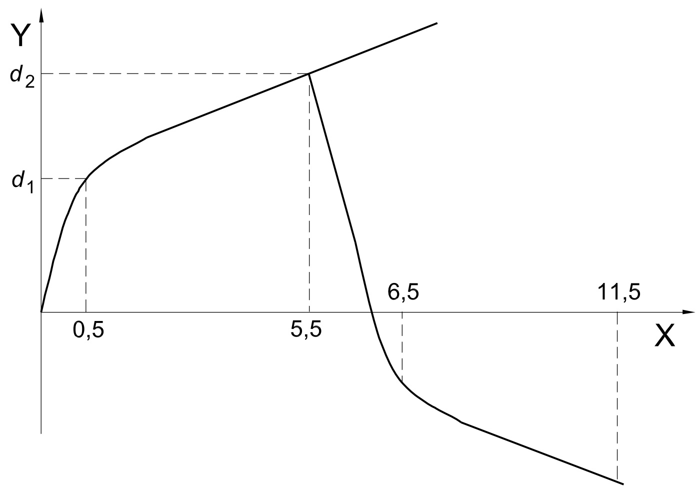


Key

Y Force (kN)

X Time (s)

Figure C.2 — Loading history for Impulsive Load Test



Key

Y Displacement (mm)

X Time (s)

Figure C.3 —Typical Displacement vs. Time Record of Impulsive Load Test

C.3.4 Overload Test

The object of the test is to verify the STU's behaviour whenever the design load is exceeded.

An STU behaves as a dynamically activated spring element, thus whenever the actual earthquake exceeds the design level, the resulting force transmitted through the device may exceed the design one. If the STU is coupled to ductile elements, the transmitted force is limited by the yielding of such elements. Whenever a certain level of force is critical for the ultimate performance of the structure, the Design Engineer may prescribe the utilization of relief valves in order to limit the maximum force transmitted through the unit.

C.3.5 Cyclic Load Test

The object of the test is to evaluate the reliability of the STU's behaviour during the earthquake.

A sinusoidal (time-dependent) time history lasting for a sufficient period of time is needed in 5.3.4.5.

Annex D
(informative)

Categories of devices

D.1 Categories of devices

NLD are mainly used in passive control systems, whose functioning is based on the increase of the flexibility of the structural system and/or on the energy dissipation capability.

Different categories of devices can be identified, according to the main features of their force-displacement cycles, deriving from the peculiar characteristics of different materials and mechanisms.

A first classification can be made according to their capability of dissipating energy and includes the following categories:

— Energy Dissipating Devices (EDD), when $\zeta > 15\%$;

— Non Linear Elastic Devices (NLED), when $\zeta \leq 15\%$.

A second classification can be made according to the variability of their stiffness as a function of the displacement, including the following categories:

— Hardening Devices (HD), when $K_2/K_1 > 1$;

— Softening Devices (SD), when $K_2/K_1 \leq 1$.

A third classification can be made according to the re-centring capability of the device, i.e. the capability to recover its initial shape when the applied external force is zero or, when it is a part of a structural system, to make the system to recover its initial shape or limiting residual displacement, at the end of an earthquake. The following categories can be singled out:

— Dynamically [Weakly] Re-Centring Devices (DRD), when the reversibly stored energy (elastic strain energy and potential energy) E_s is greater than 25% the energy dissipated by hysteretic deformation E_h.

— Statically [strongly] Re-Centring Devices (RCD), when the displacement at zero force is less than 10% the maximum attained displacement;

— Supplemental Re-Centring Devices (SRCD), when the displacement at zero force is less than 10% the maximum attained displacement, even when an external force at least equal to 10% the maximum force resist the recovering of the initial configuration of the device.

EDD's are normally softening devices based either on the hysteretic properties of metals (steel, lead, shape memory alloys) or on the frictional resistance between suitably treated surfaces. Special hydraulic jacks, whose functioning can be calibrated so as to give an almost time-independent elastic-plastic force-displacement characteristic, can be also considered as NLD. EDD can be also obtained by using special shape memory alloys.

NLED's can be either softening or hardening devices. They are sometimes based on the elastic property of special high-strength steel, some others on rubber under compression, or on the superelasticity of shape memory alloys. Their non linear behaviour is sometimes based on geometrical non linear effects due to the peculiar shape of their core elements. Other types of devices can be classified into this category, provided that the requirements given in this part are fulfilled.

Softening NLD, either EDD or NLED, with an almost zero stiffness in the second loading branch ($K_2 \approx 0$), such as elastic-perfectly-plastic or rigid-perfectly-plastic devices, can be deemed as linking elements that prevent forces stronger than their plastic threshold from being transferred between different structural parts.

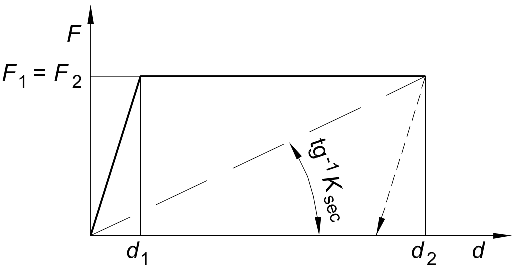


Figure D.1 - Elastic-perfectly-plastic devices

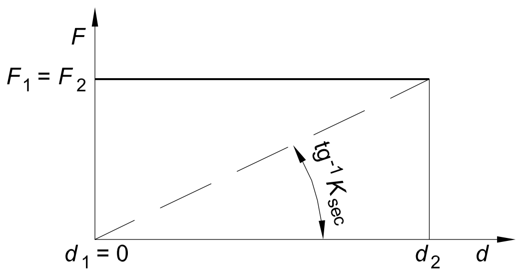


Figure D.2 - Rigid-plastic devices.

Softening Devices, either EDD or NLED, with a low initial elastic stiffness can be used to produce a favourable increase in the initial natural period of oscillation of the structural system, thus reducing seismic effects.

Hardening Devices, usually NLED, are often used as flexible constraint to limit displacements in case of earthquakes with a progressive increase of force. If the initial stiffness is low, they can produce a favourable elongation of the initial natural period of oscillation of the structural system.

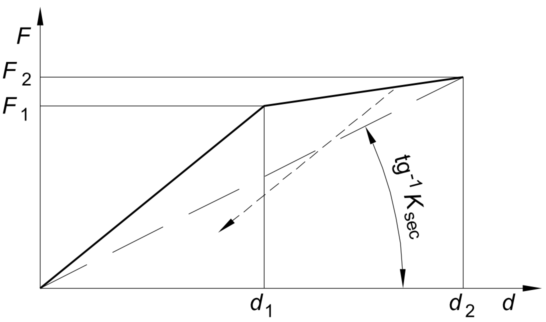


Fig. D.3 - Softening devices with low initial stiffness.

