INTERNATIONAL STANDARD

ISO 22762-2

Second edition
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Elastomeric seismic-protection isolators —

Part 2:
Applications for bridges — Specifications

Appareils d'appuis structuraux en élastomère pour protection sismique —

Partie 2: Applications pour ponts — Spécifications

Reference number
ISO 22762-2:2010(E)

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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 22762-2 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 22762-2:2005), which has been technically revised. It also incorporates the Technical Corrigendum ISO 22762-2:2005/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 22762-1 for bridges and ISO 22762-2 for buildings. This is because the isolator requirements for bridges and buildings are quite different, although the basic concept of the two products is similar. Therefore, ISO 22762-2 and the relevant clauses in ISO 22762-1 are used when ISO 22762 (all parts) is applied to the design of bridge isolators whereas ISO 22762-3 and the relevant clauses of ISO 22762-1 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.

Elastomeric seismic-protection isolators —

Part 2: Applications for bridges — Specifications

1 Scope

This part of ISO 22762 specifies minimum requirements and test methods for elastomeric seismic isolators used for bridges, as well as rubber material used in the manufacture of such isolators.

It is applicable to elastomeric seismic isolators used to provide 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 630, *Structural steels — Plates, wide flats, bars, sections and profiles*

ISO 1052, *Steels for general engineering purposes*

ISO 22762-1:2010, *Elastomeric seismic-protection isolators — Part 1: 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 properties
properties 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

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
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

Table 1 (*continued*)

Symbol	Description
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
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_0	standard temperature, 23 °C or 27 °C; where specified tolerance is ±2 °C, T_0 is standard laboratory temperature
T_r	total rubber thickness, given by $T_r = n \times t_r$
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

Table 1 (*continued*)

Symbol	Description
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
ε	compressive strain of rubber
ε_{cr}	creep strain
ε_T	tensile strain of isolator
ε_{Tb}	tensile-break strain of isolator
ε_{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

Table 1 (*continued*)

Symbol	Description
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

5 Classification

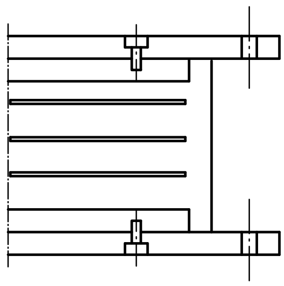
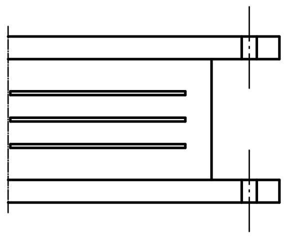
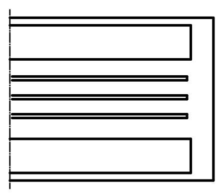
5.1 General

Elastomeric isolators are classified by construction, their ultimate properties and tolerances on their performance.

5.2 Classification by construction

Elastomeric isolators are classified by construction, as shown in Table 2. The structural engineer shall specify which construction is to be used.

Table 2 — Classification by construction

Type	Construction	Illustration
Type I	Mounting flanges are bolted to connecting flanges, which are bonded to the laminated rubber.	
Type II	Mounting flanges are directly bonded to the laminated rubber.	
Type III	Isolators without mounting flanges	

5.3 Classification by tolerances on shear stiffness

Elastomeric isolators may be classified by their tolerance on shear stiffness, as shown in Table 3. The structural engineer shall specify the tolerance required.

Table 3 — Classification by tolerance on shear stiffness

Class	Tolerance %
S-A	± 10
S-B	± 20

6 Requirements

6.1 General

Elastomeric isolators for bridges and the materials used in their manufacture shall meet the requirements specified in this clause. For test items (see Table 4) that have no specific required values, the manufacturer shall define the values and inform the purchaser prior to production.

The standard temperature for determining the properties of elastomeric isolators is 23 °C or 27°C in accordance with prevailing International Standards. However, it is advisable to establish a range of working temperatures, taking into consideration actual environmental temperatures and possible changes in temperature at the work site where the elastomeric isolators are installed.

6.2 Type tests and routine tests

6.2.1 Testing to be carried out on elastomeric isolators is classified into

a) type tests, and

b) routine tests.

6.2.2 Type tests shall be conducted either to ensure that project design parameters have been achieved (in which case the test results shall be submitted to the structural engineer for review prior to production) or to verify isolator performance and material properties during development of an isolator. The test piece for each type test shall be full-scale or one of the options specified in Table 4. The test piece shall not have been subjected to any previous test programme. The tests shall be performed on test pieces not subjected to any scragging, unless the production isolators are to be supplied after scragging. In that case, the test pieces shall be subjected to the same scragging procedure as the production isolators.

6.2.3 Previous type test results may be substituted, provided the following conditions are met.

a) Isolators are fabricated in a similar manner and from the same compound and adhesive.

b) All corresponding external and internal dimensions are within 10 % of each other.

c) The second shape factors are within ± 10 %.

d) The test conditions such as maximum and minimum vertical load applied in the ultimate property test, as described in 6.5.7, are more severe.

Table 4 — Tests on products

Properties	Test item	Test method	Routine test	Type test	Test piece[a]
Compressive properties Rotation performance	Compressive stiffness Compressive deflection	ISO 22762-1:2010, 6.2.1, method 1	X	X	Full-scale only
Shear properties	Shear stiffness Equivalent damping ratio Post-yield stiffness (for LRB) Characteristic strength (for LRB)	ISO 22762-1:2010, 6.2.2	X	X	Full-scale only
Tensile properties	Tensile fracture strength Shear strain	ISO 22762-1:2010, 6.5	N/A	Opt.	Scale B
Dependency of shear properties	Shear strain dependency	ISO 22762-1:2010, 6.3.1	N/A	X	Scale B
	Compressive stress dependency	ISO 22762-1:2010, 6.3.2	N/A	Opt.	Scale B
	Frequency dependency	ISO 22762-1:2010, 6.3.3 (m) ISO 22762-1:2010, 5.8	N/A	X(m)	Scale A, STD, SBS
	Repeated loading dependency	ISO 22762-1:2010, 6.3.4	N/A	X	Scale B
	Temperature dependency	ISO 22762-1:2010, 6.3.5 (m) ISO 22762-1:2010, 5.8	N/A	X(m)	Scale A, STD, SBS
Shear displacement capacity	Breaking strain Buckling strain Roll-out strain	ISO 22762-1:2010, 6.4	N/A	X	Scale B
Durability	Ageing	ISO 22762-1:2010, 6.6.1 (m) ISO 22762-1:2010, 5.8	N/A	X(m)	Scale A, STD, SBS
	Creep	ISO 22762-1:2010, 6.6.2	N/A	X	Scale A
Cyclic compressive fatigue	Shear stiffness	ISO 22762-1:2010, 6.6.3	N/A	X	Scale B
Reaction force characteristics at low-rate deformation	Shear stiffness or shear force	ISO 22762-1:2010, 6.7	N/A	Opt.	Scale A

X = test to be conducted with isolators; X(m) = test can be conducted either with isolators or with shear-block test pieces.

N/A = not applicable; Opt. = optional.

Scale A: Scaling such that, for a circular bearing, diameter ⩾ 150 mm, for a rectangular bearing, side length ⩾ 100 mm and, for both types, rubber layer thickness ⩾ 1,5 mm and thickness of reinforcing steel plates ⩾ 0,5 mm.

Scale B: Scaling such that, for a circular bearing, diameter ⩾ 450 mm, for a rectangular bearing, side length ⩾ 400 mm and, for both types, rubber layer thickness ⩾ 1,5 mm and thickness of reinforcing steel plates ⩾ 0,5 mm.

STD = standard test piece (see Tables 10 and 11 of ISO 22762-1:2010).

SBS = shear-block test piece specified in ISO 22762-1:2010, 5.8.3. With LRB, SBS shall only be used for ageing tests.

[a] Test piece may in all cases be a full-scale isolator. This column indicates other options, where these exist.

6.2.4 Routine tests are carried out during production for quality control. Sampling is allowed for routine testing. Sampling shall be conducted randomly and cover not less than 20 % of the production of any isolator design. For a given project, tests shall cover not less than four test pieces for each size and not less than 20 test pieces in total. If isolators are supplied after scragging, the routine test shall be performed on scragged isolators.

6.3 Functional requirements

6.3.1 Elastomeric isolators for bridges have the conventional basic functions of bridge rubber bearings, such as supporting the weight of the structure and live loads, absorbing the expansion, contraction, rotation and deflection of the superstructure. In addition, elastomeric isolators have more sophisticated functions in order to improve the deformation performance characteristics of superstructures, regulate the inherent period of superstructures, and effectively distribute inertial forces and reduce vibration energies using the spring and shock damping performance of rubber materials or a combination of rubber materials and lead plugs.

6.3.2 The elastomeric isolators shall function correctly when they are subjected to normal environmental conditions and maintenance, during an economically reasonable design service life. Where exceptional environmental and application conditions are encountered, additional precautions shall be taken. The conditions shall then be precisely defined.

6.3.3 Although seismic rubber bearings are designed to accommodate shear movements, they should not be used to provide permanent resistance to a constantly applied shear force.

6.3.4 Some caution is necessary if bearings are designed to accommodate tensile forces. The limiting values are given in Annex C.

6.4 Design compressive force and design shear displacement

The design stress and strain of an isolator are defined by the following relationships between the design force and the displacement.

$$\sigma_0 = \frac{P_0}{A}, \quad \sigma_{max} = \frac{P_{max}}{A_e}, \quad \sigma_{min} = \frac{P_{min}}{A};$$

and

$$\gamma_0 = \frac{X_0}{T_r}, \quad \gamma_{max} = \frac{X_{max}}{T_r}$$

The design compressive forces P_0, P_{max} and P_{min} and design shear displacements X_0 and X_{max} for an isolator shall be provided by the structural engineer.

6.5 Performance requirements

6.5.1 General

The isolators shall be tested and the results recorded using the specified test methods. They shall satisfy the requirements listed below. The design value for each isolator shall be specified prior to the tests. The test items are summarized in Table 4 which indicates the type tests that are optional, where a scaled isolator or a material test piece may substitute an isolator, and the tests to be performed as routine tests. Double-shear configuration testing, as described in 6.2.2 of ISO 22762-1:2010, can be employed with the approval of the structural engineer.

Some of these properties may be determined using one of the standard test pieces detailed in Tables 9 and 10 of ISO 22762-1:2010. The standard test pieces are used for non-specific product tests, such as testing in the development of new materials and products.

6.5.2 Compressive properties

6.5.2.1 General requirements

6.5.2.1.1 The maximum compressive displacement at the design load shall exceed the design requirement specified by the structural engineer.

6.5.2.1.2 When a compressive stiffness constant is required, the compressive stiffness, K_v, shall be within ± 30 % of the design requirement.

6.5.2.1.3 The values of P_1 and P_2 necessary to calculate K_v are obtained from Equations (1) and (2):

$$P_1 = A_{load} \times \sigma_1 \tag{1}$$

$$P_2 = A_{load} \times \sigma_2 \tag{2}$$

whereby the recommended values of σ_1 and σ_2 should be as below:

a) σ_1: 1,5 N/mm^2

b) σ_2: 6,0 N/mm^2

The values of σ_1 and σ_2 can also be given by the structural engineer.

6.5.2.2 Test piece

The test piece shall be a full-scale isolator for the type test and a production isolator for the routine test.

6.5.2.3 Test conditions

The standard test temperature, T_0, is 23 °C or 27 °C. If the test is carried out at a different temperature, the result shall be corrected to the value of the property at T_0 by an appropriate method.

6.5.3 Rotation properties

6.5.3.1 General requirements

The deflection measured during compressive tests at the design load shall exceed the rotation deflection specified by the structural engineer. Static rotation tests can be carried out as an option using a test piece and test method agreed with the structural engineer.

