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Elastomeric seismic-protection isolators —

Part 4: Guidance on the application of ISO 22762-3

Appareils d'appuis structuraux en élastomère pour protection sismique —

Partie 4: Lignes directrices pour l'application de l'ISO 22762-3

Reference number
ISO/TS 22762-4:2019(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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document 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/TS 22762-4:2014), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the number of the pieces in Clause 6 has been amended;

— the temperature has been changed from 20 °C to 23 °C.

A list of all parts in the ISO 22762 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Elastomeric seismic-protection isolators —

Part 4:
Guidance on the application of ISO 22762-3

1 Scope

This document provides guidance on ISO 22762-3:2018. It includes examples of design calculations, and provides data on the characteristics obtained from all types of elastomeric isolators.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 22762-1:2018, *Elastomeric seismic-protection isolators — Part 1: Test methods*

ISO 22762-3:2018, *Elastomeric seismic-protection isolators — Part 3: Applications for buildings — Specifications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22762-3:2018 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Guidance on the use of Clause 4 of ISO 22762-3:2018

No guidance is given.

5 Guidance on the use of Clause 5 of ISO 22762-3:2018

No guidance is given.

6 Guidance on the use of Clause 6 of ISO 22762-3:2018

6.1 General

Guidance is given for 6.2, 6.4, and 6.5.

6.2 Type tests and routine tests

An example of the scaled test pieces (scales A and B) for the type testing of the specific isolator size is given as follows.

Dimensions and properties of target isolator (isolator-X) are shown in Table 1.

Table 1 — Dimensions and properties of isolator-X

Outer diameter, d_o (mm)	1 000
Inner diameter, d_i (mm)	25
Thickness of one rubber layer, t_r (mm)	6,7
Thickness of reinforcing steel plate, t_s (mm)	4,4
Number of rubber layer, n	30
First shape factor, S_1	36,4
Second shape factor, S_2	5,0
Shear stiffness, K_h (N/mm × 10^3)	2,44
Equivalent damping ratio, h_{eq}	0,225
Compressive stiffness, K_v (N/mm × 10^3)	5 450

K_h and h_{eq} values are under shear strain of 100 %.

In this case, requirement for scales A and B test piece are shown in Table 4 of ISO 22762-3:2018.

Examples of dimensions and properties of scales A and B are shown in Table 2.

Table 2 — Examples of Scales A and B for Isolator-X

Characteristics	Scale A	Scale B
Scale	0,25	0,6
Outer diameter, d_o (mm)	250	600
Inner diameter, d_i (mm)	0 (6,3)	15
Thickness of one rubber layer, t_r (mm)	1,7	4,0
Thickness of reinforcing steel plate, t_s (mm)	1,2	2,2
Number of rubber layer, n	30	30
First shape factor, S_1	36,4	36,4
Second shape factor, S_2	5,0	5,0
Shear stiffness, K_h (N/mm × 10^3)	0,61	1,46
Equivalent damping ratio, h_{eq}	0,225	0,225
Compressive stiffness, K_v (N/mm × 10^3)	1 360	3 270

For any dimension, variation of ± 5 % from exact scale-downed dimensions can be allowed.

The scaling of reinforcing plate for scale A can be adjusted if the effect on characteristics of isolator is not significant. In the case of scale A in Table 2, the thickness of the plate is computed as 1,1 mm and 1,2 mm is adopted for the test piece.

Number of the test pieces required is not specified in the text. The recommended number of the test pieces is shown in Table 3 when each test piece is tested individually. Table 3 is number of the test pieces for single-shear testing arrangement. In the case that double-shear testing arrangement is used for determining the shear properties, it is recommended that three tests are performed and the number of test pieces doubled.

Table 3 — Recommended number of test pieces for each test item

Properties		Number of test pieces
Compressive properties		3
Shear properties		3
Dependency of shear properties	Shear strain dependence	3
	Compressive stress dependence	3
	Others	3
Dependency of compressive properties		3
Ultimate properties		3
Durability		2

In the case shown in Table 4, the available previous test results can be used for substitution of the test required for the newly designed isolator.

Table 4 — An example of available previous type test results: Comparison of characteristics between newly designed and previously tested isolator

Characteristics	Previously tested isolator	Newly designed isolator (−)	Newly designed isolator (+)	Remarks
Outer diameter, d_o (mm)	1 100	1 000	1 200	within ± 10 %
Inner diameter, d_i (mm)	25	25	27	within ± 10 %
Thickness of one rubber layer, t_r (mm)	7,0	6,7	7,5	within ± 10 %
Thickness of reinforcing plate, t_s (mm)	4,4	4,4	4,8	within ± 10 %
Number of rubber layer, n	30	30	30	same
First shape factor, S_1	38,4	36,4	42,0	within ± 10 %
Second shape factor, S_2	5,2	5,0	5,3	within ± 10 %
Maximum comp. stress for test, σ_{max} (MPa)	30	25	30	less than or equal to previous test
Minimum comp. stress for test, σ_{min} (MPa)	−0,5	0,5	5,0	more than previous test
Maximum shear strain for test, γ_{max}	3,5	3,0	3,2	less than previous test

6.3 Functional requirements

No guidance is given.

6.4 Design compressive force and design shear displacement

Design compressive force refers to the force under non-seismic conditions.

Any specification or guidance is not given regarding nominal stress, σ_{nom}. Recommended process to specify σ_{nom} is given as follows:

a) σ_{nom} is determined in the range less than 30 % of critical stress, σ_{cr}. Maximum σ_{nom} is less than or equal to 15 MPa;

b) Adequacy of σ_{nom} is verified so that compressive stress dependency (change of shear property under 0,5 σ_{nom} and 2,0 σ_{nom}) is acceptable. Maximum σ_{nom} is less than or equal to 15 MPa.

6.5 Performance requirements

6.5.1 General

No guidance is given.

6.5.2 Compressive properties

An example of HDR for 6.5.2 of ISO 22762-3:2018 on compressive properties is given.

a) Test piece and test conditions

Test piece is shown in Table 5.