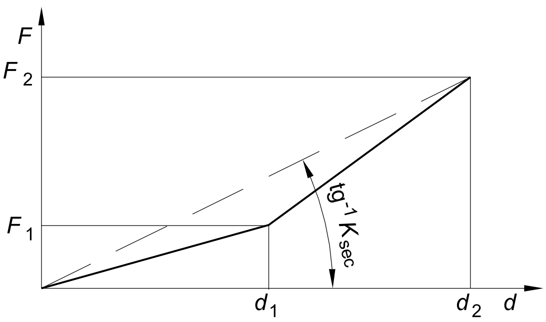
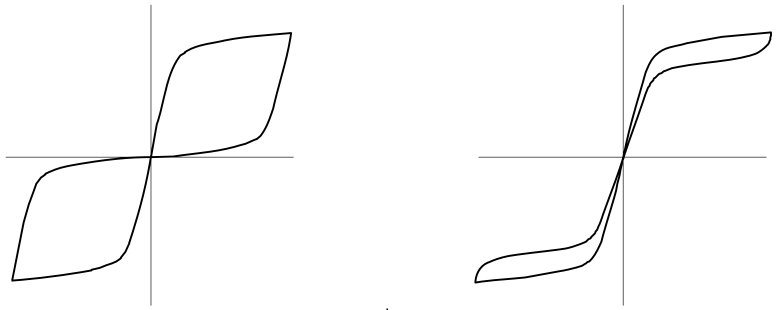


Fig. D.4 - Hardening devices.

The re-centring capability is a strongly debated question. On one hand it can be referred to the entire structural system under dynamic seismic conditions, i.e. with the system possessing both kinetic and potential energy at the end of the external action. In this case, as the kinetic terms of energy is not apriori known for a given displacement, the definition of the re-centring condition can be established only on a probabilistic or statistical base. On the other hand, it can be referred to either the single device or the entire structural system under static conditions, with reference to the shape of the force-displacement cyclic curve. In this case a re-centring device or system is one whose force at zero displacement is also zero, at any stage of loading or unloading. When the force in the unloading phase is still large for small displacement, a device is able to provide a structural system with the re-centring capability, even when parasite non conservative forces are present. In this case the device is said to have supplemental re-centring capability. Differently from dynamically re-centring systems, statically re-centring systems are able to deterministically restore the structural system in its initial configuration for any situation which fulfil the design conditions.



Statically Re-Centring Device | Supplemental Re-Centring Device

Figure D.5 — Re-centring devices

Annex E
(informative)

Examples of non-linear devices

E.1 Buffer

The buffer is a rubber-based elastic device capable of providing the structure with a force vs. deformation curve. The device has thus an elastic behaviour, but in general not a linear one. Actually, its linearity depends on the range of deformation in which the device works. This behaviour is obtained by means of a certain number of specially designed elastomeric discs, each of them vulcanised to two external steel plates. The device is designed so that the elastomeric discs are always submitted to compression, for movements in both directions. This is achieved by means of the particular rods arrangement, which allows the discs to be always compressed, no matter of the direction of the seismic forces.

The buffers are used in bridges to take horizontal loads, at abutments and/or between adjacent decks in correspondence of the expansion joints.

Annex F
(informative)

Commentary to Clause 7: Velocity dependent devices

F.1 Functional requirements

A Viscous Damper is fully defined when the Design Engineer specifies the following main design magnitudes:

- maximum force (kN)
- maximum stroke (± mm)
- maximum velocity (m/s)
- damping constant C (kN/(m/s)$^{\alpha}$)
- exponent α of the constitutive law
- stiffness K (kN/m)
- pre-load F_o
- tolerances
- rotation angle (± degrees)
- environmental temperature range

A typical constitutive law of a Fluid Viscous Damper is of the type:

$$F=Cv^{\alpha} . \tag{F.1}$$

FVDs providing for a very large stroke are better represented by a Maxwell model (spring and damper in series) whose elastic characteristic describes the effect of the fluid compressibility.

The latter is important when the Energy Dissipation Capacity needs to be evaluated.

A typical constitutive law of a Fluid Spring Damper is of the type:

$$F=F_o+kx+Cv^{\alpha} . \tag{F.2}$$

Thus, FSDs are better represented by a Kelvin-Vöigt model (spring and damper in parallel) where the elastic stiffness describes the effect of the fluid compressibility and F_o is the pre-load.

It is pertinent to note that any type of seismic device accumulates or dissipates energy in all four forms of the well-known energy balance equation and the classification into FVDs and FSDs takes into account the dominant form of energy.

For example, a Viscous Damper:

i) accumulates elastic energy through deformation of its mechanical components and the compressibility of the viscous fluid (dependence on displacement);

ii) accumulates kinetic energy in its moving parts, i.e. piston (dependence on velocity);

i) dissipates energy hysteretically into the gaskets through friction (dependence on displacement);

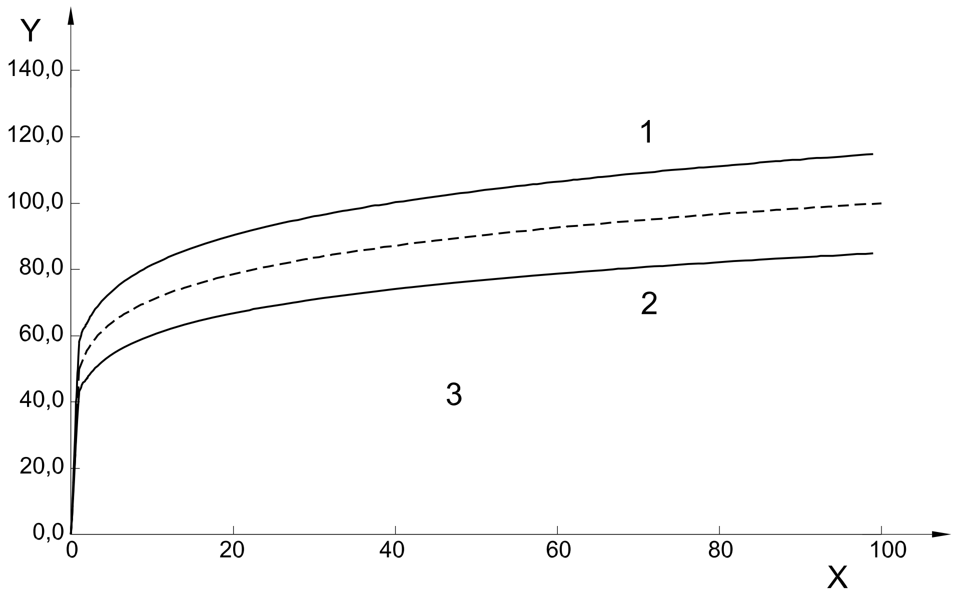
ii) dissipates energy viscously by forcing fluid flow through orifice or valve systems (dependence on velocity).

When the fourth term dominates, the device is classified as a “Fluid Viscous Damper” and the constants K and F_o may be neglected.

When both the first and the fourth terms are significant, the device is classified as a “Fluid Spring Damper”.

The amount of energy at play in a structure during a design level seismic event may range from 1 MJ to 50 MJ. The possible magnitude of the energy involved raises the fundamental question: “Will the seismic device be significantly damaged by the energy it dissipates within itself during an earthquake?”Only a very limited fraction (1-5%) of the large amount of mechanical energy it has to dissipate in the form of heat can be transferred to the environment by convection and conduction during the earthquake, and thus the device must be able to absorb the heat produced and withstand the substantial increase in its temperature.

In the following figures, typical plots of FVD and FSD constitutive laws are reported.