6.5.3.2 Test piece

The test piece shall be a full-scale isolator for the type test and a production isolator for the routine test.

6.5.4 Shear properties

6.5.4.1 General requirements

6.5.4.1.1 The shear strain shall be 100 %, 175 % or a shear strain as selected by the structural engineer.

6.5.4.1.2 The shear stiffness shall be within the tolerance selected from Table 3 for the design requirement.

6.5.4.1.3 The equivalent damping ratio shall satisfy the requirement specified by the structural engineer.

6.5.4.1.4 The test items required for determination of shear properties are given in Table 5.

Table 5 — Shear property test items

Isolator type	Test item	No. of loading cycles	Data loop
LNR	Shear stiffness, K_h	3	Third cycle
HDR	Shear stiffness, K_h Equivalent damping ratio, h_{eq}	3 or 11	Third cycle or average of the second to the eleventh. The data may be determined from a single loop (preferably the third) or from the average response over the second to eleventh loops, depending on the decision of the structural engineer.
LRB	Shear stiffness , K_h, and equivalent damping ratio h_{eq} or post-yield stiffness K_d, and characteristic strength, Q_d	3 or 11	Third cycle or average of the second to the eleventh. The data may be evaluated from a single loop (preferably the third) or from the average response over the second to eleventh loops, depending on the decision of the structural engineer.

6.5.4.2 Test piece

The test piece shall be a full-scale isolator for the type test and a production isolator for the routine test.

6.5.4.3 Test conditions

The standard temperature, T_0, is 23 °C or 27 °C. If the test is carried out at a different temperature, the result shall be corrected to the value of the property at T_0 by an appropriate method.

6.5.5 Tensile properties

6.5.5.1 General requirements

The test piece shall not break at the force specified by the structural engineer.

6.5.5.2 Test piece

The test piece shall be a full-scale or a scale B isolator.

6.5.5.3 Test conditions

The test piece shall be subjected to the shear strain specified by the structural engineer, and the force specified by the structural engineer to pull the isolator shall then be applied.

6.5.6 Dependencies of shear properties

6.5.6.1 Shear-strain dependency

6.5.6.1.1 General requirements

The shear-strain dependency shall be within a specified range agreed by both the structural engineer and the manufacturer.

6.5.6.1.2 Test piece

The test piece shall be a full-scale or a scale B isolator.

6.5.6.1.3 Test conditions

The shear properties at 0,5γ_0, 1,0γ_0, 1,5γ_0 or the maximum shear strain shall be determined. Tests can also be performed at shear strains of 0,1γ_0 and 0,2γ_0.

6.5.6.2 Compressive stress dependency

6.5.6.2.1 General requirements

The compressive stress dependency shall be within a specified range agreed on by both the structural engineer and the manufacturer.

6.5.6.2.2 Test piece

The test piece shall be a full-scale or a scale B isolator.

6.5.6.2.3 Test conditions

The shear properties at 0, 0,5σ_0, 1,0σ_0, 1,5σ_0 and the maximum tensile stress, if applicable, shall be determined, and the results normalized using the value corresponding to the design stress.

6.5.6.3 Frequency dependency

6.5.6.3.1 General requirements

The frequency dependency shall be within a specified range agreed by both the structural engineer and the manufacturer.

6.5.6.3.2 Test piece

The test piece shall be a full-scale or a scale A isolator, a standard test piece or a shear-block test piece.

6.5.6.4 Repeated loading dependency

6.5.6.4.1 General requirements

The repeated loading dependency shall be within a specified range agreed by both the structural engineer and the manufacturer.

6.5.6.4.2 Test piece

The test piece shall be a full-scale or a scale B isolator.

6.5.6.4.3 Test conditions

The shear strain amplitude shall be γ_0.

6.5.6.5 Temperature dependency

6.5.6.5.1 General requirements

The temperature dependency shall be within a specified range agreed by both the structural engineer and the manufacturer.

6.5.6.5.2 Test piece

The test piece shall be a full-scale or a scale A isolator, a standard test piece or a shear-block test piece.

6.5.6.5.3 Test conditions

The shear strain amplitude shall be γ_0.

6.5.7 Shear displacement capacity

6.5.7.1 General requirements

6.5.7.1.1 The test piece shall be subjected to shear deformation under the constant compressive force given in the design requirements until breaking, buckling or roll-out occurs in one direction. The shear deformation and shear force at occurrence of break or buckling shall be recorded.

6.5.7.1.2 The vertical forces shall be P_{max} and P_{min} in the case of dowelled or recessed bearings.

6.5.7.1.3 For bolted bearings where P_{min} is tensile, an additional test at that load shall be performed if requested by the structural engineer. The test at P_{min} can be carried out by the procedure given in 6.5 of ISO 22762-1:2010, the shear strain applied shall be γ_{max} and the isolator shall not fail under the load P_{min}.

6.5.7.2 Test piece

The test piece shall be a full-scale or a scale B isolator.

6.5.8 Durability

6.5.8.1 Ageing

6.5.8.1.1 General requirements

The change in the shear stiffness and in the damping properties shall be within ± 30 %.

6.5.8.1.2 Test piece

The test piece shall be a full-scale or a scale A isolator, a standard test piece or a shear-block test piece.

If the production isolators are to be supplied after scragging, the test pieces shall be subjected to the same scragging procedure as the production isolators. The durability test shall be carried out directly after scragging.

6.5.8.2 Creep

6.5.8.2.1 General requirements

The creep strain [see ISO 22762-1:2010, 6.6.2.6 b) for definition] shall be less than 10 % after 60 years.

6.5.8.2.2 Test piece

The test piece shall be a full-scale or a scale A isolator.

6.5.9 Cyclic compressive fatigue properties

6.5.9.1 General requirements

The change in shear stiffness after the fatigue test shall be within ± 15 %.

It shall be confirmed that there are no cracks visible on the test piece exterior.

6.5.9.2 Test piece

The test piece shall be a full-scale or a scale B isolator.

6.5.9.3 Test conditions

The shear strain shall be 70 % and, optionally, an additional test can be carried out at 0 %. Compressive shear test as described in 6.2.2 of ISO 22762-1:2010 can be employed with the approval of the structural engineer.

6.5.10 Reaction force characteristics at low-rate deformation

6.5.10.1 General requirements

The shear stiffness or shear force at low-rate deformation shall be within a specified range agreed by both the structural engineer and the manufacturer.

6.5.10.2 Test piece

The test piece shall be a full-scale or a scale A isolator.

6.6 Rubber material requirements

6.6.1 General

The rubber materials used in the manufacture of elastomeric isolators shall be tested as required in Table 6. The test results shall be properly recorded to verify that the specified requirements are satisfied. The frequency of each required routine test shall be determined in accordance with the manufacturer's quality control.

6.6.2 Tensile properties

The recommended minimum values are given in Annex E.

6.6.3 Properties after ageing in air

6.6.3.1 General requirements

The requirements for tensile strength and elongation at break shall be the following:

— change in tensile strength: within ± 25 %;

— change in elongation at break: maximum –50 %.

EXAMPLE Original 600 %, elongation at break after ageing shall not be less than 300 %.

6.6.3.2 Test conditions

6.6.3.2.1 The recommended conditions for natural rubber- and chloroprene-based rubber materials should be as the following:

— natural rubber: 70 °C for 168 h;

— chloroprene rubber: 100 °C for 72 h.

6.6.3.2.2 Other conditions can be used by agreement between the structural engineer and the manufacturer. Test conditions and requirements for other elastomers shall be recommended by the manufacturer and agreed to by the structural engineer.

Table 6 — Test items for rubber material

Property	Test item	Test method	Routine test		Type test	
			Inner rubber	Cover rubber	Inner rubber	Cover rubber
Tensile properties	Tensile strength	ISO 22762-1:2010, 5.3	X	X	X	X
	Elongation at break		X	X	X	X
	100 % modulus		N/A	N/A	X	X
Air ageing properties	Tensile strength	ISO 22762-1:2010, 5.4	Opt.	Opt.	X	X
	Elongation at break		Opt.	Opt.	X	X
	100 % modulus		N/A	N/A	X	X
Hardness	Hardness	ISO 22762-1:2010, 5.5	Opt.	Opt.	Opt.	Opt.
Adhesion properties	90° peel strength	ISO 22762-1:2010, 5.6	X	N/A	X	X
Compression set	Compression set	ISO 22762-1:2010, 5.7	Opt.	N/A	X	N/A
Shear properties	Shear modulus	ISO 22762-1:2010, 5.8	Opt.	N/A	X	N/A
	Equivalent damping ratio		Opt.	N/A	X	N/A
	Temperature dependency of shear modulus and loss factor		N/A	N/A	X	N/A
Brittleness point	Brittleness temperature	ISO 22762-1:2010, 5.10	N/A	N/A	Opt.	X
Ozone resistance	Observation of cracks	ISO 22762-1:2010, 5.11	N/A	X	N/A	X
Low-temperature crystallization	Hardness	ISO 22762-1:2010, 5.12	N/A	N/A	X[a]	X[a]

X = test to be carried out; N/A = not applicable; Opt. = optional.

[a] Test is required, unless elastomer is not susceptible to crytallization in range of service temperatures (see 5.12 of ISO 22762-1:2010).

6.6.4 Hardness

Hardness may be used as a quality control test and for other purposes when a relationship has been established with the appropriate shear modulus. Hardness should not be used for primary design purposes.

6.6.5 Adhesion properties

The requirements for adhesion properties shall be 90° peel strength: minimum 7,0 N/mm.

6.6.6 Compression set

6.6.6.1 The recommended test conditions for NR-based compounds are 70 °C for $24_{-2}^{\ 0}$ h, 25 % compression.

6.6.6.2 The corresponding requirements shall be as follows:

a) for LNR and other low-damping isolators, compression set $\leqslant$ 35 %;

b) for HDR, compression set $\leqslant$ 60 %.

6.6.6.3 The test conditions and requirements for other elastomers shall be as recommended by the manufacturer and agreed by the structural engineer.

6.6.7 Ozone resistance

6.6.7.1 There shall be no cracks on the cover rubber.

6.6.7.2 The test conditions shall be: 50 pphm (50 mPa), 20 % elongation, 40 °C for 96 h.

6.6.8 Other properties

Properties other than the ones listed above shall be determined by the test methods listed in Table 6. Each test result shall be within the tolerances specified prior to testing.

6.7 Dimensional requirements

6.7.1 Typical dimensions of elastomeric isolators are given in Table 7 as a guide for the design of elastomeric isolators.

6.7.2 The thickness of the cover rubber should be 5 mm or more and should always meet the requirements of service environments and conditions.

6.7.3 The thickness of the reinforcing steel plate should satisfy the stress check specified in 7.6, and stability against large displacements in the event of an earthquake should also be considered.

6.8 Requirements on steel used for flanges and reinforcing plates

6.8.1 Steel plates used for flanges, end plates and inner plates shall meet the strength requirements specified in Table 8.

6.8.2 ISO 630 or ISO 1052 or any other International Standard may be used, as long as the steel specified satisfies the requirements given in Table 8 or is approved by the structural engineer.

7 Design rules

7.1 General

7.1.1 The elastomeric isolators shall be designed to meet the relevant provisions of this clause, in the serviceability limit state determined from the total compressive force (dead plus live force), restraint of thermal displacement and wind force, and more frequent earthquakes than the design level earthquake frequency, and the ultimate limit state caused by the design level earthquake.

7.1.2 In the serviceability limit state, the design shall be such that the isolators will not suffer damage that would affect their proper functioning, or incur excessive maintenance costs during their intended life.

7.1.3 In the ultimate limit state, the strength and stability of the isolators shall be adequate to withstand the ultimate design forces and movements of the structure.

