INTERNATIONAL STANDARD

ISO 22762-1

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Elastomeric seismic-protection isolators —

Part 1:
Test methods

Appareils d'appuis structuraux en élastomère pour protection sismique —

Partie 1: Méthodes d'essai

Reference number
ISO 22762-1:2010(E)

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Tel. + 41 22 749 01 11
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 22762-1 was prepared by Technical Committee ISO/TC 45, *Rubber and rubber products*, Subcommittee SC 4, *Products (other than hoses)*.

This second edition cancels and replaces the first edition (ISO 22762-1:2005), which has been technically revised. It also incorporates the Technical Corrigendum ISO 22762-1:2005/Cor.1:2006.

ISO 22762 consists of the following parts, under the general title *Elastomeric seismic-protection isolators*:

- *Part 1: Test methods*
- *Part 2: Applications for bridges — Specifications*
- *Part 3: Applications for buildings — Specifications*

Introduction

ISO 22762 (all parts) consists of two parts related to specifications for isolators, i.e. ISO 22762-2 for bridges and ISO 22762-3 for buildings. This is because the isolator requirements for bridges and for buildings are quite different, although the basic concept of the two products is similar. Therefore, ISO 22762-2 and the relevant clauses in this part of ISO 22762 are used when ISO 22762 (all parts) is applied to the design of bridge isolators, whereas ISO 22762-3 and the relevant clauses of this part of ISO 22762 are used when it is applied to building isolators.

The main differences to be noted between isolators for bridges and isolators for buildings are the following.

a) Isolators for bridges are mainly rectangular in shape and those for buildings are circular in shape.

b) Isolators for bridges are designed to be used for both rotation and horizontal displacement, while isolators for buildings are designed for horizontal displacement only.

c) Isolators for bridges are designed to perform on a daily basis to accommodate length changes of bridges caused by temperature changes as well as during earthquakes, while isolators for buildings are designed to perform only during earthquakes.

d) Isolators for bridges are designed to withstand dynamic loads caused by vehicles on a daily basis as well as earthquakes, while isolators for buildings are mainly designed to withstand dynamic loads caused by earthquakes only.

For structures other than buildings and bridges (e.g. tanks), the structural engineer uses either ISO 22762-2 or ISO 22762-3, depending on the requirements of the structure.

INTERNATIONAL STANDARD **ISO 22762-1:2010(E)**

Elastomeric seismic-protection isolators —

Part 1:
Test methods

1 Scope

This part of ISO 22762 specifies the test methods for determination of

a) the properties of the rubber material used to manufacture the elastomeric seismic isolators, and

b) the characteristics of elastomeric seismic isolators.

It is applicable to elastomeric seismic isolators used to provide buildings or bridges with protection from earthquake damage. The isolators covered consist of alternate elastomeric layers and reinforcing steel plates which are placed between a superstructure and its substructure to provide both flexibility for decoupling structural systems from ground motion, and damping capability to reduce displacement at the isolation interface and the transmission of energy from the ground into the structure at the isolation frequency.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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 812, *Rubber, vulcanized or thermoplastic — Determination of low-temperature brittleness*

ISO 813, *Rubber, vulcanized or thermoplastic — Determination of adhesion to a rigid substrate — 90 degree peel method*

ISO 815-1, *Rubber, vulcanized or thermoplastic — Determination of compression set — Part 1: At ambient or elevated temperatures*

ISO 815-2, *Rubber, vulcanized or thermoplastic — Determination of compression set — Part 2: At low temperatures*

ISO 1431-1, *Rubber, vulcanized or thermoplastic — Resistance to ozone cracking — Part 1: Static and dynamic strain testing*

ISO 1827, *Rubber, vulcanized or thermoplastic — Determination of shear modulus and adhesion to rigid plates — Quadruple-shear methods*

ISO 3387, *Rubber — Determination of crystallization effects by hardness measurements*

ISO 4664-1, *Rubber, vulcanized or thermoplastic — Determination of dynamic properties — Part 1: General guidance*

ISO 7500-1:2004, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system*

ISO 7619-2, *Rubber, vulcanized or thermoplastic — Determination of indentation hardness — Part 2: IRHD pocket meter method*

ISO 11346:2004, *Rubber, vulcanized or thermoplastic — Estimation of life-time and maximum temperature of use*

ISO 22762-2, *Elastomeric seismic-protection isolators — Part 2: Applications for bridges — Specifications*

ISO 22762-3, *Elastomeric seismic-protection isolators — Part 3: Applications for buildings — Specifications*

ISO 23529, *Rubber — General procedures for preparing and conditioning test pieces for physical test methods*

3 Terms and definitions

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

3.1
breaking
rupture of elastomeric isolator due to compression (or tension)-shear loading

3.2
buckling
state when elastomeric isolators lose their stability under compression-shear loading

3.3
compressive properties of elastomeric isolator
K_v
compressive stiffness for all types of rubber bearings

3.4
compression-shear testing machine
machine used to test elastomeric isolators, which has the capability of shear loading under constant compressive load

3.5
cover rubber
rubber wrapped around the outside of inner rubber and reinforcing steel plates before or after curing of elastomeric isolators for the purposes of protecting the inner rubber from deterioration due to oxygen, ozone and other natural elements and protecting the reinforcing plates from corrosion

3.6
design compressive stress
long-term compressive force on the elastomeric isolator imposed by the structure

3.7
effective loaded area
area sustaining vertical load in elastomeric isolators, which corresponds to the area of reinforcing steel plates

3.8
effective width

⟨rectangular elastomeric isolator⟩ the smaller of the two side lengths of inner rubber to which direction shear displacement is not restricted

3.9
elastomeric isolator

rubber bearing, for seismic isolation of buildings, bridges and other structures, which consists of multi-layered vulcanized rubber sheets and reinforcing steel plates

EXAMPLE High-damping rubber bearings, linear natural rubber bearings and lead rubber bearings.

3.10
first shape factor

ratio of effectively loaded area to free deformation area of one inner rubber layer between steel plates

3.11
high-damping rubber bearing

HDR

elastomeric isolator with relatively high damping properties obtained by special compounding of the rubber and the use of additives

3.12
inner rubber

rubber between multi-layered steel plates inside an elastomeric isolator

3.13
lead rubber bearing

LRB

elastomeric isolator whose inner rubber with a lead plug or lead plugs press fitted into a hole or holes of the isolator body to achieve damping properties

3.14
linear natural rubber bearing

LNR

elastomeric isolator with linear shear force-deflection characteristics and relatively low damping properties, fabricated using natural rubber

NOTE Any bearing with relatively low damping can be treated as an LNR bearing for the purposes of isolator testing.

3.15
maximum compressive stress

peak stress acting briefly on elastomeric isolators in compressive direction during an earthquake

3.16
nominal compressive stress

long-term stress acting on elastomeric isolators in compressive direction as recommended by the manufacturer for the isolator, including the safety margin

3.17
roll-out

instability of an isolator with either dowelled or recessed connection under shear displacement

3.18
routine test

test for quality control of the production isolators during and after manufacturing

3.19
second shape factor

⟨circular elastomeric isolator⟩ ratio of the diameter of the inner rubber to the total thickness of the inner rubber

3.20
second shape factor
⟨rectangular or square elastomeric isolator⟩ ratio of the effective width of the inner rubber to the total thickness of the inner rubber

3.21
shear properties of elastomeric isolators
comprehensive term that covers characteristics determined from isolator tests:

— shear stiffness, K_h, for LNR;

— shear stiffness, K_h, and equivalent damping ratio, h_eq, for HDR and LRB;

— post-yield stiffness, K_d, and characteristic strength, Q_d, for LRB

3.22
structural engineer
engineer who is in charge of designing the structure for base-isolated bridges or buildings and is responsible for specifying the requirements for elastomeric isolators

3.23
type test
test for verification either of material properties and isolator performances during development of the product or that project design parameters are achieved

3.24
ultimate property
property at either buckling, breaking, or roll-out of an isolator under compression-shear loading

3.25
ultimate property diagram
UPD
diagram giving the interaction curve of compressive stress and buckling strain or breaking strain of an elastomeric isolator

4 Symbols and cross-section of isolator

4.1 Symbols

For the purposes of this document, the symbols given in Table 1 apply.

Table 1 — Symbols and descriptions

Symbol	Description
A	effective plan area; plan area of elastomeric isolator, excluding cover rubber portion
A_b	effective area of bolt
A_e	overlap area between the top and bottom elastomer area of isolator
A_free	load-free area of isolator
A_load	loaded area of isolator
A_p	area of the lead plug for a lead rubber bearing
a	side length of square elastomeric isolator, excluding cover rubber thickness, or length in longitudinal direction of rectangular isolator, excluding cover rubber thickness
a_e	length of the shorter side of the rectangular isolator, including cover rubber thickness

Table 1 (*continued*)

Symbol	Description
a'	length in longitudinal direction of the rectangular isolator, including cover rubber thickness
B	effective width for bending of flange
b	length in transverse direction of the rectangular isolator, excluding cover rubber thickness
b'	length in transverse direction of the rectangular isolator, including cover rubber thickness
c	distance from centre of bolt hole to effective flange section
D'	outer diameter of circular isolator, including cover rubber
D_f	diameter of flange
d_i	inner diameter of reinforcing steel plate
d_k	diameter of bolt hole
d_0	outer diameter of reinforcing steel plate
E_ap	apparent Young's modulus of bonded rubber layer
E_c	apparent Young's modulus corrected, if necessary, by allowing for compressibility
E_c^s	apparent Young's modulus corrected for bulk compressibility depending on its shape factor (S_1)
E_∞	bulk modulus of rubber
E_0	Young's modulus of rubber
F_u	tensile force on isolator by uplift
G	shear modulus
$G_\mathrm{eq}(\gamma)$	equivalent linear shear modulus at shear strain
H	height of elastomeric isolator, including mounting flange
H_n	height of elastomeric isolator, excluding mounting flange
h_eq	equivalent damping ratio
$h_\mathrm{eq}(\gamma)$	equivalent damping ratio as a function of shear strain
K_d	post-yield stiffness (tangential stiffness after yielding of lead plug) of lead rubber bearing
K_h	shear stiffness
K_i	initial shear stiffness
K_p	shear stiffness of lead plug inserted in lead rubber bearing
K_r	shear stiffness of lead rubber bearing before inserting lead plug
K_t	tangential shear stiffness
K_v	compressive stiffness
L_f	length of one side of a rectangular flange
M	resistance to rotation
M_f	moment acting on bolt
M_r	moment acting on isolator
n	number of rubber layers
n_b	number of fixing bolts
P	compressive force
P_0	design compressive force
P_max	maximum compressive force
P_min	minimum compressive force
Q	shear force

Table 1 (*continued*)

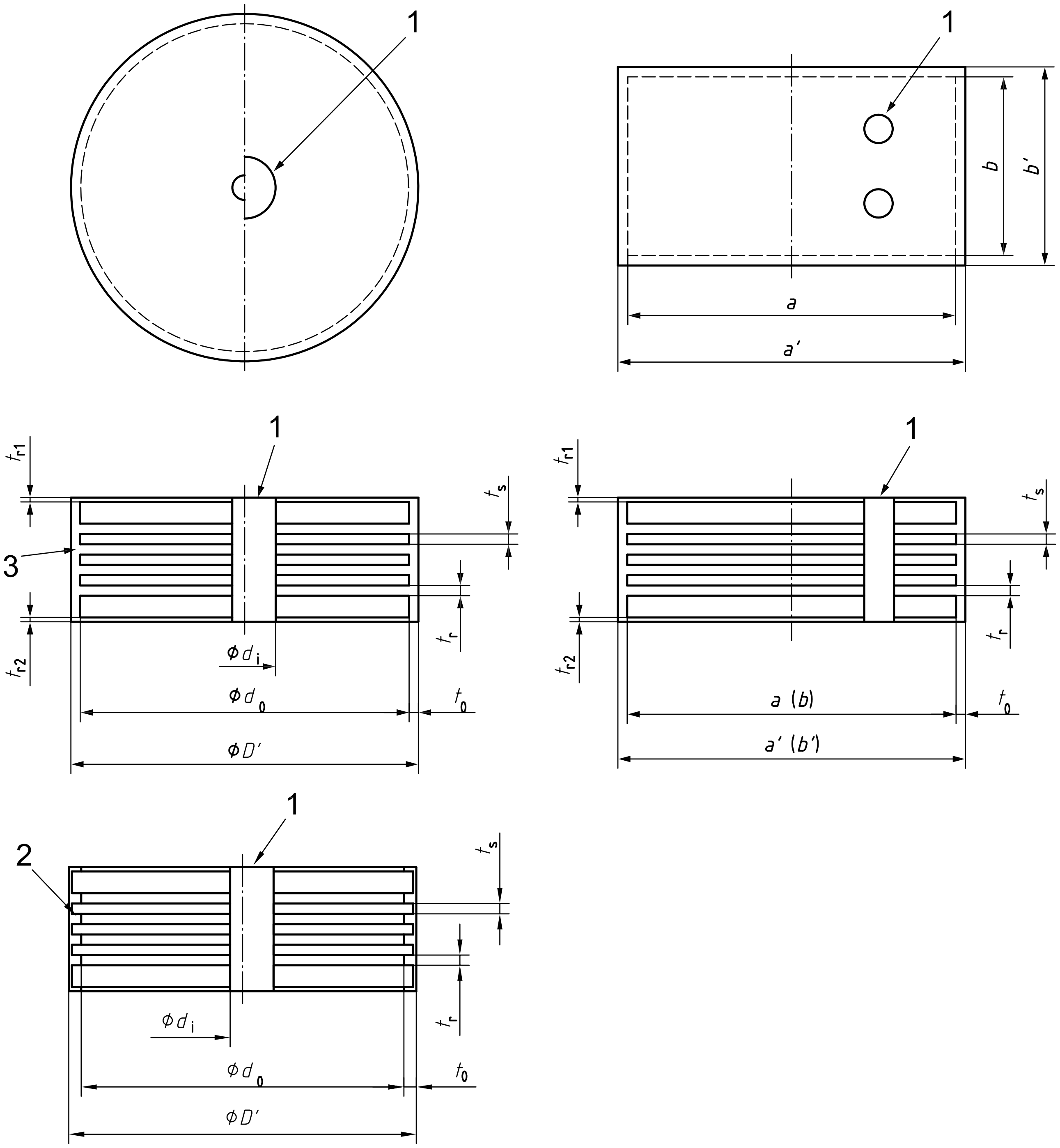
Symbol	Description
Q_b	shear force at break
Q_buk	shear force at buckling
Q_d	characteristic strength
S_1	first shape factor
S_2	second shape factor
T	temperature
T_L	minimum temperature
T_0	standard temperature, 23 °C or 27 °C; where specified tolerance is ± 2 °C, it is standard laboratory temperature
T_r	total rubber thickness, given by $T_\mathrm{r} = n \times t_\mathrm{r}$
t_r	thickness of one rubber layer
t_r1, t_r2	thickness of rubber layer laminated on each side of plate
t_s	thickness of one reinforcing steel plate
t_0	thickness of outside cover rubber
$U(\gamma)$	function giving ratio of characteristic strength to maximum shear force of a loop
V	uplift force
v	loading velocity
W_d	energy dissipated per cycle
X	shear displacement
X_0	design shear displacement
X_b	shear displacement at break
X_buk	shear displacement at buckling
X_s	shear displacement due to quasi-static shear movement
X_max	maximum shear displacement
X_d	shear displacement due to dynamic shear movement
Y	compressive displacement
Z	section modulus of flange
α	coefficient of linear thermal expansion
γ	shear strain
γ_0	design shear strain
γ_a	upper limit of the total of design strains on elastomeric isolators
γ_b	shear strain at break
γ_c	local shear strain due to compressive force
γ_d	shear strain due to dynamic shear movement
γ_max	maximum design shear strain during earthquake
γ_r	local shear strain due to rotation
γ_s	shear strain due to quasi-static shear movement
γ_u	ultimate shear strain
δ_H	horizontal offset of isolator
δ_v	difference in isolator height measured between two points at opposite extremes of the isolator

Table 1 (*continued*)

Symbol	Description
ε	compressive strain of rubber
$\varepsilon_{\mathrm{cr}}$	creep strain
ε_{T}	tensile strain of isolator
$\varepsilon_{\mathrm{Tb}}$	tensile-break strain of isolator
$\varepsilon_{\mathrm{Ty}}$	tensile-yield strain of isolator
ζ	ratio of total height of rubber and steel layers to total rubber height
θ	rotation angle of isolator about the diameter of a circular bearing or about an axis through a rectangular bearing
θ_{a}	rotation angle of isolator in the longitudinal direction (a)
θ_{b}	rotation angle of isolator in the transverse direction (b)
λ	correction factor for calculation of stress in reinforcing steel plates
η	correction factor for calculation of critical stress
κ	correction factor for apparent Young's modulus according to hardness
$\Sigma\gamma$	total local shear strain
σ	compressive stress in isolator
σ_0	design compressive stress
σ_{B}	tensile stress in bolt
σ_{b}	bending stress in flange
σ_{bf}	allowable bending stress in steel
σ_{cr}	critical stress in isolator
σ_{f}	allowable tensile stress in steel
σ_{max}	maximum design compressive stress
σ_{min}	minimum design compressive stress
σ_{nom}	for building: nominal long-term compressive stress recommended by manufacturer
σ_{s}	tensile stress in reinforcing steel plate
σ_{sa}	allowable tensile stress in steel plate
σ_{sy}	yield stress of steel for flanges and reinforcing steel plates
σ_{su}	tensile strength of steel for flanges and reinforcing steel plates
σ_{t}	tensile stress
σ_{te}	allowable tensile stress in isolator
τ_{B}	shear stress in bolt
τ_{f}	allowable shear stress in steel
ϕ	factor for computation of buckling stability
ξ	factor for computation of critical stress

4.2 Cross-section of isolator

A typical cross-section of the isolator is given in Figure 1.



NOTE The left-hand side of the figure shows LNR and HDR, shows LRB.