Key

Y Normalized Force (%)

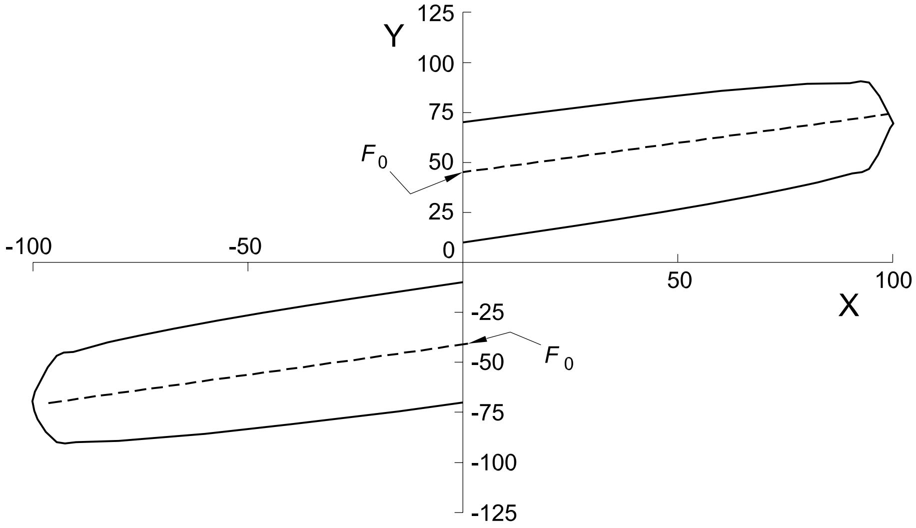
X Normalized Velocity (%)

1 Upper Bound

2 Lower Bound

3 Force vs Velocity Characteristic Curve

Figure F.1 — Typical force vs.velocity FVD output envelope



Key

Y Normalized Force (%)

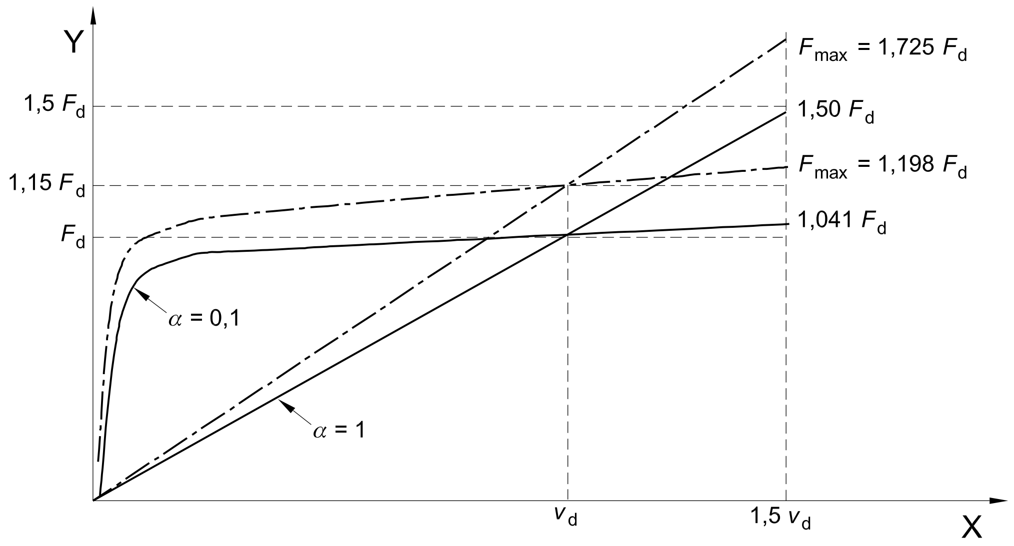
X Normalized Displacement (%)

Figure F.2 — Force vs. displacement FSD output envelope (sinusoidal input)

F.2 Design Requirements

Exceeding the design level velocity has an effect that differs according to the characteristics of the Viscous Damper.

Figure F.3 below illustrates a comparison of the effect of exceeding the design velocity v_d by 50% between two devices with different exponents α.



Key

Y Force

X Velocity

Figure F.3 — Effect of exceeding design velocity upon two devices with different exponent α

for $\alpha = 1{,}0$ (linear damper) $F_{max} = (1+0{,}15) \times 1{,}5^{1}\ F_d = 1{,}725\ F_d$

(F.3)

for $\alpha = 0{,}1$ $F_{max} = (1+0{,}15) \times 1{,}5^{0{,}1} F_d = 1{,}198\ F_d$

(F.4)

In conclusion, the over-strength factor depends on both the tolerance and the exponent α of the constitutive law.

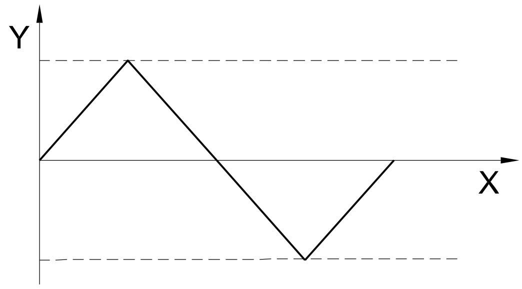
Devices characterized by extreme dimensions and weight, such as FVDs providing for strokes exceeding ±500 mm, may require a modal analysis in order to investigate the additional lateral load provided by the earthquake acceleration. In this case, the structural engineer shall provide the acceleration spectra at the location of the units.

F.3 Testing

The maximum short-term energy demand on the dampers occurs during a design level seismic event. Depending on the damper's size and the seismicity of the site, the expected dissipated energy ranges from 1 MJ to 20 MJ.

F.3.1 Low velocity test for Fluid Viscous Dampers

A typical test velocity is about 0,01 mm/s (ie <0,1mm/s). As such a low test velocity would otherwise produce a very long test, short imposed strokes are acceptable, the aim of the test being just to verify the damper reaction.



Key

Y Displacement

X Time

Figure F.4 — Loading history for impressed low velocity test

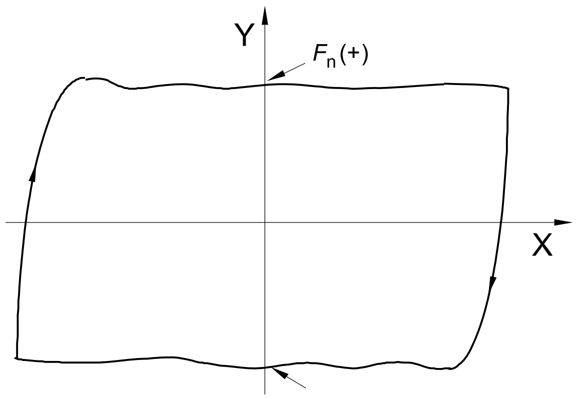
F.3.2 Low velocity test for Fluid Spring Dampers

It should be emphasised that the FSD reaction may be considerable even for a low velocity test, as two terms of its constitutive law are independent of velocity.

On such a device, a low velocity test can be used to perform the pressure test by simply imposing a stroke sufficient to generate the required internal pressure.

F.3.3 Constitutive law test for Fluid Viscous Dampers

For the sake of simplicity, the test should be performed imposing a triangular wave loading history. This input is suggested because of the ease of reading the output damper reaction. With a sinusoidal test input the maximum imposed velocity is achieved only for an instant. Nevertheless, should the triangular wave loading history induce too high a peak of acceleration, a sinusoidal time history may be y used.