Table 7 — Typical dimensions of elastomeric isolators

Dimension a or d_0 mm	**Thickness** mm			**Second shape factor** S_2	**Lead plug ratio** (for LRB only) A_p/A %	
	Rubber layer t_r		**Steel plate** t_s			
	min.	max.	min.	min.	min.	max.
400	9	16	3 (see 7.6)	4	3	10
450	10	18				
500	11	20				
550	12	22				
600	13	25				
650	14	27				
700	15	29				
750	16	31				
800	17	33				
850	18	35				
900	19	37				
950	20	39				
1 000	21	41				
1 050	22	43				
1 100	23	45				
1 150	24	47				
1 200	25	50				
1 250	27	52				
1 300	28	54				
1 350	29	56				
1 400	30	58				
1 450	31	60				
1 500	32	62				

Table 8 — Hot- and cold-rolled sheet and strip for flanges and reinforcing steel plates

Designation	Yield stress σ_{sy} N/mm^2 — Thickness of steel plate t_s mm			Tensile strength σ_{su} N/mm^2
	$t \leqslant 16$	$16 < t \leqslant 40$	$40 < t$	
SS400	$\sigma_{sy} \geqslant 245$	$\sigma_{sy} \geqslant 235$	$\sigma_{sy} \geqslant 215$	$400 \leqslant \sigma_{su} \leqslant 510$
SM490A	$\sigma_{sy} \geqslant 325$	$\sigma_{sy} \geqslant 315$	$\sigma_{sy} \geqslant 295$	$490 \leqslant \sigma_{su} \leqslant 610$

7.2 Shape factor

7.2.1 First shape factor

7.2.1.1 The first shape factor, S_1, of a rubber layer is defined as the ratio of the effective loaded area, A_{load}, to the free surface area, A_{free}, including holes in the layer of rubber. This can be expressed by Equation (3):

$$S_1 = \frac{A_{load}}{A_{free}} \tag{3}$$

7.2.1.2 The loaded area of rubber layer, A_{load}, can be expressed as follows.

Circular isolator: $$A_{load} = A = \frac{\pi}{4}\left\{d_0{}^2 - \left(n_h \times d_n{}^2 + n_p \times d_p{}^2\right)\right\} \tag{4}$$

Rectangular isolator: $$A_{load} = A = a \times b - \frac{\pi}{4}\left(n_h \times d_h{}^2 + n_p \times d_p{}^2\right) \tag{5}$$

where A_{load} is the same as the effective plan area A.

7.2.1.3 The load-free area of rubber layer, A_{free}, can be expressed as follows.

Circular isolator: $$A_{free} = \pi\left(d_0 + n_h \times d_h\right)t_r \tag{6}$$

Rectangular isolator: $$A_{free} = \left[2\left(a + b\right) + \pi \times n_h \times d_h\right] \tag{7}$$

where

d_h is the diameter of holes;

n_h is the number of holes;

d_p is the diameter of lead plugs;

n_p is the number of lead plugs.

7.2.1.4 If the holes are adequately plugged with rubber or lead, the rubber layer can be treated as having no holes in calculating the load-free area, A_{free}.

7.2.1.5 For the rubber layer without holes and lead plugs, the first shape factor is given as follows.

Circular isolators: $S_1 = \frac{d_0}{4t_r}$ (8)

Rectangular isolators: $S_1 = \frac{a \times b}{2(a+b)t_r}$ (9)

7.2.2 Second shape factor

The second shape factor, S_2, is defined as the ratio of the effective width to the total thickness of the inner rubber.

a) For circular isolators:

$$S_2 = \frac{d_0}{T_r} \tag{10}$$

b) For rectangular isolators:

when there is restriction of movement in the transverse direction:

$$S_2 = \frac{a}{T_r} \tag{11}$$

When there is no restriction of movement in the transverse direction:

$$S_2 = \frac{a}{T_r} \quad (a \leqslant b) \tag{12}$$

or

$$S_2 = \frac{b}{T_r} \quad (a > b)$$

7.3 Compressive and shear properties

7.3.1 Compressive stiffness

The compressive stiffness, K_v, is expressed as Equation (13):

$$K_v = \frac{E_c \times A}{T_r} \tag{13}$$

where E_c is as given in Annex F.

7.3.2 Shear stiffness and equivalent damping ratio

7.3.2.1 The shear stiffness is expressed as Equation (14):

$$K_h = G \frac{A}{T_r} \tag{14}$$

7.3.2.2 When the shear strain dependency on shear modulus is considered, the shear stiffness is expressed as Equation (15):

$$K_h = G_{eq}(\gamma) \times \frac{A}{T_r} \tag{15}$$

where $G_{eq}(\gamma)$ is determined as indicated in Annex G.

7.3.2.3 The equivalent damping ratio, h_{eq}, is expressed as Equation (16):

$$h_{eq} = \frac{1}{2\pi} \times \frac{W_d}{K_h \times X^2} \tag{16}$$

as shown in Annex G.

7.4 Shear strain due to horizontal displacements

The shear strain due to horizontal displacements is given by the following expressions.

a) When the shear strain is caused not by an earthquake, but by other effects such as thermally-induced movement, concrete shrinkage, warp of bridge:

$$\gamma_s = \frac{X_s}{T_r} \leqslant 70\ \% \tag{17}$$

b) During an earthquake:

$$\gamma_d = \frac{X_d}{T_r} \leqslant \frac{\gamma_u}{1,2} \tag{18}$$

7.5 Total local shear strain

7.5.1 Local shear strain due to compressive force

The local shear strain due to compressive force is given by the following expressions:

a) for rectangular isolators:

$$\gamma_c = \frac{8,5 \times S_1 \times P_{max}}{E_c{}^s \times A_e} \tag{19}$$

b) for circular isolators:

$$\gamma_c = \frac{6,0 \times S_1 \times P_{max}}{E_c{}^s \times A_e} \tag{20}$$

where

$E_c{}^s$ is as given in Annex H;

P_{max} is the maximum compressive force;

A_e is the overlap area associated with non-seismic displacements.

7.5.2 Local shear strain due to rotation

The local shear strain due to beam rotation is expressed as Equations (21) and (22):

a) For rectangular isolators:

$$\gamma_{\text{r}} = \frac{a^2 \times \theta_{\text{a}} + b^2 \times \theta_{\text{b}}}{2 t_{\text{r}}^2 n} \tag{21}$$

b) For circular isolators:

$$\gamma_{\text{r}} = 6{,}0 \times S_1^2 \times \theta / n \tag{22}$$

NOTE Equations (21) and (22) assume the rubber is incompressible. The effect of the finite compressibility is to increase the shear strain. The equations lead to an error generally less than 10 % for $S_1 < 8$.

7.5.3 Total local shear strain

The total local shear strain shall satisfy Equation (23):

$$\Sigma\gamma = \gamma_{\text{c}} + \gamma_{\text{s}} + \gamma_{\text{r}} \leqslant \gamma_{\text{a}} \tag{23}$$

where

$\Sigma\gamma$ is the total local shear strain;

γ_{a} is the upper-limit design strain value (see Annex F).

7.6 Tensile stress on reinforcing steel plates

The tensile stress on the reinforcing steel plates shall satisfy Equation (24):

$$\sigma_{\text{s}} = 2\lambda \times \frac{P_{\text{max}} t_{\text{r}}}{A_{\text{e}} \times t_{\text{s}}} \leqslant \sigma_{\text{sa}} \tag{24}$$

where

λ is as given in Annex A;

σ_{sa} is as specified by the structural engineer;

A_{e} is the overlap area associated with non-seismic displacements.

7.7 Stability

7.7.1 Maximum compressive stress in non-seismic condition

The maximum compressive stress is given by Equation (25):

$$\sigma_{\text{max}} = \frac{P_{\text{max}}}{A_{\text{e}}} \tag{25}$$

where

P_{max} is the maximum compressive force;

A_{e} is the overlap area associated with non-seismic displacements.

It is recommended that the maximum compressive stress in non-seismic condition meet the requirements given in Annex I.

7.7.2 Rotation performance check

The rotation performance by the combination of compressive stress with beam rotational loading shall satisfy Equations (26) and (27).

a) For rectangular isolators:

$$\frac{1}{C_1} \times \frac{P}{K_v} \geqslant \frac{(a \times \theta_a + b \times \theta_b)}{2} \tag{26}$$

b) For circular isolators:

$$\frac{1}{C_1} \times \frac{P}{K_v} \geqslant \frac{d_0 \times \theta}{2} \tag{27}$$

where

C_1 is a safety factor, the value of which shall be taken as 1 and 3;

P is compressive force in non-seismic condition.

NOTE The safety factor, C_1, allows for uncertainty in the value of K_v.

7.7.3 Buckling check

The buckling stability due to compressive forces under non-seismic and earthquake conditions shall satisfy Equations (28) and (29).

a) For rectangular isolators:

$$\frac{P_{max}}{A_c} \leqslant \frac{1}{\phi} \times \frac{a_c \times G \times S_1}{T_r} \tag{28}$$

b) For circular isolators:

$$\frac{P_{max}}{A_e} \leqslant \frac{1}{\phi} \times \frac{d_0 \times G \times S_1}{T_r} \tag{29}$$

where ϕ is as given in Annex B.

7.7.4 Tensile stress on isolator

The tensile stress caused by uplift forces on the isolator shall satisfy Equation (30):

$$\sigma_t = \frac{V}{A_e} \leqslant \sigma_{te} \tag{30}$$

where

σ_{te} is as given in Annex C;

A_e is the overlap area associated with non-seismic and seismic displacements.

7.8 Force, moment and deformation affecting structures

7.8.1 Shear force affecting structures due to movement

The shear force, Q, affecting structures due to shear movement is given by Equation (31):

$$Q = K_h \times X \tag{31}$$

7.8.2 Resistance to rotation

7.8.2.1 The spring-back moment due to axial rotations through the centre of an elastomeric isolator and parallel to the direction of the dimension, b, of the isolator is given by Equations (32) and (33).

a) For rectangular isolators:

$$M = \frac{G}{\gamma_m} \times \frac{\theta \times a^5 \times b}{n \times t_r^3 \times K_s} \tag{32}$$

b) For circular isolators:

$$M = \frac{G}{\gamma_m} \times \frac{\pi \times \theta \times D^6}{512 \times n \times t_r^3} \tag{33}$$

where

$\gamma_m = 1$;

K_s is a factor as given in Table 9.

Table 9 — K_s factors

b/a	0,5	0,75	1	1,2	1,25	1,3	1,4	1,5
K_s	137	100	86,2	80,4	79,3	78,4	76,7	75,3
b/a	1,6	1,7	1,8	1,9	2	2,5	10	∞
K_s	74,1	73,1	72,2	71,5	70,8	68,3	61,9	60

NOTE Equation (32) above for rectangular isolators is applicable to axial rotations parallel to b even when $b < a$.

7.8.2.2 The spring-back moment values calculated using the above equations are sufficient for most purposes. However, they shall be determined experimentally if detailed information on these values is necessary. For large vertical compressive forces, P, the stiffness in rotation of rubber bearings can be higher than that given by the equations, owing to the decrease in the effective thickness of the rubber layers.

7.8.3 Compressive displacement due to compressive force

The compressive displacement, Y, due to compressive forces is given by Equation (34):

$$Y = \frac{P}{K_v} \tag{34}$$

7.9 Design of fixings

7.9.1 External forces affecting joint members

The following are the necessary items and combinations selected as external forces to be considered in designing joint members:

a) compressive reactions (dead force reaction, live force reaction, negative reaction, lift during earthquakes, etc.);

b) shear forces caused by movement under service loads, wind, seismic loads and other actions;

c) overturning moments determined by multiplying the shear force by the effective height of the isolator;

d) eccentric moments caused by the shear displacement and compressive reaction.

7.9.2 Fixings and stresses to be checked

Stresses in fixings to be checked are given in Table 10 for bolts, in Table 11 for shear keys and in Table 12 for flanges.