NOTE The right-hand side of the figure shows LNR and HDR, shows LRB.

a) Circular type

b) Rectangular type

Key

1 lead plug

2 cover rubber added after isolator cured

3 cover rubber cured with insulator

Figure 1 — Cross-section of isolator

5 Rubber material tests

5.1 Test items

In order to assure the required quality of elastomeric isolators, it is necessary to specify the physical properties of the rubber materials and the adhesion between the rubber and the steel plates. The basic properties of rubber materials related to performance of elastomeric isolators are shown as test items in Table 2.

Table 2 — Test items of rubber materials

Property	Test item	Related International Standard
Tensile properties	Tensile strength	ISO 37
	Elongation at break	
	100 % modulus	
Ageing properties	Tensile strength	ISO 188 ISO 37
	Elongation at break	
	100 % modulus	
Hardness	Hardness	ISO 48 ISO 7619-2
Adhesion	90° peel strength between metal and rubber Classification of fracture mode	ISO 813
Compression set	Compression set	ISO 815-1 ISO 815-2
Shear properties	Shear modulus	ISO 4664-1
	Equivalent damping ratio	
	Temperature dependence of shear modulus and equivalent damping ratio	
	Repeated deformation dependence of shear modulus and equivalent damping ratio	
	Fracture strength	ISO 1827
	Fracture strain	
Brittleness point	Brittleness temperature	ISO 812
Ozone resistance	Inspection of deterioration	ISO 1431-1 (static strain test)
Low-temperature crystallization	Hardness	ISO 3387

5.2 Test conditions and test pieces

The temperature and humidity in the laboratory, the preparation of test pieces, and methods for measuring thickness and width, etc., shall be in accordance with ISO 23529.

Moulded test pieces shall be used. They shall be cured to have properties as similar as practicable to the rubber in the bulk of the isolator.

5.3 Tensile properties

The tensile test should be carried out by the method specified in ISO 37. However, the test piece specified in Table 3 can be used as an alternative.

Table 3 — Test piece dimensions

Dimensions in millimetres

Width of parallel-sided section	Length of parallel-sided section	Thickness of parallel-sided section	Distance between marked lines
5 ± 0,1	20	2,0 ± 0,2	20

5.4 Ageing test

5.4.1 Ageing properties of inner rubber

5.4.1.1 Anaerobic ageing

A set of ageing tests shall be performed on the inner rubber under anaerobic conditions, as described in Annex A. The properties monitored shall be either 100 % shear modulus and shear failure strain or the tensile properties — 100 % modulus, tensile strength and elongation at break. From the results of these tests, the activation energy is obtained based on the method specified in Annex A. Ageing conditions equivalent to the expected lifetime (60 years or the period specified by the structural engineer) at 23 °C or 27 °C shall be determined from this activation energy. An ageing test shall then be performed for the properties monitored under conditions equivalent to the expected lifetime.

5.4.1.2 Air ageing

An ageing test shall be performed on the inner rubber in accordance with the method specified in ISO 188, monitoring the tensile strength and elongation at break. The test time and temperature shall be as specified in ISO 22762-2 or ISO 22762-3.

5.4.2 Ageing properties of cover rubber

An ageing test shall be performed on the cover rubber in accordance with the method specified in ISO 188, monitoring the tensile strength and elongation at break. The test time and temperature shall be as specified in ISO 22762-2 or ISO 22762-3.

5.5 Hardness

Hardness shall be measured in accordance with the method specified in ISO 48 or ISO 7619-2.

5.6 Adhesion

An adhesion test shall be carried out as specified in ISO 813.

5.7 Compression set

Compression set shall be determined in accordance with the method specified in ISO 815-1 and ISO 815-2. The test piece shall be either a large-type or small-type cylindrical disc. Test conditions and requirements shall be as specified in ISO 22762-2 or ISO 22762-3.

5.8 Dynamic shear properties

5.8.1 General

These tests shall be carried out as specified in ISO 4664-1, except for the test piece and analysis of test results, in order to investigate the temperature, frequency, strain and repeated deformation dependence of the shear modulus and equivalent damping ratio of rubber materials.

5.8.2 Test equipment

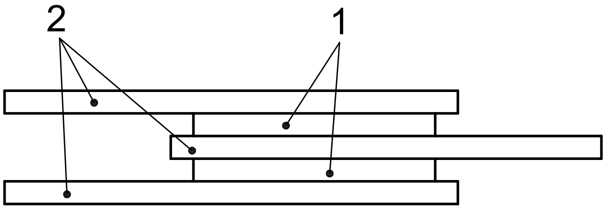
An apparatus, as described in ISO 4664-1, which can measure vibration frequencies higher than 0,2 Hz and shear strain amplitudes up to 400 % shall be used.

5.8.3 Test pieces

The shape and dimensions of the test pieces are different from those specified in ISO 4664-1. Use either of the test pieces specified below. Each test shall be performed on a previously unused test piece except when indicated otherwise.

a) Two-block lap shear type

As shown in Figure 2, this test piece consists of two rubber blocks bonded to three plates of metal. The size of one rubber block shall be 3,0 mm to 6,0 mm thick, 25 mm to 30 mm wide, and 25 mm to 30 mm long for a square pillar, or 3,0 mm to 6,0 mm thick and 25 mm to 30 mm in diameter for a cylindrical disc.



Key

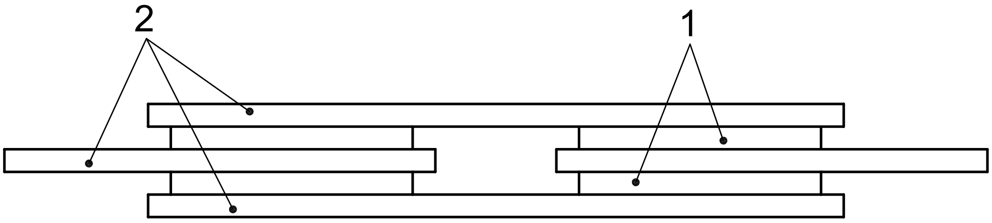
1 rubber

2 metal plate

Figure 2 — Two-block lap shear type

b) Four-block lap shear type

As shown in Figure 3, this test piece consists of four rubber blocks bonded to four plates of metal. The size of one rubber block shall be 3,0 mm to 6,0 mm thick, 25 mm to 30 mm wide, and 25 mm to 30 mm long for a square pillar, or 3,0 mm to 6,0 mm thick and 25 mm to 30 mm in diameter for a cylindrical disc.



Key

1 rubber

2 metal plate

Figure 3 — Four-block lap shear type

5.8.4 Test conditions

5.8.4.1 Test temperature

Test temperatures shall at least cover the range of service requirements. The values given in Table 4 shall be included if they are within the service range. As a minimum requirement, tests shall be performed at one frequency (0,2 Hz, 0,3 Hz or 0,5 Hz or the isolation frequency) and at one strain amplitude (100 %, 175 % or the design shear strain). Tests at more than one temperature may be carried out using one test piece, provided the tests are at one frequency and one strain amplitude, and that they are conducted in order of decreasing temperature. The tolerance shall be ± 2 °C for all temperatures.

Table 4 — Test temperatures

Test temperature °C	−20	−10	0	23 or 27	40

5.8.4.2 Frequency

The test frequencies shall be one of the sets given in Table 5, except that the isolation frequency, if known, may replace the one closest to it in the table. If the dynamic property tests of the isolators are performed at a lower frequency, this test shall also be carried out at that same frequency. As a minimum requirement, tests shall be performed at 23 °C or 27 °C and at one strain amplitude (100 %, 175 % or the design shear strain).

Tests at more than one frequency may be carried out using one test piece, provided the tests are at one temperature and one strain amplitude, and they are conducted in order of increasing frequency.

Table 5 — Vibration frequencies

Vibration frequency Hz	Set 1	0,05	0,2	1,0
	Set 2	0,05	0,3	1,5
	Set 3	0,1	0,5	2,0

5.8.4.3 Shear strain

The shear strains shall be selected from Table 6. The shear strains shown in Table 6 differ from those specified in ISO 4664-1. It is recommended that the four ranges 5 %, 10 %, 50 %, and 100 % be selected from them. The test strains shall range from 5 % to at least 1,5 times the design shear strain. As a minimum requirement, tests shall be performed at one frequency (0,2 Hz, 0,3 Hz, 0,5 Hz or the isolation frequency) and at 23 °C or 27 °C. One test piece may be used to cover a range of strains, provided the strain intervals are at least 50 % or a factor of 2, whichever is the lower; the tests are at one temperature and one frequency and they are carried out in order of increasing strain.

Table 6 — Shear strains

Shear strain %	± 5	± 10	± 25	± 50	± 75	± 100	± 150	± 175	± 200	± 250	± 300	± 350	± 400

5.8.4.4 Number of cycles

The number of loading cycles shall be either 3 cycles or 11 cycles, and should be consistent with that of the isolator tests.

5.8.5 Test results

The shear modulus and equivalent damping ratio shall be reported using the method specified in 6.2.2.6.

5.9 Fracture properties

A failure test shall be carried out as specified in ISO 1827. However, test pieces as specified in 5.8.3 shall be used.

5.10 Brittleness point

A brittleness temperature test shall be carried out as specified in ISO 812.

5.11 Ozone resistance

An ozone resistance test shall be carried out as specified in ISO 1431-1 (static strain test).

5.12 Low-temperature crystallization

For elastomers susceptible to low-temperature crystallization (e.g. those compounds based on natural rubber, chloroprene rubber and certain types of ethylene propylene), the resistance to this phenomenon shall be checked by measuring the change in the hardness at low temperature, if the service temperature falls within the range where crystallization can occur. Natural rubber shall be checked if the minimum service temperature, T_L, is < 0 °C, and chloroprene rubber, if the minimum service temperature, T_L, is < 5 °C.

The test shall be conducted in accordance with ISO 3387, except that the test temperature and the duration of the test shall be as specified in this subclause, and a reading shall be taken after 3 h.

The duration and temperature of the test shall be set by the structural engineer in accordance with the service conditions, except that the test temperature for natural rubber shall not be below −25 °C and for chloroprene rubber not below −10 °C. The duration of the test at a particular temperature shall relate to the period over which the minimum daily service temperature may be at or below that temperature. For natural rubber isolators, subjected to the service conditions in Table 7, where the time is the cumulative total for which the isolators are exposed to the specified temperatures without the temperature rising above +10 °C, a test shall be carried out for the time indicated at the test temperature corresponding to the range of the minimum service temperature, as indicated in Table 7.

Table 7 — Service and test conditions for natural rubber

Minimum temperature T_L °C	**Time** days	**Test temperature** ° C	**Test period**
$-10 \leqslant T_L < 0$	t_0	−10	$1{,}5t_0$
$-20 \leqslant T_L < -10$	t_{-10}	−20	$1{,}5t_{-10} + 0{,}1t_0$
$T_L < -20$	t_{-20}	−25	$1{,}5t_{-20} + 0{,}5t_{-10} + 0{,}05t_0$

The time and temperature of test for chloroprene rubber-based isolators shall be based on the service temperature conditions defined in Table 8, where the time is the cumulative total for which the isolators are exposed to the specified temperatures without the temperature rising above +10 °C. A test shall be carried out for the time indicated at the test temperature corresponding to the range of the minimum service temperature as indicated in Table 8.

Table 8 — Service and test conditions for chloroprene rubber

Minimum temperature T_L °C	Time days	Test temperature °C	Test period
$0 \leqslant T_L < 5$	t_5	0	$1{,}5t_5$
$-5 \leqslant T_L < 0$	t_0	-5	$1{,}5t_0 + 0{,}5t_5$
$T_L < -5$	t_{-5}	-10	$1{,}5t_{-5} + 0{,}5t_0 + 0{,}25t_5$

Some elastomers are susceptible to crystallization if the ambient temperature is low over a prolonged period. High-damping compounds of these elastomers can 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 rapid stiffening as the crystallites grow. The nucleation period shortens as the temperature is lowered to that at which the rate of crystallization is highest. The minimum test temperatures specified for natural rubber and chloroprene rubber are those at which the rate of crystallization is highest. To ensure the performance of the isolator is not compromised, it is necessary that the nucleation period not be greatly exceeded during any continuous exposure to low temperatures. Crystallites melt when the ambient temperature of the isolators is raised sufficiently, and thus the effects are completely reversible. If chloroprene rubber is used, crystallization resistant grades should be chosen where low temperature conditions are to be encountered.

NOTE The service temperature can be taken as that occurring at the isolator location averaged over a 24 h period. The bulk of an isolator does not usually experience shorter term fluctuations of temperature. For isolators installed outside, the temperature experienced at the site in a normal year can be used, unless the structure is regarded as critically important.

6 Isolator tests

6.1 General

In order to assure the required quality of elastomeric isolators, it is necessary to specify the functional requirements. The basic properties of elastomeric isolators are shown as test items in Table 9.

When the same test piece is used for several tests, it shall be noted if the performance is influenced by repetition.

NOTE Some of these properties can be determined using one of the standard test pieces detailed in Tables 10 and 11. The standard test piece is used for non-specific product testing, such as testing for the development of new materials and products.

6.2 Compression and shear stiffness tests

6.2.1 Compression properties

6.2.1.1 Principle

By measuring the compressive force and displacement, the compression stiffness and compression behaviour of the elastomeric isolator can be determined.

6.2.1.2 Test machine

The machine shown schematically in Figure 4 shall be capable of compressing the elastomeric isolator under controlled conditions. It shall also provide a method of measuring the compressive force and compressive displacement to an accuracy of less than or equal to 1 % of the maximum values recorded. The force calibration shall be based on ISO 7500-1. The machine shall maintain the parallelism of the upper and lower loading platens for the test piece attachment during the test. A Class 1 machine, as defined in Clause 7 of ISO 7500-1:2004, is recommended.

In order to accurately measure the displacement of the elastomeric isolator, uniformly place two or more compressive displacement gauges around the test piece (such that they are at the same distance from the test piece as shown in Figure 5). The average of those sensors shall be taken as a measurement value.

Table 9 — Test items for isolators

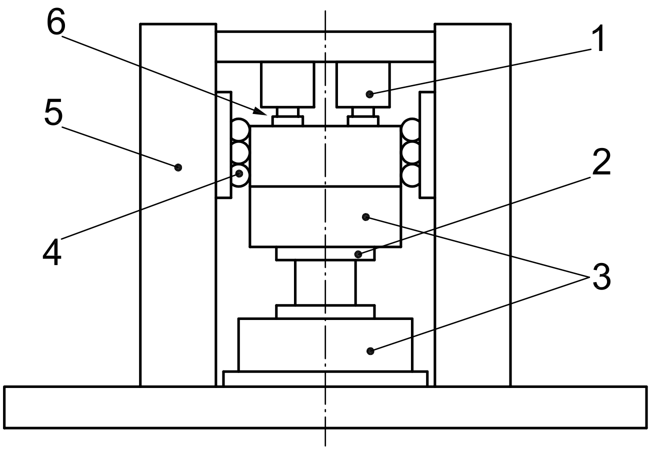
Property	Test item	Subclause
Compression properties	Compression stiffness	6.2.1
	Compression displacement	
Shear properties	Shear stiffness	6.2.2
	Equivalent damping ratio	
	Post-yield stiffness	
	Characteristic strength	
Dependency of shear properties	Shear strain dependency	6.3.1
	Compressive stress dependency	6.3.2
	Frequency dependency	6.3.3
	Repeated loading dependency	6.3.4
	Temperature dependency	6.3.5
Dependency of compressive properties	Shear strain dependency	6.3.6
	Compressive stress dependency	6.3.7
Ultimate shear properties	Breaking displacement (strain), force	6.4
	Buckling displacement (strain), force	
	Roll-out displacement (strain), force	
Tensile properties	Tensile breaking force	6.5
	Tensile yielding force	
	Shear strain	
Durability	Property change by ageing (degradation test)	6.6.1
	Creep	6.6.2
	Property change by fatigue	6.6.3
Force of reaction against low-rate deformation	Shear modulus at low-rate deformation	6.7

Table 10 — Standard test piece (square)

Item		Rubber isolator			Lead rubber isolator		
		No. 1	No. 2	No. 3	No. 1	No. 2	No. 3
Inner steel plate side length, mm	$a \times b$	100 × 100	240 × 240	400 × 400	100 × 100	240 × 240	400 × 400
Number of lead plugs	—	—	—	—	4	4	4
Diameter of lead plug, mm	—	—	—	—	14,5	34,5	57,5
Thickness of a single inner steel plate, mm	t_s	1 to 2	2 to 3	3 to 4	1 to 2	2 to 3	3 to 4
Thickness of a single rubber layer, mm	t_r	2	5	9	2	5	9
Number of rubber layers	n	6	6	6	6	6	6
Thickness of outside cover rubber, mm	t_0	5	5	10	5	5	10

Table 11 — Standard test piece (circle)

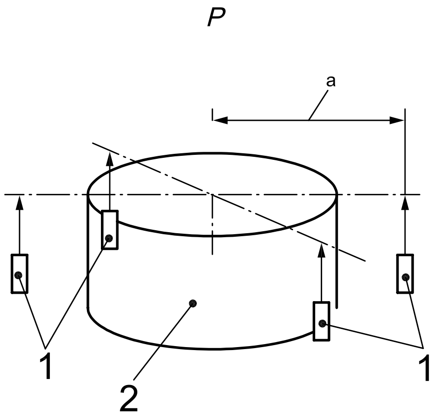
Item		Rubber isolator			Lead rubber isolator		
Inner steel plate outer diameter, mm	d_0	150	250	500	150	250	500
Inner steel plate inner diameter (diameter of lead plug), mm	d_i	7,5	12,5	25	30	50	100
Thickness of a single inner steel plate, mm	t_s	1 to 2	2 to 3	3 to 4	1 to 2	2 to 3	3 to 4
Thickness of a single rubber layer, mm	t_r	1,5	2,0	4,0	1,5	1,8	3,5
Number of rubber layers	n	20	25	25	20	28	28
Thickness of outside cover rubber, mm	t_0	4	6	8	4	6	8



Key

1 actuator
2 test piece
3 upper and lower loading platens
4 bearing
5 frame
6 compression force load cell

Figure 4 — Example of compression testing machine



Key

P compressive force
1 displacement gauge
2 test piece

[a] The distance from the core of the laminated body to each displacement gauge shall be constant.

