R-10-018E 010.6-Rev.2

High-Damping Rubber Bearings for Base Isolation

Technical Report

Product Code: HDR-X0.6R

BRIDGESTONE
PASSION for EXCELLENCE

Bridgestone Corporation
Seismic Isolation & Vibration Control Products Development

Contents

1. Construction

□Basic construction

Basic construction of High Damping Rubber Bearings (HDR-X0.6R) is shown in Figure-1.
HDR consists of alternate rubber layers and reinforcing steel plates. The inner rubber composed of the high damping materials, to demonstrate spring and damping capabilities itself.

Basic dimensional range of High Damping Rubber Bearings is shown in Table-1. As shown in table, HDR-X0.6R supplied a wide range of sizes according to axial forces and required responsibility.

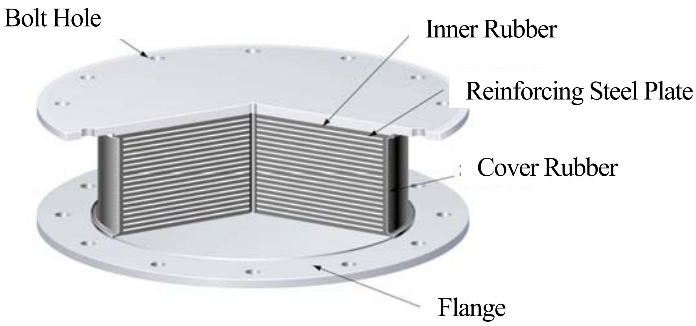


Figure-1 Basic Structure of High Damping Rubber Bearing

Table-1 Dimensional characteristics

Items		Characteristics
Rubber	Compound name	X0.6R
	Shear modulus N/mm^2	0.62
	Equivalent damping ratio	0.24
Dimension	Outer diameter, mm	φ500～1600
	Inner diameter, mm	φ15～80
Shape factor	First shape factor	35～40
	Secondary shape factor	3.0～10.0

【Note】
(1)Dimensions and product performance of each Bridgestone standard size is shown in Catalogue.
(2)Dimensional tolerance is shown in Table 2.

Table-2 Dimensional tolerance

Item	Standard
Isolator height *1	Design height ±1.5% and ± 6mm
Isolator slope *2	0.5% of Flange diameter and < 3mm
Horizontal offset	< 5mm
Rubber diameter	Design v. ±0.5% and <±4mm
Flange diameter	Design v. ±3.0mm
Flange thickness	Design v.±0.9mm
Bolt pitch center diameter	Design v. ±1.2mm

*1: Average on 4 points, temperature = 20 Degrees Celsius
*2: Difference of height located in diagonal position

□Material properties

Compound configuration of the rubber materials and material characteristics of steel plates (flanges and inner steel plates) are shown in Tables-3 and -4.

Table-3 Compound configuration (weight ratio,%)

	Natural rubber Synthetic rubber	Filler (Carbon etc.)	Sulfur etc.
Inner rubber (X0.6R)	> 35	> 25	< 40
Cover rubber	> 40	>15	> 40

Table-4 Steel material

Properties	Standard	Characteristics
Flange	JIS G3101, JIS G3106	SS400, SM490
Inner Steel Plate	JIS G3101	SS400

*JIS: Japanese Industrial Standards

Physical properties of inner rubber materials are shown in the Table 5. The rubber material tests were carried out by the method specified in JIS (Japanese Industrial Standards).

Table-5 Physical Properties of Inner Rubber Materials of HDR-X0.6

Properties	Standard	Characteristics
Compound Code	Bridgestone Code	X0.6
Hardness	JIS K 6253	53±5
100% Modulus	JIS K 6251	0.78±0.2 (N/mm^2)
Tensile Strength	JIK K6251	≧8 (N/mm^2)
Elongation at Break	JIK K 6251	≧720 (%)

【Note】

Standard painting system is shown in Table-6.

Table-6 Painting system of flanges

Items	Characteristics
Surface preparation	Sand blasting,: SSPC-SP-10(SIS Sa 2 1/2)
Primer	Zinc-rich primer 75μm×1oat
Middle coat	Epoxy resin paint 60μm×1oat
Finishing	Epoxy resin paint 35μm×1oat
Total film thickness	> 170μm

2. Horizontal Properties (Numerical Model)

□Principle

Shear stiffness 'K_{eq}', equivalent damping ratio 'H_{eq}' and ratio of characteristic strength to maximum shear force of a loop 'u' are given by the following equations (1) to (3).

Shear properties are defined at 3rd cycle of γ_0=1.0γ cyclic sinusoidal loading with frequency of 0.33 Hz. G_{eq}, H_{eq}, U are expressed as functions of shear strain γ (=δ/H) as shown below.

$$K_{eq} = {G_{eq} \cdot A}/{n \cdot t_r} \quad (1)$$

$$H_{eq} = {\Delta W}/{\left(2 \cdot \pi \cdot K_{eq} \cdot X^2\right)} \quad (2)$$

$$u = {Q_d}/{\left(K_{eq} \cdot X\right)} \quad (3)$$

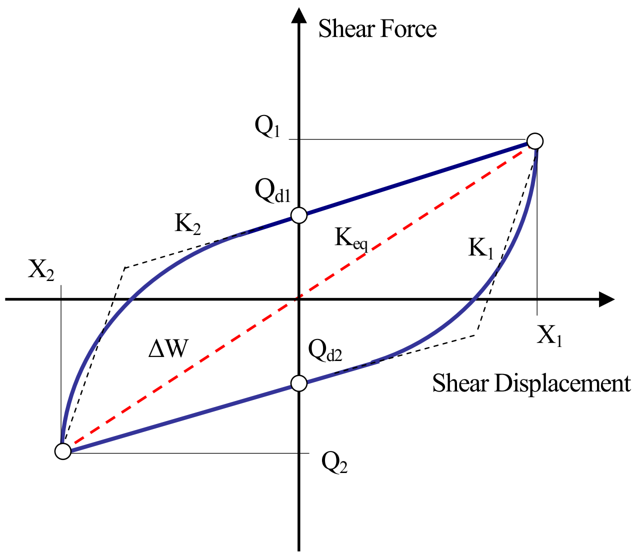


Figure-2 Determination of Shear Properties

Table-7 Design Function of High Damping Rubber Bearing

Compound	Properties at Γ=00%	Function
X0.6R	G_{eq}=62N/mm^2 H_{eq}=.240 U=0.408	(10≦γ≦270%) $G(\gamma)=1.770-2.404\gamma+1.800\gamma^2-0.630\gamma^3+0.0846\gamma^4$ $Heq(\gamma)=0.2196+0.05674\gamma-0.04330\gamma^2+0.006965\gamma^3$ $U(\gamma)=0.3683+0.1106\gamma-0.08498\gamma^2+0.013958\gamma^3$

【Note】

Components for bi-linear modeling, such as initial stiffness K_1, post-yield stiffness K_2, characteristic strength Q_d are computed by using K_{eq}, H_{eq} and U as follows.

$$K_1 = K_{eq}(u-\pi \cdot {\tan\delta}/{4} + u \cdot \pi \cdot {\tan\delta}/{4})/(u-\pi \cdot {\tan\delta}/{4}) \quad (4)$$

$$K_2 = K_{eq}(1-u) \quad (5)$$

$$Q_d = u \cdot K_{eq} \cdot H \cdot \gamma \quad (6)$$

$$\tan\delta = 2 \cdot H_{eq} \quad (7)$$

where, G is shear modulus, tanδ is loss factor, U is characteristic strength ratio, γ is shear strain, A is effective rubber area, H is total rubber height.

□Typical test loops of HDR

Functional properties of the HDR-X0.6 are specified by followings. And typical shear-strain relationship (Hysteresis Loop) of HDR-X0.6R is shown in Figure 3.

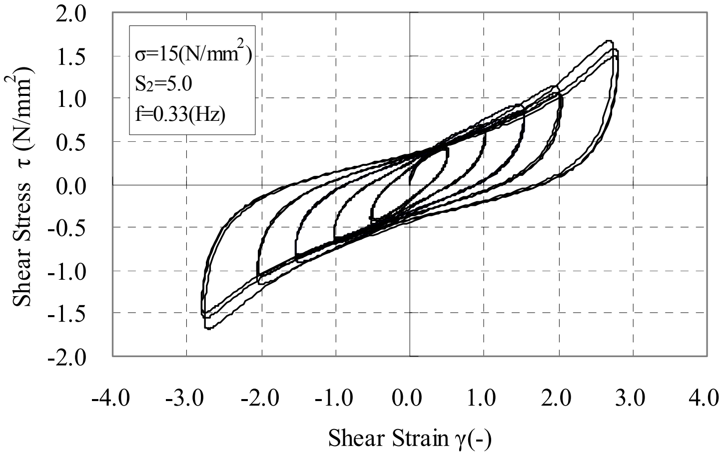


Figure-3 Typical Dynamic Shear Stress-Strain Relationship of HDR-X0.6R

Design functions of HDR-X0.6 (G_{eq}, H_{eq}, and U), empirically obtained by dynamic loading test are shown in Table 6. They were developed by dynamic shear loading test using scaled model. Shear modulus $G_{eq}(\gamma)$ is expressed as a function of the shear strain γ, such as a polynomial function, as shown in Table. And the equivalent damping ratio $H_{eq}(\gamma)$ is also expressed as a function of the shear strain γ as shown in Table.

The characteristic strength of HDR-X0.6 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 maximum shear force of a loop. As shear modulus and equivalent damping ratio, $U(\gamma)$ is also expressed empirically as a function of the shear strain γ, as shown in Table.

□Comparison of test loops and bilinear model

Comparison of test loops and bilinear model are shown in Figure 4.

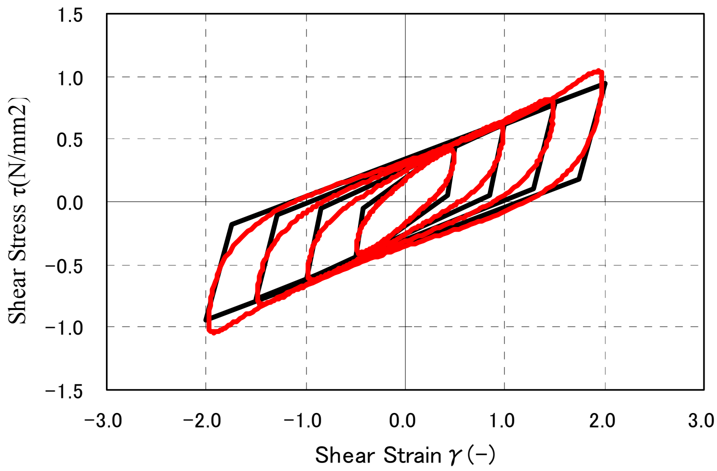


Figure-4 Comparison of test loops and bilinear model (HDR-X0.6R)

3. Variation of Horizontal Properties

Factors of variation of horizontal properties are as shown as follows.
(1) Manufacturing tolerance
(2) Temperature dependency
(3) Ageing (degradation)

Change ratio of each factor is shown in Table.