Table 10 — Bolts

	External force	Cross-section to be considered
Tensile	Tensile force resisting moment plus uplift compressive force	Cross-sectional area of bolts contributing to tensile force
Shear	Shear force	Overall area of cross-section
NOTE When calculating the tensile stress resisting moment and the cross-sectional area of bolts contributing to it, a method considered as reasonable upon discussion between the structural engineer and the manufacturer can be adopted. For example, the bending theory for single-reinforcement concrete is applicable.		

Table 11 — Shear keys

	External force	Cross-section to be considered
Compression	Shear force	Compression area common to key and flange
Shear	Shear force	Key cross-sectional area

Table 12 — Mounting flanges

	External force	Cross-section to be considered
Compression	Shear force	Compression area common to key and flange
Bending	Tensile force from resisting moment plus uplift force	Effective width of flange × thickness

7.9.3 Allowable stress

The allowable stress shall be specified by the structural engineer.

8 Manufacturing tolerances

8.1 General

Dimensional tolerances for elastomeric isolators for bridges shall be as specified below.

Product dimensions shall be specified at a standard temperature of T_0 (= 23 or 27)°C ± 5 °C. Measurement made at a different temperature shall be corrected to a standard temperature. Dimensions shall be measured at least 24 h after curing of bearing. The cooling time shall be defined according to the product size and shall be based on measurement of the internal temperature of the product or another appropriate method.

Larger bearings may need more than 24 h after curing.

8.2 Measuring instruments

The following can be used as measuring instruments:

a) vernier calipers;

b) calipers;

c) height gauge;

d) limit gauge, to be calibrated with a gauge certified to match the upper and lower tolerance limits;

e) straight rule;

f) other instruments, such as a tape measure.

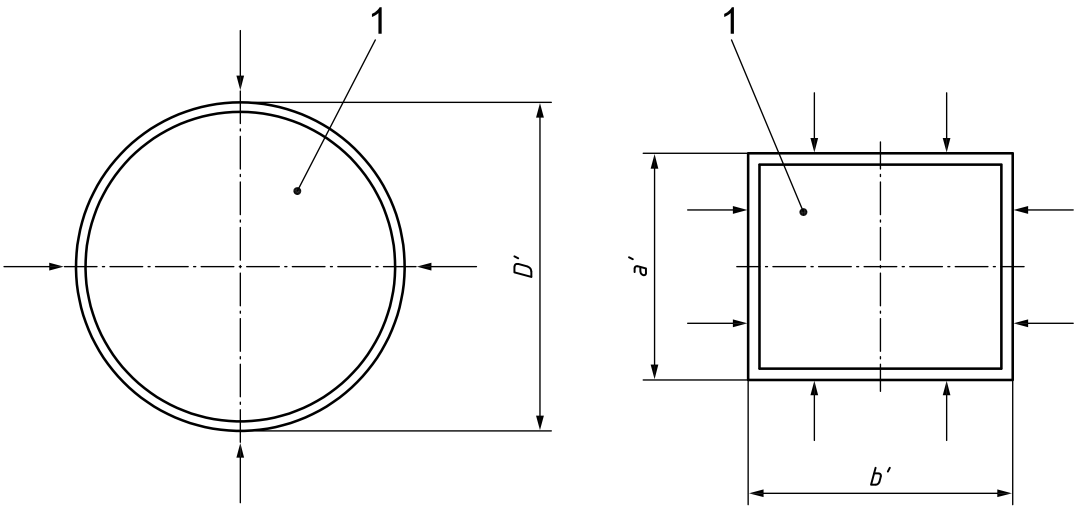
8.3 Plan dimensions of isolator body

8.3.1 Measurement method (see Figure 1)

The measurement method to determine the plan dimensions of circular and rectangular isolators shall be as follows.

a) For circular isolators: the plan dimensions shall be determined by measuring the diameter at two different locations.

b) For rectangular isolators: the plan dimensions shall be measured at two positions on each side.



Key

1 reinforcing steel plate

NOTE The measurement points are indicated by arrows.

Figure 1 — Examples of plan dimension measurement positions

8.3.2 Tolerances

Tolerances on plan dimensions (width *a*′, length *b*′ and diameter *D*′) are specified for Type I, Type II and dowelled Type III isolators in Table 13 according to the nominal dimensions of the product.

For recessed Type III isolators, the tolerance shall be ± 2 mm, or ± 0,4 % of the plan dimension, whichever is the greater.

Table 13 — Tolerances on plan dimensions (*a*′, *b*′ and *D*′) of products

Nominal plan dimensions (*a*′, *b*′, *D*′) mm		Tolerance
Above	Maximum	
—	500	± 5 mm
500	1 500	± 1 %
1 500	—	± 15 mm

8.4 Product height

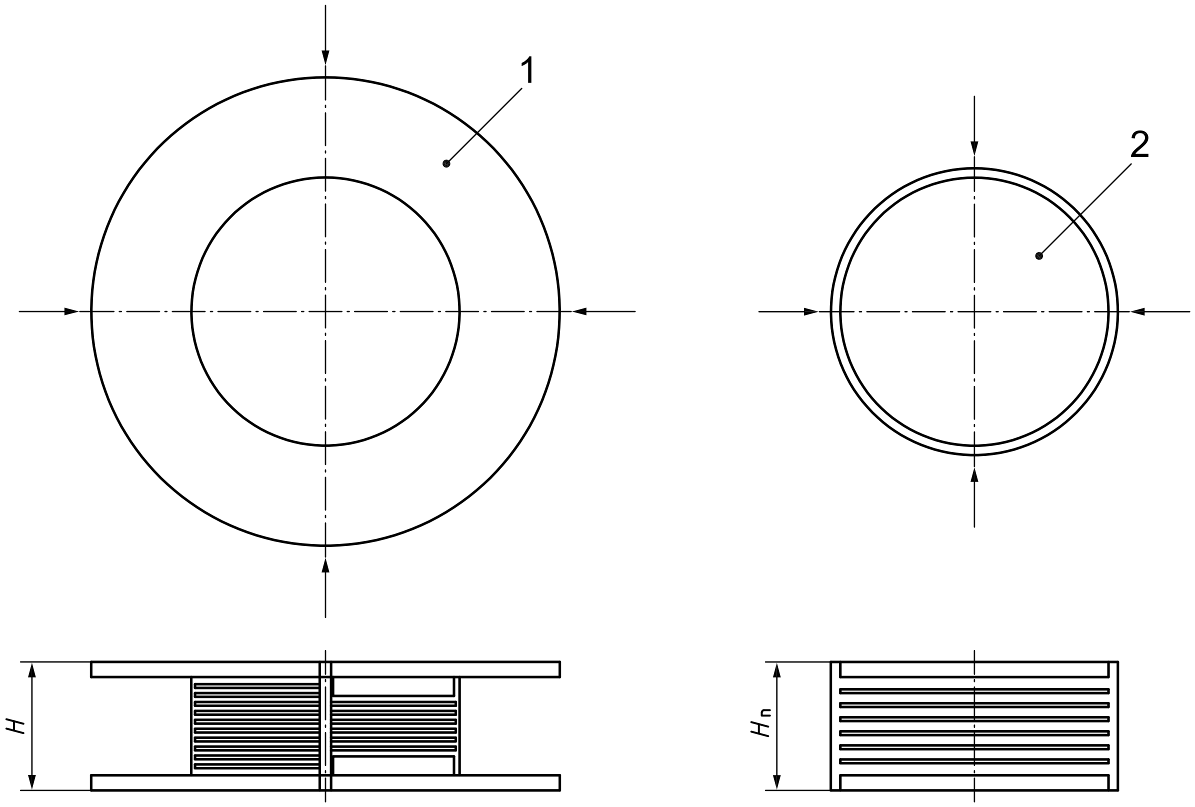
8.4.1 Measurement method

The method to measure the height of circular and rectangular isolators shall be as follows.

a) For circular isolators: the height shall be measured at the four points where two straight lines at right angles to each other which pass through the centre of the circular cross-section intersect the outer circumference (see Figure 2).

b) For rectangular isolators: the height shall be measured at each of the four corners (see Figure 3).

The product height shall be taken as the arithmetic mean of the four measured values.



a) After assembly of mounting flanges **b) Before assembly of mounting flanges**

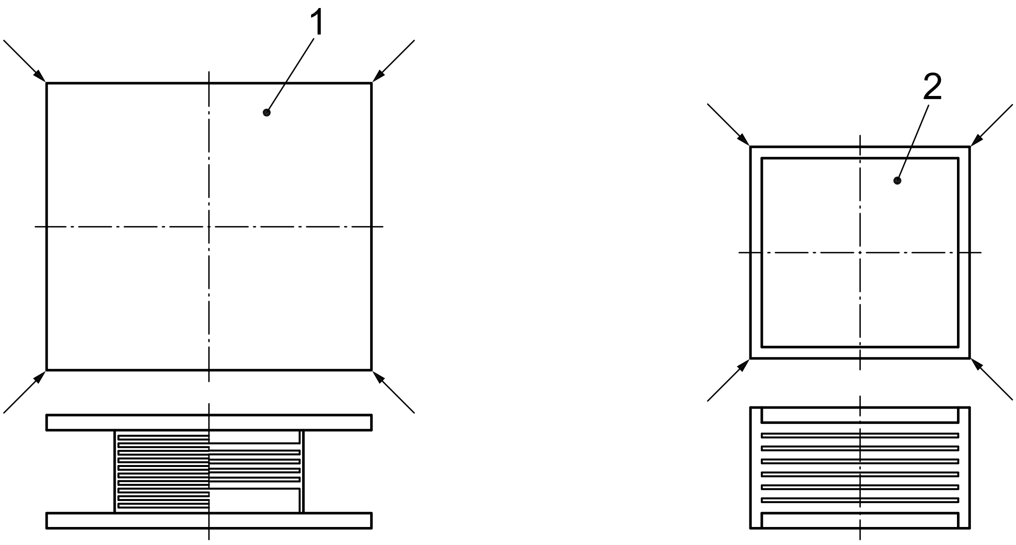
Key

1 flange

2 connecting plate

NOTE The measurement points are indicated by arrows.

Figure 2 — Height measurement positions for circular isolators



Key

1 flange

2 connecting plate

NOTE The measurement points are indicated by arrows.

Figure 3 — Height measurement positions for rectangular isolators

8.4.2 Tolerances

Tolerances on the product height are specified according to the nominal dimensions and shall be as given in Tables 14 and 15. Table 15 is not applicable to Type III bearings.

Table 14 — Tolerances on product height of isolator body, H_n

Nominal dimensions Product height, H_n mm		Tolerance
Above	Maximum	
20	160	± 2,5 %
160	—	± 4 mm

Table 15 — Tolerances on total product height, H_n

Nominal dimensions Flange diameter, D_f or side length, L_f mm		Tolerance mm
Above	Maximum	
—	1 500	± (H_n × 0,025 + 1,5)
1 500	—	± (H_n × 0,025 + 2,5)
For D_f and L_f, see Figure 5.		

8.5 Flatness of products

8.5.1 Measurement method

The flatness is the maximum difference in height at four points on the circumference of the isolator. The measurement positions shall be the same as those for product height (H_n) measurements.

8.5.2 Tolerances

The tolerance on the flatness of products is determined according to the nominal dimensions and shall be as shown in Table 16.

Table 16 — Tolerances on flatness of elastomeric isolators

Dimensions in millimetres

Nominal dimensions Plan dimensions, (a', b', D')		Tolerance
Above	Maximum	
—	1 000	1
1 000	—	(a', b' and D')/1 000

8.6 Horizontal offset

8.6.1 Measurement method

The horizontal offset is measured between the top and bottom edges of the product at two positions. For rectangular isolators, the positions shall be on adjacent sides, and for circular isolators on orthogonal diameters.

8.6.2 Tolerances

Referring to Figure 4, the horizontal offset, δ_H, of elastomeric isolators shall be as follows.