Table 5 — Test piece

Type	Outer diameter mm	Inner diameter mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of test isolator
HDR	700	15	36,4	5,0	12,0	1

Test conditions are given below:

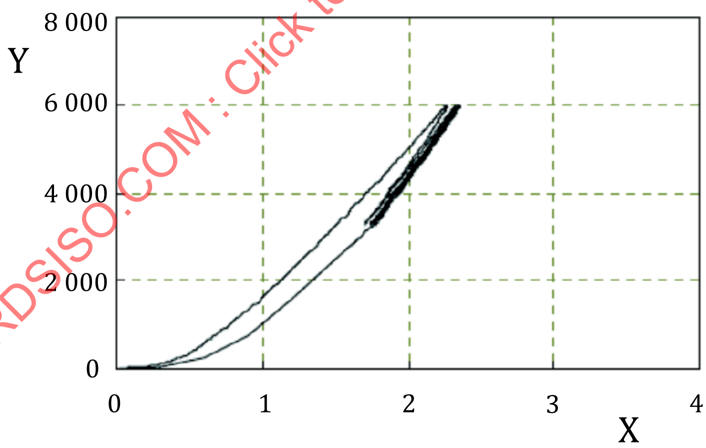
— compressive stress amplitude: 12 MPa ± 30 %;

— number of cycles: 3 cycles;

— compressive stiffness, K_v, is computed from 3rd cycle.

b) Test results

The result for one type of HDR is shown in Figure 1 and Table 6.



Key

X vertical disp. (mm)

Y vertical load (kN)

Figure 1 — Compressive property test of HDR

Table 6 — Test results

Characteristics	Test result
Compressive stiffness, K_v	4 592,0 kN/mm

6.5.3 Shear properties

An example of HDR for 6.2.2 of ISO 22762-3:2018 on shear properties is given.

a) Test piece and test conditions

Test piece is shown in Table 7.

Table 7 — Test piece

Type	Outer diameter mm	Inner diameter mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of test isolator
HDR	700	15	36,4	5,0	12,0	1

Test conditions are given below:

— test vibration frequency: 0,023 Hz, triangular wave;

— compressive stress: 12 MPa;

— shear strain amplitude: ± 100 % (141 mm);

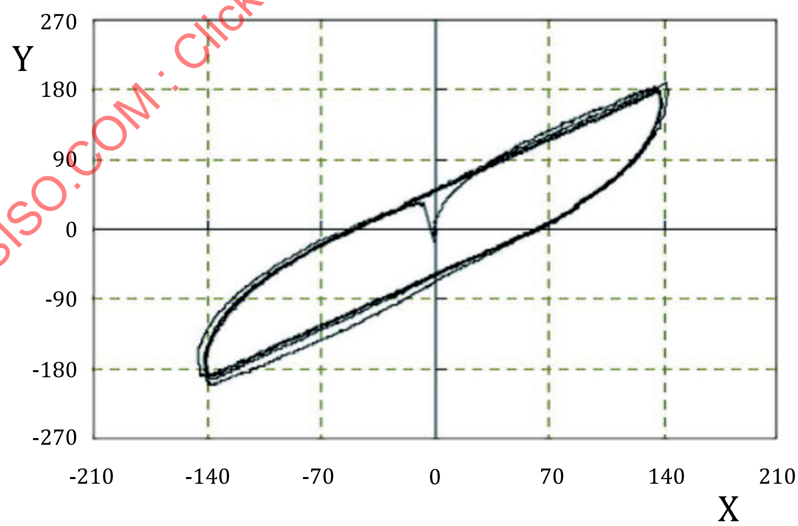
— number of cycles: 3 cycles;

— shear stiffness, K_h, and damping ratio, h_{eq}, are computed from 3rd cycle;

— test results were corrected to their counterpart with 0,33 Hz by the specified method in ISO 22762-3:2018, 6.5.5.3;

— test results were corrected to the corresponding value of the property at 23 °C by the specified method in ISO 22762-3:2018, 6.5.5.5.

The results for one type of HDR are shown in Figure 2 and Table 8.



Key

X horizontal disp. (mm)

Y horizontal load (kN)

Figure 2 — Shear property test of HDR

Table 8 — Test results

Characteristics	Test results
Shear stiffness, K_h	4 592,0 kN/mm
Equivalent damping ration, h_{eq}	0,21

6.5.4 Tensile properties

6.5.4.1 In case of LNR

Examples of LNR for 6.5.4 of ISO 22762-3:2018 on shear properties are given.

a) Test pieces and test conditions

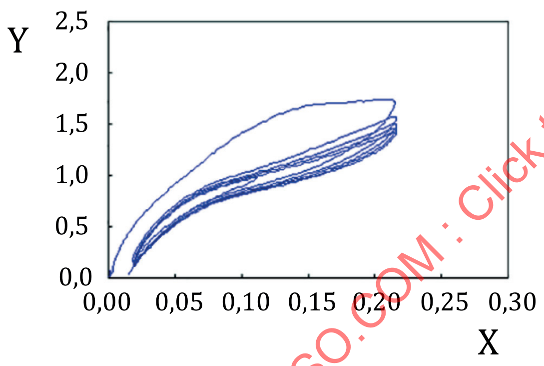
Test pieces are shown in Table 9.

Table 9 — Test pieces

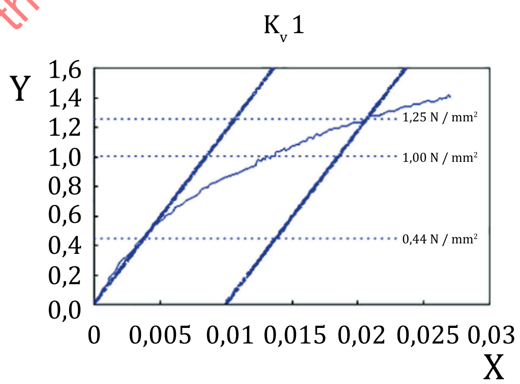
Type	Outer diameter mm	S_1	S_2
LNR	500	32,0	5,1
	800	31,7	5,1

b) Test results

Test results are shown in Figures 3 a) and b) and Table 10.



a) Relationship of tensile stress and tensile strain of LNR under shear-strain offset of 100 %



b) Measurement of tensile yield stress

Key

X tensile strain ε

Y tensile stress (N/mm²)

Figure 3 — Tensile performance at γ = 100 % (sample: LNR-D500)

Table 10 — Test results

Outer diameter mm	Tensile yield stress under shear strain of 100 % MPa
500	1,25
800	1,19

6.5.4.2 In case of HDR

Examples of HDR for 6.5.4 of ISO 22762-3:2018 on shear properties are given.

