Experimental research of service actions influence on elastomeric bearings elastic properties

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Abstract. The article includes results of shear test of rubber-metal seismic insulators (elastomers) for different service actions. Research shows influence of low temperatures, material aging and cyclic loads on horizontal stiffness and shear modulus of elastomers. Tests were carried out according to existing Russian and foreign regulatory documents. An insignificant decrease in elastic properties of elastomers is seen after aging and cyclic loading. Influence of low temperatures increases stiffness of elastomers by 23%.

1. Introduction
Seismic safety should be considered during the construction of buildings in areas with higher seismic activity. Special elastomeric bearings which provide seismic insulation [1-4] can be used in order to decrease seismic actions on buildings [5]. This article covers experimental research of physical and mechanical properties of elastomeric bearings.

Article [6] discussed the issue of justification for use of elastomeric bearing as seismic insulators. Russian [7] and foreign regulatory documents (such as EN 1337-3 [8], AASHTO LRFD Bridge Design Specifications [9] and ISO 22762-1 [10]) were studied during this research.

Solving this issue led to development of verifiable design model of building which included behavior of elastomeric bearings [11]. Therefore, values of physical and mechanical properties of elastomeric bearings were experimentally acquired in order to use for calculation of load-bearing capacity, stability, strain behavior and forecast of building life cycle. Preliminary theoretic computation of building behavior during service defined load values and conditions for elastomeric bearings.

Real-size elastomeric bearing is 1000x1100 mm in plan size and 133 mm in thickness. Table 1 and figure 1 show its full structural composition.

| Table 1. Properties of real-size elastomeric bearings |
|------------------------------------------------------|
| Edge cover                                          | 5 mm     |
| Top and bottom cover                                 | 3.5 mm   |
| Number and thickness of middle rubber layers         | 6·7 mm   |
| Total thickness of elastomer                         | 6·7+2·3.5=49 mm |
| Number and thickness of reinforcing steel plates     | 7·2 mm   |
| Top and bottom steel plates thickness                | 35 mm    |
| Elastomeric bearings height                          | 49+7·2+2·35=63+70=133 mm |
Loads that imitate different service actions which should be applied during tests to real-size specimens or to model specimens with a linear-sizes decrease scale factor of two [7] are rather high. Available laboratory equipment does not always allow to simulate them. Taking this into account, tests were carried out on smaller-scale model specimens.

Comparative tests for definition of one main property of elastomeric bearing – horizontal stiffness – were carried out on real-size and smaller-scale model specimens to justify such approach and to verify values of physical and mechanical properties acquired on smaller-scale models [12]. Acquired results showed good convergency – divergence was less than 1.9%. Article [13] shows detailed description of these tests.

Materials discussed in article [13] were presented on IPICSE-2018 conference and caused questions about change of elastomeric bearing properties during building life cycle including issues of seasonal difference of temperature, material aging, its strength and correspondence of acquired properties with regulatory documents requirements.

This article includes test methods and results for model specimens. The purpose of this work was to define shear strength and to research influence of low temperatures, material aging and cyclic loads on elastic properties of seismic insulators. Tests were carried out in load and displacement ranges predetermined by service conditions.

2. Methods and materials

As it was stated before, horizontal stiffness $K_h$ and shear modulus $G$ of elastomeric bearings are the main properties for accurate building design. Their possible change over time because of seismic loads and temperature oscillations during service can influence stress-strain behavior of structures.

Horizontal stiffness $K_h$ of seismic insulators and corresponding shear modulus $G$ in initial condition were determined on 12 specimens with a size of 275x250x133 mm, which represent elastomeric bearing model in a scale of 1:4 in horizontal sizes and in a scale of 1:1 in vertical size. Specimens were tested for shear in a machine equipped with hydraulic jacks [13] according to GOST R 57364-2016 [7] and EN 1337-3 [8].

Loading of elastomeric bearing was performed according to GOST [7] until its displacement reached $\Delta_x = 30$ mm (design value at temperature change), $\Delta_x = 40$ mm (design value at seismic action) and $\Delta_x = 60$ mm (exceeds maximum design value by 1.5).

Specimens were subjected to shear (in combination with compression load of $F_y = 37,5$ kN, which corresponds with design load on bearing of $F_y = 600$ kN) with a constant loading speed of 0,5 mm/s at temperature of 23±1°C. Each loading stage had displacement step of $\Delta = 10$ mm and 10 s hold at each stage. Displacement measurement was done using indicators with a measuring sensitivity of $c = 0,01$ mm.

Research of low temperatures influence on elastic properties of elastomers was carried out on specimens with a size of 275x250x133 mm. Specimens were cooled in a thermal chamber at a temperature of -25°C for 7 days. Loading was performed at a temperature of 20°C. During tests temperature on the edge of the bearing did not exceed -18°C [8].
Specimens of the same size were contained for 3 days at a temperature of +70°C to simulate aging. Determination of shear modulus and horizontal stiffness after aging was carried out at a temperature of +23±1°C.