$\delta_H \leqslant 5{,}0$ (mm)

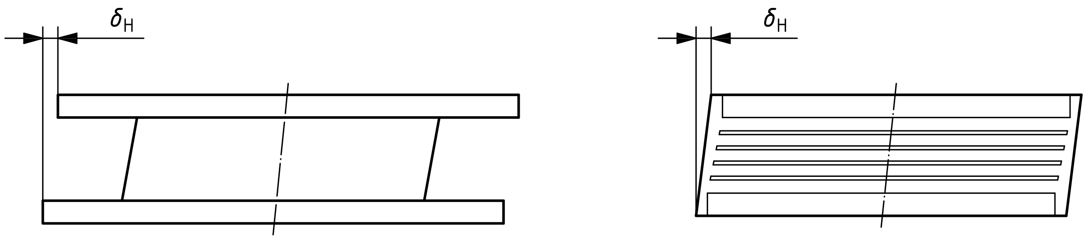


Figure 4 — Measurement of horizontal offset

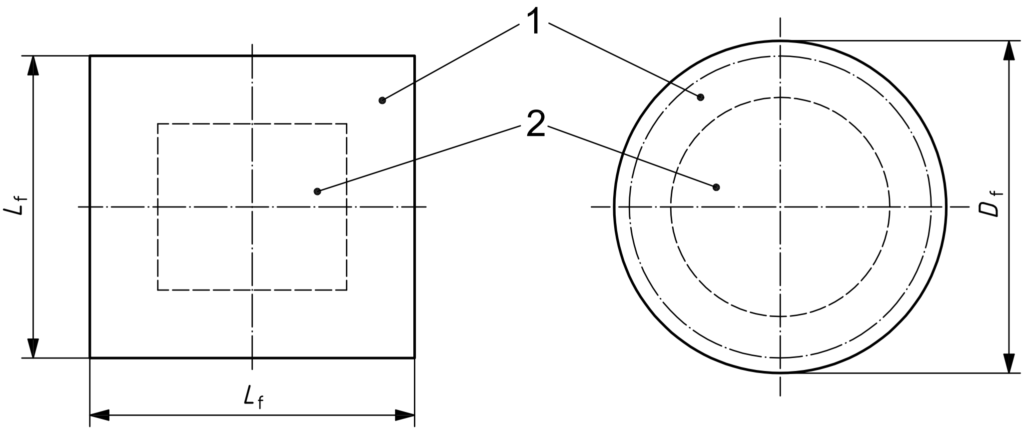
8.7 Plan dimensions of flanges

The tolerances on the plan dimensions of flanges shall be as specified in Table 17.

Table 17 — Tolerances on flange diameter and side length

Dimensions in millimetres

Thickness		D_f (or L_f) < 1 000	1 000 ⩽ D_f (or L_f) < 3 150	3 150 ⩽ D_f (or L_f) < 6 000
Above	Maximum			
6	27	± 2,0	± 2,5	± 3,0
27	50	± 2,5	± 3,0	± 3,5
50	100	± 3,5	± 4,0	± 4,5



Key

1 flange

2 isolator

Figure 5 — Measurement of plan dimensions of flanges

8.8 Flange thickness

The tolerances on flange thickness shall be as specified in Table 18.

Table 18 — Tolerances on thickness of flanges (mounting flanges and connecting flanges)

Dimensions in millimetres

Nominal dimension		D_f (or L_f) < 1 600	1 600 ⩽ D_f (or L_f) < 2 000
Above	Maximum		
16,0	25,0	± 0,65	± 0,75
25,0	40,0	± 0,70	± 0,80
40,0	63,0	± 0,80	± 0,95
63,0	100,0	± 0,90	± 1,10

8.9 Tolerances on positions of flange bolt holes

The tolerances on the positions of flange bolt holes, including the positions of tapped holes on the connecting plate, shall be as specified in Table 19.

Table 19 — Tolerances on positions of flange bolt holes

Dimensions in millimetres

Nominal dimension		Class M (Medium)	Class N (Non-critical)
Above	Maximum		
400	1 000	± 0,8	± 2,0
1 000	2 000	± 1,2	± 3,0
2 000	—	± 2,0	± 4,0

9 Marking and labelling

Marking and labelling are required for the purpose of identification of a product and its properties, and to ensure traceability of the product's history after installation. Therefore, marking and labelling are considered to be very important for quality control of a product.

9.1 Information to be provided

The following information shall be provided for marking and labelling of elastomeric isolators.

a) The manufacturer's name or corporate emblem.

b) The type of elastomeric isolator. Types of elastomeric isolator shall be identified as in Table 20.

Table 20 — Identification of elastomeric isolators according to types and designations

Type	Designation
Linear natural rubber bearing	LNR
High-damping rubber bearing	HDR
Lead rubber bearing	LRB

c) The serial number or manufacturing number.

d) The size (optional).

EXAMPLE 1 Cross-sectional area circular and diameter 800 mm: size code D-800.

EXAMPLE 2 Cross-sectional area square and side length 800 mm × 800 mm: size code 800 × 800 or S-800.

9.2 Additional requirements

Additional requirements for marking and labelling include the following.

a) Marking shall be on lateral surfaces.

b) Marking shall be water-resistant and abrasion-resistant.

c) Marking shall be large enough to be easily identified. The size of the characters shall be larger than 5 mm in width and height.

9.3 Marking and labelling examples

Marking may be in one line, as in Example 1, or in two lines, as in Example 2.

EXAMPLE 1

EXAMPLE 2

UNIVERSAL CO, LTD.

HDR D-800   00001

10 Test methods

Test methods prescribed in this clause shall be in accordance with ISO 22762-1.

11 Quality assurance

A quality assurance programme to ensure consistent manufacturing of the isolators, including, but not limited to, preparation of reinforcing steel plates, uniformity of the thickness of the reinforcing steel plates and uniformity of the vulcanized rubber layers, shall be proposed by the manufacturer and approved by the structural engineer.

Annex A
(normative)

Tensile stress in reinforcing steel plate

A.1 Method for checking strength of reinforcing steel plate

The tensile stress in the reinforcing steel plates shall satisfy Equation (A.1):

$$\sigma_s = 2\lambda \times \frac{P \times t_r}{A_e \times t_s} \leqslant \sigma_{sa} \qquad (A.1)$$

where λ is a correction factor, including a safety margin, obtained from experimental data as follows:

a) for plates without holes: $\lambda = 1,0$;

b) for plates with holes ($A_p/A = 0,03$ to $0,1$): $\lambda = 1,5$.

A.2 Verification of Equation (A.1) by compressive failure testing of isolators

A.2.1 General

The test described below was carried out to verify the applicability of Equation (A.1).

A.2.2 Test pieces

The test pieces used are described in Table A.1. The test pieces were square, measuring 240 mm × 240 mm, the thickness of one rubber layer being 5,0 mm and the test pieces having six layers of laminated rubber. The thickness of the reinforcing steel plate was 2,3 mm made of SS400 mild steel (see 6.8). One isolator had no hole in the steel plate (RB-1), whereas the other had four holes of diameter 34,5 mm which were plugged with lead cores (RB-2). Two isolators for each type (with or without hole) were subjected to the testing.

Table A.1 — Dimensional characteristics of test pieces

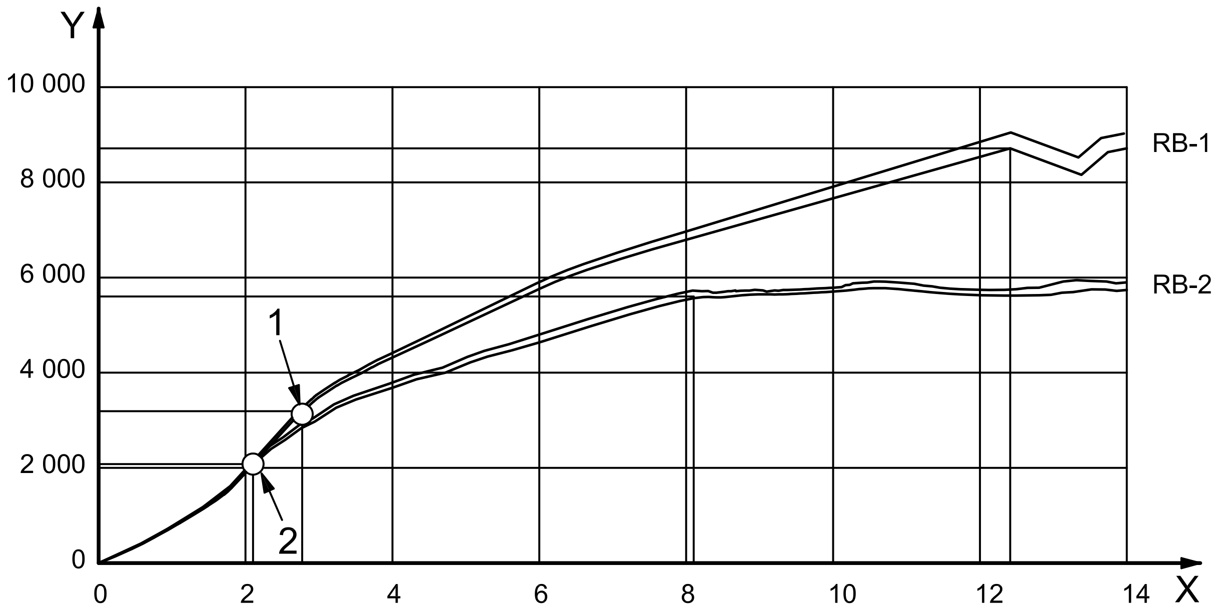
	RB-1	RB-2
Type	LNR	LRB
Plan dimension ($a \times a$), mm	240 × 240	
Hole diameter, d, mm	0	4 × 34,5
Thickness of one rubber layer, t_r, mm	5	
Number of layers	6	
Reinforcing plate thickness, t_s, mm	2,3	

A.2.3 Test conditions

Isolators were subjected to compressive loading until failure was indicated by the force-deflection curve. The horizontal displacement was maintained at zero during testing. The compressive loading rate was 32 kN/s.

A.2.4 Test results

A.2.4.1 Figure A.1 shows the plots of the force-deflection curve obtained during testing. The yield point of the plate was determined as the point on the curve where the second-order derivative of the curve was zero.



Key

X compressive deflection, δ, expressed in millimetres

Y compressive force, P, expressed in kilonewtons

1 yield point of plate for RB-1

2 yield point of plate for RB-2

Figure A.1 — Compressive force-deflection curve for isolator

A.2.4.2 The tensile stresses in the plates calculated from the compressive force at the observed yield point using Equation (A.1) are summarized in Table A.2.

Table A.2 — Summary of test results

	RB-1	RB-2	RB-1/RB-2
A Compressive force, P, at yield point, expressed in kN	3 200	2 100	0,66
B Compressive stress, σ, at yield point, expressed in N/mm^2	55,6	36,5	0,66
C Yield stress in plate, expressed in N/mm^2, computed from P and Equation (A.1)	241,6	237,9	1,016
D Design yield stress of plate, expressed in N/mm^2	235	235	—

A.2.4.3 Comparing the values of C and D in Table A.2, the applicability of Equation (A.1) can be seen to be verified.

For further details, see Reference [3].

Annex B
(normative)

Buckling stability

The values of factor for computation of buckling stability, ϕ, shall be as given below (in this annex):

a) for non-seismic: $\phi = 2,5$;

b) during earthquake: $\phi = 1,5$.

Annex C
(normative)

Allowable tensile stress in isolator

The values of the allowable tensile stress in an isolator, σ_{te}, based on experimental data, are as given below (in this annex):

a) for non-seismic conditions: $\sigma_{te} = 0$ N/mm^2;

b) during earthquake: $\sigma_{te} = 1{,}6$ N/mm^2 (modulus G: $0{,}8 \leqslant G < 1{,}0$ MPa);

$\sigma_{te} = 2{,}0$ N/mm^2 (modulus $G < 1{,}0$ MPa and above);

σ_{te} is determined by experiment when modulus G is less than 0,8 MPa.