Table-8 Design Function of High Damping Rubber Bearing

Compound	Factor	Change	Remarks
X0.6R	Manufacturing tolerance	K_{eq}: global±10% (individual±20%) H_{eq}: global±10% (individual±20%)	
	Temperature	K_{eq}: +21%(0 Degrees Celsius), -16%(40 Degrees Celsius) H_{eq}: +7%(0 Degrees Celsius), -13%(40 Degrees Celsius)	Standard temp 20 Degrees Celsius
	Ageing	K_{eq}: +10% H_{eq}: -10%	20 Degrees Celsius x 60 years

Table-9 Example of variation-combination

Compound		X0.6R	
Manufacturing tolerance *1	K_{eq}	+10%	-10%
	H_{eq}	-10%	+10%
Aging	K_{eq}	+10%	0%
	H_{eq}	-10%	0%
Temperature depend. 20 Degrees Celsius ±20 Degrees Celsius	K_{eq}	+21%	-16%
	H_{eq}	+7%	-13%
Total	K_{eq}	+41%	-26%
	H_{eq}	-13%	-3%

*1: Empirically, the manufacturing tolerance of K_{eq} and H_{eq} is related such as when K_{eq} is (+) side, H_{eq} is in (-) side.

4. Vertical Properties

Vertical properties of isolator is expressed as K_v.
K_v is determined by following equations.

$$K_v = E_c \cdot A/(n \cdot t_r) \qquad (8)$$

$$K_v = (P_2 - P_1)/(Y_2 - Y_1) \qquad (9)$$

where,

$$\frac{1}{E_c} = \frac{1}{E_{AP}} + \frac{1}{E_\infty} \qquad (10)$$

$$E_{AP} = E_0(1 + 2 \cdot \kappa \cdot S_1^2) \qquad (11)$$

$$E_c = E_0(1 + 2 \cdot \kappa \cdot S_1^2)/\left[1 + E_0(1 + 2 \cdot \kappa \cdot S_1^2)/E_\infty\right] \qquad (12)$$

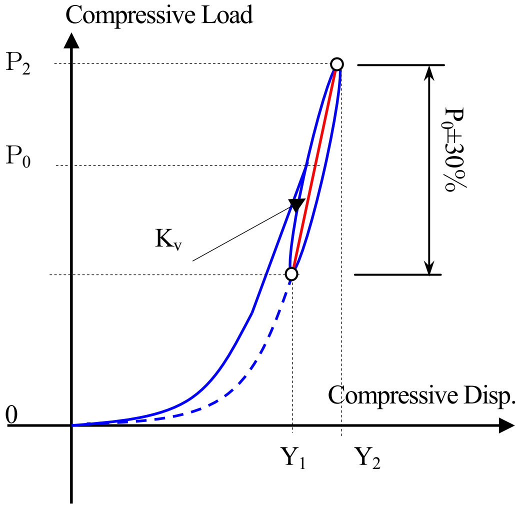


Figure-5 Determination of Compressive Properties

Where, A is effective area, H is total rubber height, S_1 is first shape factor. Material coefficient for each compound, such as Young's modulus E, correction factor κ, bulk modulus E_∞ are shown in Table-10.

Table-10 Material coefficient for K_v

Compound	E N/mm^2	κ	E_∞ N/mm^2
X0.6R	7.6	1.0	1500

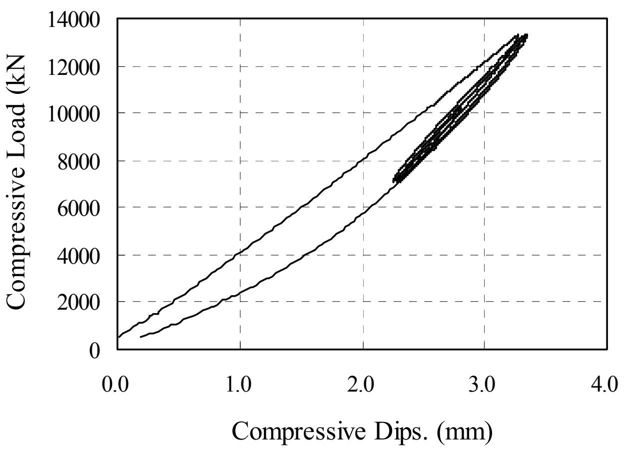


Figure-6 Figure-3 Typical Compressive Properties of HDR

【Note】
Manufacturing tolerance: for individual isolator design value ±30%.

5. Nominal Long-Term Compressive Stress

Nominal long-term compressive stress for each compound and each secondary shape factor is shown in Tables.

Table-11 Nominal compressive stress for X0.6

X0.6R	$35 \leqq S_1 \leqq 40$
$3.00 \leqq S_2 \leqq 4.55$	$\sigma_S = 5.43 \times S_2 - 9.70$
$4.55 < S_2 \leqq 10.0$	$\sigma_S = 15.0$

6. Ultimate Properties

□Ultimate properties under compressive stress

Ultimate properties of isolators are defined as fracture of rubber and buckling (instability).
Typical force-displacement curves of failure behavior of the isolators are shown in Figure 7.

$$\gamma = \delta_H / H \qquad (13)$$

$$\delta = P_0 / A \qquad (14)$$

where, H is total rubber height, A is effective area of isolator.

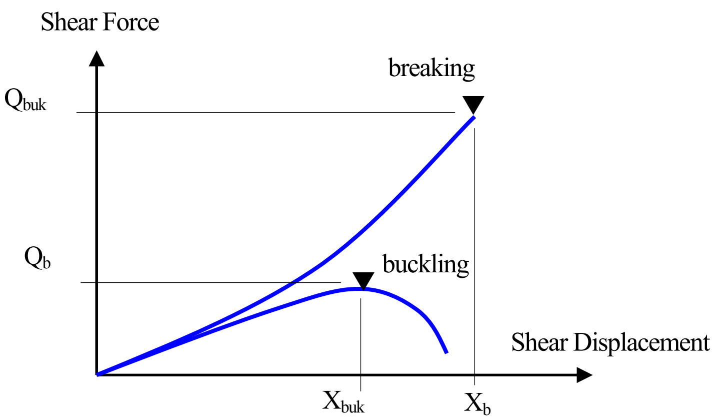


Figure-7 Determination of Ultimate Properties

Ultimate property of each standard isolator is determined by the Ultimate Property Diagram (UPD).

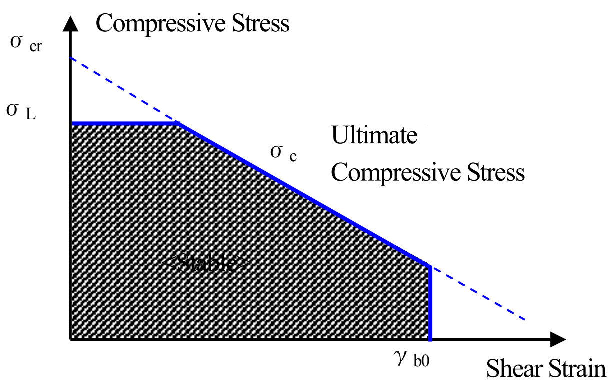


Figure-8 Ultimate Property Diagram

□Fracture Strain

Fracture strain of isolators for both compounds is determined as more than 400% shear strain.

Table-12 Nominal compressive stress

Compound	Fracture strain
X0.6R	$0.9\times S_2\times 100$: $S_2<4.5$
	400%: $S_2 \geqq 4.5$

□Buckling Stress

Buckling stress (or load) is predicted -by following empirical equation shown in Table 14.

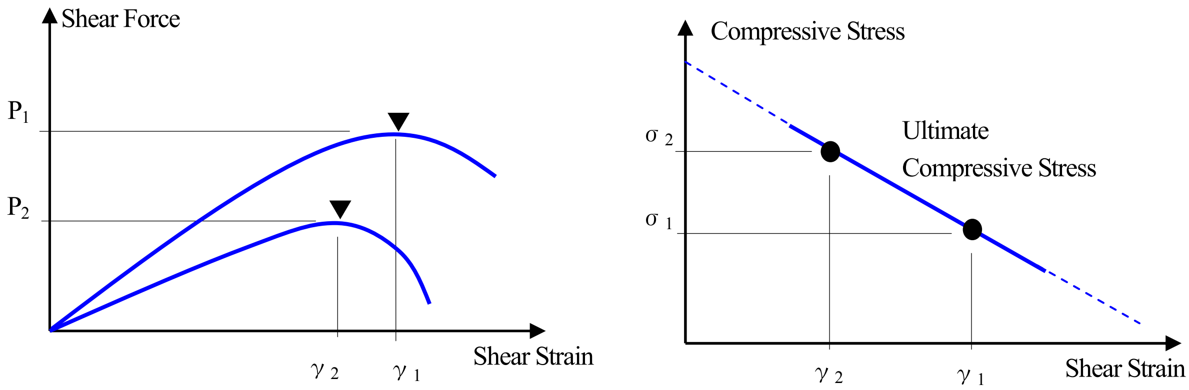


Figure-9 Determination of Ultimate Compressive Properties

Table-13 Computation of buckling stress

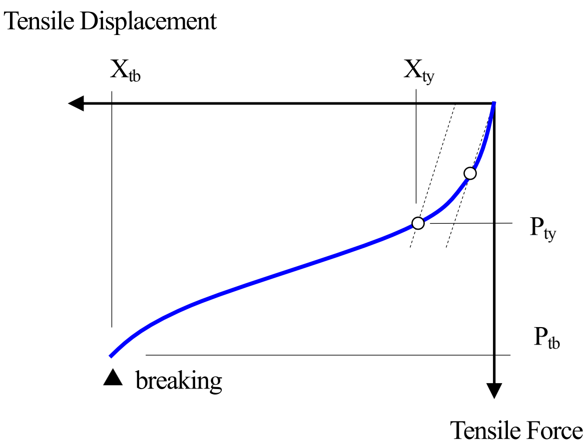
X0.6R	σ_c (N/mm^2)	$\sigma = \sigma_{cr}\left(1 - \dfrac{\gamma}{S_2}\right)$ $\sigma_{cr} = \alpha_c \cdot \dfrac{\pi}{4}\left(G_{eq} \cdot E_b\right)^{0.5} S_2$ $E_b = E(1 + 2/3 \cdot \kappa \cdot S_1^2)/\left[1 + E(1 + 2/3 \cdot \kappa \cdot S_1^2)/E_\infty\right]$ Here, α_c=1.45 $(5 \leqq S_2)$ α_c=1.45-0.3×(5-S_2) $(S_2<5)$ E=3×G_{eq} (=3×0.624=1.872)
	σ_L (N/mm^2)	σ_L =60 $(4.9 \leqq S_2)$ σ_L =48+14(S_2-4) $(4.0 \leqq S_2 < 4.9)$ σ_L =24+24(S_2-3) $(3.5 \leqq S_2 < 4.0)$ σ_L =22+28(S_2-3) $(3.0 \leqq S_2 < 3.5)$
	γ_{b0}	γ_{b0}=(5.00S_2+9.05)/(S_2+4.49)

□Tensile Strength

Tensile strength of isolators is determined as follows.