Figure 5 — Compression displacement measurement sensor

6.2.1.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.2.1.4 Test conditions

6.2.1.4.1 Test temperature

The temperature of the laboratory should preferably be in accordance with ISO 23529. When the test is conducted at another temperature, the test temperature shall be recorded.

6.2.1.4.2 Conditioning time for test piece

Test pieces < 250 mm thick shall be left for at least 24 h after vulcanization. Thicker isolators shall be left for at least 48 h.

Before a test, the test piece shall be left for 6 h to 24 h or longer in the environment where the test machine is located, and the temperature of the surface of the test piece shall be recorded. The conditioning time shall be chosen such that the temperature of the test piece is the same as the environment.

6.2.1.4.3 Compressive force used in test

The maximum compressive force shall be specified by the structural engineer. If a standard test piece is employed, it shall be loaded with the compressive force that is equivalent to the design compressive stress, σ_0, as defined in ISO 22762-2 or ISO 22762-3.

The relationship between compressive force and compressive stress is expressed as Equation (1):

$$P = A_{\text{load}} \cdot \sigma \tag{1}$$

The tolerance shall be within ± 5 % of each compressive stress.

6.2.1.4.4 Input wave

The input wave shall be a sine wave or a triangular wave.

6.2.1.4.5 Test vibration frequency

The lowest test vibration frequency shall be 0,001 Hz.

6.2.1.5 Procedure

6.2.1.5.1 Attachment of test piece and compressive displacement gauges

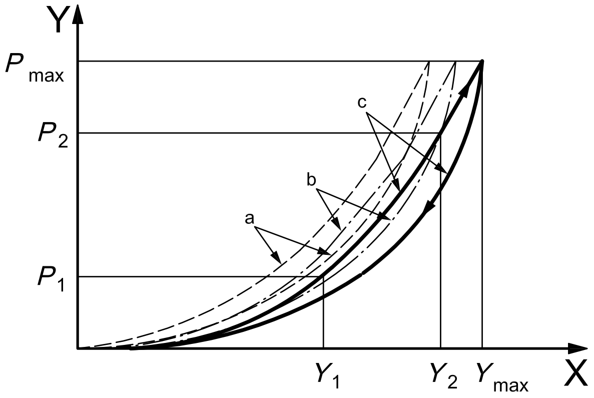
The test piece shall be attached to a test machine by the same or a mechanically equivalent manner as in the actual application. Compressive displacement gauges shall be attached to the periphery of the test piece. The compressive force at this time shall be zero, and the value of the compressive displacement shall be zero. If it is difficult to set a stable zero pressure because of machine controllability, a low arbitrary pressure may be regarded as “zero” by agreement between the structural engineer and the manufacturer.

6.2.1.5.2 Loading

An appropriate loading process shall be chosen to satisfy the requirement of the isolator design. There are two methods.

6.2.1.5.2.1 Method 1 (see Figure 6)

Load the test piece with the maximum design compressive force $P_{\max}$, and then return to a no-load state. This process shall be one cycle. Three such cycles shall be performed.



Key

X compressive displacement, Y
Y compressive force, P

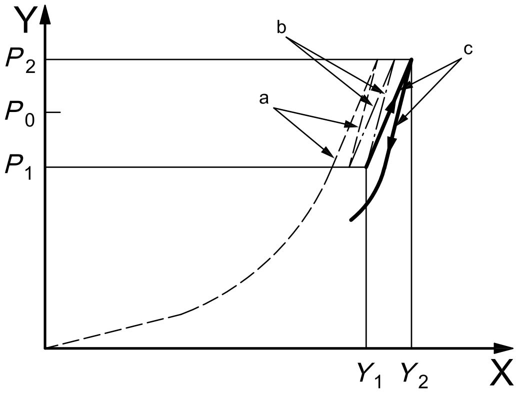
[a] First cycle.
[b] Second cycle.
[c] Third cycle.

Figure 6 — Vertical properties — Method 1

6.2.1.5.2.2 Method 2 (see Figure 7)

Load the test piece with a compressive force, P_0, which is equivalent to the design compressive stress, σ_0.

Load the test piece with three cycles of compressive force between P_2 and P_1, which are equivalent to σ_0 plus/minus a certain per cent (e.g. ± 30 %). The loading sequence shall be as follows: 0, P_0, P_2, P_0, P_1 (first), P_0, P_2, P_0, P_1 (second), P_0, P_2, P_0, P_1 (third). P_2 shall be the maximum design force.



Key

X compressive displacement, Y
Y compressive force, P

[a] First cycle.
[b] Second cycle.
[c] Third cycle.

Figure 7 — Vertical properties — Method 2

A visual check of the test piece shall be conducted during cyclic loading period and any signs of bond failure, surface cracks or other defects, misaligned reinforcing plates or non-uniform corrugations (if visible) due to bulging of rubber layers shall be recorded.

6.2.1.6 Expression of results

The amount of compressive displacement under compressive force shall be measured and the compressive stiffness, K_v, calculated using Equation (2):

$$K_\mathrm{v} = \frac{P_2 - P_1}{Y_2 - Y_1} \tag{2}$$

where (see Figures 6 and 7)

P_1 is the smaller compressive force, expressed in kilonewtons, in the third cycle;

P_2 is the larger compressive force, expressed in kilonewtons, in the third cycle;

Y_1 is the smaller displacement, expressed in millimetres, in the third cycle;

Y_2 is the larger displacement, expressed in millimetres, in the third cycle.

6.2.1.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) compressive force and compressive stress (central value plus larger and smaller values);

g) compression stiffness;

h) result of visual check;

i) plot of vertical force versus vertical displacement;

j) test date.

6.2.2 Compressive-shear test

6.2.2.1 Principle

A test piece is loaded with a constant compressive force and subjected to a shear displacement. Shear force, shear displacement, compressive force and compressive displacement are measured. From the measured data, shear properties (shear stiffness and equivalent damping ratio) are determined.

The test as described in 6.2.2.2 to 6.2.2.7 shall be the type and routine tests.

6.2.2.2 Test machine

6.2.2.2.1 General

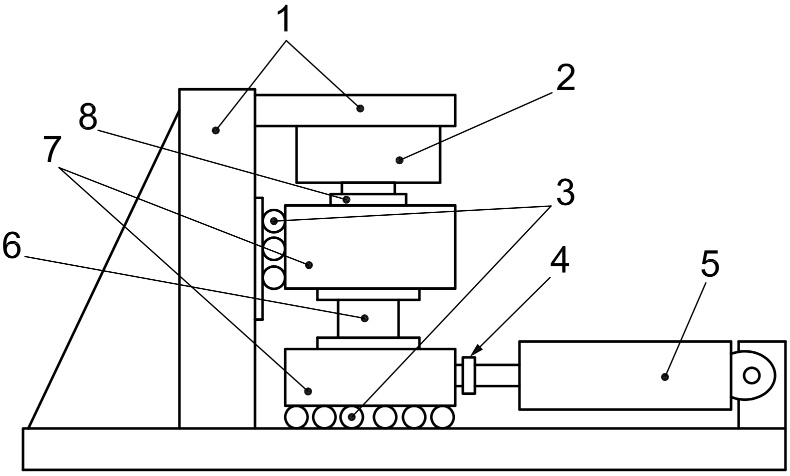
6.2.2.2.1.1 The machines, shown in Figures 8 and 9, shall be capable of compressing and shearing the elastomeric isolator under controlled conditions. They shall also provide a method of measuring the compressive force, compressive displacement, shear force and shear displacement to an accuracy of $\leqslant 1$ % of the maximum values recorded. The force calibration of the machine shall be based on ISO 7500-1. The machines shall maintain the parallelism of the upper and lower loading platens for the test piece attachment during the test. A Class 1 machine, as defined in Clause 7 of ISO 7500-1:2004, is recommended.

6.2.2.2.1.2 Despite the test piece height change, the test machine should keep the compressive force constant or within the specified tolerance which can be regarded as constant during compression-shear testing. Fixed compressive displacement equivalent to the required force may be allowed with the agreement of the structural engineer. The tolerance on fluctuation of the compressive force shall be set by the structural engineer in accordance with the requirements of the isolator and the structure.

6.2.2.2.1.3 The double-shear configuration, simultaneously testing two pieces, is acceptable, provided the compression stiffness of the two isolators is within 20 % of each other. However, it should be kept in mind that only the average performance can be measured in this configuration. Therefore, when the difference of the performance of the two test pieces cannot be ignored, tests with three mixed pairs using three isolators shall be carried out to determine the properties of each individual isolator.

6.2.2.2.1.4 Fragment(s) of a test piece are likely to fly when a test piece fractures. Therefore, it is strongly recommended that a protective barrier be put into place in the shear load direction of the test piece. It is also strongly recommended that barriers, etc., be set up to prevent access to the test machine during a test.

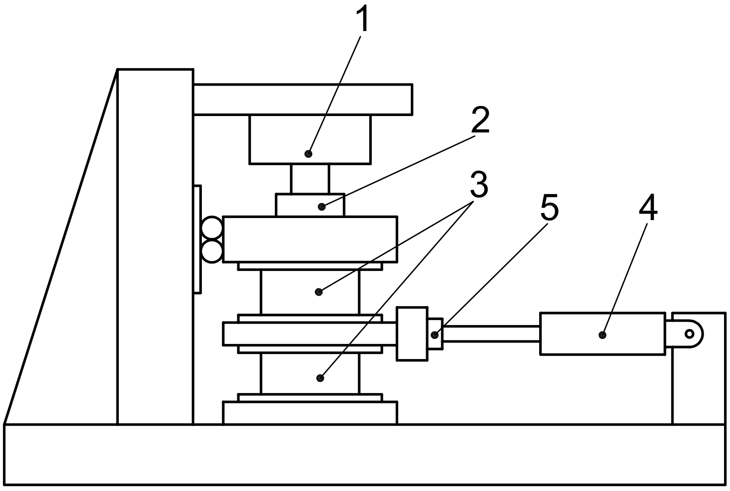
NOTE 10 % is typical tolerance for fluctuation of compressive force.



Key

1 frame
2 actuator
3 bearing
4 shear force load cell
5 actuator
6 test piece
7 upper and lower platens
8 compression load cell

Figure 8 — Compression-shear testing machine — Single isolator



Key

1	actuator
2	compression load cell
3	test piece
4	actuator
5	shear force load cell

Figure 9 — Compression-shear testing machine — Double-shear configuration

6.2.2.2.2 Force correction

6.2.2.2.2.1 The inertia force of the machine in the shear direction shall be measured and corrected (see Annex B).

6.2.2.2.2.2 In a test machine that is structured so as to include the friction force of the sliding mechanism in the measured value of the test force, the friction force shall be measured separately beforehand and shall be corrected for at the time of calculation of the property values (see Annex C for friction force correction).

6.2.2.2.2.3 A load-cell-type sensor is recommended to measure the load force. This is because, when the test machine uses an internal pressure measuring-type sensor that is influenced by the sliding resistance of an actuator, it is necessary to consider the effect of self-weight and calibrate the force in the direction of actual use. When the load cells are installed beneath test pieces, no correction of measured data by eliminating friction force and inertia force is required.

6.2.2.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.2.2.4 Test conditions

6.2.2.4.1 Test temperature

As specified in 6.2.1.4.1.

6.2.2.4.2 Conditioning time for test piece

As specified in 6.2.1.4.2.

6.2.2.4.3 Compressive force

Load the test piece with a compressive force that is equivalent to the design compressive stress or the pressure that has been agreed to by the structural engineer. The average compressive force applied shall be within ± 5 % of that required during the test.

6.2.2.4.4 Test shear strain amplitude

The test shear strain amplitude shall be as defined in ISO 22762-2 or ISO 22762-3. The tolerance shall be within ± 5 % of the target shear strain amplitude.

6.2.2.4.5 Input wave

The input wave shall be a sine wave or a triangular wave. If the shear properties are influenced by the input wave, it shall be selected with the agreement of both the structural engineer and the manufacturer.

6.2.2.4.6 Test vibration frequency

The standard test vibration frequency shall be between 0,001 Hz and the isolation frequency or 0,5 Hz. When any other frequency is used, it shall be selected with the agreement of both the structural engineer and the manufacturer.

6.2.2.5 Procedure

6.2.2.5.1 Attachment of a test piece

The test piece shall be attached to the test machine by the same or a mechanically equivalent manner as in the actual application.

6.2.2.5.2 Loading

The test piece should be loaded as follows.

a) Load the test piece with constant compressive force.

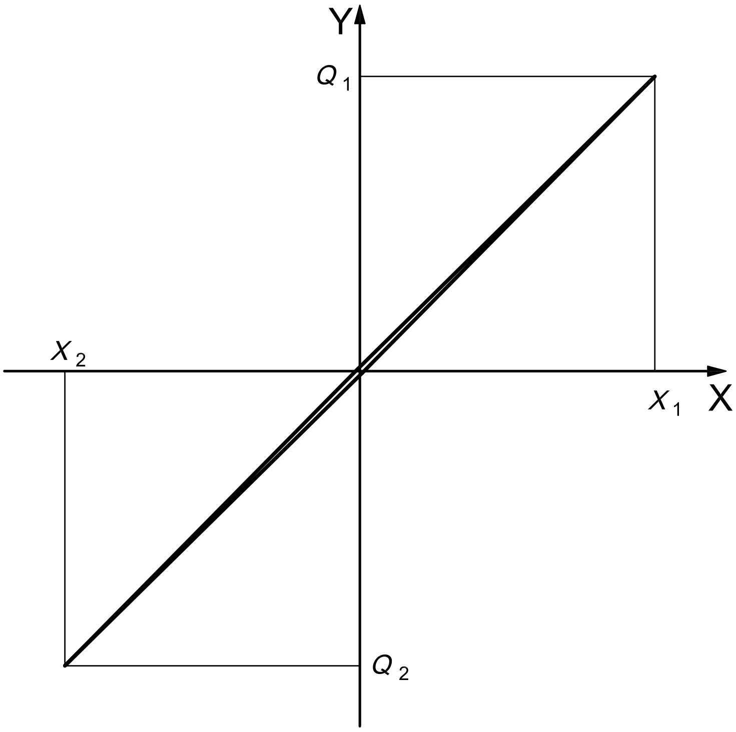
b) Load the test piece with 3 cycles to 11 cycles of the reference shear displacement. The number of cycles shall be specified by the structural engineer.

6.2.2.6 Expression of results

The method used to determine shear properties shall be specified and reported.

The following method describes how to obtain shear properties from one hysteresis loop. The structural engineer shall specify how the shear properties of the isolator are to be calculated. Generally, the third loop or the average of the second to the eleventh loop is used.

An example of a typical hysteresis loop of an LNR isolator is shown in Figure 10, and of an HDR isolator or an LRB isolator in Figure 11.

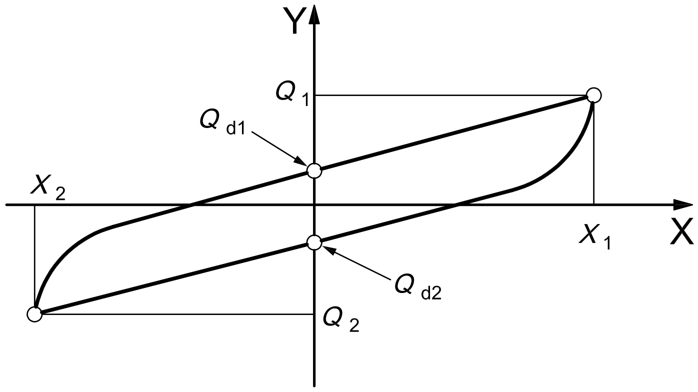


Key

X shear displacement, X

Y shear force, Q

Figure 10 — Determination of shear stiffness for LNR



Key

X shear displacement, X

Y shear force, Q

ΔW = area of hysteresis loop

Figure 11 — Determination of shear properties of LRB and HDR

Shear stiffness, K_h, equivalent damping ratio, h_{eq}, post-yield stiffness, K_d, and characteristic strength, Q_d, are given by the following expressions (for LRB, K_d and Q_d may, alternatively, be determined as shown in Annex F):

$$K_h = \frac{Q_1 - Q_2}{X_1 - X_2} \tag{3}$$

$$h_{eq} = \frac{2 \times \Delta W}{\pi \times K_h (X_1 - X_2)^2} \tag{4}$$

$$K_d = \frac{1}{2} \times \left(\frac{Q_1 - Q_{d1}}{X_1} + \frac{Q_2 - Q_{d2}}{X_2} \right) \tag{5}$$

$$Q_d = \frac{1}{2} \times \left(Q_{d1} - Q_{d2} \right) \tag{6}$$

where

Q_1	is the maximum shear force;
Q_2	is the minimum shear force;
X_1	is the maximum displacement $X_1 = T_r \times \gamma$;
X_2	is the minimum displacement $X_2 = T_r \times (-\gamma)$;
Q_{d1}, Q_{d2}	are the points where the loop crosses the shear-force axis, on the positive and the negative side, respectively;
ΔW	is the area enclosed by the hysteresis loop.

6.2.2.7 Test report

6.2.2.7.1 The test report shall include the following items:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) direction of shear force applied to test piece;

g) compressive force and shear displacement amplitude (or compressive stress and shear strain);

h) essential parameters, such as shear stiffness, equivalent damping ratio, method of determination (e.g. the third loop or the average of the second to the eleventh loop) and post-yield stiffness and characteristic strength in the case of LRB;

i) plot of shear force versus shear displacement (hysteresis loop);

j) test date.

6.2.2.7.2 In addition to 6.2.2.7.1, the following items shall be recorded, if requested.

a) Graph showing the relationship between isolator height reduction and shear displacement.

b) Graph showing the relationship between compressive force and shear displacement.

6.3 Various dependence tests

6.3.1 Strain dependence of shear properties

6.3.1.1 Principle

A test piece is attached to a compression-shear testing machine and subjected to a constant compressive force. In this state, the test piece is subjected to multiple levels of shear displacement. The shear force and the shear displacement are measured. By means of these measurements, the dependence of the shear properties on shear strain (shear stiffness and equivalent damping ratio) is determined.

6.3.1.2 Test machine

As in 6.2.2.2.