Annex D
(informative)

Dependency of ultimate properties on shape factor

D.1 General

The ultimate properties of elastomeric isolators depend on the shape of the isolator.

This annex shows the shape factor dependency of the ultimate properties.

D.2 Specification of test pieces

To confirm the influence of the shape factor on the ultimate properties, five test pieces of different shapes were subjected to an ultimate property test. The specification and geometry of the test pieces were as shown in Table D.1 and Figure D.1.

Table D.1 — Test pieces

Ultimate property test	Shape No.				
	1	2	3	4	5
Rubber material	NR (shear modulus $G = 1,0$ MPa)				
Effective side length (mm)	400 × 400				
Thickness of outside cover rubber (mm)	10				
Thickness of one inner steel plate (mm)	3,2				
Thickness of one rubber layer (mm)	18	9	6,5	9,5	9
Number of rubber layers	3	6	8	12	4
Total thickness of rubber layers (mm)	54	54	52	114	36
Height of test piece, h, (mm)	60,4	70	74,4	149,2	45,6
First shape factor, S_1	5,6	11,1	15,4	10,5	11,1
Second shape factor, S_2	7,4	7,4	7,7	3,5	11,1
Number of test pieces	3				

Dimensions in millimetres

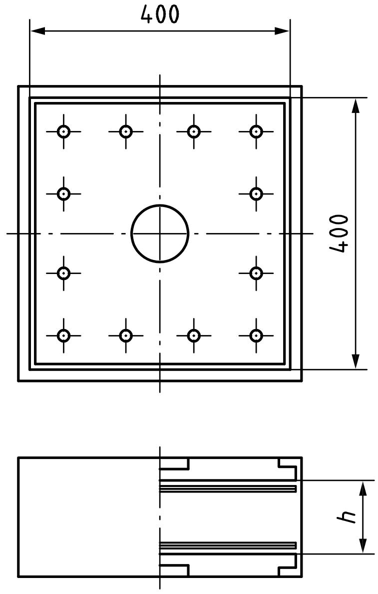


Figure D.1 — Test piece

D.3 Test conditions

The horizontal load was applied at a constant speed in one direction until the elastomeric isolator was broken. The test conditions were as shown in Table D.2.

Table D.2 — Test conditions

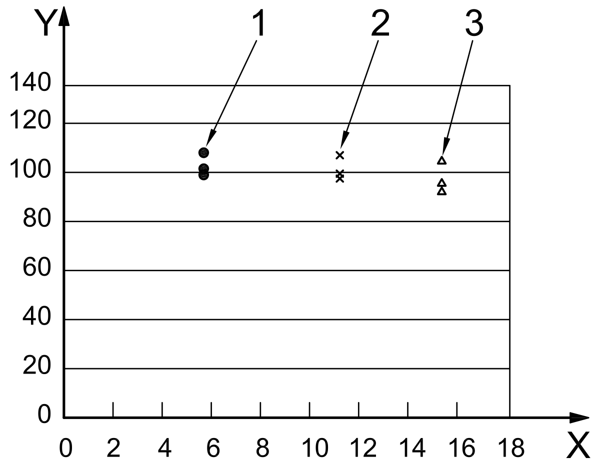
Test parameter	Shape No.				
	1	2	3	4	5
Compressive stress (N/mm^2)	6,0				
Compressive force (kN)	960				
Shear strain rate (%/s)	7,0				
Shear rate (mm/s)	3,8	3,8	3,6	8,0	2,5

D.4 Dependency of ultimate properties on shape factor

D.4.1 The dependency of the first and the second shape factors on breaking shear strain are shown in Figures D.2 and D.3, respectively.

D.4.2 The first shape factor has a limited dependency, whereas the second shape factor has a large dependency. The breaking shear strain is increased by an increase in the second shape factor.

D.4.3 These results cover S_1 from 5,6 to 15,4 and S_2 from 3,5 to 11,1, and the performance of the isolators having S_1 or S_2 outside this range needs to be confirmed by additional tests. See Y. Miyauchi (Reference [4]) for details.



Key

X first shape factor, S_1

Y normalized breaking shear strain (with average value of ISO standard specimen as 100)

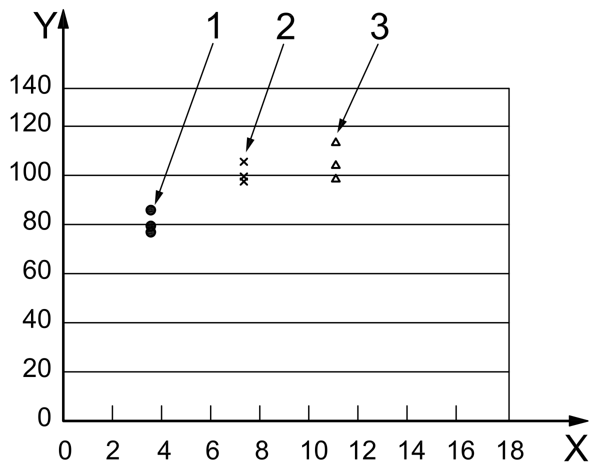
1 shape No.1

2 shape No. 2 (ISO standard specimen; see Table 10 of ISO 22762-1:2010)

3 shape No. 3

NOTE S_2 was constant at either 7,4 or 7,7.

Figure D.2 — Dependency on first shape factor



Key

X second shape factor, S_2

Y normalized breaking shear strain (with average value of ISO standard specimen as 100)

1 shape No. 4

2 shape No. 2 (ISO standard specimen; see Table 10 of ISO 22762-1:2010)

3 shape No. 5

NOTE S_1 was constant at either 11,1 or 10,5.

Figure D.3 — Dependency on second shape factor

Annex E
(informative)

Minimum recommended tensile properties for rubber materials

The minimum recommended tensile properties of rubber materials are as described in Table E.1.

Table E.1 — Recommended tensile properties of rubber materials

Property	Shear modulus G MPa[a]		
	0,8	1,0	1,2
Tensile strength (MPa)			
HDR Moulded test piece Test piece from isolator	 ⩾ 10 ⩾ 8		
LNR Moulded test piece Test piece from isolator	 ⩾ 15 ⩾ 13		
Elongation at break (%)			
HDR Moulded test piece Test piece from isolator	 ⩾ 650 ⩾ 600	 ⩾ 600 ⩾ 550	 ⩾ 550 ⩾ 500
Low-damping chloroprene rubber Moulded test piece Test piece from isolator	 ⩾ 450 ⩾ 400	 ⩾ 450 ⩾ 400	 ⩾ 450 ⩾ 400
LNR and LRB natural rubber Moulded test piece Test piece from isolator	 ⩾ 550 ⩾ 500	 ⩾ 550 ⩾ 500	 ⩾ 500 ⩾ 450

[a] The shear modulus, G, is that at 100 % to 175 % of the shear strain.

NOTE γ_a in 7.5 can be obtained from the values of the elongation at break of test pieces taken from an isolator with a safety factor of 1,5. For example, for HDR ($G = 0,8$), $\gamma_a = 600/1,5$.

Annex F
(informative)

Compressive stiffness

F.1 Compressive stiffness, K_v

The compressive stiffness, K_v, is given by Equation (F.1).

$$K_v = \frac{E_c \times A}{T_r} \tag{F.1}$$

F.2 Apparent Young's modulus, E_c

F.2.1 The apparent Young's modulus, E_c, is calculated using Equation (F.2):

$$E_c = \left(\frac{1}{E_{ap}} + \frac{1}{E_\infty} \right)^{-1} \tag{F.2}$$

F.2.2 Various formulae have been proposed for determining, E_{ap}, such as in F.2.2.1 and F.2.2.2 [Equations (F.3) and (F.4)]:

F.2.2.1 Formula 1:

$$E_{ap} = E_0 \times \left(1 + 2\kappa S_1{}^2 \right) \tag{F.3}$$

where

E_0 may be taken to be approximately equal to $3G$, where G is the shear modulus of rubber.

Examples of constants for several natural rubber compounds are listed in Table F.1. In practice, manufacturers apply their own constants for the design of isolators.

Table F.1 — Examples of constants for design of elastomeric isolators (see Reference [5])

IRHD	E_0 MPa	G MPa	κ	E_∞ MPa
30	0,92	0,30	0,93	$1,00 \times 10^3$
40	1,50	0,45	0,85	$1,00 \times 10^3$
50	2,20	0,64	0,73	$1,03 \times 10^3$
60	5,34	1,06	0,57	$1,15 \times 10^3$
70	7,34	1,72	0,53	$1,27 \times 10^3$

F.2.2.2 Formula 2:

$$E_{ap} = 3G_{eq}(\gamma) \times \left(1 + 2S_1^2\right) \quad \text{(F.4)}$$

where

$G_{eq}(\gamma)$ is the shear modulus at the average shear strain, γ, produced by the compressive load.

γ can be determined from Equation (F.5):

$$\gamma = \sqrt{6} S_1 \varepsilon \quad \text{(F.5)}$$

where

ε is the compressive strain in the rubber layer.

Neither of the formulae proposed in F.2.2.1 or F.2.2.2 considers the non-linearity introduced when ε becomes greater than about 0,1.

For isolators with an unplugged central hole, formulae for the compression stiffness are given in Reference [6]. Expressions for compression stiffness based on the first shape factor, S_1, modified to take account of the hole may not give reliable results.

F.3 Empirical expressions for apparent Young's modulus, E_c

The following empirical expressions for apparent Young's modulus, E_c, have been derived from tests on bridge isolators.

a) For rectangular isolators:

$$E_c = \beta \times S_1 \times G \quad \text{(F.6)}$$

b) For circular isolators:

$$E_c = 0{,}75\, \beta \times S_1 \times G \quad \text{(F.7)}$$

where

β is an empirical factor, based on the test data (see Figures F.1, F.2 and F.3), which modifies E_c;

for LNR $\beta = 35$;

for HDR and LRB $\beta = 45$.