Table-14 Computation of Tensile Strength

Compound	Tensile strength
X0.6R	1.0 N/mm^2



Key

X_{ty}: displacement corresponding to 1% total rubber thickness

X_{tb}: breaking displacement

P_{ty}: tensile yielding force

P_{tb}: breaking force

Table-14 Computation of Tensile Strength

Annex-A
<u>Temperature Dependence on Shear Properties</u>

Shear modulus and equivalent damping ratio of high-damping rubber bearings becomes harder as temperature becomes lower. Following table shows the test results by the scaled model specimen.

Table-1A Temperature dependence of shear modulus and damping ratio

Compound	Items	-10 Degrees Celsius	0 Degrees Celsius	30 Degrees Celsius	40 Degrees Celsius
X0.6R	G_{eq}	+46%	+21%	-6%	-16%
	H_{eq}	+12%	+7%	-5%	-13%

(n=7)

The relationship between temperature and change rate of properties is shown in Figure-1. The standard temperature is 20 Degrees Celsius.

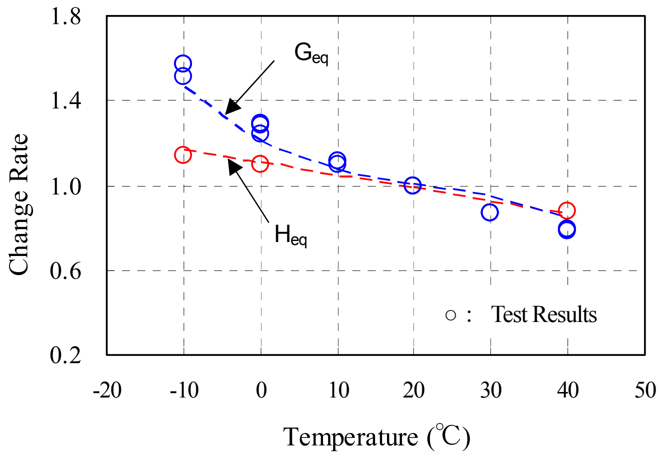


Figure-1A Relationship between Temperature and Change Rate of Shear Properties of HDR-X0.6R

Temperature-correction factor is computed by following equation.

For shear modulus: $$\beta k = \frac{1}{a + bt + ct^2 + dt^3} \quad (1A)$$

For Equivalent damping ratio: $$\beta h = \frac{1}{e + ft + gt^2 + ht^3} \quad (2A)$$

where, t is test temperature (Degrees Celsius). The value for *a, b, c, d, e, f, g* and *h* are shown in Table 2A.

Table-2A Temperature Correction Factor for Compound X0.6R

Compound	*a*	*b*	*C*	*d*
X0.6R	1.21	-1.86×10^{-2}	5.99×10^{-4}	-8.99×10^{-6}

Compound	*e*	*f*	*g*	*H*
X0.6R	1.06	-4.13×10^{-3}	1.10×10^{-4}	-3.10×10^{-6}

Annex-B

Change of Restoring Force Characteristics by Ageing

□The Degradation of Shear Properties

The aging properties of isolators are able to be evaluated by accelerated heat-ageing test. The relationship between ageing period in real-time scale to and accelerated-time scale t1 is expressed as follows.

$$\frac{t_0}{t_1} = exp\left\{\frac{Ea}{R}\left(\frac{1}{T_0} - \frac{1}{T_1}\right)\right\} \qquad (1B)$$

where, t_1: Accelerated Time, t_0: Real Time, T_1: Ageing Temperature, T_0: Ambient Temperature (=20 Degrees Celsius =273K), Ea: Activation Energy (J/mol) and R: Gas Constant (=8.32J/mol).

The test conditions and results of accelerated ageing for the compounds X0.6R is shown in Tables 1B and 2B.

Table-1B Heat Ageing Condition

Compound	Activation *E*	Condition: 20 Degrees Celsius×60yearsEq.
X0.6R	9.13×10^4 J/mol	90 Degrees Celsius × 16days

Table-2B Test Results- Change Rate from Initial Value (20 Degrees Celsius × 60years)

Compound	Outer Dia.	S1	S2	G_{eq}	H_{eq}
X0.6R	158	35	5.0	+9%	-10%
X0.6R	158	35	5.0	+10%	-5%
X0.6R	158	35	5.0	+7%	-6%

Considering the deviation of rubber compound for 20%, the standard value for aging is defined as Table 3B.

Table-3B Standard Value for Ageing

Compound	Items	(20 Degrees Celsius × 60years)/(Initial)
X0.6R	G_{eq}	Maximum +13%
	H_{eq}	Minimum -10%

□The Degradation of Ultimate Shear Properties

The ultimate strength of isolators is able to be evaluated by accelerated heat-ageing test. The degradation of ultimate shear properties of isolators is as shown in Table-4B and Figure-1B. Here, the corresponded time is 30 years and 60 yeas of used.

After ageing of 60 years, the change ratio (degradation) of the ultimate shear strength is within a few percent which compare with initial properties.

Table-4B Change Ratio of Ultimate Shear Strain by Ageing

Compound	Outer Dia.	S_1	S_2	Compressive Stress (N/mm^2)	Ultimate Shear Strain		
					Initial	30Years	60Years
X0.6R	158	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

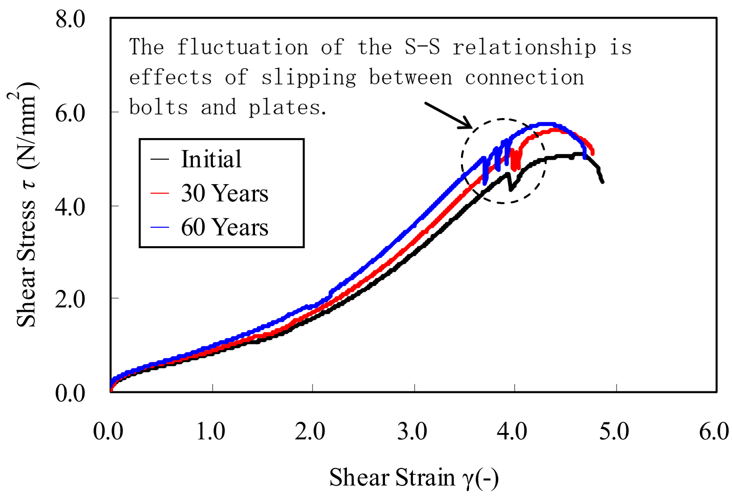


Figure-1B Degradation of ultimate shear strength by ageing

Annex-C
Creep Properties

Compressive Creep of HDR depend on there axial stress (force) and first shape factor. The compressive creep becomes larger when axial stress is bigger and first shape factor is smaller. The creep properties of isolators are able to be evaluated by accelerated heat-ageing and environmental-temperature ageing tests.
The creep of HDR after 60years of use can be expressed as follows.

$$\varepsilon(\%) = C_0 \cdot \sigma^p \cdot Y^q / G_{eq} / S_1^r \qquad (1C)$$

where, σ is axial stress (N/mm^2), Y is corresponded years (Year) and G_{eq} is shear modulus (N/mm^2). The value for C_0, p, q and r are shown in Table 1C.

Table-1C Creep Correction Factor for Compound X0.6R

Compound	C_0	p	q	r
X0.6R	0.872	1.28	0.468	1.03

To evaluate the creep of HDR after 60years of used, the ageing test is effective. By measuring the change in the compressive displacement, following table and figure shows test results by the scaled model specimen. The test conditions such as a period and temperature is specified as follows: The ageing period is corresponded to 60 years, the ageing temperature is 30 Degrees Celsius and axial stress is 15 (N/mm^2).

Table-2C Creep-Ratio of X0.6R

Axial Stress σ (N/mm^2)	Creep ε (%)
7.0 and 8.0	within 4%
9.0	within 5%
10.0	within 6%
12.0	within 7%
15.0	within 9%

*20 Degrees Celsius × 60years (S_1=35)

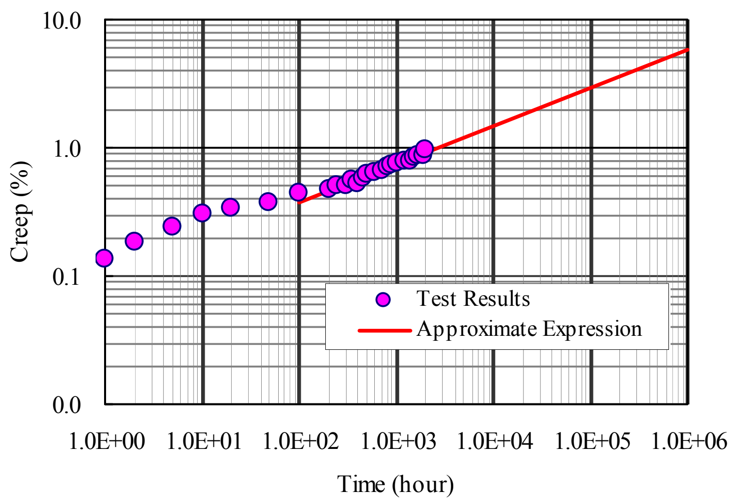


Figure-1C Creep Properties of HDR-X0.6R

Annex-D
Frequency Dependency of Restoring Force Characteristics

The characteristics of HDR such as shear modulus and equivalent damping ratio depend on testing frequencies. Shear modulus and equivalent damping ratio of high-damping rubber bearings show a tendency to become harder as frequency becomes higher.
Following figure shows the test results by the scaled model specimen, which show the relationship between test frequency and characteristics of high-damping rubber bearings.