6.3.1.3 Test piece

Test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.3.1.4 Test conditions

6.3.1.4.1 Test temperature

As in 6.2.1.4.1.

6.3.1.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.3.1.4.3 Compressive force

As in 6.2.2.4.3.

6.3.1.4.4 Test shear strain amplitudes

Levels of shear strain shall be selected by the structural engineer in accordance with the specifications for elastomeric isolators.

The tolerance shall be within ± 5 % of each shear strain amplitude value.

The sequence of shear loading shall be in the order of increasing strain, considering loading history dependency.

6.3.1.4.5 Input wave

As in 6.2.2.4.5.

6.3.1.4.6 Test vibration frequency

As in 6.2.2.4.6. The test vibration frequency of each shear strain level shall be the same.

6.3.1.5 Procedure

6.3.1.5.1 Attachment of test piece

The test piece shall be attached to a compression-shear testing machine as specified in 6.2.2.5.1.

6.3.1.5.2 Loading of test piece

The test piece shall be loaded as follows.

a) Subject the test piece to a compressive force that is equivalent to the design compressive stress, σ_0.

b) Load the test piece with shear displacements equivalent to each of the shear strain amplitude to be tested. Load the test piece in the order of increasing shear strain, in the number of cycles specified in 6.2.2.5.2 for each shear strain.

6.3.1.6 Expression of results

With the method used in 6.2.2.6, determine each property value for each test shear strain.

6.3.1.7 Test report

The test report shall include the following items:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) direction of shear force applied to test piece;

g) compressive force and shear displacement (or compressive stress and shear strain);

h) essential parameters such as shear stiffness, equivalent damping ratio, method of determination (e.g. the third loop or the average of the second to the eleventh loop);

i) graph showing the relationship between each property and shear strain;

j) graph showing the relationship between compressive force and shear displacement, if requested;

k) plot of shear force versus shear displacement (hysteresis loop);

l) test date.

6.3.2 Compressive force dependence of shear properties

6.3.2.1 Principle

A test piece is attached to a compression-shear testing machine and subjected to multiple levels of constant compressive force. In this state, the test piece is subjected to shear displacement. The shear force, the shear displacement, the compressive force and the compressive displacement are measured. The shear properties such as shear stiffness and equivalent damping ratio are evaluated and their dependence on the compressive force (compressive stress) determined.

6.3.2.2 Test machine

As in 6.2.2.2.

6.3.2.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.3.2.4 Test conditions

6.3.2.4.1 Test temperature

As in 6.2.1.4.1.

6.3.2.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.3.2.4.3 Compressive force

The levels of compressive force, and tensile force, if required, shall be selected by the structural engineer in accordance with the specifications for the isolator.

The tolerance shall be within ± 5 % of each compressive stress.

6.3.2.4.4 Test shear strain amplitude

As in 6.2.2.4.4.

6.3.2.4.5 Input wave

As in 6.2.2.4.5.

6.3.2.4.6 Test vibration frequency

As in 6.2.2.4.6.

6.3.2.5 Procedure

6.3.2.5.1 Attachment of test piece

The test piece shall be attached to a compression-shear testing machine as specified in 6.2.2.5.1.

6.3.2.5.2 Loading of test piece

The test piece shall be loaded as follows.

a) Subject the test piece to the selected test compressive force. The test piece shall be loaded in increasing magnitude of test compressive force.

b) At each test compressive force, load the test piece with 3 cycles or 11 cycles of shear displacement. The number of cycles shall be as specified by the structural engineer.

6.3.2.6 Expression of results

With the method used in 6.2.2.6, determine each property value for each test compressive stress.

6.3.2.7 Test report

6.3.2.7.1 The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) direction of shear force applied to test piece;

g) compressive force and shear displacement amplitude (or compressive stress and shear strain);

h) essential parameters such as shear stiffness, equivalent damping ratio, method of determination (e.g. the third loop or the average of the second to the eleventh) at each compressive stress;

i) graph showing relationship between each property and compressive stress;

j) plot of shear force versus shear displacement (hysteresis loop);

k) test date.

6.3.2.7.2 In addition to the items listed in 6.3.2.7.1, the following items shall be recorded, if requested.

a) Graph showing the relationship between isolator height reduction and shear displacement.

b) Graph showing the fluctuation of the compressive force with shear displacement.

6.3.3 Frequency dependence of shear properties

6.3.3.1 Principle

A test piece is attached to a compression-shear testing machine and subjected to constant compressive force. In this state, the test piece is subjected to shear displacement at multiple levels of frequencies. The shear force, the shear displacement, the compressive force and the compressive displacement are measured. The shear properties, such as shear stiffness and equivalent damping ratio, are evaluated and their dependence on the frequency determined.

The frequency test specified in 5.8.4.2 can be substituted for these tests, with the agreement of both the structural engineer and the manufacturer.

6.3.3.2 Test machine

As in 6.2.2.2.

6.3.3.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.3.3.4 Test conditions

6.3.3.4.1 Test temperature

As in 6.2.1.4.1.

6.3.3.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.3.3.4.3 Compressive force

As in 6.2.2.4.3, except that no compressive force need be applied when a shear block test piece is used.

6.3.3.4.4 Test shear strain amplitude

As in 6.2.2.4.4.

6.3.3.4.5 Input wave

As in 6.2.2.4.5.

6.3.3.4.6 Test vibration frequency

Several test vibration frequencies shall be selected from the seven levels shown in Table 12.

Table 12 — Test frequencies

Frequency Hz	0,001	0,005	0,01	0,1	0,5	1,0	2,0

Testing at the design isolation-frequency may be added to the conditions.

6.3.3.5 Procedure

6.3.3.5.1 Attachment of test piece

The test piece shall be attached to a compression-shear testing machine as specified in 6.2.2.5.1, except that any suitable connection system is permitted when a shear block or standard test piece is used.

6.3.3.5.2 Loading of test piece

The test piece shall be loaded as follows.

a) Subject the test piece to a compressive force, if required, that is equivalent to the design compressive stress, σ_0, as defined in ISO 22762-2 or ISO 22762-3.

b) Load the test piece for 3 cycles to 11 cycles of shear displacement amplitude, for each frequency selected in 6.3.3.4.6. The frequencies shall be applied in increasing order. The number of cycles shall be as specified by the structural engineer.

6.3.3.6 Expression of results

With the method used in 6.2.2.6, determine each property value for each vibration frequency.

The rate of change of each property shall be determined as the ratio of each value to that at the reference frequency. The reference frequency shall be 0,5 Hz or the design isolation frequency.

6.3.3.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) direction of shear force applied to test piece;

g) compressive force and shear displacement (or compressive stress and shear strain);

h) shear strain amplitude;

i) essential parameters such as shear stiffness, equivalent damping ratio, method of determination (e.g. the third loop or the average of the second to the eleventh) at each frequency;

j) graph showing relationship between the rate of change of each property and the vibration frequency;

k) graph showing relationship between compressive force and shear displacement, if requested;

l) plot of shear force versus shear displacement (hysteresis loop), if necessary;

m) test date.

6.3.4 Repeated deformation dependence of shear properties

6.3.4.1 Principle

A test piece is attached to a compression-shear testing machine and loaded with a constant compressive force. In this state, the test piece is subjected to 50 cycles of shear displacement, or for a number of cycles specified by the structural engineer. The shear force and the shear displacement are measured. The shear properties, such as shear stiffness and equivalent damping ratio, are evaluated and their dependence on the number of repetitions determined.

In order to differentiate between the change in properties due to temperature rise and that due to repeated deformation, the test piece is cooled down to the initial pre-load temperature after the repeated cycles of deformation. The shear properties are then evaluated again.

6.3.4.2 Test machine

As in 6.2.2.2.

6.3.4.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.3.4.4 Test conditions

6.3.4.4.1 Test temperature

As in 6.2.1.4.1.

6.3.4.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.3.4.4.3 Compressive force

As in 6.2.2.4.3.

6.3.4.4.4 Test shear strain amplitude

As in 6.2.2.4.4.

6.3.4.4.5 Input wave

As in 6.2.2.4.5.

6.3.4.4.6 Test vibration frequency

As in 6.2.2.4.6.

6.3.4.5 Procedure

6.3.4.5.1 Attachment of test piece

The test piece shall be attached to a compression-shear testing machine as specified in 6.2.2.5.1.

6.3.4.5.2 Loading of test piece

The test piece shall be loaded as follows.

a) Subject the test piece to a compressive force that is equivalent to the design compressive stress, σ_0, as defined in ISO 22762-2 or ISO 22762-3.

b) Subject the test piece with the specified number of 50 cycles of shear displacement.

c) After completion, cool the test piece down to the initial pre-load temperature. Then, load the test piece again with 3 cycles or 11 cycles under the same conditions. The number of cycles shall be as specified by the structural engineer.

6.3.4.6 Expression of results

With the method used in 6.2.2.6, determine each property value from the 1st, 3rd, 5th, 10th, 30th and 50th cycle or as specified by the structural engineer. Determine the reference value of the property from the first 3 cycles or 11 cycles in accordance with 6.2.2. Determine the change in properties after the repeated cycling from the 3 cycles or 11 cycles of loading executed at the end of the test or as specified by the structural engineer.

The change in each property shall be expressed as the ratio of each value to the reference value.

6.3.4.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) direction of shear force applied to test piece;

g) compressive force and shear displacement amplitude (or compressive stress and shear strain);

h) properties, such as shear stiffness and equivalent damping ratio, at each cycle for which they were determined;

i) change in each property with cycling;

j) graph showing relationship between the rate of change of each property and the number of repetitions;

k) graph showing relationship between compressive force and shear displacement, if requested;

l) plots of shear force versus shear displacement (hysteresis loop);

m) test date.

6.3.5 Temperature dependence of shear properties

6.3.5.1 Principle

The test piece is attached to a compression-shear testing machine. The test piece is subjected to constant compressive force. In this state, the test piece is subjected to repeated shear displacement. The shear force and the shear displacement are measured. The shear properties, such as shear stiffness and equivalent damping ratio, are evaluated and their dependence on the change in environmental temperature determined.

The temperature test specified in 5.8.4.1 may be substituted for this test, except for lead rubber bearings, with the agreement of both the structural engineer and the manufacturer.

6.3.5.2 Test machine

As in 6.2.2.2.

6.3.5.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.3.5.4 Test conditions

6.3.5.4.1 Test temperature

The tests shall be conducted at the test temperatures defined in Table 13. The reference temperature shall be set at 23 °C or 27 °C. The tolerance shall be within ± 2 °C. Test temperatures shall at least cover the range of service requirements. When considering the test for a cold district, the test shall be conducted at a temperature lower than −20 °C. Tests shall be conducted in order of decreasing temperature.

If the machine is not equipped with a suitable temperature-controlled chamber, the test piece shall have reached the test temperature in a separate chamber, and shall be transferred to the test machine sufficiently quickly for the test to be conducted while the outside of the bearing satisfies the temperature tolerance of ± 2 °C. The length of time for keeping a test piece at a specific temperature shall be less than that for crystallization nucleation.

Table 13 — Test temperatures

Temperature °C	−20	−10	0	23 (or 27)	40

NOTE Isolators fabricated from elastomer susceptible to low-temperature crystallization might show an additional time-dependent stiffening if held for a prolonged period at low temperature.

6.3.5.4.2 Conditioning time for test piece

The test piece shall be conditioned as specified in 6.2.1.4.2 in a temperature-controlled environment.

6.3.5.4.3 Compressive force

As in 6.3.3.4.3.

6.3.5.4.4 Test shear strain amplitude

As in 6.2.2.4.4.

6.3.5.4.5 Input wave

As in 6.2.2.4.5.

6.3.5.4.6 Test vibration frequency

As in 6.2.2.4.6.

6.3.5.5 Procedure

6.3.5.5.1 Attachment of test piece

As in 6.3.3.5.1.

6.3.5.5.2 Loading of test piece

As specified in 6.3.3.5.2.

6.3.5.6 Expression of results

The dependence of each property, determined by the method used in 6.2.2.6, on the temperature shall be reported.

6.3.5.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22672-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) direction of shear force applied to test piece;

g) compressive force and shear displacement amplitude (or compressive stress and shear strain);

h) essential parameters such as shear stiffness, equivalent damping ratio, method of determination (e.g. the third loop or the average of the second to the eleventh loop) at each temperature;

i) fractional change in each property relative to its value at the reference temperature;

j) graph showing relationship between the normalized value of each property and temperature;

k) graph showing relationship between compressive force and shear displacement, if requested;

l) plots of shear force versus shear displacement (hysteresis loop);

m) test date.

6.3.6 Dependence of compression properties on shear strain

6.3.6.1 Principle

A test piece is subjected to shear displacement and to a compressive force. The compression stiffness is measured.

6.3.6.2 Test machine

As in 6.2.2.2.

6.3.6.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.3.6.4 Test conditions

6.3.6.4.1 Test temperature

As in 6.2.1.4.1.

6.3.6.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.3.6.4.3 Compressive force

As in 6.2.2.4.3.

6.3.6.4.4 Test shear strain

The test piece shall be subjected to constant shear displacement. The shear displacement shall have three levels of shear strain, to be chosen from Table 14 by the structural engineer.

γ_0 in Table 14 is the design shear strain defined in ISO 22762-2 or ISO 22762-3. The tolerance shall be within ± 5 % of each shear strain.

Table 14 — Shear strains

Shear strain %	0	0,5 γ_0	γ_0	1,5 γ_0

If 1,5 γ_0 is larger than γ_{max}, γ_{max} may be selected instead of 1,5 γ_0.

6.3.6.4.5 Input wave

As in 6.2.1.4.4.

6.3.6.4.6 Test vibration frequency

As in 6.2.1.4.5.

6.3.6.5 Procedure

6.3.6.5.1 Attachment of test piece and compressive displacement gauges

As in 6.2.1.5.1.

6.3.6.5.2 Loading

The loading process shall be as follows.

a) Load the test piece with a compressive force that is equivalent to the design compressive stress, σ_0, as defined in ISO 22762-2 or ISO 22762-3.

b) Subject the test piece to the required shear strain.

c) Load the test piece with 3 cycles of compressive force as in 6.2.1.5.2.

6.3.6.6 Expression of results

As in 6.2.1.6.

At each shear strain, determine the fractional change in compression stiffness relative to the stiffness at zero shear strain.

6.3.6.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) compressive force and compressive stress (central value plus larger and smaller values) and shear displacement;

g) compression stiffness;

h) fractional change in compression stiffness relative to stiffness at zero shear strain;

i) plot of fractional change in compression stiffness relative to stiffness at zero shear strain versus the shear strain;

j) plot of vertical force versus vertical displacement;

k) test date.

6.3.7 Dependence of compressive stiffness on compressive stress range

6.3.7.1 Principle

A test piece is subjected to compression tests under three different loading conditions. The compressive stiffness is measured in each test, and the dependence of compressive stiffness on compressive force determined.

6.3.7.2 Test machine

As in 6.2.2.2.

6.3.7.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.3.7.4 Test conditions

6.3.7.4.1 Test temperature

As in 6.2.1.4.1.

6.3.7.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.3.7.4.3 Loading conditions

The loading conditions shall be as shown in Table 15. The shear strain shall be maintained at zero during loading.

σ_0 in Table 15 is the design compressive stress, which corresponds to the design compressive force, P_0, as defined in ISO 22762-2 or ISO 22762-3. The tolerance shall be within ± 5 % of each stress.

Table 15 — Loading conditions

Compressive stress	$\sigma_0 \pm 0{,}3\sigma_0$	$\sigma_0 \pm 0{,}5\sigma_0$	$\sigma_0 \pm 1{,}0\sigma_0$

6.3.7.4.4 Input wave

As in 6.2.1.4.4.

6.3.7.4.5 Test vibration frequency

As in 6.2.1.4.5.

6.3.7.5 Procedure

6.3.7.5.1 Attachment of test piece and compressive displacement gauges

As in 6.2.1.5.1.

6.3.7.5.2 Loading

The loading process shall be as described in 6.2.1.5.2.

Load the test piece for 3 cycles under the conditions specified in Table 15.

6.3.7.6 Expression of results

The result shall be expressed as in 6.2.1.6.

Under each loading condition, determine the compression stiffness relative to the stiffness at $\sigma_0 \pm 0{,}3\sigma_0$.

6.3.7.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) compressive force and compressive stress (central value plus larger and smaller values);

g) compression stiffness;

h) compressive stiffness relative to stiffness under the loading condition $\sigma_0 \pm 0{,}3\sigma_0$;

i) plot of vertical force versus vertical displacement under each loading condition;

j) test date.

6.4 Ultimate shear properties

6.4.1 Principle

This test establishes the shear displacement capacity of the isolator under the maximum design compressive force. For isolators located by dowels or recesses, and for bolted isolators subjected to tensile loads, the shear displacement capacity is also measured at the minimum design compressive force. A test piece is attached to a compression-shear testing machine and subjected to the required constant compressive force. Under this load, the test piece is subjected to unidirectional shear displacement until failure occurs, or until the specified displacement is reached. Failure is defined as breaking or buckling in the case of bolted bearings, or as the onset of roll-out in the case of recessed or dowelled bearings. The specified displacement, or the displacement at failure if this occurs before the specified displacement is reached, and the maximum shear force are recorded.

6.4.2 Test machine

As in 6.2.2.2.

6.4.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3. If tests at both maximum and minimum vertical loads are required, the same test piece may be used for the second test, provided no signs of failure are apparent in the first test.

6.4.4 Test conditions

6.4.4.1 Test temperature

As in 6.2.1.4.1.

6.4.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.4.4.3 Compressive force

As in 6.2.2.4.3.

6.4.5 Procedure

6.4.5.1 Attachment of test piece

The test piece shall be attached to a compression-shear testing machine as specified in 6.2.2.5.1.

6.4.5.2 Loading

The test piece shall be loaded as follows.