Key

Y F (kN)

X d (mm)

Figure F.5 — Typical force vs. displacement hysteresis loop (at constant velocity)

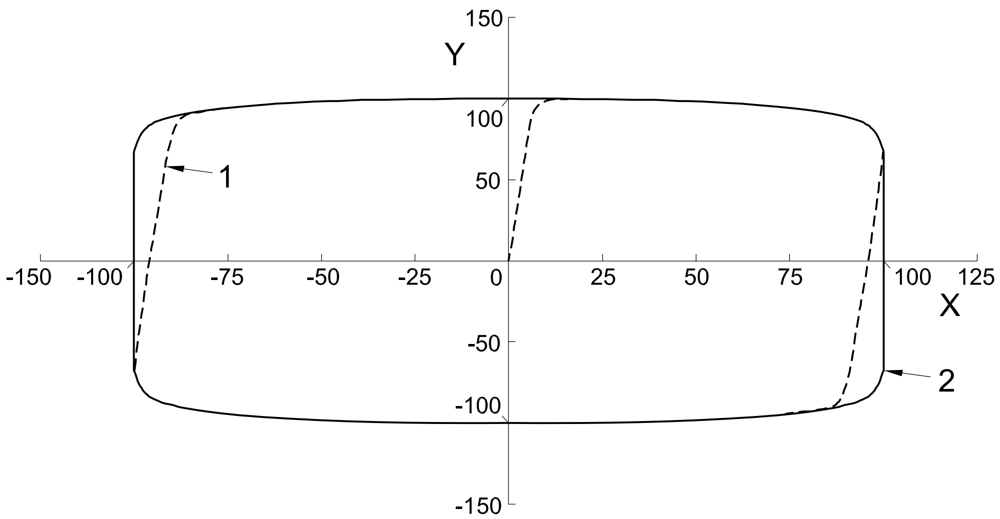
F.3.4 Damping efficiency test

The dissipative efficiency of any energy dissipating seismic device is defined as the ratio between the area of the measured force-displacement hysteresis loop and the corresponding theoretical value. The efficiency is expressed in mathematical terms as:

$$\eta = \frac{\text{EDC}}{\oint F(x,v)dx} \tag{F.5}$$

where, F(x,v) and x are the force and the displacement respectively and EDC is Energy Dissipation per Cycle.

In the case of Fluid Viscous Dampers, the force F(v) depends predominantly on the imposed velocity. Therefore, the energy dissipation efficiency η depends on the type of impressed input. A sinusoidal displacement input is conventionally adopted in the evaluation of the energy dissipation efficiency of viscous dampers. As already mentioned, for the correct evaluation of the theoretical Energy Dissipation per Cycle (EDC) a Maxwell model should be used. The utilisation of a simple non-linear force vs velocity constitutive law (dash-pot model) overestimates the theoretical energy dissipation capacity (see figure F.6*).



Key

Y Normalized Force (%)

X Normalized Displacement (%)

1 Maxwell Model

2 Dash-Pot Model

Figure F.6 — Comparison between a simple non-linear dash-pot and a Maxwell model for Fluid Viscous Dampers (*)

(*) The shape of the plot corresponding to a Maxwell model has been magnified for the sake of clarification.

Annex G
(informative)

Commentary to Clause 8 Elastomeric isolators

G.1 Ageing conditions

A prediction of the ageing conditions equivalent to 60 years at the average service temperature may be made on the basis of a series of tests conducted over a range of temperatures and times and interpreted according to an Arrhenius Law:

$$t_N = t_o e^{Q/RT} \tag{G.1}$$

where t_N is the time for the modulus to change by a certain factor N; t_o is a reference time; Q is the activation energy; R is the gas constant and T°K is the temperature. The highest test temperature should be 70°C. Even then the observations may not follow an Arrhenius relation, thus making reliable prediction difficult. If an Arrhenius relation is obeyed, the time for the modulus to change by the factor N at the average service temperature can be estimated.

If test pieces are not prepared from an aged device, anaerobic ageing conditions can be produced by either:

a) using moulded test pieces and encapsulating these in an impermeable material during ageing

b) producing block specimens with a minimum dimension of at least 100mm, and ageing the block aerobically. The aged test pieces should be taken from the block such that they were at least 30mm from any surface of the block.

G.2 Low temperature crystallisation

Some elastomers are susceptible to crystallization if the ambient temperature is low over a prolonged period. High damping compounds of these elastomers may be more susceptible than conventional low damping ones. The crystallization process involves a nucleation period during which little change in rubber stiffness occurs followed by a rapid stiffening as the crystallites grow. The nucleation period shortens as the temperature is lowered and any applied rubber strain is increased. To ensure performance of the isolator is not compromised it is necessary that the nucleation period is not exceeded during any continuous exposure to low temperatures. Crystallites melt when the ambient temperature of the isolators is raised sufficiently (above about 5°C for NR based compounds), and thus the effects are completely reversible.

Recommended test conditions for natural rubber-based compounds and chloroprene-based compounds are given in Tables G.1 and G.2 respectively.

Table G-1 Service and test conditions for natural rubber

Minimum service temperature , T_L °C	$-10 \le T_L < 0$	$-20 \le T_L < -10$	$T_L < -20$
Time (days) at temperature in above range	t_0	t_{-10}	t_{-20}
Test temperature, °C	-10	-20	-25
Test period	$1,5t_o$	$1,5t_{-10} + 0,1t_0$	$1,5t_{-20} + 0,5t_{-10} + 0,05t_0$

Table G-2 Service and test conditions for chloroprene rubber

Minimum service temperature , T_L °C	$0 \le T_L < 5$	$-5 \le T_L < 0$	$T_L < -5$
Time (days) at temperature in above range	t_5	t_0	t_{-5}
Test temperature, °C	0	-5	-10
Test period	$1,5t_5$	$1,5t_0 + 0,5t_5$	$1,5t_{-5} + 0,5t_0 + 0,25t_5$

G.3 Commentary Basis of design

G.3.1 Shape Factor

For bearings with a rectangular section:

$$S = \frac{ab}{2t_r(a+b)} \tag{G.2}$$

where *a* and *b* are the lengths of the sides of the steel reinforcing plates. For circular bearings with an unplugged hole of diameter d_H :

$$S = \frac{(D' - d_H)}{4t_r} \tag{G.3}$$

G.3.2 Design shear strain due to compression by vertical loads.

The formula 8.1 is given in:

James M. Kelly, Earthquake-Resistant Design with Rubber, 2nd edition, Springer-Verlag, London.

For larger shape factors, S > 8, the use of E'_C uncorrected for the effect of bulk compressibility leads to a more substantial underestimation of $\varepsilon_{c,E}$, However, correcting for the effect of bulk compressibility results in a more substantial overestimation of $\varepsilon_{c,E}$. See ISO22762-2 Annex I.

Because the shape factor of conventional structural bearings is generally smaller than that of seismic bearings, EN 1337-3:2005 does not consider rubber compressibility in calculating $\varepsilon_{c,E}$.