a) Test pieces and test conditions

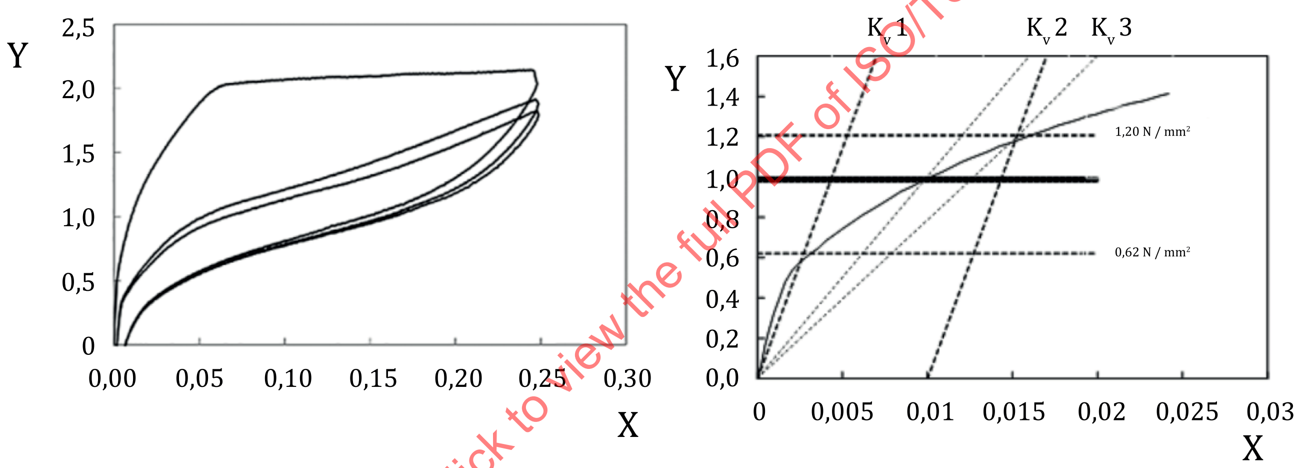
Test pieces are shown in Table 11.

Table 11 — Test pieces

Type	Outer diameter mm	S_1	S_2
HDR	800	36,1	4,0
	600	36,6	3,0

b) Test results

Test results are shown in Figures 4 a) and b) and Table 12.



a) Relationship of tensile stress and tensile strain of HDR under shear-strain offset of 100 %

b) Measurement of tensile yield stress

Key

X tensile strain ε

Y tensile stress (N/mm²)

Figure 4 — Tensile performance at γ = 100 % (sample: HDR-D500)

Table 12 — Test results

Outer diameter mm	Tensile yield stress under shear strain of 100 % MPa
800	1,2
600	1,4

6.5.5 Dependencies of shear properties

6.5.5.1 Shear strain dependency

Examples of HDR for 6.5.5.1 of ISO 22762-3:2018 on shear strain dependency are given.

a) Test pieces and test conditions

1) Scaled model

Test pieces of scaled model are shown in Table 13.

Table 13 — Test pieces

Type	Outer dia. mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of isolators tested
HDR	225	35,2	3,3	9,3	1
	225	35,2	5,0	15,0	2
	225	35,2	8,3	15,0	1

Test conditions are given below:

— test vibration frequency: 0,33 Hz, sinusoidal wave;

— shear strain amplitude: γ = ± 10 %, ± 20 %, ± 50 %, ± 100 %, ± 150 %, ± 200 %, and ± 270 %;

— loading cycles: 3 cycles, respectively;

— reference cycle: 3rd cycle;

— test temperature: 20 °C;

— test results were corrected to the corresponding value of the property at 23 °C by the specified method in ISO 22762-3:2018, 6.5.3.3.3.

2) Full scale isolators

Test pieces of full scale isolators are shown in Table 14.

Table 14 — Test pieces

Type	Outer dia. mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of isolators tested
HDR	600	36,6	3,0	6,6	1
	800	36,1	4,0	12,1	1
	1 000	36,4	5,0	15,0	1
	1 200	35,8	6,0	15,0	1
	1 600	36,5	6,4	15,0	1

Test conditions are given below and in Table 15.

— test wave: triangular wave;

— shear strain amplitude: γ = ± 50 %, ± 100 %, and ± 200 %;

— loading cycles: 3 cycles, respectively;

— reference cycle: 3rd cycle;

— test vibration frequency: see Table 15;

— test results were corrected to their counterpart with 0,33 Hz by the specified method in ISO 22762-3:2018, 6.5.5.3;

— test temperature: 25,3 °C, 25,6 °C, 24,5 °C, 22,5 °C and 24,0 °C for 600 mm, 800 mm, 1 000 mm, 1 200 mm and 1 600 mm of Outer diameter in Table 14, respectively;

— test results were corrected to the corresponding value of the property at 23 °C by the specified method in ISO 22762-3:2018, 6.5.5.5.

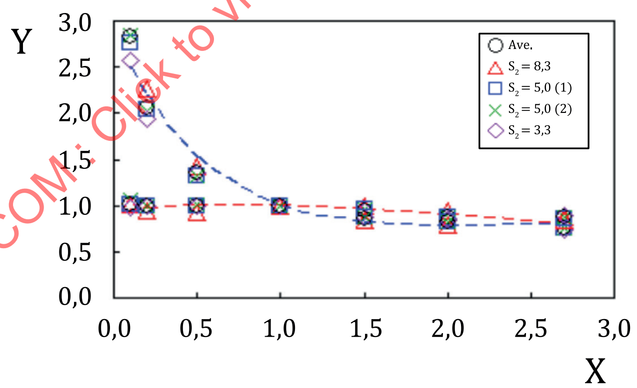
Table 15 — Test velocities

		Test velocity mm/s frequency (Hz)		
Shear strain		±50 %	±100 %	±200 %
Velocity Frequency	Outer dia.: 600, 800, 1 000 and 1 200	13,0 [0,033)	13,0 [0,017)	10,0 [0,006)
Velocity Frequency	Outer dia.: 1 600	13,0 [0,026)	13,0 [0,013)	10,0 [0,005)

b) Test results

1) Scaled model

Figure 5 shows the test results by the scaled model specimens.



Key

X shear strain γ (−)

Y $G_{eq}(\gamma)/G_{eq}(\gamma = 100\ \%)$

$H_{eq}(\gamma)/H_{eq}(\gamma = 100\ \%)$

Figure 5 — Shear strain dependency of shear properties of HDR (scaled isolator)

The shear strain dependence of the shear properties (shear modulus, damping, and *u* function introduced in ISO 22762-1:2018, Annex E) of HDR, as measured in dynamic loading tests are expressed by polynomial functions of shear strain, as shown in Table 16.