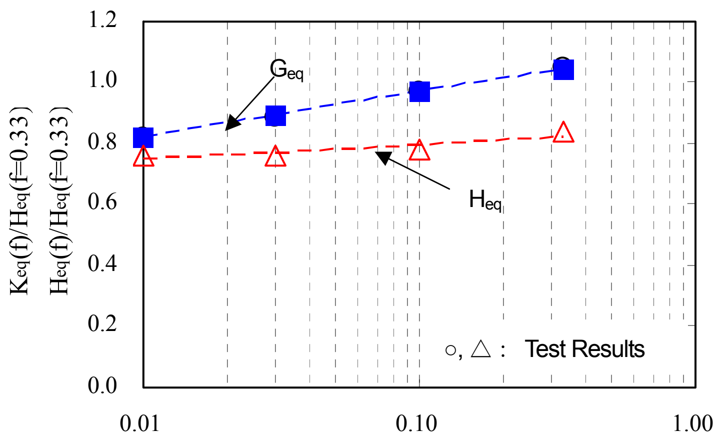


Figure-1D Frequency dependency of HDR-X0.6R
(G_{eq}=0.62, 225-1.6×35, S_1=35, S_2=5.0)

Velocity (frequency) correction factor for Shear stiffness 'K_{eq}' and equivalent damping ratio 'H_{eq}' is computed by following equation.

For Shear Stiffness: $$a_\kappa = \frac{1}{a_\kappa \log(f) + b_k} \quad \text{(1D)}$$

For Equivalent damping ratio: $$a_h = \frac{1}{a_h \log(f) + b_h} \quad \text{(2D)}$$

Loading Frequency: $$f = \frac{1}{4 \cdot \delta_H \cdot 60/v} \quad \text{(3D)}$$

where, a_k and a_h is correction factor for Shear stiffness 'K_{eq}' and equivalent damping ratio 'H_{eq}', f is loading frequency, δ_H is loading displacement (=displacement of 1cycl loading=4*δ_H) and v is loading velocity of the test. The value for a_k, b_k, a_h and b_h are shown in Table 1C, which is according to test results by the scaled model specimen.

Table-1D Velocity Correction Factor for Compound X0.6R

Compound	Nominal Frequency	a_k	b_k	a_h	b_h
X0.6R	0.33Hz	0.151	1.12	0.0497	0.846

Annex-E
Shear Strain Dependency of Restoring Force Characteristics

Restoring force performance of high-damping rubber bearings show nonlinear behavior and its shear modulus becomes harder at the area of less than 100% of shear strain.
On the other hand, to compare with shear strain dependency of shear modulus and equivalent damping ratio of high-damping rubber bearings, the dependency of shear strain amplitude to equivalent damping ratio is smaller than shear modulus.

Following figure shows the test results by the scaled model specimen, which show the relationship between test shear strain amplitude and characteristics of high-damping rubber bearings.

Here, in the figure, dotted lines show the design formula of high-damping rubber bearing which shown in Table-7 on page 5.

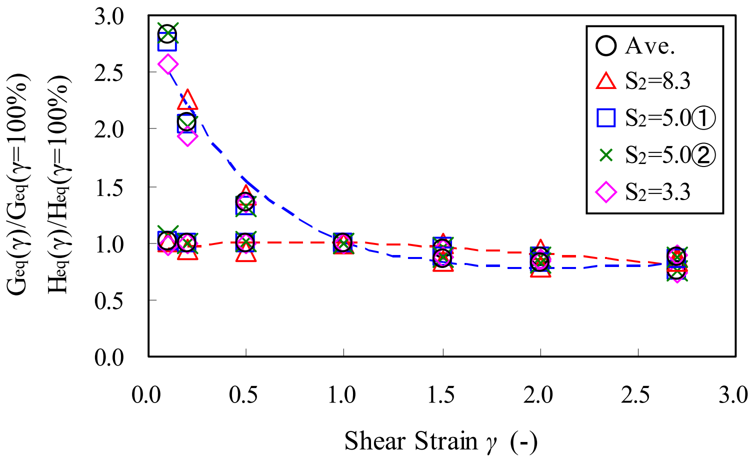


Figure-1E Shear strain dependency of restoring force performance of HDR-X0.6

Annex-F
Tensile Fracture Strength

Tensile stiffness (tensile stress and tensile strain relationship) of high-damping rubber bearings show linear behavior when tensile stress is smaller than 1 N/mm^2.
Therefore, as long as tensile stress becomes larger than 1 N/mm^2, tensile restoring force performance of high-damping rubber bearing changes dramatically and tensile stiffness starts to show nonlinear behavior and also tensile strain shows a sharp increase with yielding of tensile rubber strength.
(Yielding of tensile rubber strength arise from voids of inner rubber which arise from a tensile stress.)

Table-1F Relationship between tensile yield stress and shear strain

Characteristics				Shear strain (%)		
Compound	Outer Dia.	S_1	S_2	0	100	200
X0.6R	800	36	4	-	1.9	1.4
	600	36	3	-	1.4	-

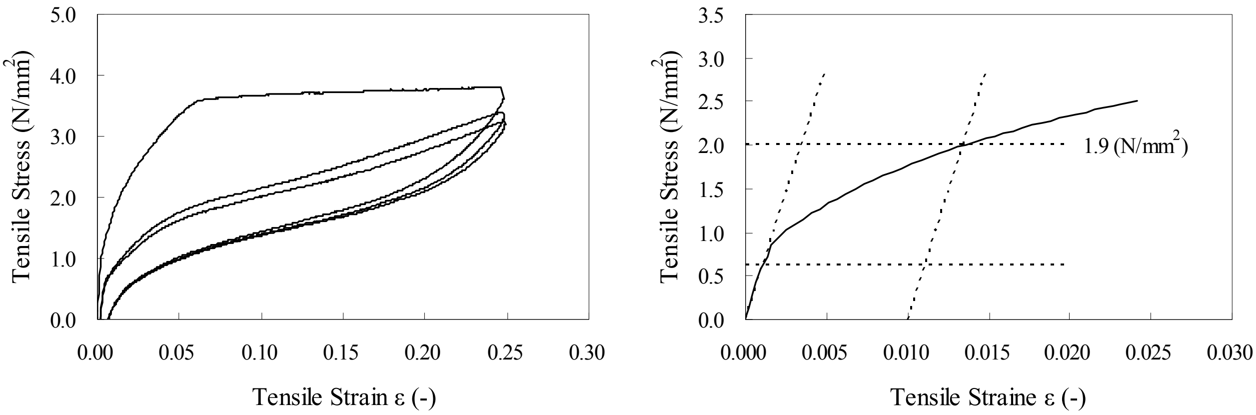


Figure-1F Tensile performance of HDR-X0.6 at γ=100%
G=0.62, φ800-5.4×37, (S_1=36, S_2=4.0)

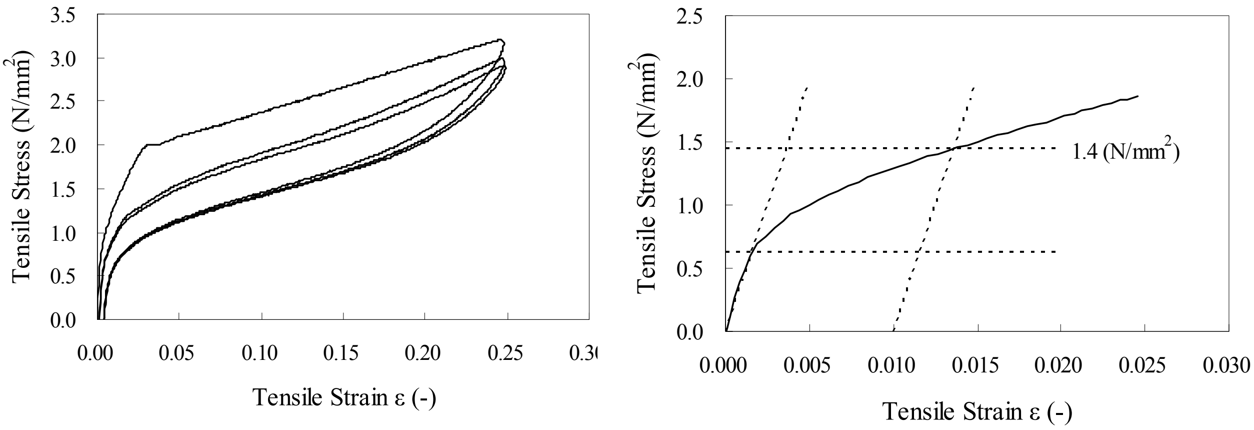


Figure-2F Tensile performance of HDR-X0.6 at γ=200%
G=0.62, φ800-5.4×37, (S_1=36, S_2=4.0)

Annex-G

Repeated Loading Dependency of Restoring Force Characteristics

The characteristics of HDR such as shear modulus and equivalent damping ratio show a tendency to become smaller under continuous repeated shear loading.
Figure and Table show the test results by the scaled model specimen, which conducted under following conditions.