G.3.3 Isolator stiffnesses

G.3.3.1 Vertical stiffness

The reason for selecting the value of G in the formula for the calculation of E'_c as the value at the design shear strain due to the earthquake-imposed horizontal displacement is to simplify the design process by choosing a single value of G in all the different formulae. This value of G is conservative for the calculation of $\varepsilon_{c,Ed}$ in comparison to the value of G at the shear strain due only to compression by vertical loads, because it is lower than the latter.

For devices with large shape factors, as are most of the devices used as seismic isolators, the assumption of incompressible rubber leads to significant overestimation of the compression modulus and vertical stiffness. Rubber compressibility may be taken into account with the simple approach given by:

> Gent, A.N., Lindley, P.B. (1959). The compression of bonded rubber blocks. Proc. Instn Mech. Eng, Vol. 173, No. 3, pp. 111-122.

Thus E_c, ,the compression modulus, is given by:

$$\frac{1}{E_c} = \frac{1}{E'_c} + \frac{1}{E_b} \tag{G.4}$$

E_b is the bulk modulus of the elastomer. In the absence of measured data, E_b may be taken as 2000MPa. This formula is preferred to the empirical equation 20 in EN1337-3.

The total vertical stiffness, K_v, of a laminated elastomeric isolator is the sum of the vertical deflections of the individual layers given by:

$$K_v = \frac{A'}{\sum \frac{t_i}{E_{ci}}} \tag{G.5}$$

where E_{ci} is the compression modulus for the single rubber layer, given by 8.2 and 8.3, of thickness t_i.

G.3.3.2 Horizontal stiffness

The theoretical value of the horizontal stiffness is given by:

$$K_b = \frac{GA}{T_q} \tag{G.6}$$

where:

A is the total plan area of the device;

G is the shear modulus at the design shear strain due to earthquake-imposed horizontal displacement.

G.3.3.3 Bending stiffness

The theoretical value of the bending stiffness about an axis through the centre of the device, parallel to the length (b direction), is given by the following expressions:

For rectangular devices:

$$K_\varphi = \frac{Ga^5 b}{n t_i^3 k_R} \tag{G.7}$$

For circular devices:

$$K_\varphi = \frac{G\pi d_0^6}{512 n t_i^3} \tag{G.8}$$

To determine k_R see Table G.3 hereafter.

G.3.3.4 Compression modulus, E'_c, for annular devices with unplugged hole

E'_c for annular devices with unplugged hole is:

$$E_c' = 3G\left(1 + 2\frac{(1+\rho^2)\ln\rho + (1-\rho^2)}{(1-\rho)^2\ln\rho}S^2\right) \quad \text{(G.9)}$$

ρ is the ratio between internal and external diameters of the steel reinforcing plates.

Table G-3 — Values of parameter k_R

b/a	0.5	0.75	1	1.2	1.25	1.3	1.4	1.5
k_R	137	100	86.2	80.4	79.3	78.4	76.7	75.3
b/a	1.6	1.7	1.8	1.9	2	2.5	10	∞
k_R	74.1	73.1	72.2	71.5	70.8	68.3	61.9	60

NOTE 1 If $b < a$ the formula is still applicable for rotation about the axis parallel to *b*, but in this case *b* is the shorter dimension and *a* is the longer dimension, in contrast with the definitions.

NOTE 2 The calculated value of the bending stiffness is sufficient for most purposes but if a precise knowledge of its value is necessary then the value shall be determined experimentally.

Annex H
(normative)

Equipment for combined compression and shear

H.1 General requirements

The transducer outputs shall be calibrated and shall be accurate to ±2% of the peak output being measured in a particular test. The transducers, amplifiers and recording equipment shall be capable of responding at the test frequency without any significant attenuation. The test report shall include evidence of transducer calibration and evidence of any checks (eg. regarding the effect of friction in load train) required.

When specified, the exact order of tests and the interval between tests shall be strictly adhered to. The instructions regarding the use of an isolator for more than one test shall also be strictly adhered to.

NOTE These controls are necessary because of strain history effects in the rubber.

H.2 Data Acquisition

Analogue or digital data acquisition may be employed. Data shall be digitised or sampled at a rate at least equal to 100 times the frequency of loading. A digital acquisition system shall sample all data channels so that the maximum time skew between channels is less than 1% of the sampling interval.

H.3 Combined compression and shear equipment

The compressive displacement shall be measured directly between the load platens of the machine. It shall be the average obtained from at least three transducers spaced evenly around the isolator.

If there is any source of friction in the compressive load train, the effect on the compressive load as measured shall be <3%.

The shear displacement shall be the average of that measured at two points on opposite sides of the isolator(s), along a line orthogonal to the shear loading direction. The shear displacement attained shall be within ±5% of that specified. The equipment shall be capable of applying a sinusoidal or triangular displacement of the specified amplitude at the test frequency.

The shear load shall preferably be measured in the case of a single isolator configuration by a transducer between the isolator and the reaction support. For whatever test configuration, if a transducer located in the force train of the actuator is to be used, the magnitude of any frictional effects on the force shall be reported and correction made. The shear load train shall be capable of accommodating both the compressive displacement of the isolator(s) and, if tests are conducted under compressive force control rather than displacement control, the change in height of the isolator(s) during their shear deformation. The lateral load plane shall remain within ±0,08 rad of the bottom and top reaction support planes.

The shear load and displacement shall be continuously recorded.

The vertical load should preferably be applied under load control. It should preferably be maintained constant such that:

(i) average load is within ±10% of specified load

(ii) maximum and minimum loads during test are within ±10% of average applied.

(iii) area of any hysteresis loops observed in the compressive load train is less than 5% of the shear force-displacement hysteresis loop.

(iv) any source of friction between the compressive load cell and the isolator(s) contributes energy losses <5% of the shear force-displacement hysteresis loops.

If any of the four conditions cannot be met, the compressive load during the tests may be under displacement control, such that, after applying the specified vertical load, the isolator(s) are held at that displacement during the shear deformation. Displacement control of the compressive load may also be used if the shear load train cannot accommodate the change in height of the isolator(s) during shear. Notwithstanding the above, the test of lateral displacement capacity shall be performed with the compressive load held constant under load control. Displacement control of the compressive load shall not be used with curved surface sliders.

The compressive load and displacement (as well as the shear load and displacement) shall be recorded to enable a check to be made that the conditions applicable to the former are satisfied.

H.4 Load Platens

The isolators shall be attached to the load platens with the type of system to be used for the installed isolators.

The platens shall be larger in plan area than the isolators and thick enough to prevent significant distortion (<2% of the isolator compressive deflection at the maximum load).

The angle between the upper and lower platens shall be less than 0,003 radians.

The floating platen(s) shall be such that they do not:-

(i) rotate about a vertical axis by more than 0,08 radians.

(ii) move orthogonally to the loading directions by more than 10% of the shear displacement.

H.5 Data analysis

The dynamic horizontal force-displacement data shall be analysable cycle by cycle. The method of analysis shall express the stiffness as:

$$\text{Stiffness,} \quad K_{\mathrm{b}} = \frac{F^{+} - F^{-}}{d^{+} - d^{-}} \qquad \text{(H.1)}$$

where F and d are the horizontal force and displacement respectively. d^+ and d^- are the maximum and minimum values of displacement in the cycle, and F^+ and F^- are the values of force at those displacements. The equivalent viscous damping ratio ξ, shall be expressed as:

$$\xi = \frac{2H}{\pi K_b (d^+ - d^-)^2} \tag{H.2}$$

where H is the area of the hysteresis loop.