Table 16 — An example of function for HDR

Properties at γ = 100 %	Polynomial function
G_{eq} = 0,62 (N/mm²) H_{eq} = 0,240 u_0 = 0,408	$G_{eq}(\gamma)=G_{eq}\times(2{,}855-3{,}878\gamma+2{,}903\gamma^2-1{,}016\gamma^3+0{,}136\,4\gamma^4)$ $H_{eq}(\gamma)=H_{eq}\times(0{,}915\,0+0{,}236\,4\gamma-0{,}1804\gamma^2+0{,}029\,02\gamma^3)$ $u_0(\gamma)=u_0\times(0{,}902\,8+0{,}271\,1\gamma-0{,}208\,3\gamma^2+0{,}034\,21\gamma^3)$

c) Full scale isolator

The test results for the full scale isolators are shown in Table 17.

Table 17 — Test results: Horizontal characteristics normalized by value at 100 % strain

Diameter mm	Items	Shear strain	
		±50 %	±200 %
600	K_{eq}	1,40	0,84
	H_{eq}	0,98	0,95
800	K_{eq}	1,27	0,91
	H_{eq}	0,96	0,95
1 000	K_{eq}	1,37	0,91
	H_{eq}	0,98	0,91
1 200	K_{eq}	1,38	0,89
	H_{eq}	0,95	0,95
1 600	K_{eq}	1,35	0,91
	H_{eq}	0,95	0,95

6.5.5.2 Compressive stress dependency

Examples of HDR for 6.5.5.2 of ISO 22762-3:2018 on compressive stress dependency are given.

a) Test pieces and test conditions

Test pieces are shown in Table 18.

Table 18 — Test pieces

Type	Outer diameter mm	Inner diameter mm	S_1	S_2	Nominal compressive stress, σ_s N/mm²	Total thickness of rubber mm
HDR	600 (15)	15	36,6	3,0	6,6	200
	800 (20)	20	36,1	4,0	12,1	200
	1 200 (55)	55	35,8	6,0	15,0	200

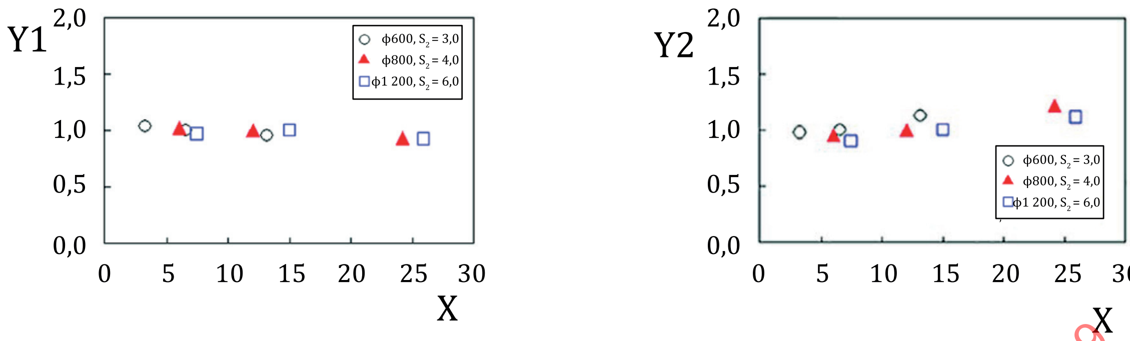
Test conditions are given below:

— shear strain amplitude: γ = 100 (%);

— reference cycle: 3rd (cycle).

b) Test results

Test results are shown in Table 19, Figures 6 a) and b).



a) Compressive stress dependency on shear modulus G_{eq}

b) Compressive stress dependency on equivalent damping ratio H_{eq}

Key

X compressive stress σ (N/mm^2)

Y1 $G_{eq}/G_{eq,0}$

Y2 $H_{eq}/H_{eq,0}$

Figure 6 — Compressive stress dependency

Table 19 — Change in horizontal characteristics with respect to values at compressive stress, σ_s

Outer diameter mm	Characteristics	Effect of compressive stress	
		$\sigma = 0,5\sigma_s$	$\sigma = 2\sigma_s$
600 (15)	K_{eq}	3,89 %	−4,39 %
	H_{eq}	−2,30 %	12,6 %
800 (20)	K_{eq}	2,13 %	−6,81 %
	H_{eq}	−4,76 %	21,5 %
1 200 (55)	K_{eq}	−3,06 %	−8,47 %
	H_{eq}	−10,5 %	11,6 %

6.5.5.3 Frequency dependency

6.5.5.3.1 In case of HDR

Example of HDR for 6.5.5.3 of ISO 22762-3:2018 on frequency dependency is given.

a) Test piece and test conditions

Test piece is shown in Table 20. Shear block specimen can be used for the test.

Table 20 — Test piece

Type	Outer diameter mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of test isolator
HDR	225	35,2	5,0	15,0	2

Test conditions are given below:

— test vibration frequency: 0,01 Hz, 0,03 Hz, 0,1 Hz and 0,33 Hz, sinusoidal wave;

— shear strain amplitude: $\gamma = \pm 100$ %;

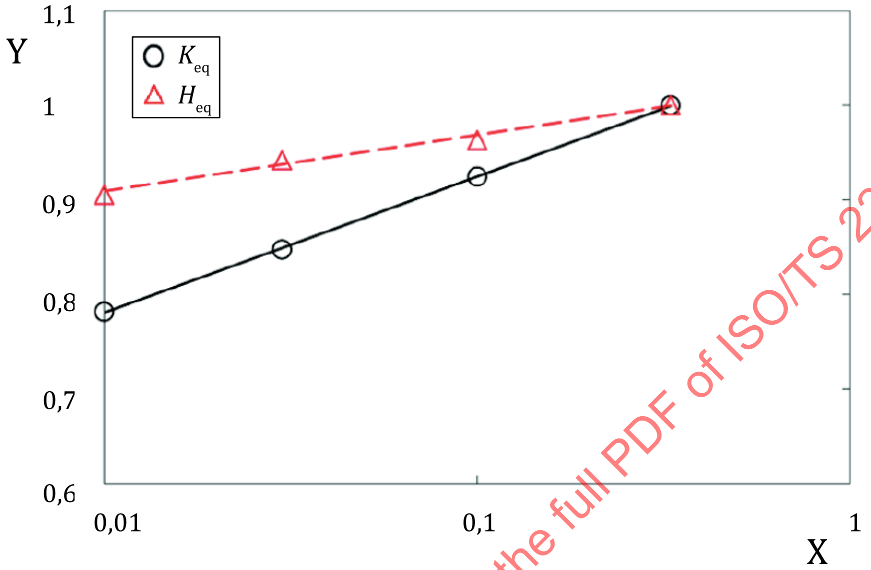
— loading cycles: 3 cycles, respectively;

— reference cycle: 3rd cycle;

— test results were corrected to the corresponding value of the property at 23 °C by the specified method in ISO 22762-3:2018, 6.5.5.5.

b) Test results

Test results are plotted in Figure 7.