(1) The test vibration frequency: 0.33(Hz).
(2) The shear strain amplitude: γ=250(%)
(3) The repeated loading number: 100(cycle)
(4) The reference cycle: 3rd (cycle)

Table-1G Test Results- Change Rate from reference cycle (at 100cycle)

Period	K_{eq}	H_{eq}	ΔW
1	1.121	1.040	1.165
3	1.000	1.000	1.000
10	0.909	1.034	0.940
20	0.855	0.996	0.851
50	0.790	0.878	0.693
100	0.750	0.782	0.587

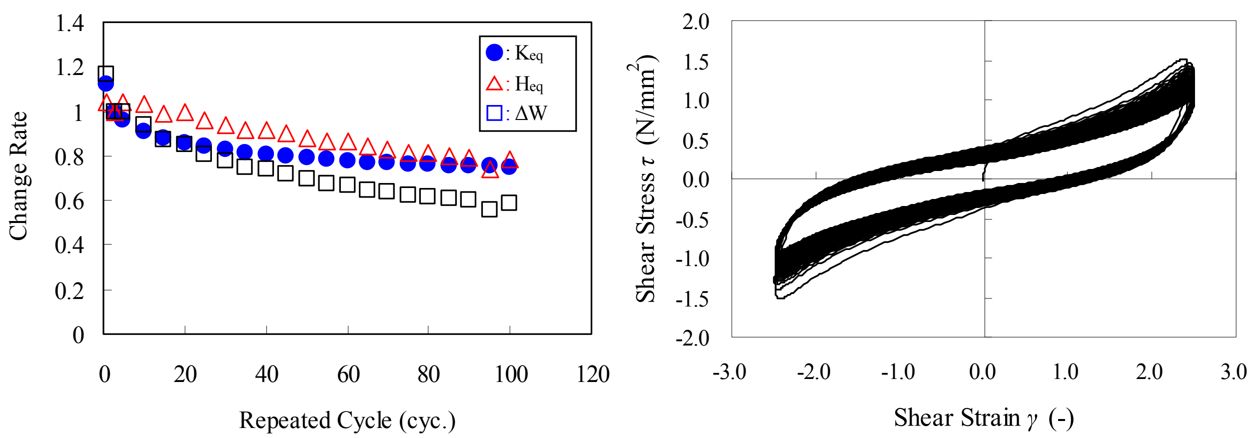
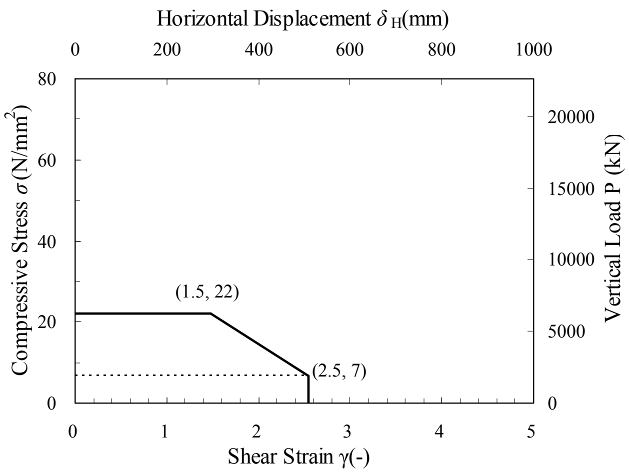


Figure-1G Repeated loading dependency of restoring force performance of HDR-X0.6
G=0.62, φ225 (S_1=35.1, S_2=5.0)

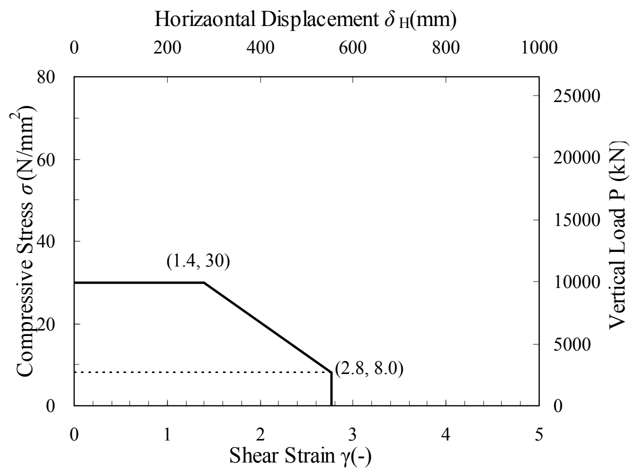
Annex-H Ultimate Property Diagram

The relationship of shear strain and compressive stress amplitude of standard isolators are as shown as follows. Ultimate property of each standard isolator is determined by the Ultimate Property Diagram (UPD) as shown in Figure-8 (page10). Here, the dotted line shows a nominal stress of each isolator.

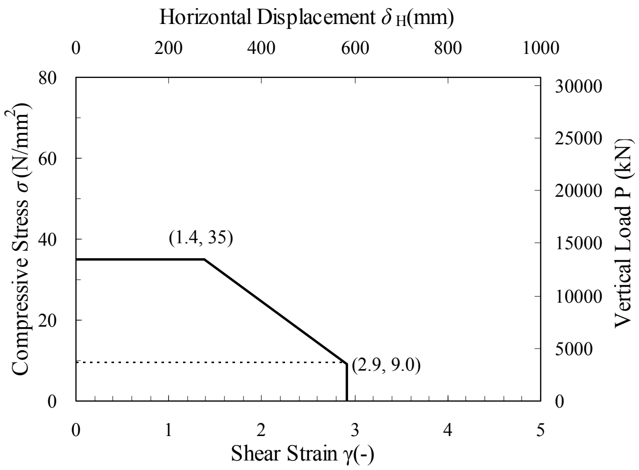
□HH-Series (Total Rubber Thickness: 200mm)



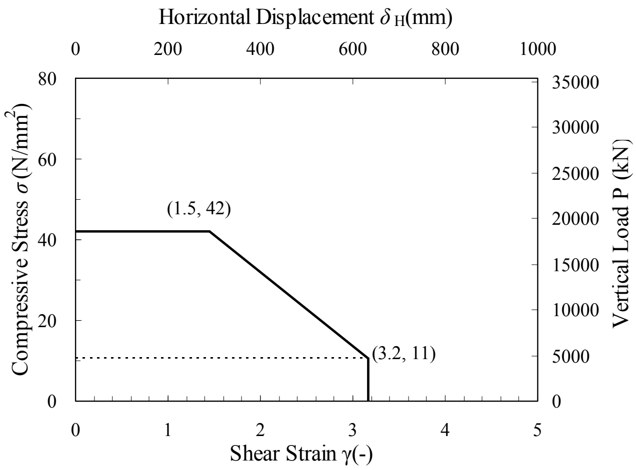
HH060X6R:G_{eq}=0.62(N/mm^2), S_1=36.6, S_2=3.0



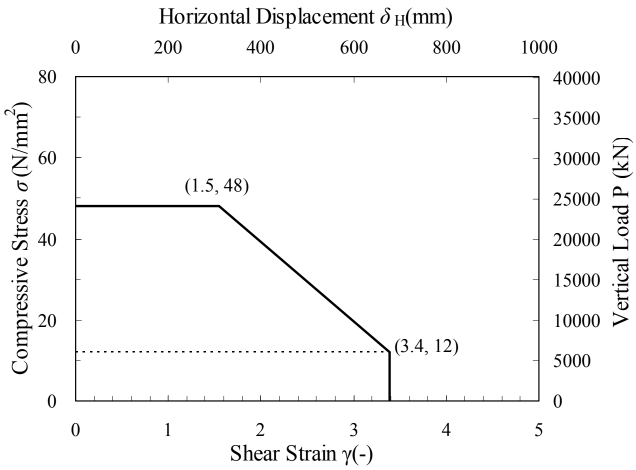
HH065X6R:G_{eq}=0.62(N/mm^2), S_1=36.1, S_2=3.3



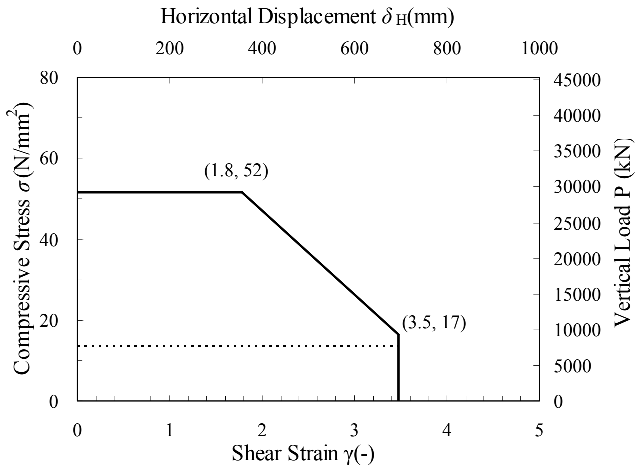
HH070X6R:G_{eq}=0.62(N/mm^2), S_1=36.4, S_2=3.5



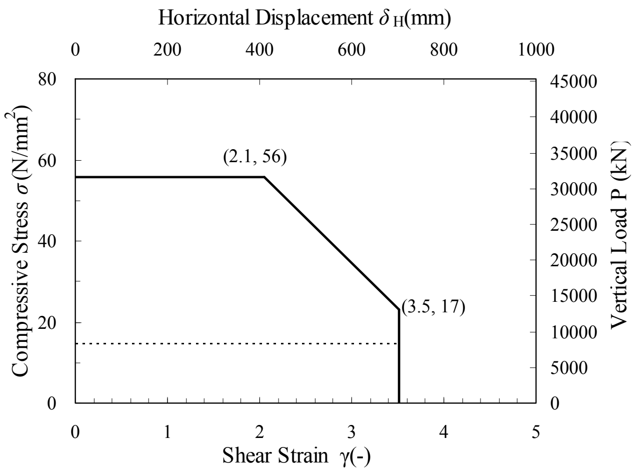
HH075X6R:G_{eq}=0.62(N/mm^2), S_1=36.8, S_2=3.8



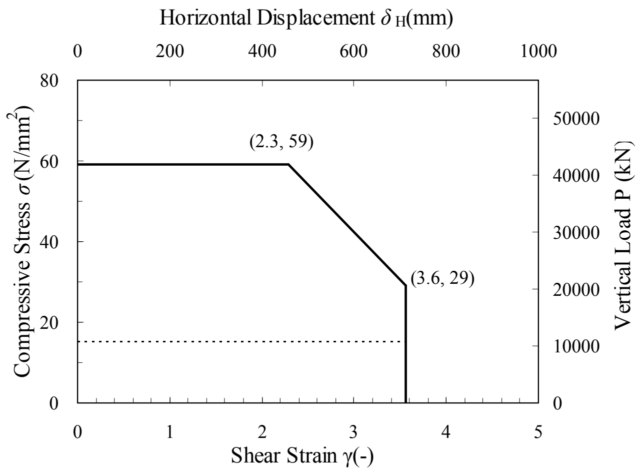
HH080X6R:G_{eq}=0.62(N/mm^2), S_1=36.1, S_2=4.0