For LRB the horizontal characteristics may be determined as the second branch (or post-yield) stiffness, K_2, and characteristic strength, Q_d, See Figure H.1 —. The value of Q_d shall be taken as the average value of the intercepts on the force axis. The stiffness, K_2, shall be taken as:

$$K_2 = \frac{F(d^+) - F(d^+/2) + F(d^-/2) - F(d^-)}{d} \tag{H.3}$$

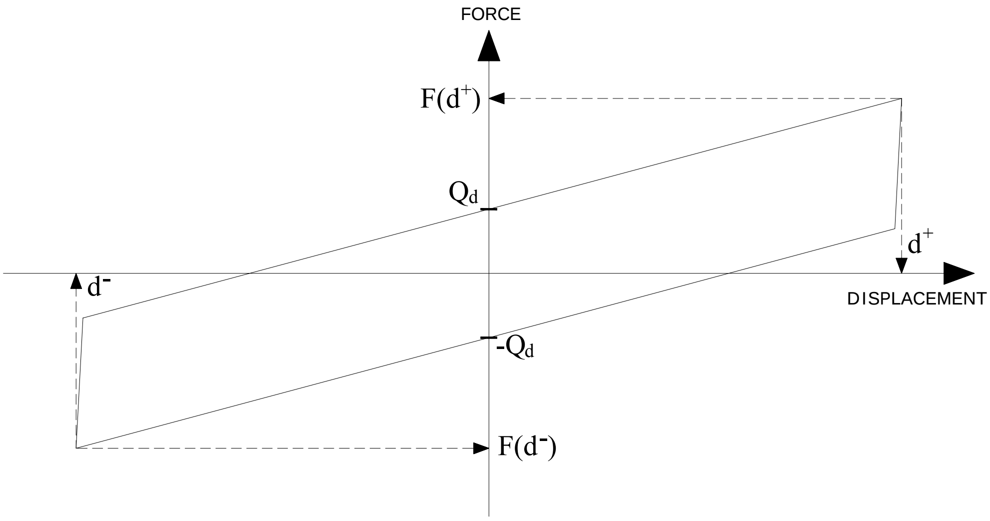


Figure H.1 — Schematic force-displacement loop for LRB

Annex I
(informative)

Examples of sliders

Examples of a slider combined with hysteretic dampers are shown in figure I.1 and I.2, and examples of a slider combined with hysteretic damper and rigid connection device (shock transmitter) are shown in figures I.3 to I.5.

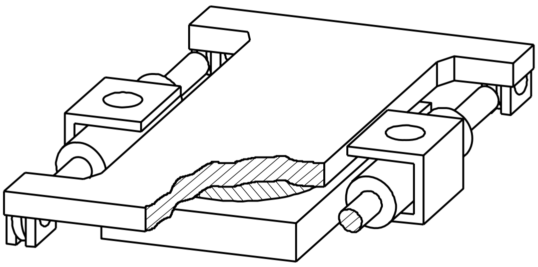


Figure I.1 — Slider combined with Shock Transmission Units

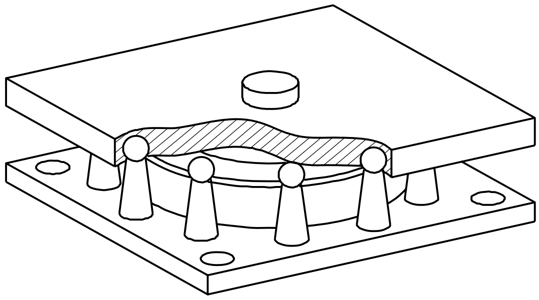


Figure I.2 — Slider combined with tapered pin steel hysteretic elements

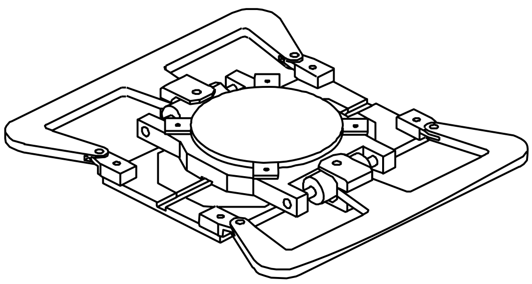


Figure I.3 —Sliding guided pot bearing combined with E-shaped hysteretic elements and Shock Transmission Units

Annex ZA
(informative)
Clauses of this European Standard addressing the provisions of the EU Construction Products Directive

ZA.1 Scope and relevant characteristics

This European Standard has been prepared under Mandate M/104 Structural bearings as amended by M/132 given to CEN by the European Commission and the European Free Trade Association.

The clauses of this European Standard shown in this annex meet the requirements of the mandate given under the EU Construction Products Directive (89/106/EEC).

Compliance with these clauses confers a presumption of fitness of the anti-seismic devices covered by this annex for the intended uses indicated herein; reference shall be made to the information accompanying the CE marking.

> **WARNING:** Other requirements and other EU Directives, not affecting the fitness for intended uses, can be applicable to the anti-seismic devices falling within the scope of this European Standard.

NOTE 1 In addition to any specific clauses relating to dangerous substances contained in this standard, there may be other requirements applicable to the products falling within its scope (e.g. transposed European legislation and national laws, regulations and administrative provisions). In order to meet the provisions of the EU Construction Products Directive, these requirements need also to be complied with, when and where they apply.

NOTE 2 An informative database of European and national provisions on dangerous substances is available at the Construction web site on EUROPA (accessed through http://europa.eu.int/comm/enterprise/construction/internal/dangsub/dangmain.htm).

This annex establishes the conditions for the CE marking of the anti-seismic devices intended for the uses indicated in Tables ZA.1.a. to ZA.1.e and shows the relevant clauses applicable:

This annex has the same scope as Clause 1 of this standard and is defined by Tables ZA.1.a. to ZA.1.e.

Table ZA.1. – Relevant clauses

Table ZA.1.a

Product: **<u>RIGID CONNECTION DEVICES</u>** covered by the scope of this standard **Intended use:** In buildings and civil engineering works			
Essential Characteristics	**Requirement clauses in this and other European Standard(s)**	**Levels and/or classes**	**Notes**
Load bearing capacity (compression and tension) (Axial load transmission capability)	N/A	None	-
Resistance to seismic loads/shock absorption (Survivability against repeated load cycling)	prEN 1337-8 5.1 5.2.1, 5.2.2 5.3.1, 5.3.2	None	Design value, in kN
Shear modulus (Stiffness)	N/A	None	-
Rotation capability (Re-centring capability)	prEN 1337-8 5.1 5.3.1	None	Design value, in radians
Friction coefficient (Energy dissipation capability)	N/A	None	-
Horizontal distorsion capability (Lateral flexibility)	5.2.1, 5.2.2, 5.2.4.2 5.3.1, 5.3.2	None	
Durability aspects (durability against ageing, temperature, corrosion)	5.2.4.2, 5.3.4.2	None	