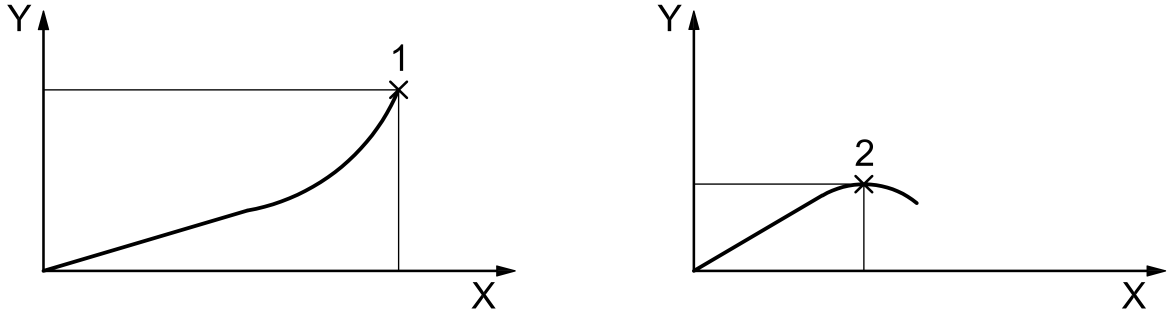
a) Subject the test piece to the required compressive or tensile force, as defined in ISO 22762-2 or ISO 22762-3.

b) Subject the test piece to unidirectional shear deformation at a constant speed until breaking, buckling or roll-out of the test piece occurs, or until the specified displacement is achieved.

6.4.6 Expression of results

The result shall be expressed as follows.

6.4.6.1 Typical force-displacement curves for two types of bolted bearings can be plotted as shown in Figure 12.



a) Non-buckling case

b) Buckling case

Key

X shear displacement

Y shear force

1 breaking point

2 buckling point

Figure 12 — Ultimate shear properties

6.4.6.2 At the time of breaking, the displacement and the shear force shall be determined as the shear displacement at break, X_b, and the shear force at break, Q_b, respectively.

6.4.6.3 When buckling occurs, the displacement and the shear force shall be determined as the shear displacement at buckling X_buk and the shear force at buckling, Q_buk, respectively.

6.4.6.4 If roll-out occurs with dowelled or recessed bearings, the displacement and shear force at the onset of roll-out shall be recorded.

6.4.6.5 If the test is stopped before obvious failure, the bearing shall be held at the maximum displacement and examined for signs of failure (with caution). The shear force and displacement at the point at which the test is stopped shall define the ultimate shearing capacity, provided there are no significant signs of failure and the force-displacement curve has been increasing monotonically up to that displacement.

6.4.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) shear speed;

f) direction of shear force applied to test piece;

g) compressive force (compressive stress);

h) when breaking occurs

   — the breaking shear displacement (shear strain) and breaking shear force;

i) when buckling occurs

   — the buckling failure shear displacement (shear strain) and buckling failure shear force;

j) when roll-out occurs

   — the roll-out shear displacement (shear strain) and roll-out force;

k) when test is stopped without any failure

   — the final displacement (shear strain) and final shear force;

l) result of visual examination;

m) plots of shear force versus shear displacement (ultimate shear properties);

n) test date.

6.5 Tensile testing

6.5.1 Principle

A test piece is attached to a tensile shear test machine, subjected to a constant shear displacement and loaded with tensile force until plastic deformation or fracture occurs. The tensile force, tensile displacement, shear force and shear displacement are measured. The tensile force and the shear displacement of the test piece at yield or fracture are determined.

6.5.2 Test machine

The machine shall be capable of applying tension and shear to the elastomeric isolator under controlled conditions. It shall also provide a method of measuring the tensile force, tensile displacement, shear force and shear displacement to an accuracy of better than or equal to 1 % of the maximum values recorded. The force calibration of the machine shall be based on ISO 7500-1. The machine shall maintain the parallelism of the upper and lower loading platens for the test piece attachment during the test. A Class 1 machine, as specified in Clause 7 of ISO 7500-1:2004, is recommended.

During tensile shear testing, the test machine should keep the shear displacement constant.

In order to measure the tensile displacement of the test piece accurately, place two or more tensile displacement gauges uniformly around the test piece (so that they are at the same distance from the test piece as shown in Figure 5). The average data from these sensors shall be taken as the measurement value. Generally, tensile displacement is much larger than compressive displacement, so the displacement gauges should be selected carefully.

For tests at non-zero shear displacement, the use of the double-shear configuration is permitted as described in 6.2.2.2.

Fragments of test piece are likely to fly when a test piece fractures. Therefore, it is strongly recommended that a protective barrier be put into place in the direction of the shear load on the test piece. It is also strongly recommended that barriers, etc., be set up to prevent access to the test machine during a test.

6.5.3 Test piece

As specified in ISO 22762-2 or ISO 22762-3.

6.5.4 Test conditions

6.5.4.1 Test temperature

As in 6.2.1.4.1.

6.5.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.5.4.3 Test shear strain

The test shear strain shall be zero or the one selected from Table 6. The tolerance shall be within ± 5 %.

6.5.4.4 Test speed

The test speed shall be selected with the agreement of both the structural engineer and the manufacturer. The tensile loading speed should be slow enough to ensure safety during the test.

6.5.5 Procedure

6.5.5.1 Attachment of test piece

The test piece shall be attached to the test machine by the same or a mechanically equivalent manner as in the actual application. Shear keys should be set between the test piece and test machine in order to transmit the shear force, and the test piece should be fastened to the test machine by enough bolts in order to transmit the tensile force.

6.5.5.2 Loading

The test piece shall be loaded as follows.

a) Apply the prescribed shear strain to the test piece.

b) Apply the tensile force specified in ISO 22762-2 or ISO 22762-3 to the test piece, or load it until failure is observed.

6.5.6 Expression of results

The tensile force at break shall be recorded. Otherwise, it shall be recorded that no obvious signs of failure were observed at the maximum applied tensile force.

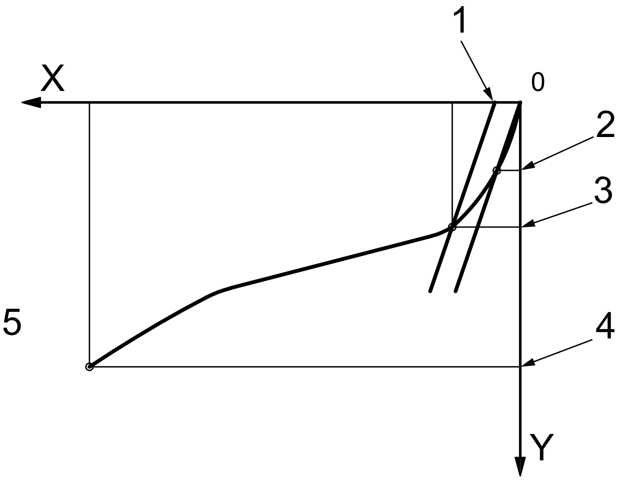
An example of a typical tensile force-displacement curve is shown in Figure 13.

The yield force shall be determined as follows.

a) Draw a line through the origin and the point on the curve where the force at the point coincides with the shear modulus, G (under design compressive stress and design shear strain).

b) Offset the line for 1 % of the total rubber thickness.

c) The force at the point where the offset line and force-displacement curve cross is defined as the yield force.



Key

X tensile displacement
Y tensile force

1 displacement corresponding to 1 % of total rubber thickness
2 force corresponding to shear modulus, G
3 tensile yield force, P_{Ty}
4 tensile break force, P_{Tb}
5 break

Figure 13 — Typical force-displacement curve from tensile test

6.5.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) test speed;

f) shear displacement (if any);

g) tensile yield force, P_{Ty}, or tensile break force, P_{Tb};

h) test date;

i) tensile force-displacement curve.

6.6 Durability testing

6.6.1 Degradation test

6.6.1.1 Principle

The test piece for this test is an isolator or a rubber test piece. The test piece is aged for a given period of time at a specified temperature. After ageing, the shear properties (shear stiffness and equivalent damping ratio) and ultimate shear properties are measured. By evaluating the change during ageing as a percentage of the value before ageing, the resistance of the elastomeric isolator to thermal degradation can be assessed.

NOTE Annexes H and I show examples of durability investigation of isolators used in an actual bridge and building. The results indicate the degradation test supplies a prediction with reasonable accuracy.

6.6.1.2 Test machine

6.6.1.2.1 Air ageing oven

An air ageing oven or similar device with an automatic thermo-regulator shall be used for ageing of the test piece. The temperature inside the oven shall be maintained such that the temperature of the test piece in the oven is within ± 2 °C of the preset temperature.

6.6.1.2.2 Compression-shear testing machine

As in 6.2.2.2.

6.6.1.3 Test piece

An isolator test piece as defined in ISO 22762-2 or ISO 22762-3 or a rubber test piece as defined in 5.8.3 shall be used.

The change in the dynamic shear properties may be determined using a single test piece tested before and after ageing.

Because of the variability in ultimate properties, the degradation of ultimate shear properties may be determined using three pairs of test pieces prepared from the same lot of material. From each pair, one is tested before ageing and one after ageing.

6.6.1.4 Test conditions

Based on the ageing conditions defined in Annex A, the temperature and time shall be selected so that, when converted to 23 °C or 27 °C, the time corresponds to 60 years or the period specified by the structural engineer.

The ageing temperature shall be 80 °C or lower.

6.6.1.5 Procedure

The initial properties of an isolator test piece shall be determined as specified in 6.2.2 (compressive-shear test) and 6.3 (ultimate shear properties). The initial properties of a rubber test piece shall be determined as specified in 5.8 and 5.9; for the former, the test shear strain amplitude shall be as specified in 6.2.2, and for the latter, the test temperature and frequency shall be as specified in 5.8. Then, the test piece shall be placed in the oven and aged under the conditions specified in 6.6.1.4. If a rubber test piece is used, the ageing conditions shall be anaerobic (see A.2).

After the test piece has been subjected to ageing for the specified time, it shall be taken out from the air ageing oven and cooled for 24 h or longer. It shall be conditioned as specified in 6.2.1.4.2. The properties after ageing shall be determined in the same way as the initial properties.

6.6.1.6 Expression of results

The percentage change in the shear properties and ultimate shear properties is calculated using Equation (7):

$$A_\text{C} = \frac{B_1 - B_0}{B_0} \times 100 \tag{7}$$

where

A_C is percentage change in the measured value before ageing with respect to the measured value after ageing;

B_0 is the measured value before ageing;

B_1 is the measured value after ageing.

Determine the activation energy, the ageing conditions corresponding to the expected life, or the estimated life time as described in Annex A.

6.6.1.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) percentage change in shear properties and ultimate shear properties;

c) for isolator test pieces, type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

d) for rubber test pieces, type and dimensions, and method used to ensure anaerobic ageing;

e) ageing temperature and ageing time/estimated years at 23 °C or 27 °C;

f) activation energy;

g) test date;

h) other information, if necessary.

6.6.2 Creep test

6.6.2.1 Principle

A test piece is subjected to a constant compressive force without shear displacement. During a specified length of time, the compressive displacement is measured at intervals. By measuring the change in the compressive displacement, the creep of the elastomeric isolator after many years of use can be estimated. See Annex G.

6.6.2.2 Test machine

a) The machine shall be capable of applying a constant compressive force to the test piece for up to several weeks, and of measuring the compression displacement of the test piece. The compressive force shall be within ± 5 % of the preset value. The fluctuation of the compressive force during a test shall be within ± 5 % of the preset value.

   The accuracy of the results at long times should be carefully assessed with regard to the magnitude and timescale of the load fluctuation. If the fluctuation is a steady drift, the results at long times may be misleading.

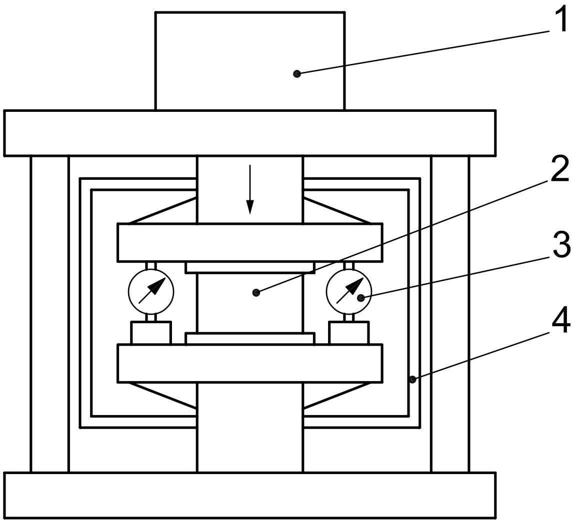
b) The machine shall maintain the parallelism of the upper and lower loading platens for the test piece attachment during the test.

c) The compressive force shall be applied by a dead weight or another suitable device.

d) The machine should preferably control the temperature of the test piece; if not, the surface temperature of the test piece shall be measured in order to be able to correct for the height change caused by temperature fluctuations.

e) The displacement gauges used to measure the compression displacement shall be capable of measuring to the nearest 0,01 mm.

An example of a creep testing machine is shown in Figure 14.



Key

1 loading device (hydraulic, pneumatic, dead weight type, etc.)
2 test piece
3 displacement gauge
4 thermostat

Figure 14 — Example of a creep testing machine

6.6.2.3 Test piece

The test piece shall be as specified in ISO 22762-2 or ISO 22762-3.

6.6.2.4 Test conditions

6.6.2.4.1 Test temperature

The test shall be conducted at 23 °C ± 2 °C or 27 °C ± 2 °C.

6.6.2.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.6.2.4.3 Compressive force

The accuracy and fluctuation of the compressive force shall be as specified in 6.6.2.2 a).

6.6.2.4.4 Total measurement time and measurement intervals

The total measurement time shall be 1 000 h or longer. The measurement time should be as long as possible to reduce uncertainty in the constants in the creep equation [see 6.6.2.6 e)].

Measurements shall be made at equal intervals at a minimum of 10 points in each time span of 10^0 h to 10^1 h, 10^1 h to 10^2 h, and 10^2 h to 10^3 h.

6.6.2.5 Procedure

6.6.2.5.1 Attachment of test piece and compressive displacement gauges

As specified in 6.2.1.5.1.

6.6.2.5.2 Loading

The test piece shall be loaded as follows.

a) Subject the test piece to a compressive force that is equivalent to the design compressive stress, σ_0, as described in ISO 22762-2 or ISO 22762-3. The loading time shall be less than 1 min.

b) The compressive displacement about 1 min after the compressive force reaches the preset value shall be taken as the zero point. The compressive displacement and the surface temperature of the test piece shall be measured at the time intervals defined in the second paragraph of 6.6.2.4.4. The compressive displacement shall be measured at two or more positions which are symmetrical in relation to the centre of the test piece. The compression displacement shall be taken as the average of the values obtained from the displacement gauges used.

6.6.2.6 Expression of results

The result shall be expressed as follows.

a) When the test is not conducted at 23 °C ± 2 °C or 27 °C ± 2 °C, the change in vertical displacement from the zero point at each measurement time shall be converted to the standard laboratory temperature using Equation (8). The coefficient of linear expansion, α, in the vertical direction of the test piece in this equation is obtained by the method shown in D.6.

$$\Delta H_{\mathrm{T0}} = \Delta H_{\mathrm{T}} + \alpha \times n \times t_{\mathrm{r}} \times (T - T_0) \tag{8}$$

where

ΔH_{T0} is the change in vertical displacement at T_0°C;

ΔH_{T} is the change in vertical displacement at T °C;

T is the surface temperature, in degrees Celsius, of the test piece;

T_0 is the standard laboratory temperature, in degrees Celsius;

α is the coefficient of linear thermal expansion (T °C to T_0°C).

b) The creep strain at each measurement time is calculated using Equation (9):

$$\varepsilon_{\mathrm{cr}} = \frac{\Delta H_{\mathrm{T}_0}}{n \times t_{\mathrm{r}}} \times 100 \tag{9}$$

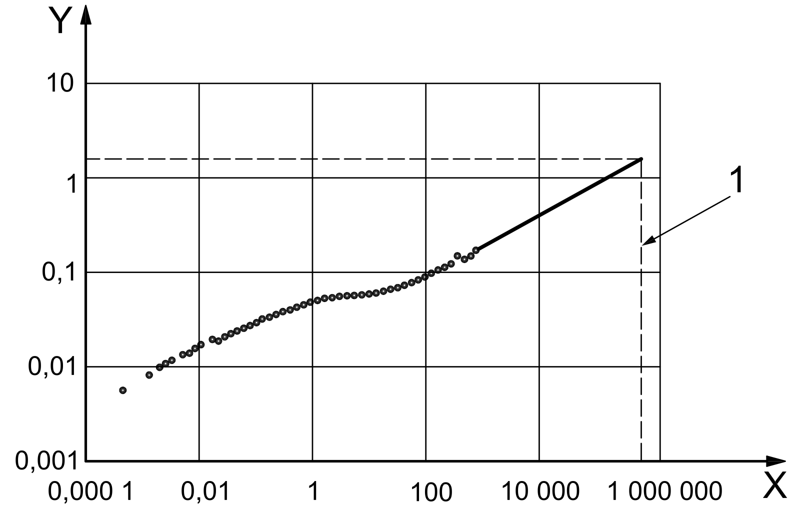
where

ε_{cr} is the creep strain, in per cent, at T_0 °C;

n number of rubber layers;

t_r thickness of one rubber layer.

c) The relationship between the creep strain and time obtained in accordance with b) shall be plotted as a logarithmic graph. An example is shown in Figure 15.



Key

X elapsed time, expressed in hours

Y compression creep strain, expressed in per cent

1 60 years

Figure 15 — Example of creep curve

d) Using the least-squares method and the data for time = 100 h to time = 1 000 h, linear regression can be performed on the logarithmic plot. From this regression line, coefficients a and b in Equation (10) are obtained:

$$\lg_{10} \varepsilon_{cr} = \lg_{10} a + b \lg_{10} t \tag{10}$$

where

ε_{cr} is the creep strain, in per cent, at 23 °C;

t is time, in hours.

e) The estimate of the creep at time, t, shall be obtained from Equation (11):

$$\varepsilon_{cr} = a \times t^b \tag{11}$$

6.6.2.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) drawing of test piece;

c) brief description of test machine;

d) compressive force (compressive stress);

e) graph showing relationship between surface temperature of test piece and time;

f) log-log graph showing relationship between creep strain and time;

g) estimated creep strain at specified time, t;

h) standard laboratory temperature, T_0;

i) test date;

j) other information, if necessary.