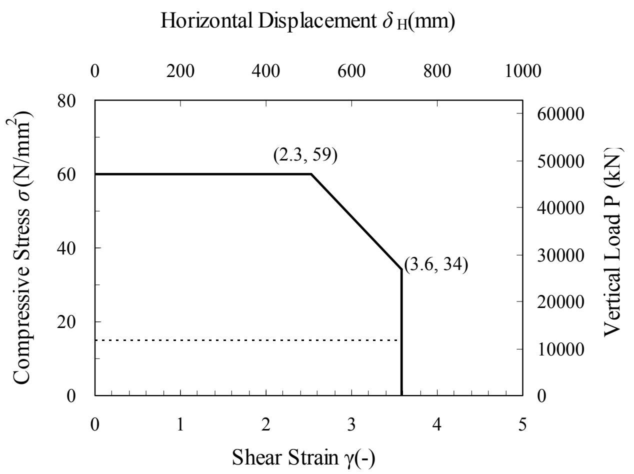
HH085X6R:G_{eq}=0.62(N/mm^2), S_1=36.4, S_2=4.3



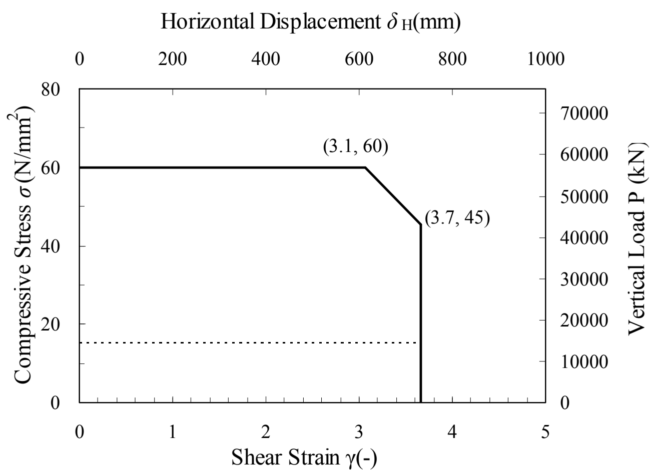
HH090X6R:G_{eq}=0.62(N/mm^2), S_1=36.7, S_2=4.6



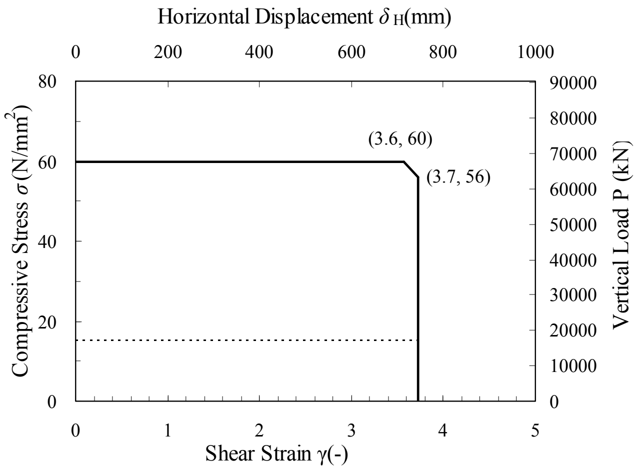
HH095X6R:G_{eq}=0.62(N/mm^2), S_1=36.3, S_2=4.8



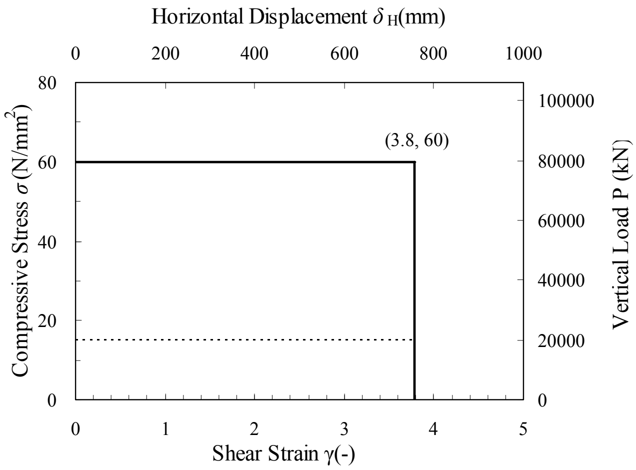
HH100X6R:G_{eq}=0.62(N/mm^2), S_1=36.4, S_2=5.0



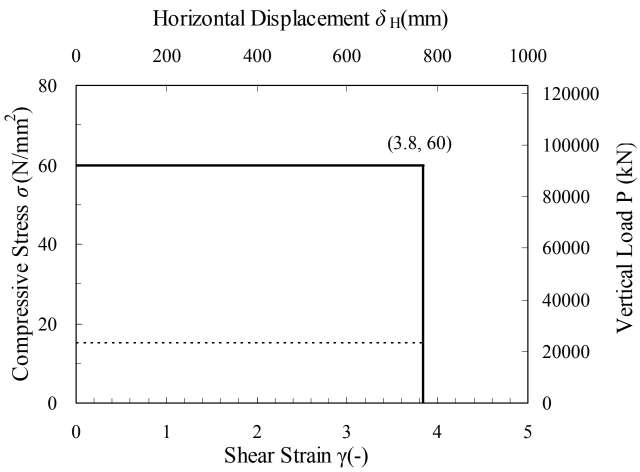
HH110X6R:G_{eq}=0.62(N/mm^2), S_1=35.3, S_2=5.5



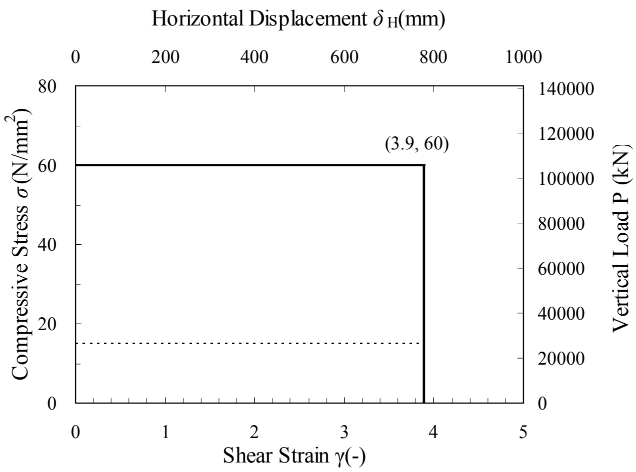
HH120X6R:G_{eq}=0.62(N/mm^2), S_1=35.8, S_2=6.0



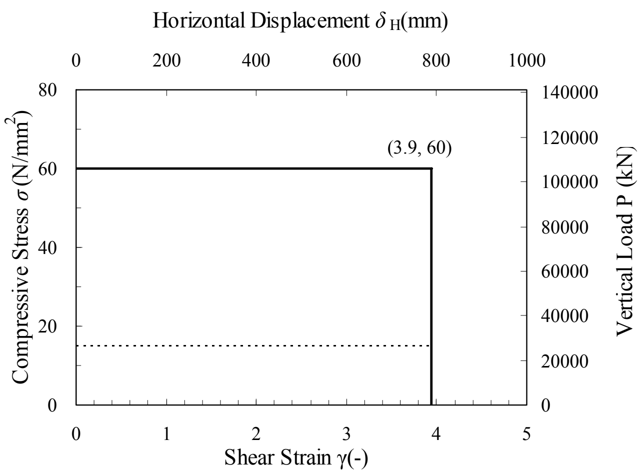
HH130X6R:G_{eq}=0.62(N/mm^2), S_1=35.8, S_2=6.5



HH140X6R:G_{eq}=0.62(N/mm^2), S_1=35.1, S_2=7.0

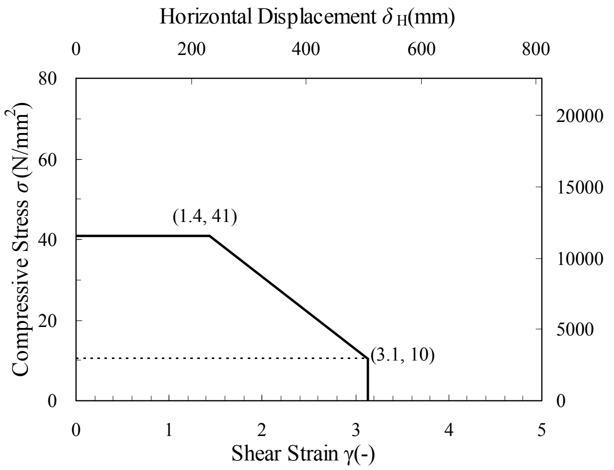


HH150X6R:G_{eq}=0.62(N/mm^2), S_1=35.9, S_2=7.5

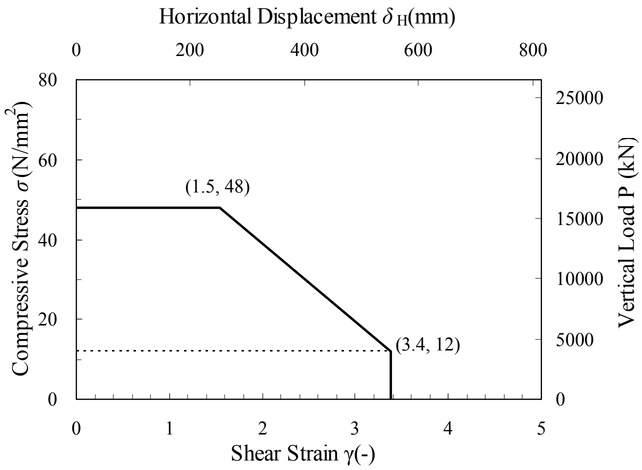


HH160X6R:G_{eq}=0.62(N/mm^2), S_1=36.5, S_2=8.1

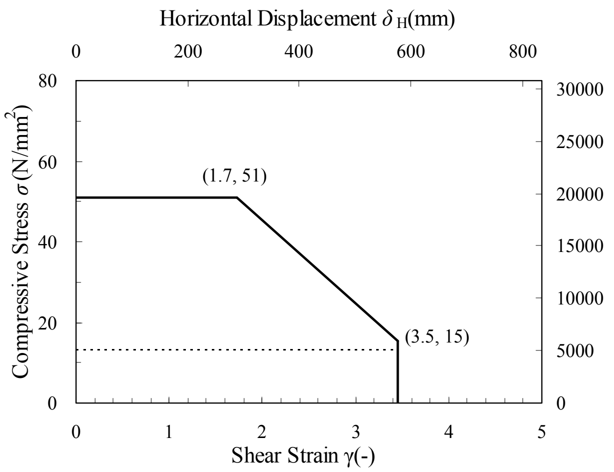
□HL-Series (Total Rubber Thickness: 160mm)