Table ZA.1.b

Product: **LINEAR DEVICES** covered by the scope of this standard **Intended use:** In buildings and civil engineering works			
Essential Characteristics	**Requirement clauses in this and other European Standard(s)**	**Levels and/or classes**	**Notes**
Load bearing capacity (compression and tension) (Axial load transmission capability)	6.1.1	None	Design value, in kN
Resistance to seismic loads/shock absorption (Survivability against repeated load cycling)	6.1.1	None	Number of cycles
Shear modulus (Stiffness)	6.1.1	None	Design value, in kN/m
Rotation capability (Re-centring capability)	6.1.1	None	Pass/fail criterion
Friction coefficient (Energy dissipation capability)	6.1.1	None	Information on characteristics
Horizontal distorsion capability (Lateral flexibility)	N/A	None	-
Durability aspects (durability against ageing, temperature, corrosion)	6.1.3.3	None	Information on characteristics

Table ZA.1.c

Product: **NON-LINEAR DEVICES** covered by the scope of this standard **Intended use:** In buildings and civil engineering works			
Essential Characteristics	**Requirement clauses in this and other European Standard(s)**	**Levels and/or classes**	**Notes**
Load bearing capacity (compression and tension) (Axial load transmission capability)	6.2.1	None	Design value, in kN
Resistance to seismic loads/shock absorption (Survivability against repeated load cycling)	6.2.1	None	Number of cycles
Shear modulus (Stiffness)	6.2.1	None	Design value, in kN/m
Rotation capability (Re-centring capability)	6.2.1	None	Pass/fail criterion
Friction coefficient (Energy dissipation capability)	6.2.1	None	Information on characteristics
Horizontal distorsion capability (Lateral flexibility)	N/A	None	-
Durability aspects (durability against ageing, temperature, corrosion)	6.2.3.3	None	Information on characteristics

Table ZA.1.d

Product: **VISCOUS DAMPERS** covered by the scope of this standard **Intended use:** In buildings and civil engineering works			
Essential Characteristics	**Requirement clauses in this and other European Standard(s)**	**Levels and/or classes**	**Notes**
Load bearing capacity (compression and tension) (Axial load transmission capability)	N/A	None	-
Resistance to seismic loads/shock absorption (Survivability against repeated load cycling)	7.2.1, 7.2.2, 7.2.3	None	Design value, in kN
Shear modulus (Stiffness)	7.1	None	Design value, in kN
Rotation capability (Re-centring capability)	7.1	None	Design value, in radians
Friction coefficient (Energy dissipation capability)	N/A	None	-
Horizontal distorsion capability (Lateral flexibility)	7.1, 7.2.1	None	
Durability aspects (durability against ageing, temperature, corrosion)	7.1, 7.4.1.7, 7.4.1.8	None	

Table ZA.1.e

Product: **<u>ELASTOMERIC ISOLATORS</u>** covered by the scope of this standard **Intended use:** In buildings and civil engineering works			
Essential Characteristics	**Requirement clauses in this and other European Standard(s)**	**Levels and/or classes**	**Notes**
Load bearing capacity (compression and tension) (Axial load transmission capability)	- 8.1.2.5 - 8.1.2.7 - 8.2.1.6 - 8.3.4.2 - 8.3.4.3 - 8.3.4.4/8.3.4.5	None	Pass/fail criteria Information on characteristics Pass/fail criteria Pass/fail criteria Information on material characteristics and geometry Pass/fail criteria
Resistance to seismic loads/shock absorption (Survivability against repeated load cycling)	N/A		-
Shear modulus (Stiffness)	- 8.1.2.2 - 8.1.2.3 - 8.1.2.4 - 8.2.1.3.6 - 8.2.1.5	None	Information on characteristics Information on characteristics Information on characteristics Pass/fail criteria Pass/fail criteria
Rotation capability (Re-centring capability)	For bridge isolators: - EN 1337-3 clause 4.3.5 - 8.3.4.2	None	Information on characteristics Pass/fail criteria
Friction coefficient (Energy dissipation capability)	N/A		-
Horizontal distorsion capability (Lateral flexibility)	- 8.1.2.6 - 8.2.1.4 - 8.3.4.1 - 8.3.4.2	None	Pass/fail criteria
Durability aspects (Durability against ageing, temperature, corrosion)	- 8.1.2. - 8.2.1.2 For bridge isolators: - EN 1337-3 clause 4.3.4	None	Pass/fail criteria Pass/fail criteria Pass/fail criteria

The requirement on a certain characteristic is not applicable in those Member States (MSs) where there are no regulatory requirements on that characteristic for the intended use of the product. In this case, manufacturers placing their products on the market of these MSs are not obliged to determine nor declare the performance of their products with regard to this characteristic and the option “No performance determined” (NPD) in the information accompanying the CE marking (see ZA.3) may be used. The NPD option may not be used, however, where the characteristic is subject to a threshold level.

ZA.2 Procedure(s) for attestation of conformity of anti-seismic devices

ZA.2.1 System(s) of attestation of conformity

The system(s) of attestation of conformity of anti-seismic devices indicated in Tables ZA.1.a to ZA.1.e, in accordance with the Decision of the Commission 95/467/EC of 1995-10-24 as given in Annex III of the mandate for "Structural bearings", is shown in Table ZA.2 for the indicated intended use(s) and relevant level(s) or class(es):

Table ZA.2 – System(s) of attestation of conformity

Product(s)	Intended use(s)	Level(s) or class(es)	Attestation of conformity system(s)
Anti-seismic devices	In buildings and civil engineering works where requirements on individual devices are critical [a]	None	1
	In buildings and civil engineering works where requirements on individual devices are not critical [b]		3

System 1: See Directive 89/106/EEC (CPD) Annex III.2.(i), without audit testing of samples.

System 3: See Directive 89/106/EEC (CPD) Annex III.2.(ii), Second possibility.

[a] Critical in the sense that those requirements may, in case of failure of the device, put the works or parts thereof in states beyond those regarded as serviceability and ultimate limit states.

[b] Not critical in the sense that those requirements may not, in case of failure of the device and under normal circumstances, put the works or parts thereof in states beyond those regarded as serviceability and ultimate limit states.

The attestation of conformity of the anti-seismic devices in Tables ZA.1.a to ZA.1.e shall be based on the evaluation of conformity procedures indicated in Tables ZA.3.a and ZA.3.b resulting from application of the clauses of this or other European Standard indicated therein.