6.6.3 Fatigue test

6.6.3.1 Principle

A test piece is subjected to a specified shear displacement, which may be zero, and then loaded with a cyclic compressive force. The change in appearance and properties is determined in order to evaluate the fatigue resistance of the elastomeric isolator.

6.6.3.2 Test machine

The machine shall be capable of applying a constant shear displacement and rapidly repeating compressive force to the test piece for a long period of time. Both the shear displacement and the compressive force shall remain within ± 5 % of the preset value.

The machine shall maintain the parallelism of the upper and lower loading platens for the test piece attachment during the test.

6.6.3.3 Test piece

As specified in ISO 22762-2 or ISO 22762-3.

6.6.3.4 Test conditions

6.6.3.4.1 Test temperature

As in 6.2.1.4.1.

6.6.3.4.2 Conditioning time for a test piece

As in 6.2.1.4.2.

6.6.3.4.3 Compressive force

The compressive force shall be applied cyclically from the maximum force to the minimum force. The maximum force corresponds to the specified maximum compressive stress, and the minimum force corresponds to the specified minimum compressive stress. The structural engineer shall specify both stresses.

NOTE The maximum and minimum compressive stresses in this test represent the range of traffic-induced loads amplified to accelerate the test.

The test shall be carried out for 2 000 000 compression cycles or as agreed by the structural engineer and manufacturer.

6.6.3.4.4 Test shear strain

The shear deformation shall be constant during this test. A constant shear displacement selected by the structural engineer and representing a typical non-seismic value may be selected.

6.6.3.4.5 Input wave

The input wave of repeated compressive stress shall be a sine wave or a triangular wave.

6.6.3.4.6 Test vibration frequency

The frequency shall be agreed by both the structural engineer and the manufacturer. Generally, the test frequency is between 2 Hz and 5 Hz.

6.6.3.5 Procedure

6.6.3.5.1 Attachment of test piece

The test piece shall be attached to a compression-shear test machine as specified in 6.2.2.5.1.

6.6.3.5.2 Loading

The test piece shall be loaded as follows.

a) First, load the test piece with a compressive force equal to either the maximum or minimum specified force. Next, subject the test piece to the specified constant shear displacement and apply the cyclic compressive stress.

b) In order to evaluate the change in properties, measurement of the compressive stiffness and shear properties, and a visual inspection, shall be carried out before and after fatigue loading at 500 000 cycles, 1 000 000 cycles, 1 500 000 cycles, 2 000 000 cycles and at other numbers of cycles agreed by both the structural engineer and the manufacturer.

c) The compressive stiffness and shear properties shall be measured in accordance with the methods given in 6.2.1 and 6.2.2, respectively.

6.6.3.6 Expression of result

The result shall be expressed as follows.

a) All basic properties shall be determined in accordance with the methods used in 6.2.1.6 and 6.2.2.6. The change in each property shall be determined as the ratio of the value after fatigue loading to that measured before fatigue loading.

b) The test piece shall be checked at each round of testing for the presence of cracks and other visible changes produced.

6.6.3.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) input wave and vibration frequency;

f) direction of shear force applied to test piece;

g) static compressive stress and amplitude of cyclic compressive stress and shear strain (if any) applied;

h) properties such as compressive stiffness, shear stiffness and equivalent damping ratio at each number of cycles at which testing was carried out;

i) fractional change in each property;

j) graph showing relationship between the fractional change in each property and the number of fatigue cycles;

k) test date;

l) plots of shear force versus shear displacement (hysteresis loop).

6.7 Reaction force due to low-rate deformation

6.7.1 Principle

6.7.1.1 General

This test is used to determine the reaction force in an isolator caused by very-low-rate deformation (to be specified by the structural engineer, e.g. 0,003 %/s), such as elongation or shrinkage of a bridge girder due to changes in temperature.

The determination of the reaction force can be determined via two methods as described in 6.7.1.2 and 6.7.1.3.

6.7.1.2 Extrapolation method

The reaction force caused by very-low-rate deformation can be estimated by extrapolation using the values of shear stiffness at several low rates of loading.

The test piece is subjected to the specified compressive force, and also to three or more levels of shear deformation corresponding to the specified strain amplitudes at a rate of 5,0 %/s or slower. The shear elastic modulus is then measured. Extrapolation is carried out to obtain the shear elastic modulus for a rate lower than 0,003 %/s. See Annex H.

6.7.1.3 Stress relaxation method

For ordinary test machines which cannot produce shear deformation at very low rates, the reaction force produced by very-low-rate deformation can be estimated by measuring the shear stress after relaxation for a specified period of time. When the specified time is a day (24 h), a practical method is as follows.

The elastomeric isolator is subjected to the specified compressive force, and also to a shear deformation which is 1/4 of the specified strain amplitude at the normal rate. The strain is maintained for 1,5 h. Next, the shear strain is increased by another 1/4 of the specified strain amplitude, and maintained for another 1,5 h. This process is repeated until the shear strain reaches the specified strain, giving a total of 6 h. The shear stress is measured at the end of each 1,5 h period. The relationship between the shear force and the shear displacement is determined from the four values obtained (plus zero) (see Annex H).

6.7.2 Test machine

The compression-shear testing machine specified in 6.2.2.2 shall be used.

For the extrapolation method, the test machine shall be capable of a range of displacement rates covering at least 0,01 mm/s to 50 mm/s.

For the stress relaxation method, the machine shall be capable of maintaining the specified strain for 1,5 h and measuring the stress at 1,5 h intervals.

6.7.3 Test piece

As specified in ISO 22762-2 or ISO 22762-3.

6.7.4 Test conditions

6.7.4.1 Test temperature

As in 6.2.1.4.1.

6.7.4.2 Conditioning time for test piece

As in 6.2.1.4.2.

6.7.4.3 Compressive force

A test piece shall be loaded with a compressive force that is equivalent to the design compressive stress or a pressure that has been selected with the agreement of both the structural engineer and the manufacturer.

The fluctuation of the compressive force shall be within ± 10 % during a test.

6.7.4.4 Test shear strain

The test shear strain shall be decided by the structural engineer. For example 50 % may be selected for the extrapolation method, and a set comprising 12,5 %, 25 %, 37,5 % and 50 % may be selected for the stress relaxation method.

6.7.5 Procedure

6.7.5.1 Attachment of test piece

The test piece shall be attached to the compression-shear test machine as specified in 6.2.2.5.1.

6.7.5.2 Loading

6.7.5.2.1 General

The loading rate shall be selected with the agreement of both the structural engineer and the manufacturer.

The following examples are provided for reference:

a) For the extrapolation method: 0,04 %/s; 0,1 %/s; 0,2 %/s; 1,0 %/s; 2,0 %/s; 10,0 %/s; 20,0 %/s.

b) For the stress relaxation method: 0,2 %/s.

6.7.5.2.2 Extrapolation method

Subject the test piece to the specified compressive force. Then, apply the specified shear strain for three loading/unloading cycles at each specified loading rate. From the third loading cycle, calculate the shear stiffness as the ratio between the maximum force and the maximum displacement.

6.7.5.2.3 Stress relaxation method (example)

Subject the test piece to the specified compressive force. Then, apply 12,5 % shear strain at a speed of 1 mm/s. Maintain the strain for 1,5 h. After 1,5 h, subject the test piece to 25 % strain for 1,5 h. Continue this procedure for shear strains of 37,5 % and 50 %. Measure the shear force after 1,5 h at each shear strain.

6.7.6 Expression of result

The result shall be expressed by converting the measured shear stiffness or shear force to the shear modulus using Equations (12) and (13):

$$G_\mathrm{s} = \frac{K_\mathrm{h} \times T_\mathrm{r}}{A_\mathrm{load}} \tag{12}$$

$$G_\mathrm{s} = \frac{Q \times T_\mathrm{r}}{A_\mathrm{load} \times X} \tag{13}$$

where

G_s is the shear modulus at low-rate deformation;

A_load loaded area of isolator;

K_h is the shear stiffness obtained from the hysteresis loop of the third cycle at each loading rate;

Q is the shear force after stress relaxation at each strain;

X is the shear displacement at each strain;

T_r is the total thickness of the rubber.

6.7.7 Test report

The test report shall include the following:

a) reference to this part of ISO 22762, i.e. ISO 22762-1:2010;

b) type and classification, shape and dimensions, first shape factor and second shape factor of test piece;

c) name of test machine;

d) test temperature;

e) compressive force (compressive stress);

f) drawing of test piece;

g) test method;

h) shear modulus;

i) shear force-deflection curve or shear stiffness at low-rate deformation;

j) details of any additional requirements;

k) test date.

Annex A
(normative)

Determination of accelerated ageing conditions equivalent to expected life at standard laboratory temperature (23 °C or 27 °C)

A.1 General

This annex specifies the determination of the ageing conditions equivalent to the expected life at 23 °C or 27 °C. It is based on the method given in ISO 11346.

A.2 Test conditions

Tests shall be carried out at a minimum of three ageing temperatures up to 80 °C and for a minimum of four periods of ageing at each test temperature. Test conditions are only acceptable if accurately observable changes in properties are produced.

For the inner rubber, ageing shall be conducted under anaerobic conditions, such as those produced by the following two methods:

a) using a test piece cut out from a rubber block aged in air;

b) shielding the test piece from the air by wrapping it in metal foil.

Methods such as replacing the air in the ageing oven by nitrogen gas or applying a vacuum are not recommended because volatile compounding ingredients will be lost.

A.3 Test method

After ageing in accordance with A.2, the 100 % shear modulus and shear failure strain shall be measured by the methods defined in 5.8 and 5.9 or, optionally, tensile properties (tensile strength, elongation at break, 100 % modulus) may be measured by the methods specified in ISO 37.

A.4 Calculation method

A.4.1 As shown in Figure A.1, for each property under evaluation (100 % shear modulus, shear failure strain, tensile strength, elongation at break and 100 % modulus), draw a graph to show the relationship between ageing time and the decrease in a material property.

A.4.2 Use this graph to obtain, for each ageing temperature, the ageing time required for a specified decrease in the property.

A.4.3 As shown in Figure A.2, make an Arrhenius plot with the inverse of ageing temperature (absolute temperature) on the X-axis and the natural logarithm of the ageing time obtained from A.4.2 on the Y-axis. This plot shall be made for each property under evaluation.

A.4.4 Fit a straight line to the points plotted on the Arrhenius plot and determine the activation energy from the gradient

$$\frac{E_\mathrm{a}}{R}$$

where

E_a is the activation energy, in J/mol;

R is the gas constant [8,314 J/(mol·K)].

A.4.5 From the activation energies obtained in A.4.4 for each property, use the lowest activation energy to calculate the ageing conditions. The lowest activation energy is chosen for safety reasons.

Use Equation (A.1) to determine the ageing conditions that correspond to the expected life at 23 °C or 27 °C:

$$\ln(t_y) = \frac{E_a}{R} \times \left(\frac{1}{T_y} - \frac{1}{T_0} \right) + \ln(t) \tag{A.1}$$

where

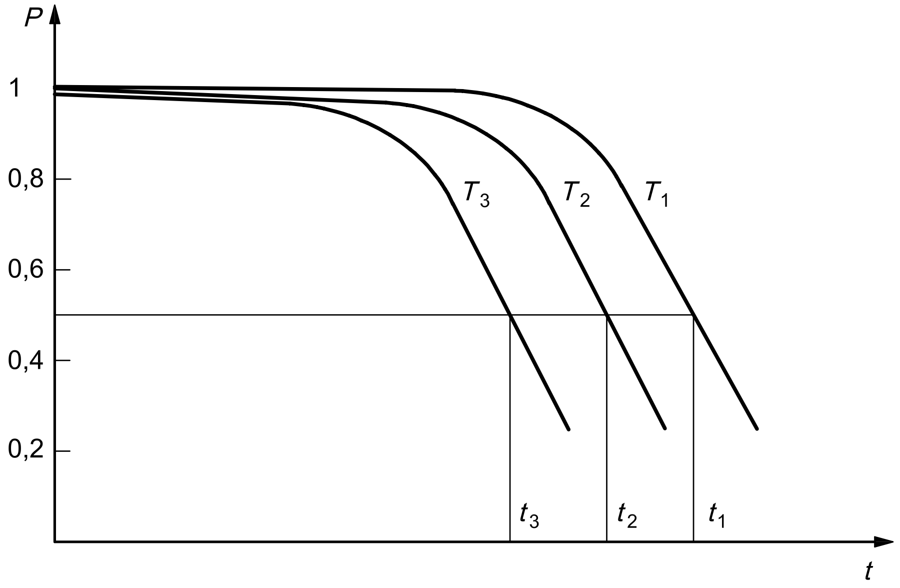
T_0 is 23 °C (= 296 K) or 27 °C (= 300 K);

T_y is the ageing temperature;

t is the expected life at 23 °C or 27 °C;

t_y is the ageing time.

Figures A.1 and A.2 correspond to Figures 1 and 2 in ISO 11346:2004.



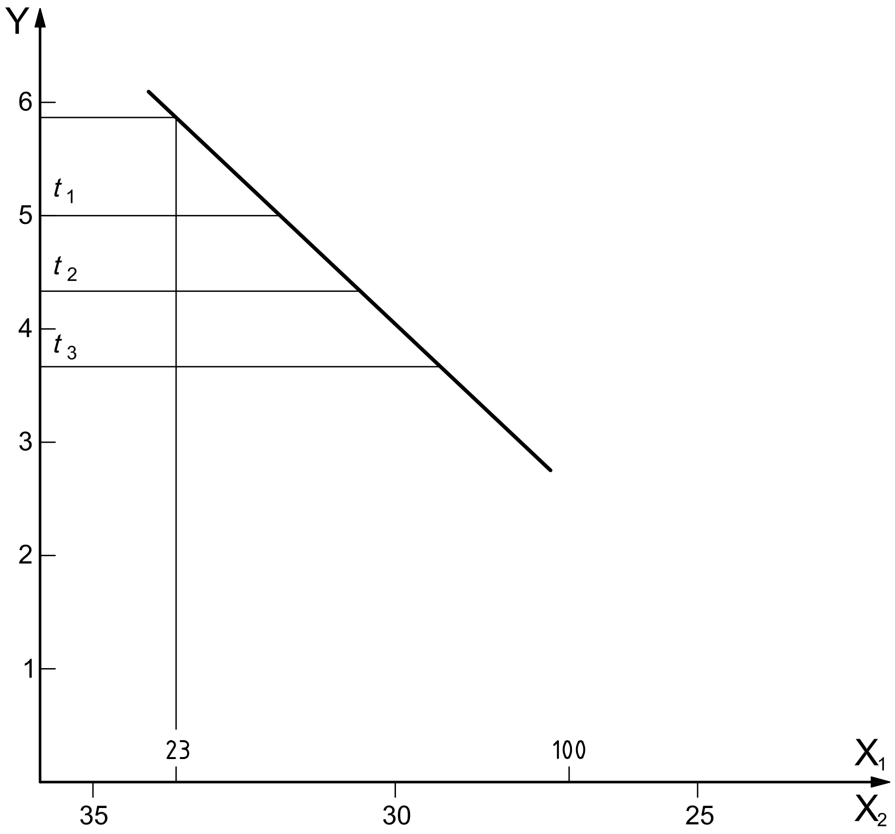
Key

P value of property (as a fraction of initial value)

t time, expressed in hours

T temperature, expressed in degrees Celsius

Figure A.1 — Change in property against time



Key

X$_1$ temperature, T, expressed in degrees Celsius

X$_2$ $\frac{1}{T} \times 10^4$, T expressed in kelvins

Y time, t, expressed in hours

Figure A.2 — Arrhenius plot — Time against temperature

Annex B
(normative)

Inertia force correction

B.1 Principle

During the determination of the properties of an elastomeric isolator, a high-speed load is applied, and an inertia force is generated. The inertia force is equal to the product of the mass of the moving components of the test machine (excluding the test piece) and the acceleration of these components. If the load cell is attached to the actuator (as in Figure B.1), this inertia force is recorded together with the actual shear force. The total force is considered as the apparent shear force.

The method specified in this annex measures the inertia force of the moving components (excluding the test piece). Then, this value is subtracted from the apparent shear force to obtain the true shear value.

B.2 Measurement of inertia force

B.2.1 Direct method

Without a test piece attached, operate the compression-shear test machine under the same test conditions as those used when testing. The shear force measured by the load cell is considered as the inertia force (see Figure B.1).

B.2.2 Indirect method by means of acceleration

Attach an accelerometer to the compression-shear test machine, and carry out the compression-shear test. Measure the acceleration. The product of the mass of the moving components (excluding the test piece) and the acceleration is the inertia force (see Figure B.2).

B.3 Correction to allow for inertia force

The inertia force is corrected for using Equation (B.1):

$$Q = Q_{\mathrm{a}} - Q_{\mathrm{i}} \tag{B.1}$$

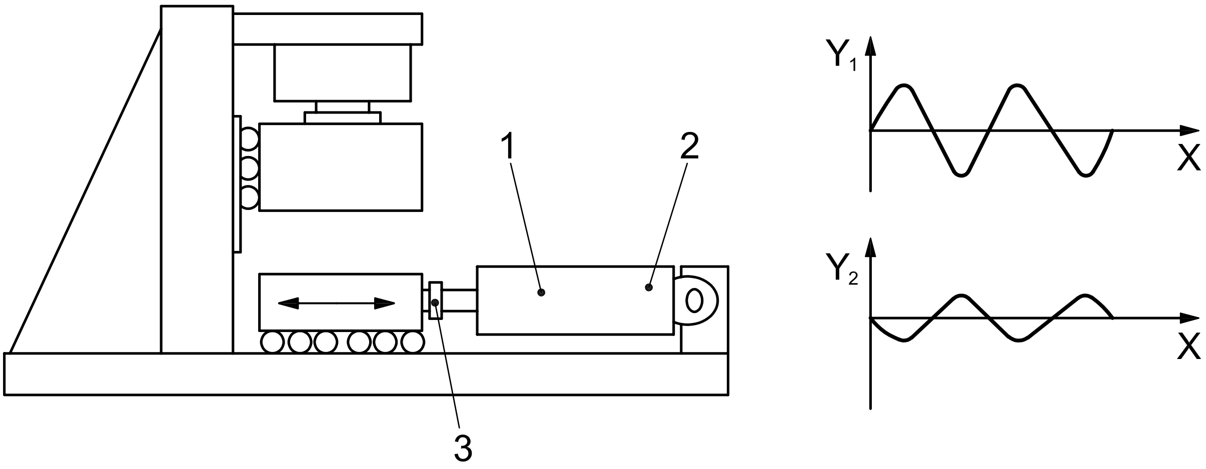
where

Q is the shear force, expressed in newtons;

Q_{a} is the apparent shear force, expressed in newtons;

Q_{i} is the inertia force, expressed in newtons.