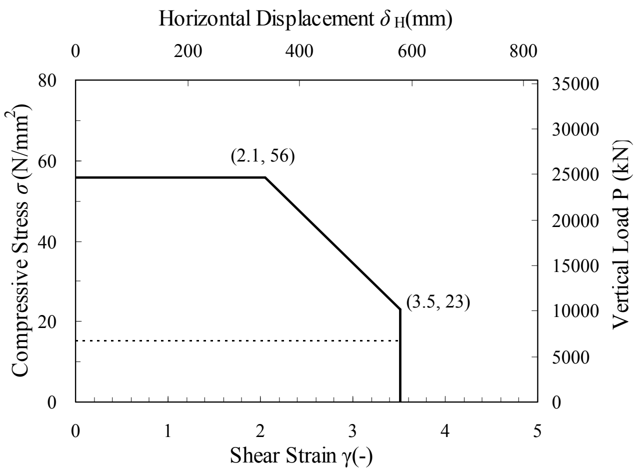
HL060X6R:G_{eq}=0.62(N/mm^2), S_1=37.0, S_2=3.7



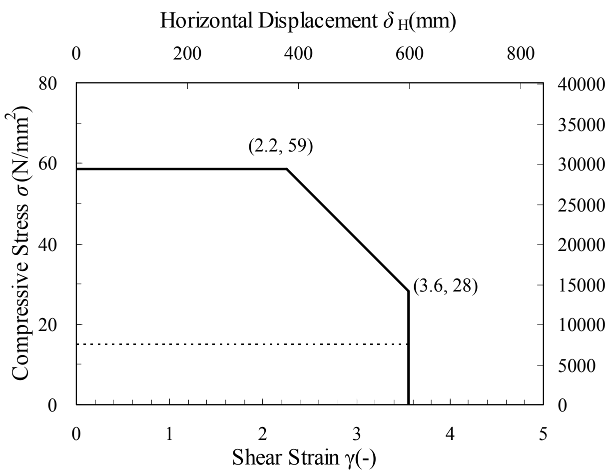
HL065X6R:G_{eq}=0.62(N/mm^2), S_1=36.1, S_2=4.0



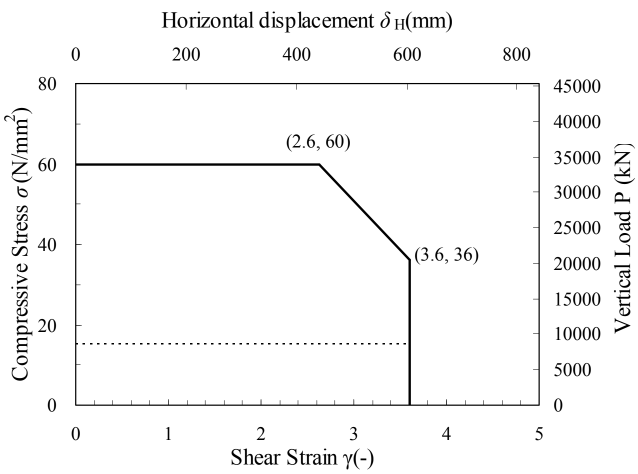
HL070X6R:G_{eq}=0.62(N/mm^2), S_1=34.9, S_2=4.2



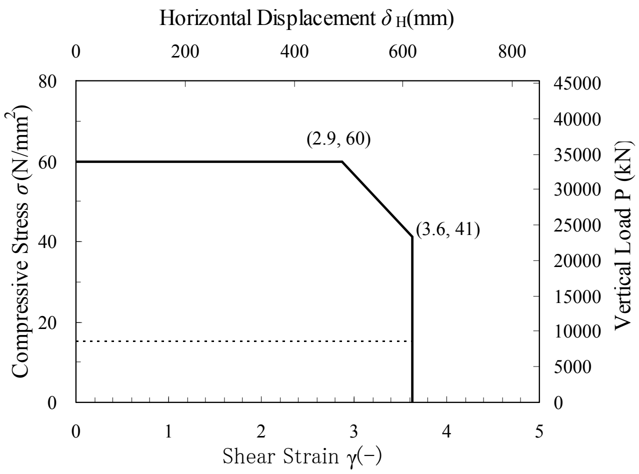
HL075X6R:G_{eq}=0.62(N/mm^2), S_1=37.9, S_2=4.6



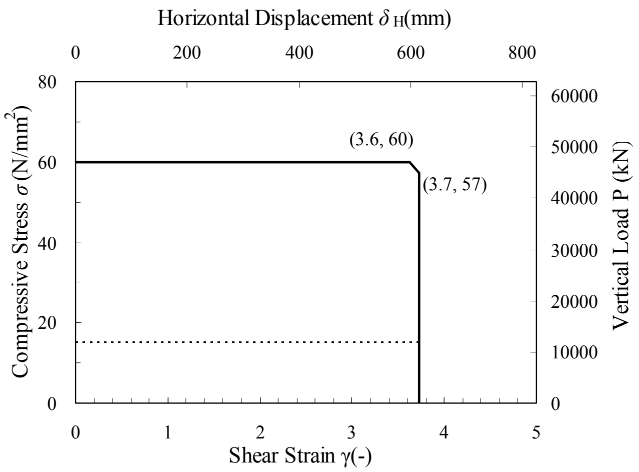
HL080X6R:G_{eq}=0.62(N/mm^2), S_1=38.2, S_2=4.75



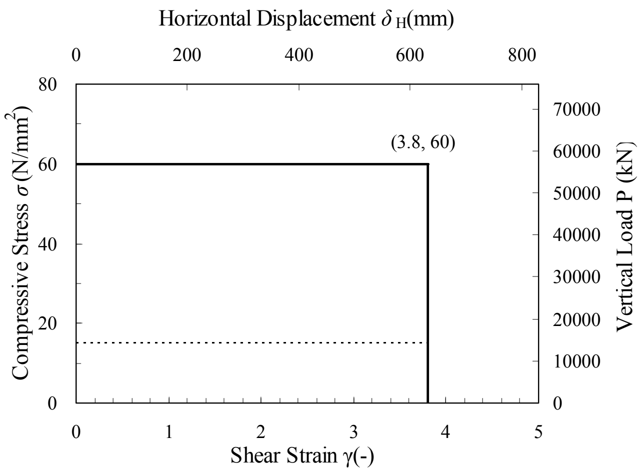
HL085X6R:G_{eq}=0.62(N/mm^2), S_1=39.5, S_2=5.1



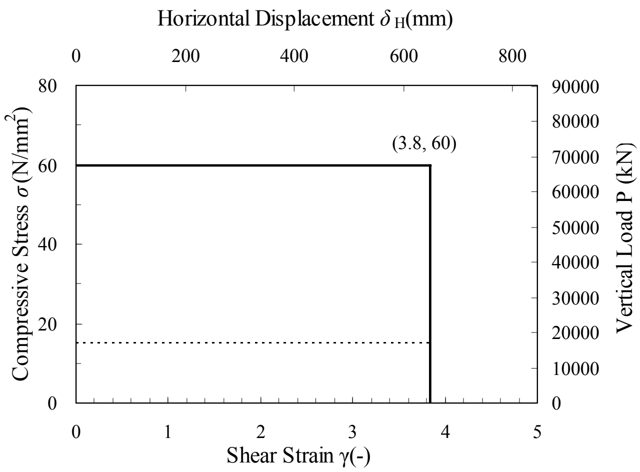
HL090X6R:G_{eq}=0.62(N/mm^2), S_1=38.9, S_2=5.3



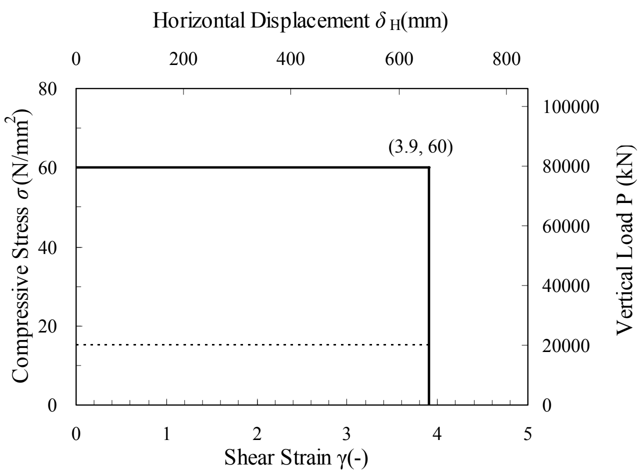
HL100X6R:G_{eq}=0.62(N/mm^2), S_1=38.4 S_2=6.1



HL110X6R:G_{eq}=0.62(N/mm^2), S_1=36.3, S_2=6.6

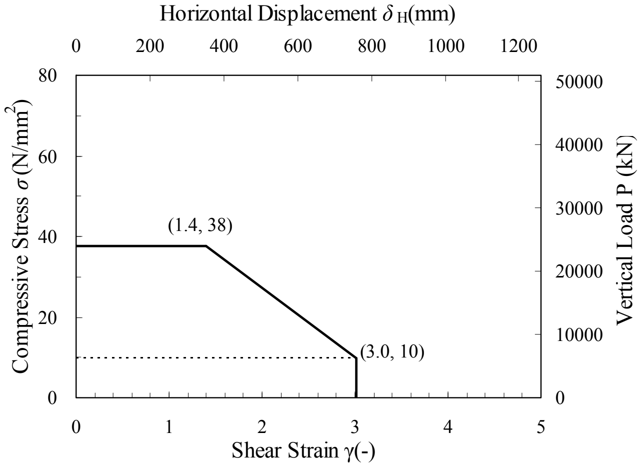


HL120X6R:G_{eq}=0.62(N/mm^2), S_1=37.2, S_2=7.08

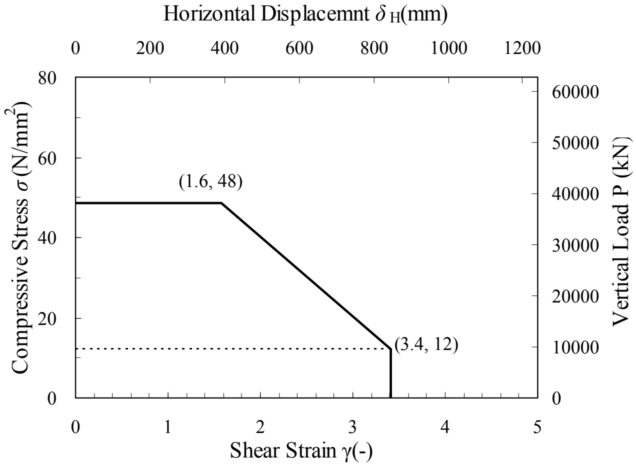


HL130X6R:G_{eq}=0.62(N/mm^2), S_1=38.9, S_2=7.7

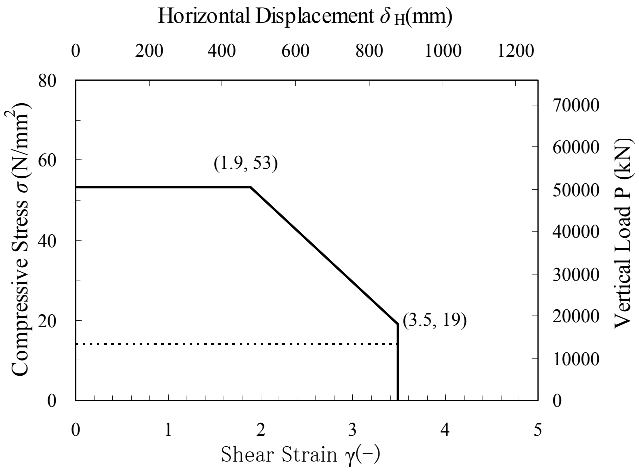
□HT-Series(Total Rubber Thickness: 250mm)