Key

X f (Hz)

Y $K_{eq}(f)/K_{eq}(0)$, $H_{eq}(f)/H_{eq}(0)$

Figure 7 — An example of frequency dependency test results of HDR

The test result for each frequency is normalized by the result for the isolation frequency. By curve-fitting the results, correction factors that convert shear property values obtained at the testing frequency to values at the isolation frequency can be determined. Correction factors for loading frequency, f, can be derived as follows.

For shear stiffness:

$$\alpha_{\kappa} = \frac{1}{a_{\kappa} \log(f) + b_{\kappa}} \tag{1}$$

For equivalent damping ratio:

$$\alpha_{h} = \frac{1}{a_{h} \log(f) + b_{h}} \tag{2}$$

where

α_k is the correction factor for shear stiffness, K_{eq};

α_h is the equivalent damping ratio, H_{eq};

f is the loading frequency.

The values for a_k, b_k, a_h, and b_h, which are obtained from test results on a scaled model specimen are shown in Table 21 for one type of HDR.

Table 21 — An example of frequency correction factor

Isolation frequency	a_k	b_k	a_h	b_h
0,33 Hz	0,144	1,07	0,059 4	1,010

The test results are corrected for frequency by multiplying the results of the shear property test by α_k and α_h.

For shear stiffness:

$$K_{eq}(0{,}33\,\text{Hz}) = K_{eq}(f\text{:test frequency}) \cdot \alpha_k \tag{3}$$

For equivalent damping ratio:

$$H_{eq}(0{,}33\ \text{Hz}) = H_{eq}(f\text{:test frequency}) \cdot \alpha_h \tag{4}$$

6.5.5.3.2 In case of LRB

Example of LRB for 6.5.5.3 of ISO 22762-3:2018 on frequency dependency is given.

a) Test piece and test conditions

Test piece is shown in Table 22. Shear block specimen is also available for this test.

Table 22 — Test piece

Type	Outer diameter mm	Lead plug diameter mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of test isolator
LRB	208	41,6	28,9	4,8	7,8	2

Test conditions are given below:

— test vibration frequency: 0,01 Hz, 0,03 Hz, 0,1 Hz, and 0,33 Hz, sinusoidal wave;

— shear strain amplitude: $\gamma = \pm$ 100 %;

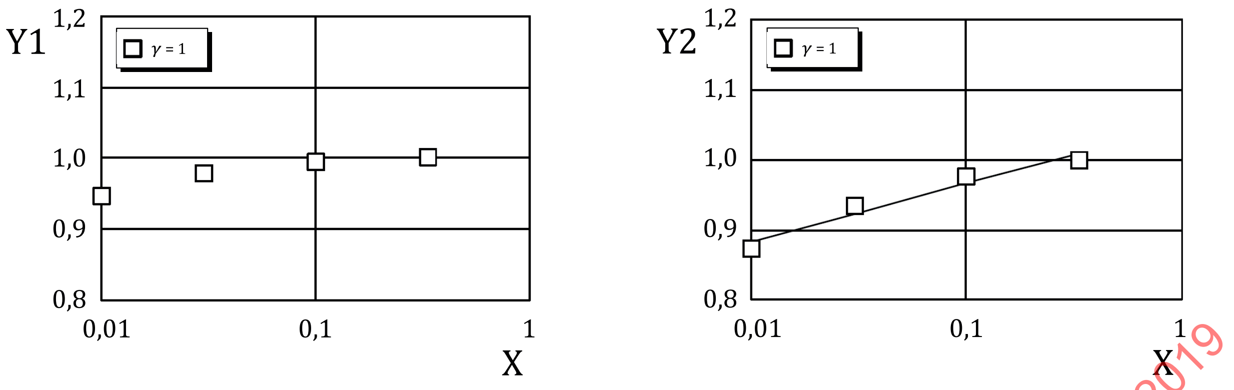
— loading cycles: 3 cycles, respectively;

— reference cycle: 3rd cycle;

— test results were corrected to the corresponding value of the property at 23 °C by the specified method in ISO 22762-3:2018, 6.5.5.5.

b) Test results

The results for one type of LRB are plotted in Figure 8.



a) Frequency dependency on K_d b) Frequency dependency on Q_d

Key

X f (Hz)

Y1 K_d/K_d*

Y2 Q_d/Q_d*

Q_d sine wave

Q_d* sine wave, f = 0,33 Hz

Figure 8 — An example of frequency dependency test results of LRB

The correction factor for frequency, f, can be derived using Formula (5).

For characteristic strength, Q_d:

$$\alpha_{Qd} = \frac{1}{a_Q \log_{10}(f) + b_Q} \tag{5}$$

where

α_{Qd} is the correction factor for characteristic strength, Q_d;

f is the loading frequency.

The values for a_Q and b_Q, which are obtained from test results on a scaled model specimen are shown in Table 23 for one type of LRB.

Table 23 — An example of frequency correction factor

Isolation frequency	a_Q	b_Q
0,33 Hz	0,082 9	1,049

The test results are corrected for frequency by multiplying the results of the shear property test by α_{Qd}.

For characteristic strength, Q_d:

$$Q_d\ (0{,}33\ \text{Hz}) = Q_d\ (f\text{:test frequency}) \cdot \alpha_k \tag{6}$$

6.5.5.3.3 In case of LNR

Example of LNR for 6.5.5.3 of ISO 22762-3:2018 on frequency dependency is given.

a) Test piece and test conditions

Test piece is shown in Table 24.

Shear block specimen can be used for the test.

Table 24 — Test isolators (scaled isolator)

Type	Outer diameter mm	Inner diameter mm	First shape factor	Second shape factor	Compressive stress N/mm2	Number of test isolator
LNR	253	29	20,0	7,0	10,0	2

Test conditions are given below:

— test vibration frequency: 0,01 Hz, 0,25 Hz, 0,5 Hz, and 1,0 Hz, sinusoidal wave;

— shear strain amplitude: $\gamma = \pm 100$ %;

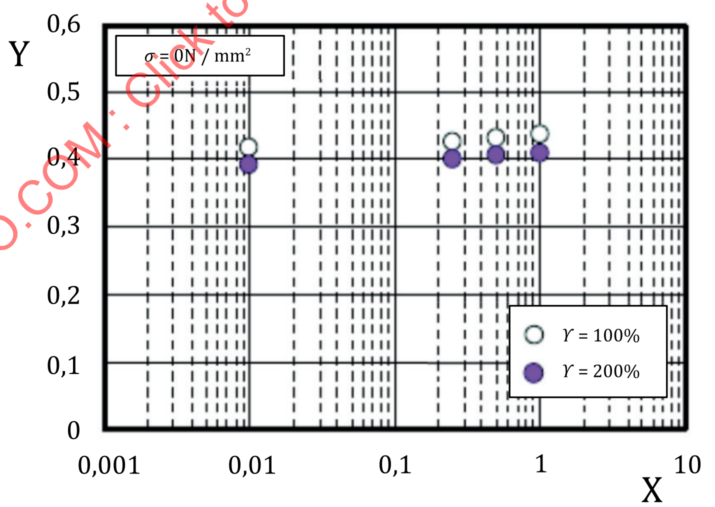
— loading cycles: 3 cycles, respectively;

— reference cycle: 3rd cycle;

— test results were corrected to the corresponding value of the property at 23 °C by the specified method in ISO 22762-3:2018, 6.5.5.5.

b) Test results

The results for one type of LNR are plotted in Figure 9.