Table ZA.3.a - Assignment of evaluation of conformity tasks for anti-seismic devices under system 1

<table>
<tr><td colspan="2">Tasks</td><td>Content of the task</td><td>Evaluation of conformity clauses to apply</td></tr>
<tr><td rowspan="4">Tasks under the responsibility of the manufacturer</td><td>Factory production control (FPC)</td><td>Parameters related to all relevant characteristics of Table ZA.1</td><td>10.2</td></tr>
<tr><td>Further testing of samples taken at factory</td><td>All relevant characteristics of Table ZA.1</td><td>10.2</td></tr>
<tr><td>Initial type testing by a notified test lab</td><td>Load bearing capacity (compression and tension) (Axial load transmission capability)
Shear modulus (Stiffness)
Rotation capability (Re-centring capability)
Friction coefficient (Energy dissipation capability)
Horizontal distorsion capability (Lateral flexibility)</td><td>10.2</td></tr>
<tr><td>Initial type testing by the manufacturer</td><td>Resistance to seismic loads/shock absorption (Survavibility against repeated load cycling)
Durability aspects (durability against ageing, temperature, corrosion)</td><td>10.2</td></tr>
<tr><td rowspan="3">Tasks under the responsibility of the product certification body</td><td>Initial type testing</td><td>Load bearing capacity (compression and tension) (Axial load transmission capability)
Shear modulus (Stiffness)
Rotation capability (Re-centring capability)
Friction coefficient (Energy dissipation capability)
Horizontal distorsion capability (Lateral flexibility)</td><td>10.2</td></tr>
<tr><td>Initial inspection of factory and of FPC</td><td>Load bearing capacity (compression and tension) (Axial load transmission capability)
Shear modulus (Stiffness)
Rotation capability (Re-centring capability)
Friction coefficient (Energy dissipation capability)
Horizontal distorsion capability (Lateral flexibility)</td><td>10.2</td></tr>
<tr><td>Continuous surveillance, assessment and approval of FPC</td><td>Load bearing capacity (compression and tension) (Axial load transmission capability)
Shear modulus (Stiffness)
Rotation capability (Re-centring capability)
Friction coefficient (Energy dissipation capability)
Horizontal distorsion capability (Lateral flexibility)</td><td>10.2</td></tr>
</table>

Table ZA.3.b – Assignment of evaluation of conformity tasks for anti-seismic devices under system 3

Tasks		Content of the task	Evaluation of conformity clauses to apply
Tasks under the responsibility of the manufacturer	Factory production control (FPC)	Parameters related to all relevant characteristics of Table ZA.1	10.2
	Initial type testing by the manufacturer	Resistance to seismic loads/shock absorption (Survavibility against repeated load cycling) Durability aspects (durability against ageing, temperature, corrosion)	10.2
	Initial type testing by a notified test laboratory	Load bearing capacity (compression and tension) (Axial load transmission capability) Shear modulus (Stiffness) Rotation capability (Re-centring capability) Friction coefficient (Energy dissipation capability) Horizontal distorsion capability (Lateral flexibility)	10.2

ZA.2.2 EC Certificate and Declaration of conformity

When compliance with the conditions of this annex is achieved, the certification body shall draw up a certificate of conformity (EC Certificate of conformity), which entitles the manufacturer to affix the CE marking.

The certificate shall include:

— name, address and identification number of the certification body;

— name and address of the manufacturer, or his authorised representative established in the EEA, and place of production;

— description of the product (type, identification, use, ...);

— provisions to which the product conforms (i.e. Annex ZA of this EN);

— particular conditions applicable to the use of the product (e.g. provisions for use under certain conditions);

— the number of the certificate;

— conditions and period of validity of the certificate, where applicable;

— name of, and position held by, the person empowered to sign the certificate.

In addition, the manufacturer shall draw up a declaration of conformity (EC Declaration of conformity) including the following:

- name and address of the manufacturer, or his authorised representative established in the EEA;
- number of the accompanying EC Certificate of conformity;
- name of, and position held by, the person empowered to sign the declaration on behalf of the manufacturer or of his authorised representative.

The above mentioned declaration and certificate shall be presented in the official language or languages of the Member State in which the product is to be used.

ZA.3 CE marking and labelling

The manufacturer or his authorised representative established within the EEA is responsible for the affixing of the CE marking. The CE marking symbol to affix shall be in accordance with Directive 93/68/EC and shall be shown on the anti-seismic device (or when not possible it may be on the accompanying label, the packaging or on the accompanying commercial documents e.g. a delivery note). The following information shall accompany the CE marking symbol:

- identification number of the certification body;
- name or identifying mark and registered address of the producer;
- the last two digits of the year in which the marking is affixed;
- number of the EC Certificate of conformity or factory production control certificate (if relevant);
- reference to this European Standard;
- description of the product: generic name, material, dimensions, … and intended use;
- information on those relevant essential characteristics listed in Table ZA.1.a to ZA.1.e which are to

be declared presented as:

- declared values and, where relevant, level or class (including “pass” for pass/fail requirements, where necessary) to declare for each essential characteristic as indicated in "Notes" in Table ZA.1.a to ZA.1.e;
- “No performance determined” for characteristics where this is relevant;
- as an alternative, a standard designation which shows some or all of the relevant characteristics (where the designation covers only some characteristics, it will need to be supplemented with declared values for other characteristics as above.

The “No performance determined” (NPD) option may not be used where the characteristic is subject to a threshold level. Otherwise, the NPD option may be used when and where the characteristic, for a given intended use, is not subject to regulatory requirements in the Member State of destination.

Figure ZA.1 gives an example, for anti-seismic devices under system 1, of the information to be given on the product, label, packaging and/or commercial documents.

CE 01234	*CE conformity marking, consisting of the "CE"-symbol given in Directive 93/68/EEC.* *Identification number of the certification body (where relevant)*
12.3.1 AnyCo Ltd, PO Box 21, B-1050 **04** 01234-CPD-00234	*Name or identifying mark and registered address of the producer* *Last two digits of the year in which the marking was affixed* *Certificate number (where relevant)*
EN XXXX Rigid connection devices **Load bearing capacity, in kN** **Resistance to seismic loads/shock absorption, in kN** **Rotation capability, in radians** **Friction coefficient** **Horizontal distortion capability** **Durability, conforming**	*No. of European Standard* *Description of product* *and* *information on regulated characteristics*

Figure ZA.1 – Example CE marking information

In addition to any specific information relating to dangerous substances shown above, the product should also be accompanied, when and where required and in the appropriate form, by documentation listing any other legislation on dangerous substances for which compliance is claimed, together with any information required by that legislation.

NOTE European legislation without national derogations need not be mentioned.

Bibliography

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

[2] EN 1998-2, Eurocode 8: Design of structures for earthquake resistance - Part 2: Bridges (will replace ENV 1998-2:1994)

[3] EN 1998-3, Eurocode 8: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings (will replace ENV 1998-1-4:1996)

[4] EN 1998-4, Eurocode 8: Design of structures for earthquake resistance - Part 4: Silos, tanks and pipelines

[5] EN 1998-5, Eurocode 8: Design of structures for earthquake resistance - Part 5: Foundations, retaining structures and geotechnical aspects

[6] EN 1998-6, Eurocode 8: Design of structures for earthquake resistance - Part 6: Towers, masts and chimneys

[7] EN 1337-1, Structural bearings - Part 1: General design rules

[8] EN 1337-2, Structural bearings - Part 2: Sliding elements

[9] EN 1337-4, Structural bearings - Part 4: Roller bearings

[10] EN 1337-6, Structural bearings - Part 6: Rocker bearings

[11] EN 1337-7, Structural bearings - Part 7: Spherical and cylindrical PTFE bearings

[12] EN 1337-9, Structural bearings - Part 9: Protection

[13] EN 1337-10, Structural bearings - Part 10: Inspection and maintenance

[14] EN 1337-11, Part 11: Transport, storage and installation

[15] EN 1337-3, Structural bearings - Part 3: Elastomeric bearings

[16] EN 1337-5, Structural bearings - Part 5: Pot bearings

[17] pr EN 1337-8, Structural bearings - Part 8: Guide bearings and restrain bearings