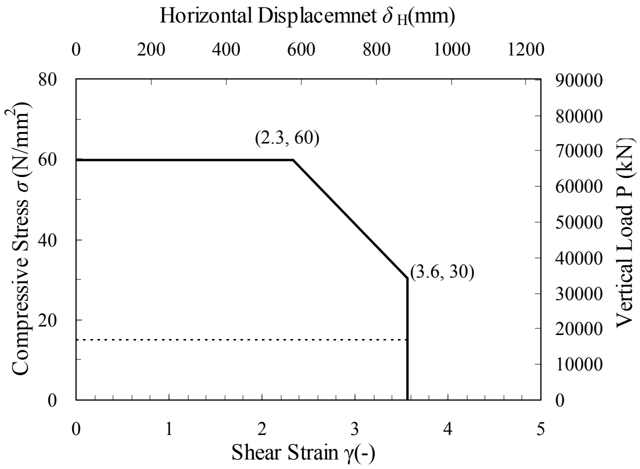
HT090X6R:G_{eq}=0.62(N/mm^2), S_1=36.7, S_2=3.6



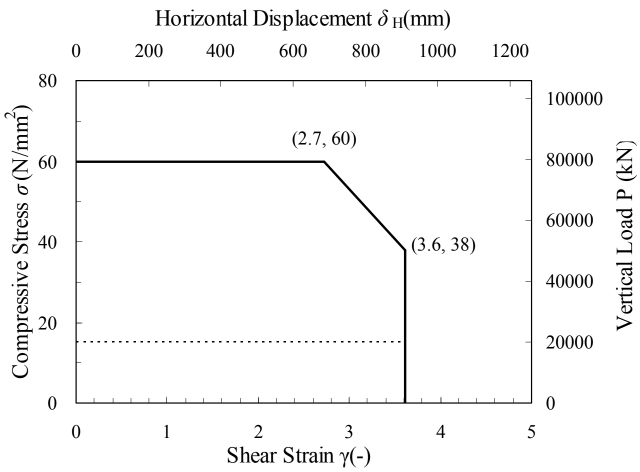
HT100X6R:G_{eq}=0.62(N/mm^2), S_1=36.4, S_2=4.0



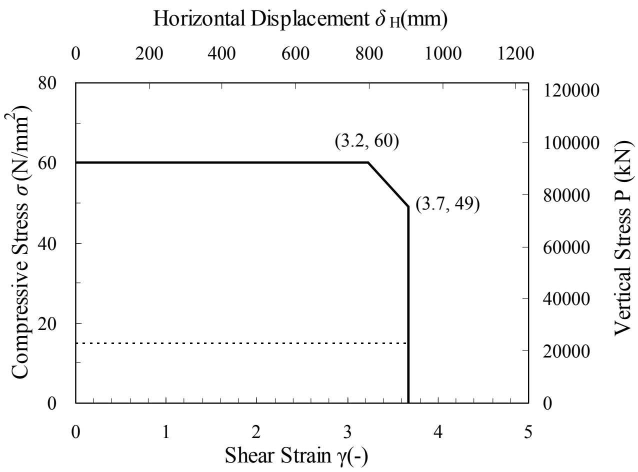
HT110X6R:G_{eq}=0.62(N/mm^2), S_1=35.3, S_2=4.4



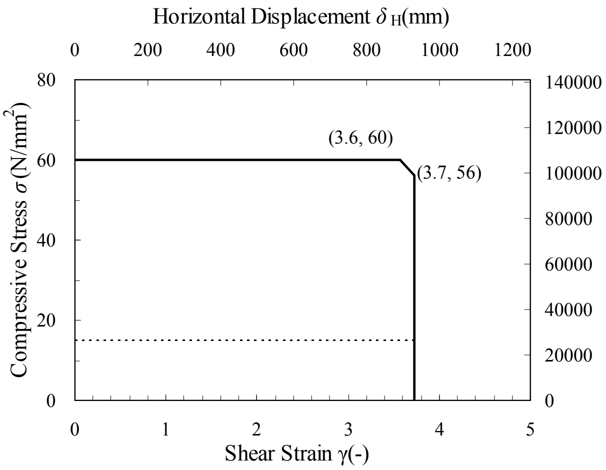
HT120X6R:G_{eq}=0.62(N/mm^2), S_1=35.8, S_2=4.8



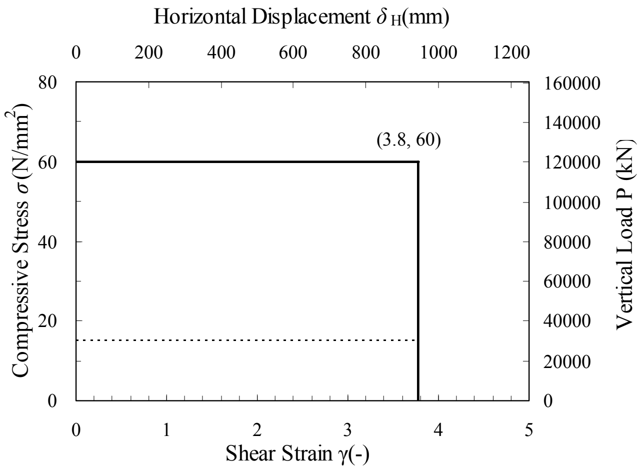
HT130X6R:G_{eq}=0.62(N/mm^2), S_1=35.8, S_2=5.2



HT140X6R:G_{eq}=0.62(N/mm^2), S_1=35.1, S_2=5.7



HT150X6R:G_{eq}=0.62(N/mm^2), S_1=35.9, S_2=6.0



HT160X6R:G_{eq}=0.62(N/mm^2), S_1=36.5, S_2=6.4

Annex-I

Compressive Stress Dependency of Restoring Force Characteristics

The Shear modulus of high-damping rubber bearings shows a tendency to become harder as compressive stress becomes larger. In contrast, the equivalent damping ratio of high-damping rubber bearings shows a tendency to decrease as compressive stress becomes larger.

These properties are deeply depends on their shapes, such as a first and secondly shape factors.
As shown in Table and Figure, the compressive dependencies of restoring force characteristics vary with shape factors. Hence, as long as the isolator has enough shape factors, an effect of compressive dependency becomes slightly and the isolator shows a stable performance.

Figure and Table show the test results, which conducted under following conditions.

(1)The shear strain amplitude: γ=100(%)
(2)The reference cycle: 3rd (cycle)

Table-1I Test Results- Compressive Stress Dependency of HDR (change ratio)

Construction of Isolators				Nominal Compressive Stress σ_s (N/mm^2)	Total Thickness of Rubber (mm)	Characteristics	Change Ratio		
Compound	Outer Dia.	S_1	S_2				$\sigma=0.5\sigma_s$	$\sigma=1.0\sigma_s$	$\sigma=2\sigma_s$
X0.6R	600(15)	36.6	3.0	6.6	200	K_{eq}	3.89%	0%	-4.39%
						H_{eq}	-2.30%	0%	12.6%
	800(20)	36.1	4.0	12.1	200	K_{eq}	2.13%	0%	-6.81%
						H_{eq}	-4.76%	0%	21.5%
	1200(55)	35.8	6.0	15.0	200	K_{eq}	-3.06%	0%	-8.47%
						H_{eq}	-10.5%	0%	11.6%

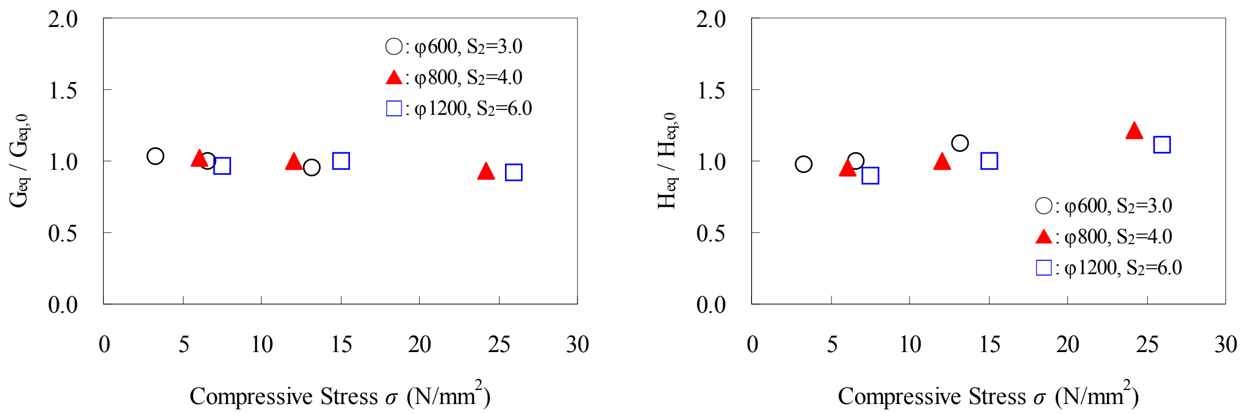


Figure-1I Test Results- Compressive Stress Dependency of HDR (change ratio)