Key

X frequency, f (Hz)

Y shear modulus, G (MPa)

Figure 9 — An example of frequency dependency test results of LNR

Frequency dependency of LNR is negligible. Generally, no correction for frequency is required.

6.5.5.4 Repeated loading dependency

Example of HDR for 6.5.5.4 of ISO 22762-3:2018 on repeated loading dependency is given.

a) Test piece and test conditions

Test piece is shown in Table 25.

Table 25 — Test piece

Type	Outer diameter mm	Inner diameter mm	First shape factor	Second shape factor	Compressive stress N/mm²	Number of test isolator
HDR	700	15	36,4	5,0	12,0	1

Test conditions are given below:

— test vibration frequency: 0,008 Hz, triangle wave;

— shear strain amplitude: γ = ± 100 %;

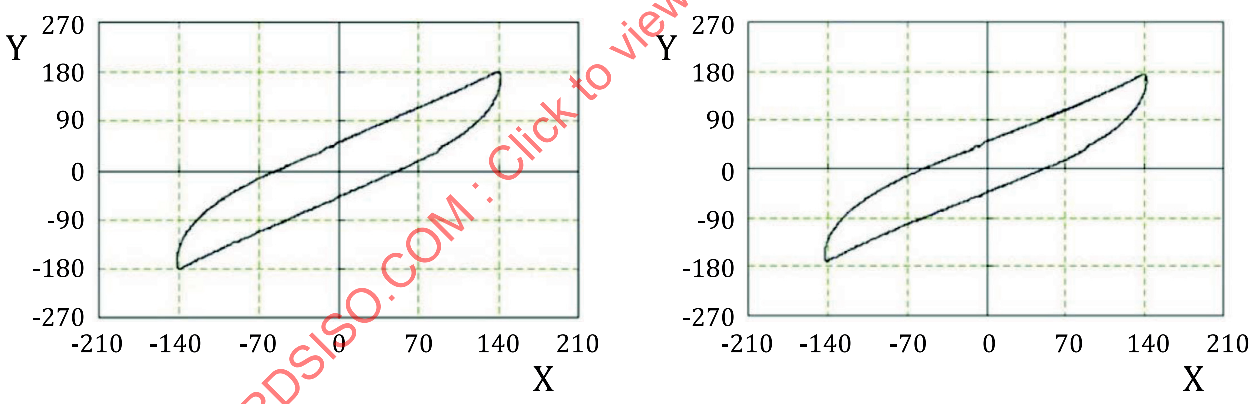
— loading cycles: 50 cycles;

— reference cycle: 3rd cycle;

— test results were corrected to the corresponding value of the property at 23 °C by a specified method.

b) Test results

The results are given in Figure 10 and Table 26.



a) Hysteresis loop (3rd cycle)

b) Hysteresis loop (30th cycle)

Key

X horizontal disp. (mm)

Y horizontal load (kN)

Figure 10 — Repeated loading dependency of shear characteristics

Table 26 — Effect of repeated cycling [values normalized by corresponding value after third cycle (same correction as other part)]

Number of cycles	K_{eq}	H_{eq}
3	1,000	1,000
5	0,99	0,99
10	0,98	0,97
30	0,95	0,95
50	0,94	0,92

6.5.5.5 Temperature dependency

6.5.5.5.1 In case of HDR

Example of HDR for 6.5.5.5 of ISO 22762-3:2018 on temperature dependency is given.

a) Test piece and test conditions

Test piece is shown in Table 27. Shear block specimen can be used for the test.

Table 27 — Test piece

Type	Outer diameter mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of test isolator
HDR	225	35,2	5,0	15,0	3

Test conditions are given below:

— test vibration frequency: 0,33 Hz, sinusoidal wave;

— test temperature: −10 °C, 0 °C, 23 °C, 30 °C, and 40 °C;

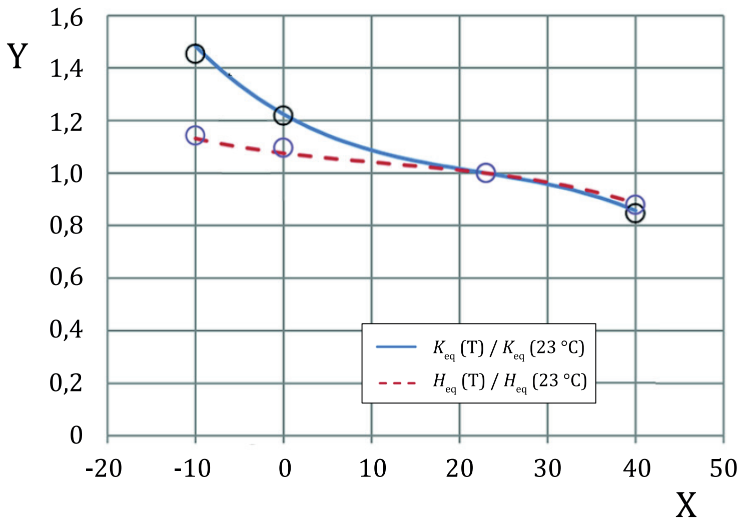
— shear strain amplitude: $\gamma = \pm$ 100 %;

— loading cycles: 3 cycles, respectively;

— reference cycle: 3rd cycle.

b) Test results

The results for one type of HDR are plotted in Figure 11.



Key

X temperature (°C)

Y $K_{eq}(T)/K_{eq}$ (23 °C), $h_{eq}(T)/h_{eq}$(23 °C)

Figure 11 — An example of temperature dependency test results of HDR

The result at each temperature is normalized by the result for 23 °C.

Curve-fitting of the data gives a function expressing the dependence of the shear property on the temperature, *T* °C. Hence, a factor converting the value obtained at *T* °C to that, at 23 °C, can be derived as follows.