If the inertia force obtained by either method in B.2 is less than 1 % of the apparent shear force that was measured with the test piece attached, then it is not necessary to correct for the inertia force.



Key

X time

Y$_1$ horizontal displacement

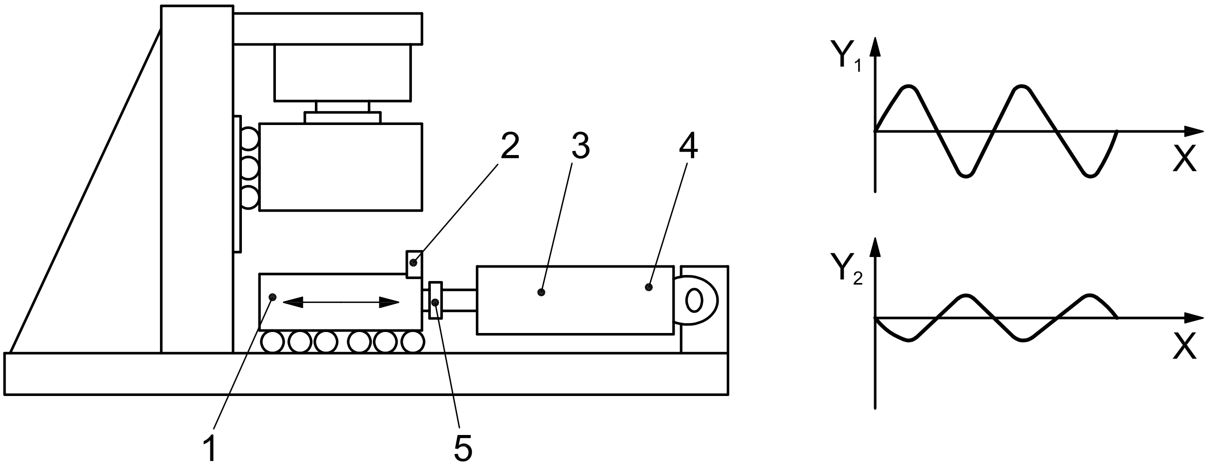
Y$_2$ inertia force

1 horizontal actuator

2 horizontal-displacement transducer

3 horizontal-force load cell

Figure B.1 — Direct method of determining inertia force



Key

X time

Y$_1$ horizontal displacement

Y$_2$ acceleration

Inertia force = mass × acceleration

1 known mass

2 accelerometer

3 horizontal actuator

4 horizontal-displacement transducer

5 horizontal-force load cell

Figure B.2 — Determination of inertia force from acceleration

Annex C
(normative)

Friction force correction

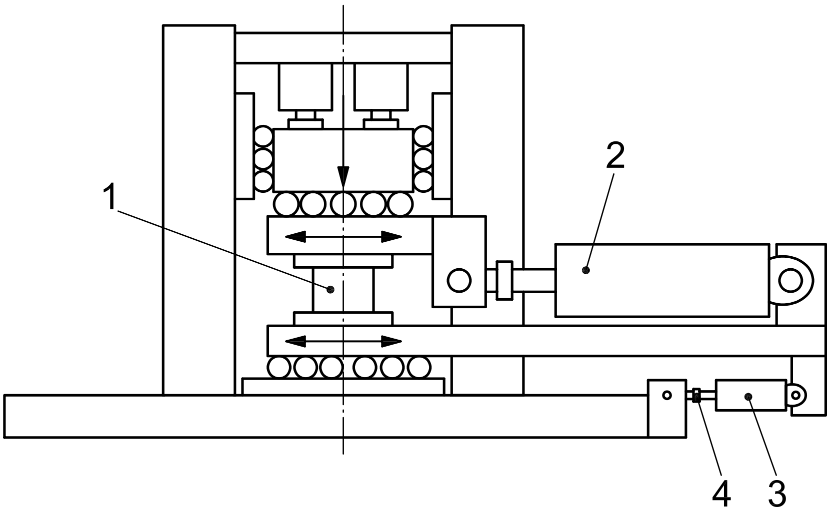
C.1 Principle

In the compressive-shear test, the following should be noted. When loading platens and other moving parts have a sliding mechanism, they generate a friction force in the sliding mechanism. The friction force is superimposed on the shear force deforming the isolator and, if the load cell is attached to the actuator (as in Figure C.1), the force recorded is an apparent shear force.

The method specified in this annex measures the friction force of the moving components (excluding the test piece). This friction force is then subtracted from the apparent shear force to obtain the true shear value.

C.2 Test machine

The compressive-shear test machine for this correction shall contain a friction force measurement load cell and a moving actuator. An example of a friction force correction test machine is given as Figure C.1.



Key

1 standard test piece

2 horizontal actuator

3 moving actuator

4 friction force measurement cell (force measured = $2F_r$)

Figure C.1 — Example of friction force correction test machine

C.3 Measurement of friction force

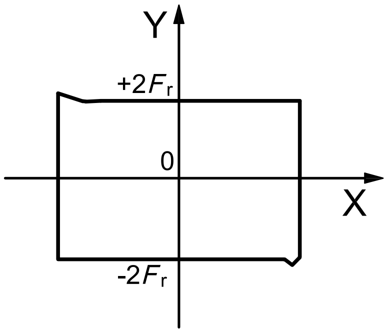
Instead of a test isolator, any suitable dummy test piece shall be attached to the machine. It shall be subjected to the same compressive force as that applied by the compressive-shear test machine in the actual test. The actuator in the shear direction is fixed. Under these conditions, the moving actuator shall move the upper and lower loading platens in the same direction. The force required to move the platens shall be measured by the moving actuator.

Half of the measured force value shall be considered as the friction force.

The friction force measured by this method is the friction in two sets of bearings: the upper and the lower. The friction force that is measured as an apparent shear force during a test, however, is the friction in one set of bearings. Therefore, the friction force to be used for correction shall be half the value that is measured by this method.

In some cases, only one set of bearings is used for the slide mechanism in the shear direction. For such test machines, one more identical set of bearings shall be prepared. This set of bearings shall be installed in the place of the dummy test piece, and the friction force shall be measured using the method above.

This test should preferably be conducted at various levels of compressive force. For each compressive force, the relationship between the moving-actuator displacement and the measured friction force should be obtained, as shown in Figure C.2. The relationship between the compressive force and the coefficient of friction should be plotted on a graph as shown in Figure C.3.

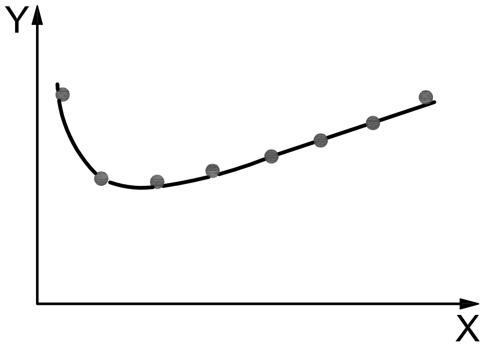


Key

X moving-actuator displacement

Y force measured

Figure C.2 — Relationship between moving-actuator displacement and friction force



Key

X compressive force

Y coefficient of friction

Figure C.3 — Relationship between compressive force and coefficient of friction

C.4 Calculation method

The friction force is corrected by Equation (C.1):

$$Q = Q_\mathrm{a} - F_\mathrm{r} \tag{C.1}$$

where

Q is the shear force, expressed in newtons;

Q_a is the apparent shear force, expressed in newtons;

F_r is the friction force, expressed in newtons.

If the friction force obtained by either method in C.3 is less than 1 % of the apparent shear force, it is not necessary to correct for the friction force.

Annex D
(normative)

Determination of coefficient linear thermal expansion

D.1 Principle

The compression creep test should, in principle, be conducted at 23 °C ± 2 °C or 27 °C ± 2 °C. However, because of the length of time required to conduct the test, the test is often conducted at an ambient temperature which is outside this range. By using the coefficient of linear thermal expansion, the value of creep shall be converted to standard laboratory temperature, 23 °C or 27 °C.

The method specified in this annex measures the height of the rubber bearing when the ambient temperature is changed, and gives the coefficient of linear expansion in the height direction.

D.2 Test piece

The test piece shall be an isolator of the same type used for the creep test.

D.3 Test temperature

The reference temperature is the standard laboratory temperature, 23 °C or 27 °C. In addition, any three other temperatures shall be selected in the range between 0 °C and 40 °C.

The minimum temperature difference between each of these three other test temperatures shall be 10 °C.

D.4 Conditioning time for a test piece

The conditioning time for each test temperature shall be the same as that specified in 6.2.1.4.2.

D.5 Test method

The test piece shall be conditioned at each test temperature under the conditions specified in 6.2.1.4.2, and then the height of the test piece measured to the nearest 0,01 mm.

D.6 Calculation method

The coefficient of linear thermal expansion at each testing temperature is calculated using Equation (D.1):

$$\alpha = \frac{H_{\mathrm{T}} - H_{\mathrm{T0}}}{h_{\mathrm{T0}}\left(T - T_0\right)} \qquad \text{(D.1)}$$

where

α is the coefficient of linear thermal expansion [between T °C and T_0 °C (= 23 °C or 27 °C)];

H_{T0} is the height of the test piece at standard laboratory temperature;

H_{T} is the height of the test piece at T °C;

T is the test temperature, in degrees Celsius;

h_{T0} is the total thickness of the rubber at T_0 °C.

The linear coefficients of thermal expansion measured at the non-standard temperatures T_1, T_2 and T_3 are α_{T1}, α_{T2} and α_{T3}, respectively. The average of these values is α.

The above calculation methods are also applied when 27 °C is selected as the reference temperature.

The parameters such as H23, h23 or the number “23” in Equation (D.1) for α are analogously replaced for the temperature of 27 °C.

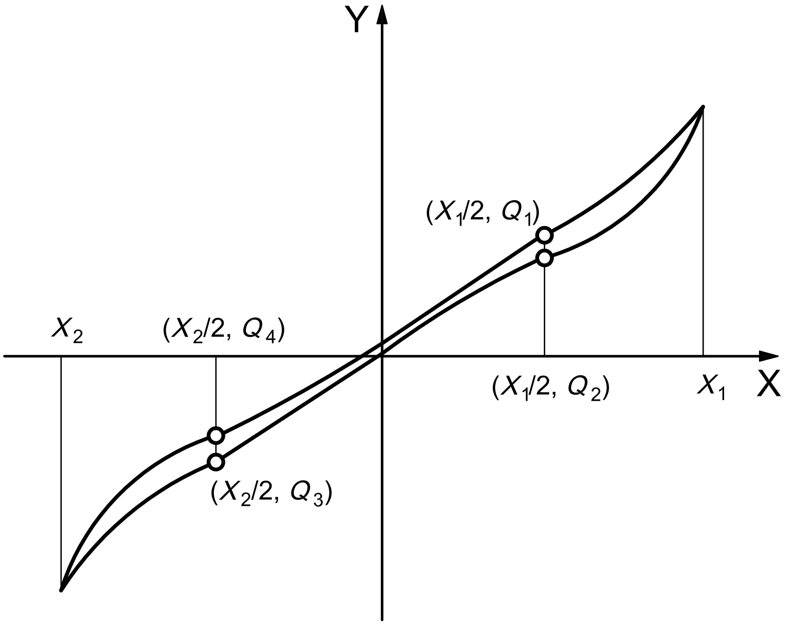
Annex E
(informative)

Alternative methods of determining shear properties

E.1 Tangential stiffness

The tangential stiffness, K_t, of an elastomeric isolator may be determined as follows.

The gradients of the lines between points on both the upper and the lower sides of the hysteresis loop, for example at half the maximum and minimum shear displacement, $X_1/2$ and $X_2/2$, respectively, are measured (see Figure E.1). Then, the average of both gradients is computed. Tangential stiffness of LRB may be treated as equivalent characteristics to the post-yield stiffness, K_d (Figure E.2).



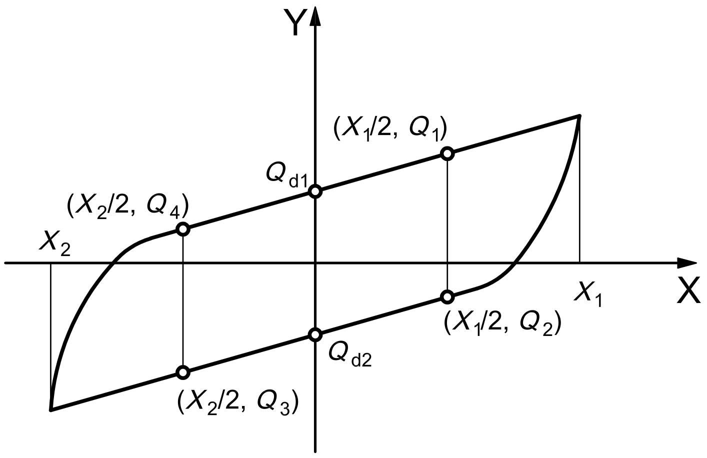
Key

X	shear displacement
Y	shear force

Equation (E.1) can be used to express the tangential stiffness.

$$K_t = \left[\frac{Q_2 - Q_3}{(X_1 - X_2)/2} + \frac{Q_1 - Q_4}{(X_1 - X_2)/2} \right] \Big/ 2 \tag{E.1}$$

Figure E.1 — Tangential stiffness of linear natural rubber bearings



Key

X shear displacement

Y shear force

Equation (E.2) can be used to express the post-yield stiffness.

$$\begin{aligned} K_\mathrm{t} = K_\mathrm{d} &= \left[\frac{Q_1 - Q_4}{(X_1 - X_2)/2} + \frac{Q_2 - Q_3}{(X_1 - X_2)/2}\right] \Big/ 2 \\ Q_\mathrm{d} &= \left[\frac{X_2 Q_1 - X_1 Q_4}{X_2 - X_1} - \frac{X_2 Q_2 - X_1 Q_3}{X_2 - X_1}\right] \Big/ 2 \end{aligned} \qquad \text{(E.2)}$$

Figure E.2 — Tangential stiffness (= post-yield stiffness) of lead rubber bearings

E.2 Characteristic strength

The characteristic strength, Q_d, of LRB can alternatively be determined as follows.

The forces at the crossing-points of the lines defined in E.1 and the shear-force axis, on both the upper and the lower sides of the hysteresis loop, are measured (see Figure E.2), and the average of the two forces calculated.

Annex F
(informative)

Creep test

F.1 General

As the service life of elastomeric isolators is intended to be equivalent to the life of the structures they protect, it is necessary to estimate how much creep can be expected after 50 years to 100 years. At present, this estimate is made at standard laboratory temperature or at an elevated temperature. The creep test at standard laboratory temperature is the test that better approximates the actual installation environment of an elastomeric isolator. However, it takes a long time to evaluate phenomena occurring over a period of 50 years to 100 years. Long-term creep arises from two components — physical creep, which increases linearly with log(time), and chemical creep, which in many cases varies linearly with time, but typically becomes comparable in absolute terms with physical creep after a few years. Although creep may be accelerated by raising the temperature, such a strategy does not form a sound basis for a short test, as the exact correlation between the creep properties at high temperature and the creep properties at standard laboratory temperature is not known. The test method in this part of ISO 22762, therefore, refers the creep properties to laboratory temperature. Creep testing at elevated temperatures remains a topic to be studied in the future.

F.2 Compressive stress — Compressive force

The appropriate pressure for estimating creep should be specified based on the design compressive stress by the dead load (weight of upper structure).

F.3 Forecasting formula

C.J. Derham (see Reference [1]) measured the creep of rubber bearings used in the Albany Court Building for 8 years. B. Davies (see Reference [2]) later reported the creep of the same bearings after 15 years. They report that Equation (F.1) expresses well the creep of rubber bearings:

$$\varepsilon_{\mathrm{cr}} = a\log(t) + bt \tag{F.1}$$

where

a, b are constant values.

However, other results using scaled isolators show that Equation (F.2) expresses the creep better than Equation (F.1) (see Reference [3]).

$$\varepsilon_{\mathrm{cr}} = a\log(t) + bt^{\mathrm{c}} \tag{F.2}$$

where

c is constant value.

This equation expresses the fact that the first term, $a\log(t)$, is more dominant shortly after the start of the test, while the second term, bt^{c}, is more dominant at long times. This part of ISO 22762 is intended to estimate the long-term creep, and thus the first term, $a\log(t)$, is eliminated from this equation. This part of ISO 22762 therefore uses Equation (F.3) as the formula for forecasting creep:

$$\varepsilon_{\mathrm{cr}} = bt^{\mathrm{c}} \tag{F.3}$$

F.4 Creep curves

For creep curves, a full logarithmic plot or a semi-logarithmic plot is used. A full logarithmic plot is used when the creep is large (see Reference [4]). For this reason, this part of ISO 22762 uses a full logarithmic plot to estimate creep. This is based on safety considerations.

F.5 Factors affecting creep of bearings

The creep of a vulcanizate is affected by the following factors:

a) type of raw elastomer;

b) filler type and content;

c) vulcanizing system used.