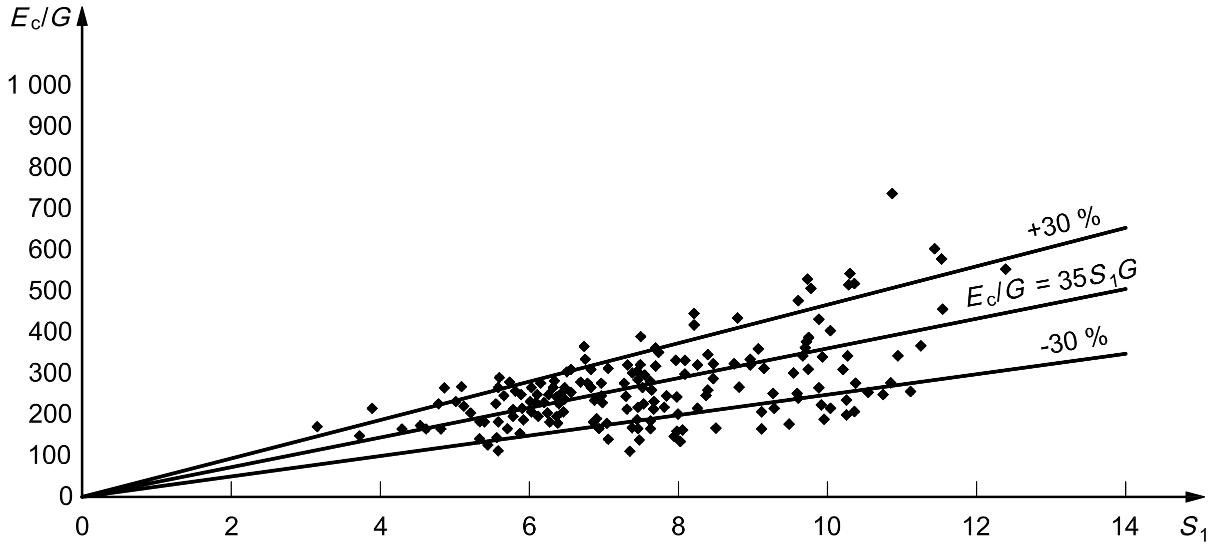


Figure F.1 — S_1 vs. E_c/G for LNR

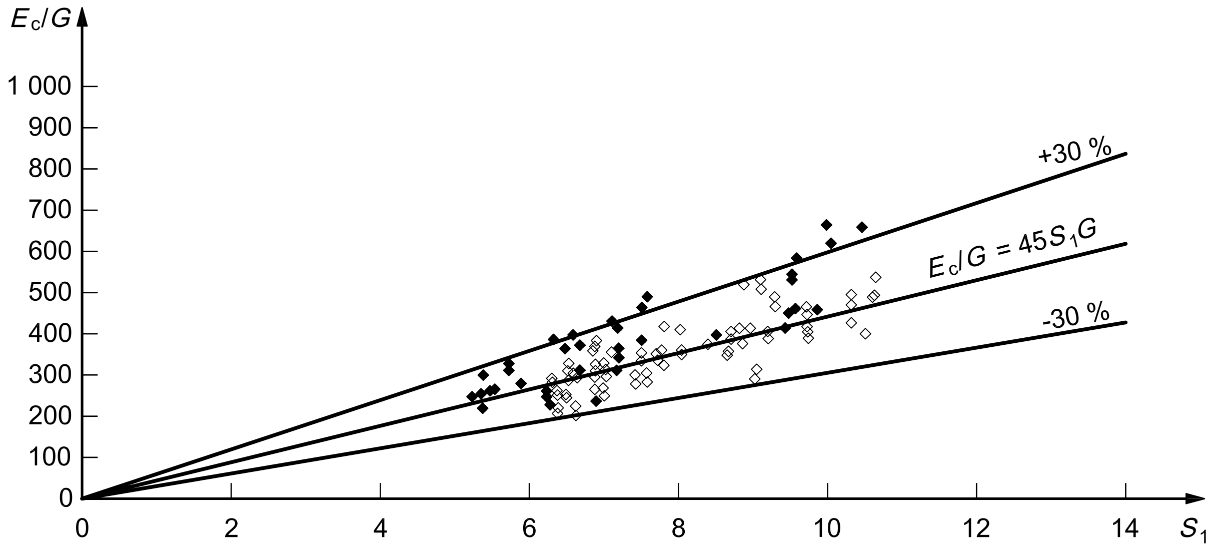


Figure F.2 — S_1 vs. E_c/G for HDR

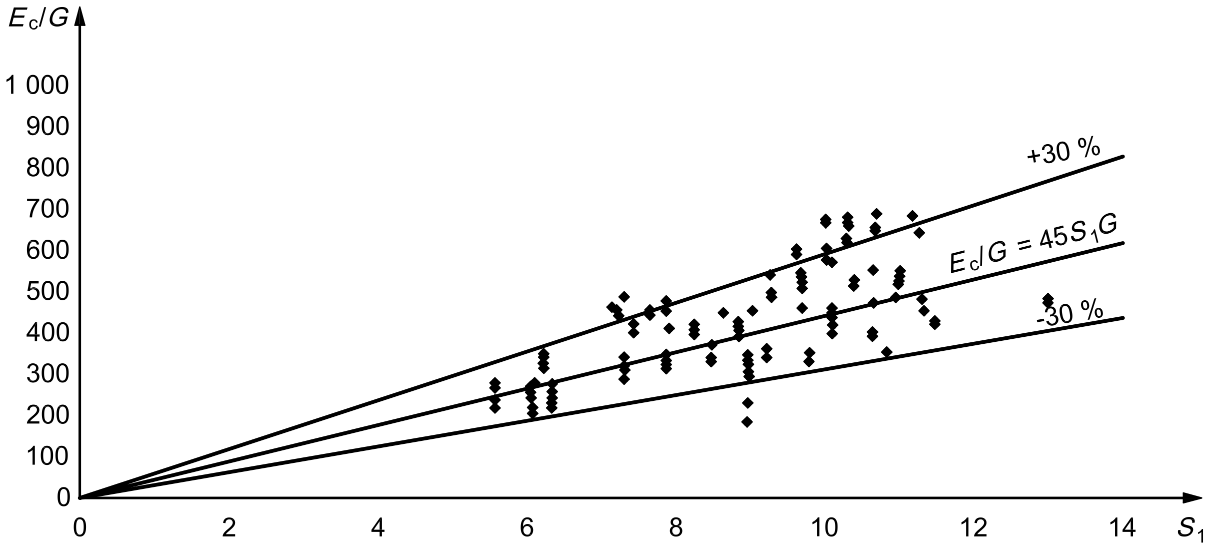


Figure F.3 — S_1 vs. E_c/G for LRB

Annex G
(informative)

Determination of shear properties of elastomeric isolators

G.1 Shear properties of linear natural rubber bearings

The shear stiffness, K_h, of LNR can be calculated from Equation (G.1).

$$K_h = G \frac{A}{T_r} \tag{G.1}$$

Alternatively, the tangential stiffness, K_t, can be taken as a representative shear property of LNR. K_t can be determined as indicated in Annex E of ISO 22762-1:2010.

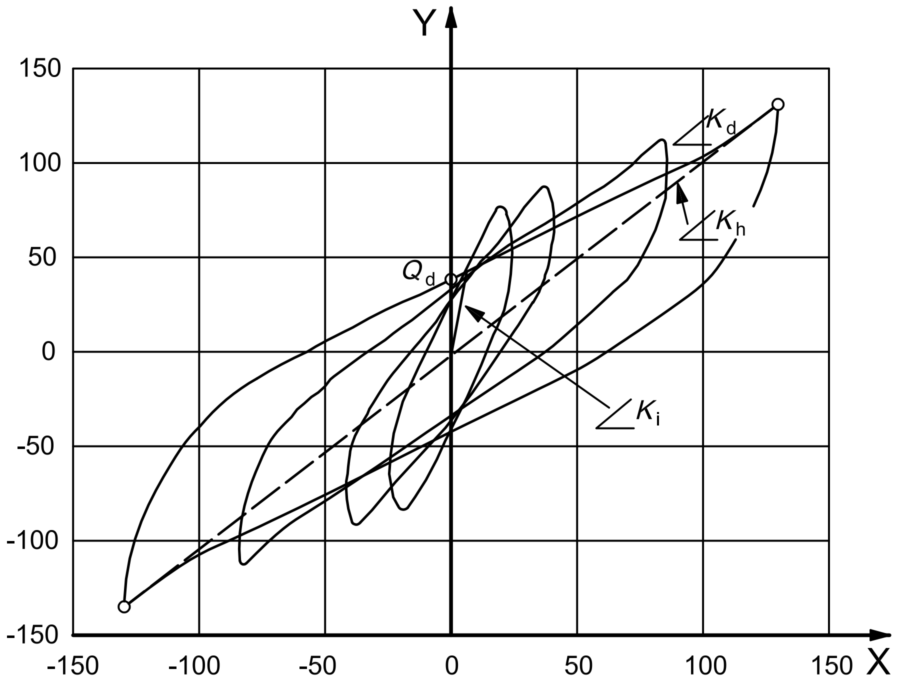
G.2 Shear properties of high-damping rubber bearings

G.2.1 A typical force-displacement curve for high-damping rubber bearings is shown in Figure G.1. The shear stiffness, K_h, or the equivalent of this shear stiffness, which is defined as the secant slope from peak to peak of the loop, is dependent on the deflection of the elastomeric isolator. The shear stiffness, K_h, can be calculated from Equation (G.2):

$$K_h = G_{eq}(\gamma) \times \frac{A}{T_r} \tag{G.2}$$

where

$G_{eq}(\gamma)$ is the equivalent shear modulus, derived from experimental data, and expressed as a function of the shear strain γ.



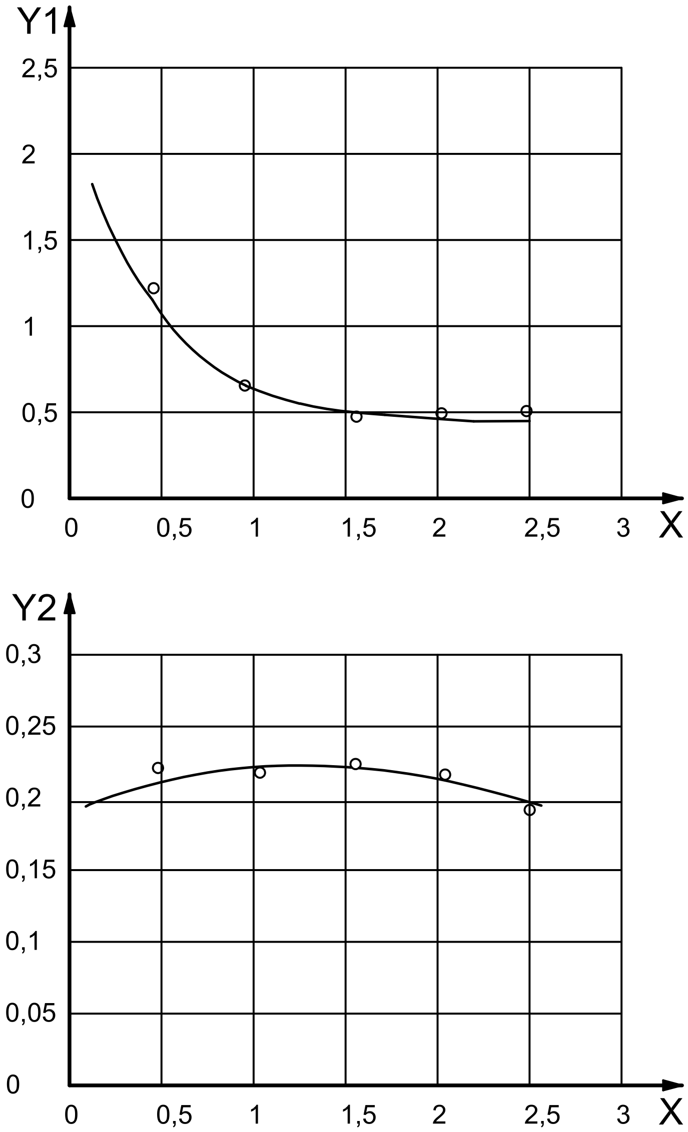
Key

X shear displacement, X

Y shear force, Q

Figure G.1 — Shear force vs. displacement curve for high-damping rubber bearing

G.2.2 Examples of the strain dependence of the apparent shear modulus and damping ratio for a high-damping rubber are as shown in Figure G.2.



Key

X shear strain, γ

Y_1 shear modulus, $G_{eq}(\gamma)$ (MPa)

Y_2 equivalent damping ratio, $h_{eq}(\gamma)$

Figure G.2 — Examples of strain dependence of $G_{eq}(\gamma)$ and $h_{eq}(\gamma)$ for high-damping rubber bearing

where

$G_{eq}(\gamma)$ is expressed as a function of the shear strain, γ, such as a polynomial function, as shown in Equation (G.3).

$$G_{eq}(\gamma) = a_0 + a_1 \times \gamma + a_2 \times \gamma^2 + a_3 \times \gamma^3 + a_4 \times \gamma^4 + a_5 \times \gamma^5 + \cdots = \sum_{j=0}^{n} a_j \times \gamma^j \quad \text{(G.3)}$$

G.2.3 The equivalent damping ratio, h_{eq}, is also expressed as a function of the shear strain, γ, as in Equation (G.4):

$$h_{eq}(\gamma) = \sum_{j=0}^{n} b_j \times \gamma^j \tag{G.4}$$

where

$h_{eq}(\gamma)$ at each shear strain is calculated from experimental data using Equation (G.5):

$$h_{eq}(\gamma) = \frac{1}{\pi} \times \frac{W_d}{2K_h \left(T_r \times \gamma\right)^2} \tag{G.5}$$

where

W_d is the amount of energy dissipated per cycle.