For shear modulus:

$$\beta_{\mathrm{k}} = \frac{1}{a + bT + cT^2 + dT^3} \quad (7)$$

For equivalent damping ratio:

$$\beta_{\mathrm{h}} = \frac{1}{e + fT + gT^2 + hT^3} \quad (8)$$

The values for *a*, *b*, *c*, *d*, *e*, *f*, *g*, and *h* for one type of HDR are shown in Table 28.

Table 28 — An example of temperature correction factor

a	*b*	*c*	*d*
1,224	$-1,892 \times 10^{-2}$	$6,087 \times 10^{-4}$	$-9,135 \times 10^{-6}$
e	*f*	*g*	*h*
1,076	$-4,175 \times 10^{-3}$	$1,107 \times 10^{-4}$	$-3,133 \times 10^{-6}$

The test results can be corrected for temperature by multiplying the results of the shear property test by β_{k} and β_{h}.

For shear stiffness:

$$K_{\text{eq}}(23\ °\text{C}) = K_{\text{eq}}(T\text{:test temperature}) \cdot \beta_{\text{k}} \tag{9}$$

For equivalent damping ratio:

$$H_{\text{eq}}(23\ °\text{C}) = H_{\text{eq}}(T\text{:test temperature}) \cdot \beta_{\text{h}} \tag{10}$$

6.5.5.5.2 In case of LRB

Example of LRB for 6.5.5.5 of ISO 22762-3:2018 on temperature dependency is given.

a) Test piece and test conditions

Test piece is shown in Table 29.

Table 29 — Test piece

Type	Outer diameter mm	Lead plug diameter mm	First shape factor	Second shape factor	Compressive stress N/mm2	Number of test isolator
LRB	250	38	41,7	4,8	6,2	2

Test conditions are given below:

— test vibration frequency: 0,33 Hz, sinusoidal wave;

— test temperature: −10 °C, 0 °C, 23 °C, 30 °C, 40 °C;

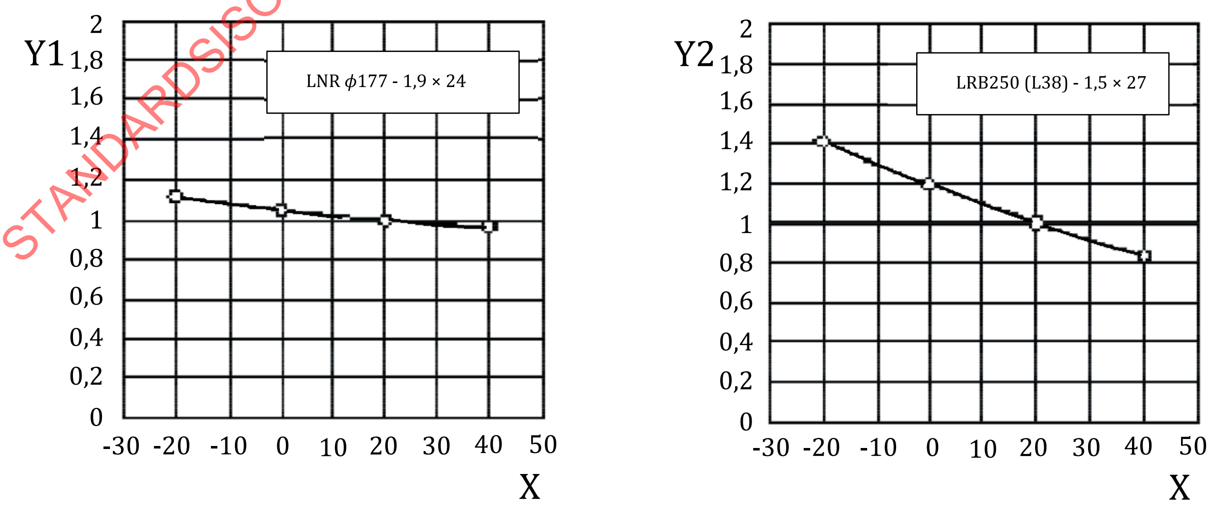
— shear strain amplitude: γ = ± 100 %;

— loading cycles: 3 cycles, respectively;

— reference cycle: 3rd cycle.

b) Test results

The results for one type of LRB are plotted in Figure 12.



a) b)

Key

X temperature (°C)

Y1 K_d/K_d (23 °C)

Y2 Q_d/Q_d (23 °C)

Figure 12 — An example of temperature dependency test results of LRB

The result at each temperature is normalized by the result for 23 °C.

Curve-fitting the data gives a function expressing the dependence of the shear property on the temperature, T °C. Hence, a factor converting the value obtained at T °C to that, at 23 °C, can be derived as follows.

For shear modulus of post-yielding stiffness:

$$\beta_{\mathrm{kd}} = \frac{1}{a + bT + cT^2} \tag{11}$$

For characteristic strength:

$$\beta_{\mathrm{Qd}} = \frac{1}{d + eT + fT^2} \tag{12}$$

The values for a, b, c, d, e, f, g, and h for one type of LRB are shown in Table 30.

Table 30 — An example of temperature correction factor

a	b	c
1,052	−2,955 × 10^{-3}	1,895 × 10^{-5}
d	e	f
1,192	−1,017 × 10^{-2}	2,722 × 10^{-5}

The test results can be corrected for temperature by multiplying the results of the shear property test by β_{kd} and β_{Qd}.

For post-yielding stiffness:

$$K_{\mathrm{d}}(23\ ^\circ\mathrm{C}) = K_{\mathrm{d}}(T\text{:test temperature}) \cdot \beta_{\mathrm{kd}} \tag{13}$$

For characteristic strength:

$$Q_{\mathrm{d}}(23\ ^\circ\mathrm{C}) = Q_{\mathrm{d}}(T\text{:test temperature}) \cdot \beta_{\mathrm{Qd}} \tag{14}$$

6.5.5.5.3 In case of LNR

Example of LNR for 6.5.5.5 of ISO 22762-3:2018 on temperature dependency is given.

a) Test piece and test conditions

Test piece is shown in Table 31.