Same specimens were used to study influence of cyclic loading on shear modulus and horizontal stiffness of elastomeric bearing. Four hundred cycles of symmetric loading with displacement amplitude of $\Delta_x = \pm 30$ mm in combination with compression load of $F_y = 37.5$ kN were applied to the specimen.

Shear strength of elastomeric bearings was determined using specimens 51·51 mm in plan dimensions and 36 mm in thickness. Loading was done using test machine Instron 3382 (figure 2).

«Load-displacement» diagram was recorded during each of the tests. Horizontal stiffness $K_h$ was calculated using formula:

$$K_h = \frac{\Delta F_x}{\Delta x} \quad (1),$$

where $\Delta_x$ – elastomer displacement in a range from 0,27$T_q$ to 0,58$T_q$ [5,8]; $T_q$ – elastomer specimen thickness without steel plates; $\Delta F_x$ – load change corresponding with displacement $\Delta_x$.

Shear modulus $G$ was calculated using formula:

$$G = \frac{K_q T_q}{A} \quad (2),$$

where $A$ – specimen area.
3. Test results
Figure 3 shows «Load-displacement» diagram for shear test till specimen fracture. Table 2 shows results of this test.

Table 2. Stress-strain behavior of elastomeric bearing during shear tests

| Fracture load $F_p$, kN | Shear strength $R$, MPa | Displacement at fracture load $\Delta_{\text{max}}$, mm | Relative displacement at fracture load $\gamma_p$, % | Relative displacement at $\Delta_x=60$ mm, % | Shear stress at $\Delta_x=60$ mm, MPa |
|------------------------|-------------------------|----------------------------------------|----------------|----------------------------|-------------------------|
| 23,23                  | 4.46                    | 103.75                                 | 288            | 122                        | 1.16                    |

![Figure 3. «Load-displacement» diagram for shear tests](image)

Figures 4 and 5 show «Load-displacement» diagram for definition of elastomeric bearing horizontal stiffness in initial condition at the third loading cycle with displacement amplitude $\Delta_x = 30$ mm and $\Delta_x = 40$ mm accordingly. Figure 6 shows «Load-displacement» diagram with elastomer displacement of $\Delta_x = 60$ mm which is 1.5 higher than maximum design value.

![Figure 4. «Load-displacement» diagram with displacement amplitude of 30 mm](image)
Figure 5. «Load-displacement» diagram with displacement amplitude of 40 mm

Figure 6. «Load-displacement» diagram with elastomer displacement of 60 mm

Table 3 shows values of horizontal stiffness and shear modulus for six pairs of elastomer specimens in initial condition. Tables 4, 5 and 6 show change of horizontal stiffness initial value after aging, cyclic loading and low temperature action accordingly.

| Table 3. Values of horizontal stiffness and shear modulus for elastomeric bearing in initial condition |
|---|---|---|---|---|---|---|---|---|
| Displacement Δ, mm | Elastomer property | 1+2 | 3+4 | 5+6 | 7+8 | 9+10 | 11+12 | Mean value | Variation coefficient |
| 30 | $K_h$, kN/m·10$^3$ | 1.38 | 1.43 | 1.36 | 1.42 | 1.33 | 1.45 | 1.40 |
| | G, MPa | 0.98 | 1.02 | 0.97 | 1.01 | 0.95 | 1.04 | 1.00 |
| 40 | $K_h$, kN/m·10$^3$ | 1.39 | 1.50 | 1.37 | 1.42 | 1.35 | 1.47 | 1.42 |
| | G, MPa | 0.99 | 1.08 | 0.98 | 1.01 | 0.97 | 1.04 | 1.01 |
| 60 | $K_h$, kN/m·10$^3$ | 1.53 | 1.41 | 1.49 | 1.45 | 1.42 | 1.45 | 1.46 |
| | G, MPa | 1.09 | 1.01 | 1.06 | 1.04 | 1.01 | 1.04 | 1.04 |

$K_h$, kN/m·10$^3$ 1.43 1.45 1.41 1.43 1.37 1.46 1.43 2.25%
Table 4. Change of horizontal stiffness and shear modulus values after aging of elastomeric bearing

| Displacement Δ, mm | Elastomer property | Initial condition | After aging | Property change, % |
|--------------------|-------------------|------------------|-------------|-------------------|
|                    | K_h, kN/m·10^{-3} |                  |             |                   |
| 30                 |                   | 1+2 5+6          | 1+2 5+6    | 0.0/-2.2          |
|                    | G, MPa            | 0.98 0.97        | 0.98 0.95  | 0.0/-2.1          |
| 40                 |                   | 1+2 5+6          | 1+2 5+6    | 0.0/-5.1          |
|                    | G, MPa            | 0.99 0.99        | 0.99 0.93  | 0.0/-5.1          |
| 60                 |                   | 1+2 5+6          | 1+2 5+6    | -3.9/-0.7         |
|                    | K_s, kN/m·10^{-3} |                  |             |                   |
|                    | G, MPa            | 1.09 1.06        | 1.05 1.05  | -3.7/-0.9         |