G.2.4 The characteristic strength of HDR is a function of the amplitude of the cyclic shear strain loading $U(\gamma)$. This is defined as the ratio of the characteristic strength to the maximum shear force of the loop, as shown in Equation (G.6).

$$U(\gamma) = \frac{Q_d}{K_{eq} \times \left(T_r \times \gamma\right)} \tag{G.6}$$

where

$G_{eq}(\gamma)$ and $h_{eq}(\gamma)$, $U(\gamma)$ is expressed empirically as a function of the shear strain, γ, as follows:

$$U(\gamma) = \sum_{j=0}^{n} c_j \times \gamma^j \tag{G.7}$$

G.2.5 The initial stiffness, K_i, and post-yield stiffness, K_d, for HDR, assuming bi-linear modelling of the hysteresis loop, can be calculated using Equations (G.8) and (G.9).

$$K_d = \left[1 - U\left(\gamma\right)\right] \times K_{eq} \tag{G.8}$$

$$K_i = \frac{2U\left(\gamma\right) - \pi \times h_{eq}\left(\gamma\right) \times \left[1 - U\left(\gamma\right)\right]}{2U\left(\gamma\right) - \pi \times h_{eq}\left(\gamma\right)} \times K_{eq} \tag{G.9}$$

G.3 Shear properties of lead rubber bearings

G.3.1 The horizontal properties of a lead rubber bearing are represented by the equivalent shear stiffness, K_h, post-yield stiffness, K_d, and sectional load (characteristic strength), Q_d, as expressed in the following equations.

$$K_h = \frac{Q_d}{\gamma \times T_r} + K_d \tag{G.10}$$

The post-yield stiffness, K_d, is given by Equation (G.11):

$$K_d = C_r\left(\gamma\right) \times K_r + C_p\left(\gamma\right) \times K_p \tag{G.11}$$

where

K_r is the shear stiffness of the elastomeric isolator $\left(K_r = G\dfrac{A}{T_r}\right)$;

K_p is the stiffness of the inserted lead plug;

$C_r(\gamma)$ is a correction factor for the shear stiffness of the isolator;

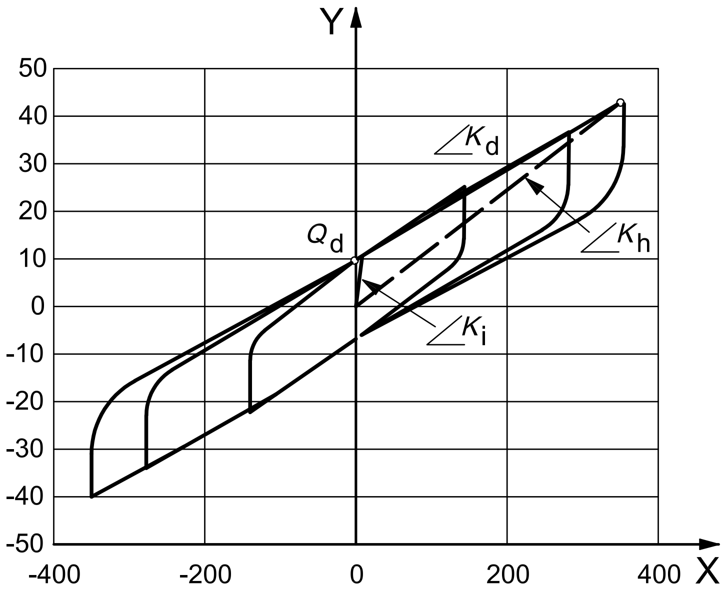
$C_p(\gamma)$ is a correction factor for the stiffness of the inserted lead plug;

$C_r(\gamma)$ and $C_p(\gamma)$ are derived empirically from experimental data.

G.3.2 The initial stiffness, K_i, can be derived by multiplying K_d by a constant, α_i, as follows:

$$K_i = \alpha_i \times K_d \tag{G.12}$$

where a typical reference value for α_i is 5 to 15.



Key

X shear displacement

Y shear force

Figure G.3 — Shear force vs. shear displacement curve for lead rubber bearing

Annex H
(informative)

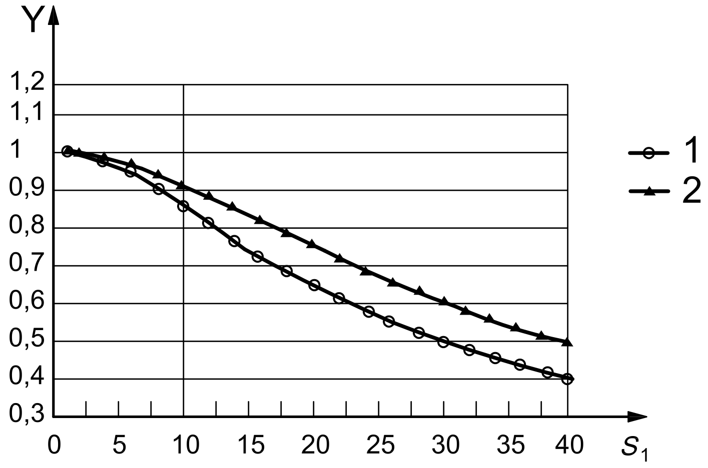
Determination of local shear strain due to compression

In the formulae in 7.5.1 [Equations (19) and (20)], the value of the parameter $E_c{}^s$ is not defined in a simple way if the apparent Young's modulus of the bonded layers within the isolator is a significant fraction of the bulk modulus of the rubber, E_∞ (E_∞ is of the order of 2 000 MPa). This is typically the case for isolators of shape factor S_1 greater than 8. Accurate determination of γ_c requires an analysis of the shear strains within the rubber layer that takes account of the compression of the layer associated with the bulk compressibility of the rubber.

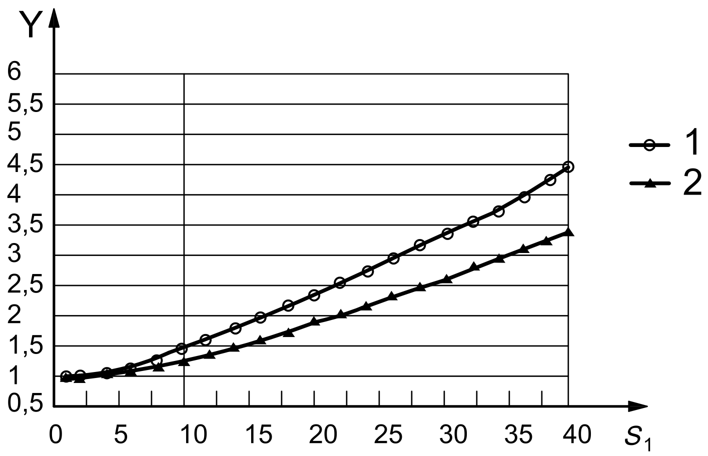
For isolators with $S_1 \leqslant 8$, the formulae in 7.5.1 are quite accurate when $E_c{}^s$ is made equal to E_{ap} (i.e. the compressive Young's modulus is not corrected for the effect of bulk compressibility); the use of E_{ap} leads to a slight underestimation of γ_c of less than 10 %. For larger shape factors, the use of E_{ap} leads to a more substantial underestimation of γ_c, such that, for $S_1 = 30$, γ_c is half the value determined by the full analysis. Making $E_c{}^s$ equal to E_c (i.e. the compressive Young's modulus of the rubber layer corrected for the effect of bulk compressibility) in the formulae, on the other hand, results in a substantial overestimation of γ_c, such that, for $S_1 = 30$, γ_c can be overestimated by a factor of 3. These figures are based on an analysis of circular and square layers of shear modulus 1 MPa. The results of the analysis are summarized in Figures H.1 and H.2.

For isolators with large shape factors ($S_1 > 15$), if the margin in checking the requirement given in 7.5.3 is sufficiently small for errors in estimating γ_c to be significant, the value of γ_c should be determined by full analysis (taking account of the bulk compressibility) of the shear strain in the rubber layer. An alternative but approximate method is to estimate γ_c from the following empirical expression based on the results of the analysis carried out for circular and square layers referred to above:

$$\gamma_c = \frac{\left[\gamma_c(E_c{}^s = E_c) + 3\gamma_c(E_c{}^s = E_{ap})\right]}{4} \tag{H.1}$$



a) $E_c{}^s = E_{ap}$



b) $E_c{}^s = E_c$

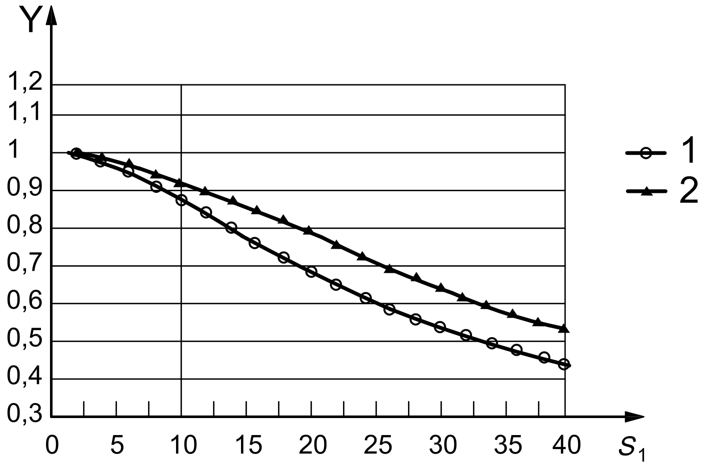
Key

Y ratio of local shear strains ($\gamma/\gamma_{\text{full analysis}}$)

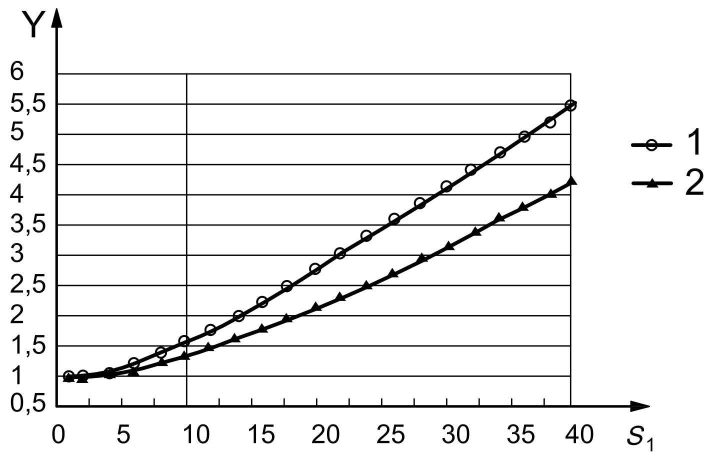
1 E_∞ = 1 150; G = 1,0 (MPa)

2 E_∞ = 2 000; G = 1,0 (MPa)

Figure H.1 — Accuracy of local shear strain due to compression for circular layers



a) $E_c{}^s = E_{ap}$



b) $E_c{}^s = E_c$

Key

Y ratio of local shear strains ($\gamma/\gamma_{\text{full analysis}}$)

1 $E_\infty = 1\ 150$; $G = 1{,}0$ (MPa)

2 $E_\infty = 2\ 000$; $G = 1{,}0$ (MPa)

Figure H.2 — Accuracy of local shear strain due to compression for square layers

Annex I
(informative)

Maximum compressive stress

Maximum compressive stress should meet the requirements, which are dependent on S_1, given in Table I.1.

Table I.1 — Recommended values of maximum compressive stress

S_1 N/mm^2	**Maximum compressive stress** N/mm^2
$S_1 < 8$	$\sigma_{max} \leqslant 8$
$8 \leqslant S_1 < 12$	$\sigma_{max} \leqslant S_1$
$12 \leqslant S_1$	$\sigma_{max} \leqslant 12$

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