Table 31 — Test piece

Type	Outer diameter mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of test isolator
LNR	225	35,2	5,0	15,0	1

Test conditions are given below:

— test vibration frequency: 0,33 Hz, sinusoidal wave;

— test temperature: −10 °C, 0 °C, 23 °C, 30 °C, 40 °C;

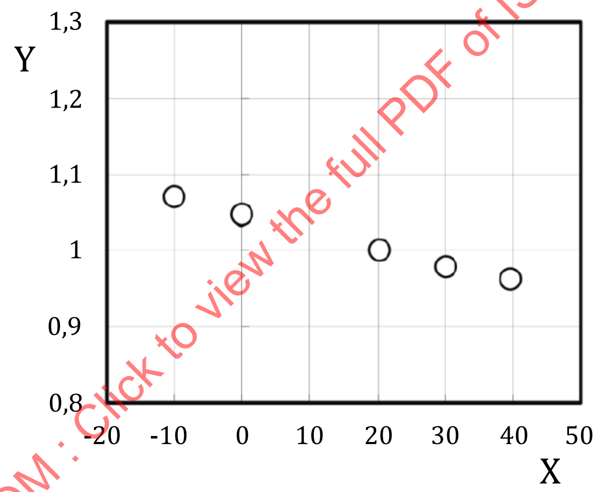
— shear strain amplitude: γ = ± 100 %;

— loading cycles: 3 cycles, respectively;

— reference cycle: 3rd cycle.

b) Test results

The results for one type of LNR are plotted in Figure 13.



Key

X temperature (°C)

Y K_h/K_h (23 °C)

Figure 13 — An example of temperature dependency test results of LNR

The result at each temperature is normalized by the result for 23 °C.

Curve-fitting the data gives a function expressing the dependence of the shear property on the temperature, T °C. Hence, a factor converting the value obtained at T °C to that, at 23 °C, can be derived as follows.

For shear modulus of shear stiffness:

$$\beta_k = \frac{1}{a + bT + cT^2} \tag{15}$$

The values for a, b, and c for one type of LNR are shown in Table 32.

Table 32 — An example of temperature correction factor

a	*b*	*c*
1,052	$-2{,}955 \times 10^{-3}$	$1{,}895 \times 10^{-5}$

The test results can be corrected for temperature by multiplying the results of the shear property test by β_k and β_h.

For stiffness:

$$K_h(23\ °C) = K_h(T\text{:test temperature}) \cdot \beta_k \qquad (16)$$

For characteristic strength:

$$Q_d(23\ °C) = Q_d(T\text{:test temperature}) \cdot \beta_h \qquad (17)$$

6.5.6 Dependencies of compressive properties

No guidance is given.

6.5.7 Shear displacement capacity

Example of HDR for 6.5.7 of ISO 22762-3:2018 on shear displacement capacity is given.

a) Test piece and test conditions

Test piece for ramp loading test is shown in Table 33.

Table 33 — Test piece

Type	Outer diameter mm	Inner diameter mm	First shape factor	Second shape factor	Compressive stress N/mm^2	Number of isolators
HDR	800	20	36,1	4,0	12,1	2

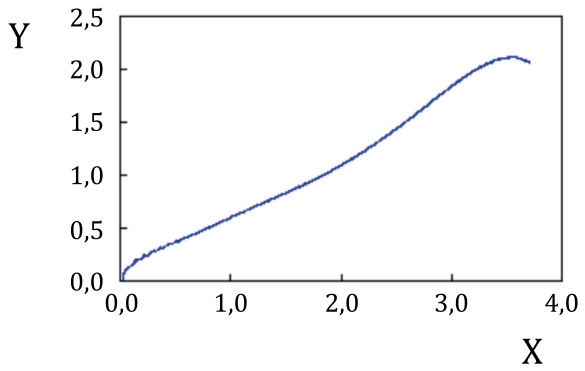
Test conditions are given below:

— test wave: triangular wave (V = 18 mm/sec);

— loading cycles: 1 cycle, respectively.

b) Test results

The Figure 14 and Table 34 show the test results.



Key

X shear strain γ

Y shear stress τ (N/mm²)

Figure 14 — Horizontal deformation capacity of HDR 800 mm diameter under ramp loading

Table 34 — Test results

Compressive stress N/mm²	**Test shear strain** %	**Test results**
12,1	357	No failure

6.5.8 Durability

6.5.8.1 Change in properties on aging

Example for 6.5.8.1 of ISO 22762-3:2018 on durability is given.

a) Test pieces and test conditions

Test pieces are shown in Table 35.

Table 35 — Test pieces

Type	**Outer diameter** mm	**First shape factor**	**Second shape factor**	**Compressive stress** N/mm²	**Number of isolators**	**Remark**
HDR	160	35	5,0	0,0	2	Initial
				0,0	1	30 years
				15,0	1	30 years
				0,0	1	60 years
				15,0	1	60 years

Accelerated aging condition for expected life under 23 °C is determined according to ISO 22762-1:2018, Annex A as shown in Table 36.

Table 36 — Accelerated ageing condition

Activation energy	**Condition: 23 °C × 60 y Eq.**
$9,13 \times 10^4$ J/mol	90 °C × 16 d

b) Test results

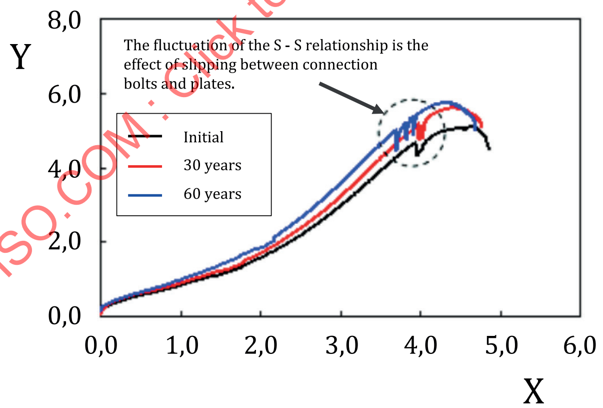
Test results for property changes in shear properties and ultimate properties are shown in Tables 37 and 38. Ultimate property test results are plotted in Figure 15.

Table 37 — Test results: Shear property changes from initial value

Outer diameter mm	First shape factor	Second shape factor	G_{eq}	H_{eq}
160	35	5,0	+9 %	−10 %
	35	5,0	+10 %	−5 %
	35	5,0	+7 %	−6 %

Table 38 — Test results: Ultimate property changes

Outer diameter mm	First shape factor	Second shape factor	Compressive stress N/mm²	Ultimate shear strain		
				Initial	30 years	60 years
160	35	5,0	15	4,51	—	—
				4,47	—	—
				—	4,43	—
				—	4,40	—
				—	4,54	—
				—	—	4,47
				—	—	4,32
				—	—	4,48
Average				4,49	4,46	4,42



Key

X shear strain γ (−)

Y shear stress τ (N/mm²)

Figure 15 — Change of ultimate shear strength with ageing

6.5.8.2 Creep

Example for 6.5.8.2 of ISO 22762-3:2018 on durability is given.

a) Test piece and test conditions

Test piece is shown in Table 39.