Table 5. Change of horizontal stiffness and shear modulus values after cyclic load action

| Displacement Δ, mm | Elastomer property | Initial condition | After cyclic loading | Property change, % |
|--------------------|-------------------|------------------|----------------------|-------------------|
|                    | K_h, kN/m·10^{-3} |                  |                      |                   |
| 30                 |                   | 9+10 11+12       | 9+10 11+12           | -7.5/-14.5        |
|                    | G, MPa            | 0.95 1.04        | 0.88 0.89            | -7.4/-14.4        |
| 40                 |                   | 9+10 11+12       | 9+10 11+12           | -8.1/-14.3        |
|                    | G, MPa            | 0.97 1.04        | 0.89 0.89            | -8.2/-14.4        |
| 60                 |                   | 9+10 11+12       | 9+10 11+12           | -11.3/-9.6        |
|                    | G, MPa            | 1.01 1.04        | 0.89 0.94            | -11.8/-9.6        |

Table 6. Change of horizontal stiffness and shear modulus values after low temperatures action

| Displacement Δ, mm | Elastomer property | Initial condition | After low temperatures | Property change, % |
|--------------------|-------------------|------------------|------------------------|-------------------|
|                    | K_h, kN/m·10^{-3} |                  |                        |                   |
| 30                 |                   | 3+4 7+8          | 3+4 7+8                | +4.9/+11.3        |
|                    | G, MPa            | 1.43 1.50        | 1.50 1.58              | +4.0/+11.2        |
| 40                 |                   | 3+4 7+8          | 3+4 7+8                | +4.7/+11.3        |
|                    | G, MPa            | 1.50 1.57        | 1.58 1.58              | +4.6/+10.9        |
| 60                 |                   | 3+4 7+8          | 3+4 7+8                | +19.9/+22.8       |
|                    | G, MPa            | 1.41 1.69        | 1.78 1.27              | +19.8/+22.1       |

4. Discussion

Table 2 shows strength and relative displacements of elastomeric bearing at fracture. Maximum values of stress corresponding to maximum design displacement of Δ_s=60 mm equals 1.16 MPa while the strength of specimen is R=4.46 MPa. Maximum relative displacement at the same load level is 122% which twice as less as relative displacement value at fracture.

Results presented in table 3 show that values of horizontal stiffness and shear modulus vary in the range of K_h = 1,33·10^3 – 1,53·10^3 kN/m; G = 0.97 – 1.09 MPa. Maximum difference in values of obtained properties was approximately 11% with variation coefficient of v = 2.3%. Obtained values of shear modulus meet the requirements of EN 1337-3-2005 and GOST R 57364-2016 (0.7 ≤ G ≤ 1.1 MPa).

Table 4 shows horizontal stiffness and shear modulus values change after aging. An insignificant decrease in acquired properties is seen. Maximum decrease was 5.1% which is less than admissible value by the requirements of GOST R 57364-2016 (5.1% < 20%).

Displacement amplitude during cyclic loading and number of cycles were Δ_s = ±30 mm and 400 cycles accordingly. Admissible change of horizontal stiffness and shear modulus is 30% according to GOST R 57364-2016. Decrease of 14.4% in initial values of elastomers elastic properties (K_h and G) was seen after cyclic action (table 5).

The most significant change of horizontal stiffness and shear modulus values was seen after low temperatures action. Table 6 shows that cooling of specimens in thermal chamber at a temperature of -25°C for 7 days led to increase of 22.8% in elastic properties at displacement of Δ_s = 60 mm. Horizontal stiffness increase at displacements of Δ_s = 30 mm and Δ_s = 40 mm did not exceed 11.5%.
Admissible increase of $K_h$ and $G$ after low temperatures action should not exceed 80% according to GOST R 57364-2016.

5. Conclusions
Initial horizontal stiffness $K_h$ and shear modulus $G$ of 12 elastomeric bearings at displacement of $\Delta_x = 30$ mm, $\Delta_x = 40$ mm and $\Delta_x = 60$ mm changed in a range of $K_h = 1,33 \times 10^3 - 1,53 \times 10^3$ kN/m; $G = 0,97 - 1,09$ MPa. Acquired values of elastic properties of elastomeric bearings correspond with requirements of EN 1337-3-2005 [8] and GOST R 57364-2016 [7], where $0,7 < G \leq 1,1$ MPa and a minimal admissible $K_h = 1,25 \times 10^3$ kN/m.

Horizontal stiffness and shear modulus of elastomeric bearing after cyclic loading and aging decreased by 3.9–11.8% in comparison with initial values. Increase in elastic properties after action of low temperatures was up to 23%. Change of required properties did not exceed admissible values according to GOST R 57364-2016.

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