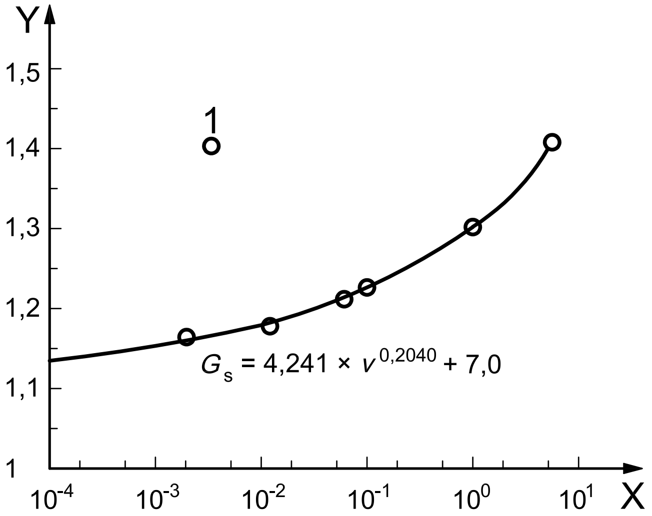
Stiffer and higher-damping rubbers can show more creep because of their larger filler content and high viscosity extenders for high damping.

Annex G
(informative)

Determination of reaction force due to low-rate deformation

G.1 Extrapolation method

This method is applicable to all elastomeric-isolator earthquake-protection systems. This part of ISO 22762 assumes the test machine is capable of displacement speeds from 0,02 mm/s to 50 mm/s. However, if the test machine is capable of slower speeds, carrying out the test at such slower speeds is recommended. As an example, Figure G.1 shows the relationship between the equivalent shear modulus of a high-damping rubber bearing and displacement speed and the extrapolation of the modulus to lower speeds.



Key

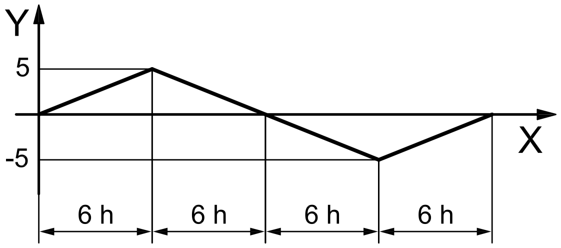
X displacement speed
Y shear elastic modulus

1 actual value

Figure G.1 — An example of the determination by extrapolation of the shear modulus of a high-damping rubber at low-rate deformation

G.2 Stress relaxation method

This method is applicable to high-damping laminated rubber bearings in which relaxation of the internal stress occurs with elapsed time. The measurement time is specified as a total of 6 h, because it takes 24 h for the temperature to rise and fall, as shown in Figure G.2.



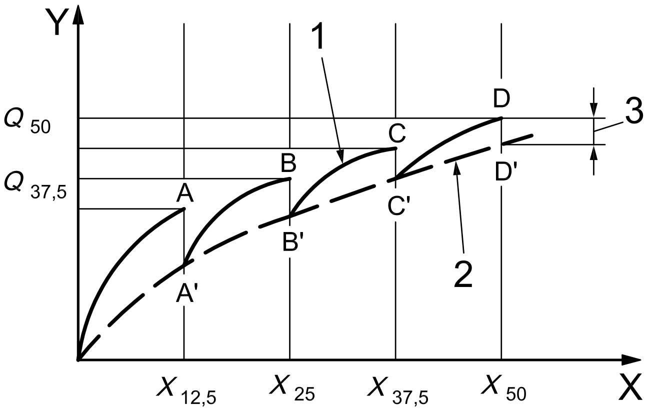
Key

X time, expressed in hours

Y temperature, expressed in degrees Celsius

Figure G.2 — Change in temperature of a construction in a day

Figure G.3 is a hysteresis curve of shear force and displacement for an elastomeric isolator, obtained by the stress relaxation method. Here, the curve 0-A-A'-B-B'-C-C'-D-D' is an actual hysteresis curve. Points A', B', C' and D' indicate the shear force after stress relaxation for 1,5 h at a shear strain of 12,5 %, 25 %, 37,5 % and 50 %, respectively. The curve connecting points 0, A', B', C' and D’, shown as a dotted line, indicates the shear properties approximated and corrected by the stress relaxation that occurs during a period of 6 h.



Key

X horizontal displacement, X

Y shear force, Q

1 actually measured hysteresis curve

2 characteristic curve at time of slow-speed deformation

3 stress relaxation after 1,5 h

Figure G.3 — Shear force properties at low-rate deformation

Annex H
(informative)

Durability investigation of elastomeric isolators used for 10 years in a bridge

H.1 General

In order to measure the changes in performance of elastomeric isolators which had been used for approximately 10 years in a bridge, two isolators were removed from the bridge and compression testing, compressive-shear testing and ultimate shear property testing were conducted. The results were compared to the predictions of the accelerated ageing test specified in Annex A. From these comparisons, it was concluded that predictions made using the accelerated ageing test are of practical use in estimating the degradation of elastomeric isolators (see Reference [5]).

H.2 Profile of seismically-isolated bridge

The following can be the profile of the seismically-isolated bridge.

a)	Name	Yama-age Bridge
b)	Location	Tochigi prefecture, Japan
c)	Structure	Six spans of continuous pre-stressed concrete (PC) box girder; 246,3 m
d)	Built	1992
e)	Isolators used	Length 970 mm, width 1 520 mm, height 277 mm [t_r = 18,7 mm, eight layers, HDR(G8)]

H.3 Shear and compressive restoring force properties of the isolators

Table H.1 gives the original measured values and those obtained after 10 years, together with the percentage change, for each property.

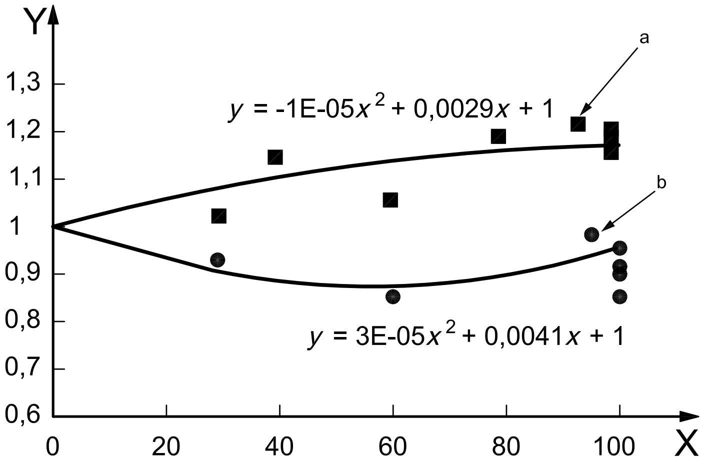
Table H.1 — Measurements and change after 10 years

Property	Isolator	Original (Oct. 1991)	After 10 years (Jan. 2002)	Change
Shear stiffness, (kN/mm)	G1	7,61	7,92	+4,1 %
	G2	7,48	7,73	+3,3 %
Equivalent damping ratio	G1	0,186	0,182	−2,2 %
	G2	0,174	0,181	+4,0 %
Compression stiffness, (kN/mm)	G1	$11,1 \times 10^3$	$11,5 \times 10^3$	+4,0 %
	G2	$11,3 \times 10^3$	$11,1 \times 10^3$	−1,7 %
Ultimate shear property [breaking shear strain (%)]	G1	—	456	—

H.4 Comparison with prediction by the accelerated ageing test

The activation energy of the HDR used in the Yama-age Bridge, determined by the method described in Annex A, was 78,9kJ/mol. The average temperature of the Yama-age Bridge site is 13 °C. The results of several compressive-shear tests on aged isolators were plotted as shown in Figure H.1 (square and circle plots). From these plots, a prediction function was obtained by the least-squares method. The shear stiffness was predicted to increase by about 3 % and the equivalent damping ratio was predicted to decrease by about 4 % after 10 years (see Figure H.1).

By comparing the measured performance changes (see Table H.1) with these predictions, it was concluded that the prediction of shear stiffness was sufficiently accurate for the design of seismic isolators, and that the prediction of the equivalent damping ratio was not so accurate, but nevertheless conservative.



Key

X converted period (years)

Y normalized property

[a] Shear stiffness.

[b] Equivalent damping ratio.

Figure H.1 — Prediction of shear properties

Annex I
(informative)

Durability investigation of elastomeric isolators used for seven years in a building

I.1 General

Two full-scale isolators and one spare isolator were removed from a building approximately seven years after installation and the change in properties was measured. Compression testing, shear testing and ultimate property testing were conducted and the results were analysed. For comparison of the ultimate properties, two isolators of exactly the same dimensions were manufactured from the same compound and tested as references. Simultaneously, the degradation of the rubber material, which was sampled by sectioning the isolator, was evaluated. Minor changes in both isolator and rubber material properties were observed in comparison with the original values. Reasonable agreement was obtained with the predicted data from heat-accelerated ageing tests (see Reference [6]).

I.2 Profile of base-isolated building

The building used was the “Taisei-Yagoto-Ryo”, a company dormitory in Japan. The isolators were installed in 1996, and construction of the building was completed in June 1997. The building is constructed of steel-reinforced concrete with six floors and a penthouse. The height of the building is 18,40 m and the total floor area is 5 482,69 m^2. The soil is classified as “stiff” soil.

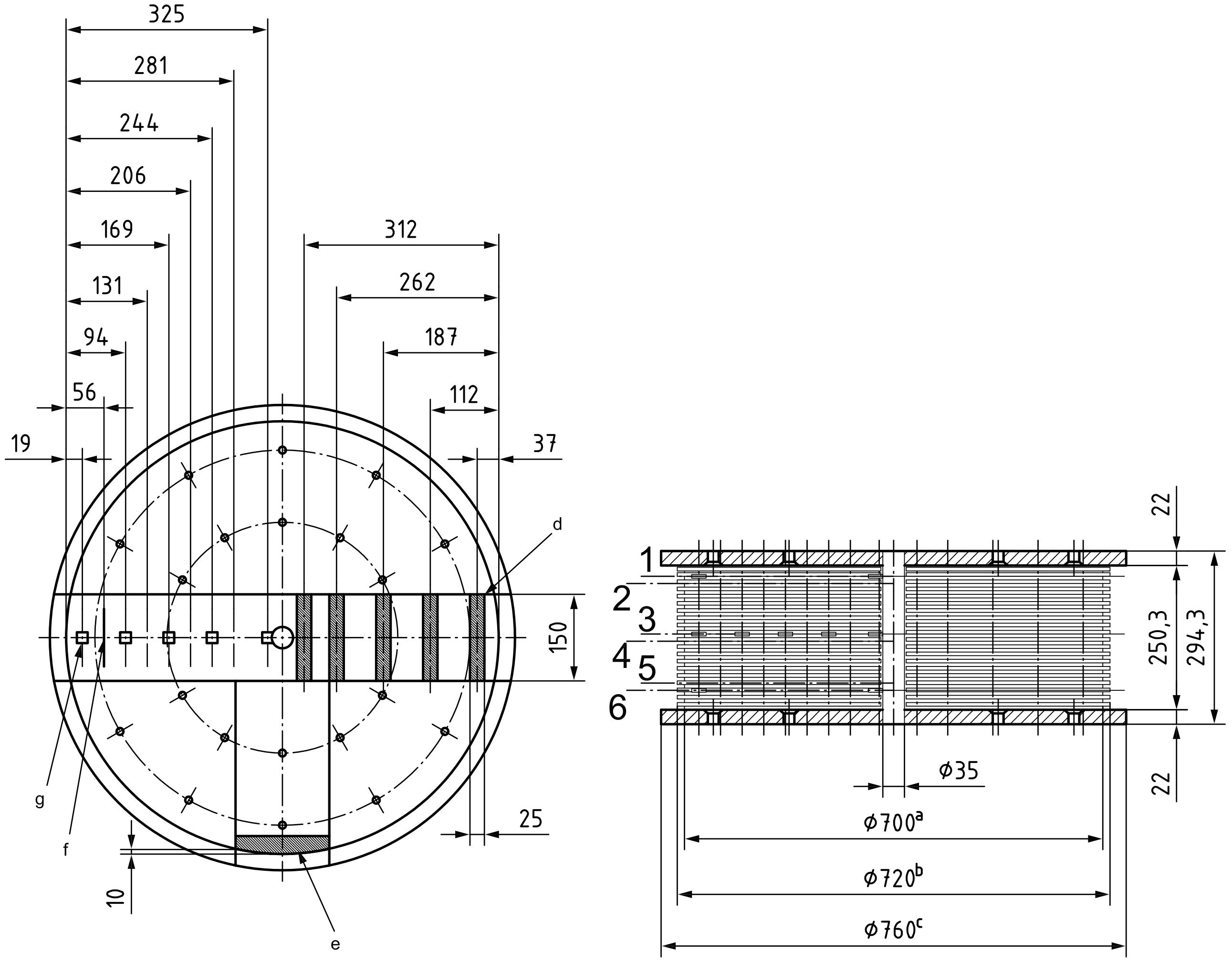
I.3 Base-isolation system

The isolation system consists of 25 LNRs and a total of 20 sliding bearings. The design shear modulus of the LNRs is 0,34 MPa. The LNRs have diameters of 500 mm (18 bearings), 600 mm (5 bearings) and 700 mm (2 bearings). One spare isolator was placed at the site for regular checks of performance changes.

I.4 Replacement and test programme

The two 700-mm-diameter isolators and the 500-mm-diameter spare isolator were removed from the building. The 700-mm-diameter isolators were replaced by newly manufactured isolators. Two reference isolators of exactly the same design were manufactured for comparison purposes. The properties measured are shown in Table I.1. A reference isolator and one removed from the building were sectioned to investigate the properties of the material within each isolator. The material properties measured were micro-hardness, tensile properties, oxygen content, antioxidant content, crosslink density, chemical composition and bond strength. The sampling positions inside each isolator are shown in Figure I.1.

Dimensions in millimetres



Key

1 3rd layer
2 4th layer
3 13th layer
4 14th layer
5 23rd layer
6 24th layer

[a] Inner rubber diameter.

[b] Reinforcing-plate diameter.

[c] Flange diameter.

[d] Bond strength.

[e] Micro-hardness.

[f] Tensile properties.

[g] Oxygen content, crosslink density, antioxidant content and chemical composition.

Figure I.1 — Sampling positions for material tests

Table I.1 — Properties measured

Isolator	Designation	Isolator properties				Rubber material properties
		Height	Compressive stiffness	Shear stiffness	Ultimate properties	
No.1	RB700-1	○	○	○	○	—
No. 2	RB700-2	○	○	○	—	○
Spare	RB500	—	○	○	—	—
Ref. No.1	RB700-R1	—	○	○	—	○
Ref. No. 2	RB700-R2	—	○	○	○	—

I.5 Isolator test results

The shear and compressive stiffness results and the changes from the corresponding initial values are shown in Table I.2. The maximum change in shear stiffness was +6,1 % in RB500, and the average was +5,5 %. The maximum change in compressive stiffness was +4,2 % in RB700-1, and the average was 3,0 %. The results of the ultimate property tests are summarized in Table I.3. The breaking strains for RB700-1 and RB700-R2 were 503,5 % and 495,5 %, respectively. There was no significant difference between the replaced isolator and the reference isolator. It can be deduced that the degradation of the ultimate properties after seven years was very little.

Table I.2 — Test results — Change in compression and shear properties

Isolator designation	Shear stiffness kN/mm			Compressive stiffness kN/mm		
	1996-05	2002-11	Change	1996-05	2002-11	Change
RB700-1	0,849 9	0,885 6	+4,8 %	2 402	2 503	+4,2 %
RB700-2	0,845 9	0,893 8	+5,7 %	2 455	2 540	+3,5 %
RB500	0,620 6	0,658 4	+6,1 %	1 936	1 962	+1,3 %

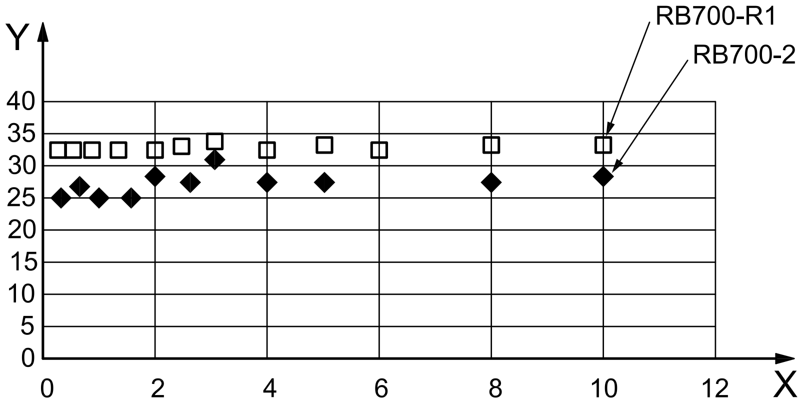
Table I.3 — Test results — Ultimate properties

Property	RB700-1	RB700-R2
Breaking force (kN)	1 626	1 423
Breaking stress (N/mm^2)	4,235	3,707
Breaking displacement (mm)	693,8	682,9
Breaking strain (%)	503,5	495,5

NOTE Breaking stress = (Breaking force)/(Effective area of isolator).

I.6 Rubber-material test results

The micro-hardness and tensile strength at various distances from the bearing surface of the 13th layer are shown in Figures I.2 and I.3. Compared with the results for the reference isolator RB700-R1, the value of each property is slightly high, but there is reasonable agreement.

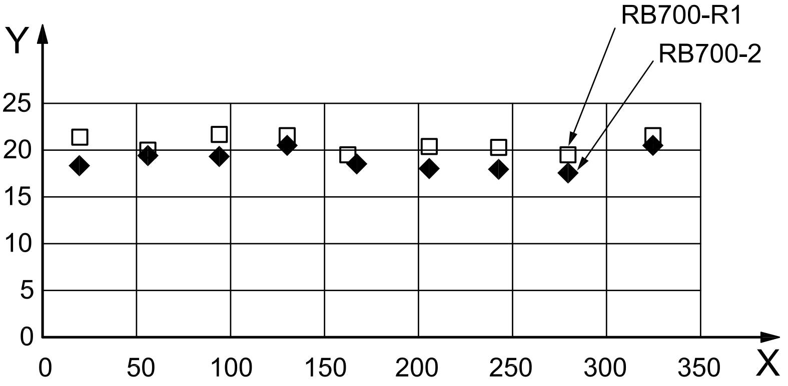


Key

X distance from surface, expressed in millimetres

Y micro-hardness, expressed in IRHD

Figure I.2 — Micro-hardness of 13th layer



Key

X distance from surface, expressed in millimetres

Y tensile strength, expressed in megapascals

Figure I.3 — Tensile strength of 13th layer

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