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Testing of rubber bearings for the dynamic damper of seismic isolated buildings

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Abstract. The paper describes the testing facilities and the methodology on testing of laminated rubber bearings envisaged for application in the system of Dynamic Damper (DD) of seismic isolated buildings, as well as the obtained results. For the first time in Armenia laminated rubber bearings were tested simultaneously under the action of horizontal shear force and vertical tension force. The test results have proven the possibility of using rubber bearings as elements subjected to tension due to action of the mass of DD. Also it was confirmed that the suggested structural concept of DD for reducing the displacements and shear forces of seismic isolation systems will have reliable behavior during the design level earthquakes.

Keywords: seismic isolation; dynamic damper; testing; rubber bearing; shear; tension; modulus; stiffness; displacement.

1. Introduction

The concept of seismic isolation is currently widely accepted for protecting structures from earthquake ground motions, and there are now many applications of modern anti-seismic technologies in Armenia, Italy, Japan, New Zealand, the P.R. China, Russia, the United States and other countries. However, at the implementation of base isolation special attention should be given to the horizontal displacements of the whole isolation system and to their restriction (Naeim and Kelly 1999).

Different dampers have been designed and implemented along with high damping rubber bearings or lead-rubber bearings to reduce and control the horizontal displacements (Skinner, *et al*. 1993). Among them the steel-beam dampers (Takayama, *et al*. 1988, Parducci and Medeot 1987), lead-extrusion dampers (Robinson and Greenbank 1976), hydraulic dampers (Kaneko, *et al*. 1990) are well known. Every type of damper requires mechanical connectors and routine maintenance. Obviously this brings to the increasing of the cost of isolation system. The “life” of steel-beam dampers is limited by their fatigue characteristics on cycling. The extrusion dampers have a long life and their principle is simple but the design and manufacturing is not necessarily so.

The structural concept of the Dynamic Damper (DD) was suggested in the year 2000 for controlling and reducing the displacements of seismic isolation systems of buildings and structures (Melkumyan 2000). It was proposed to use the space under the pavement around the seismic isolated building for

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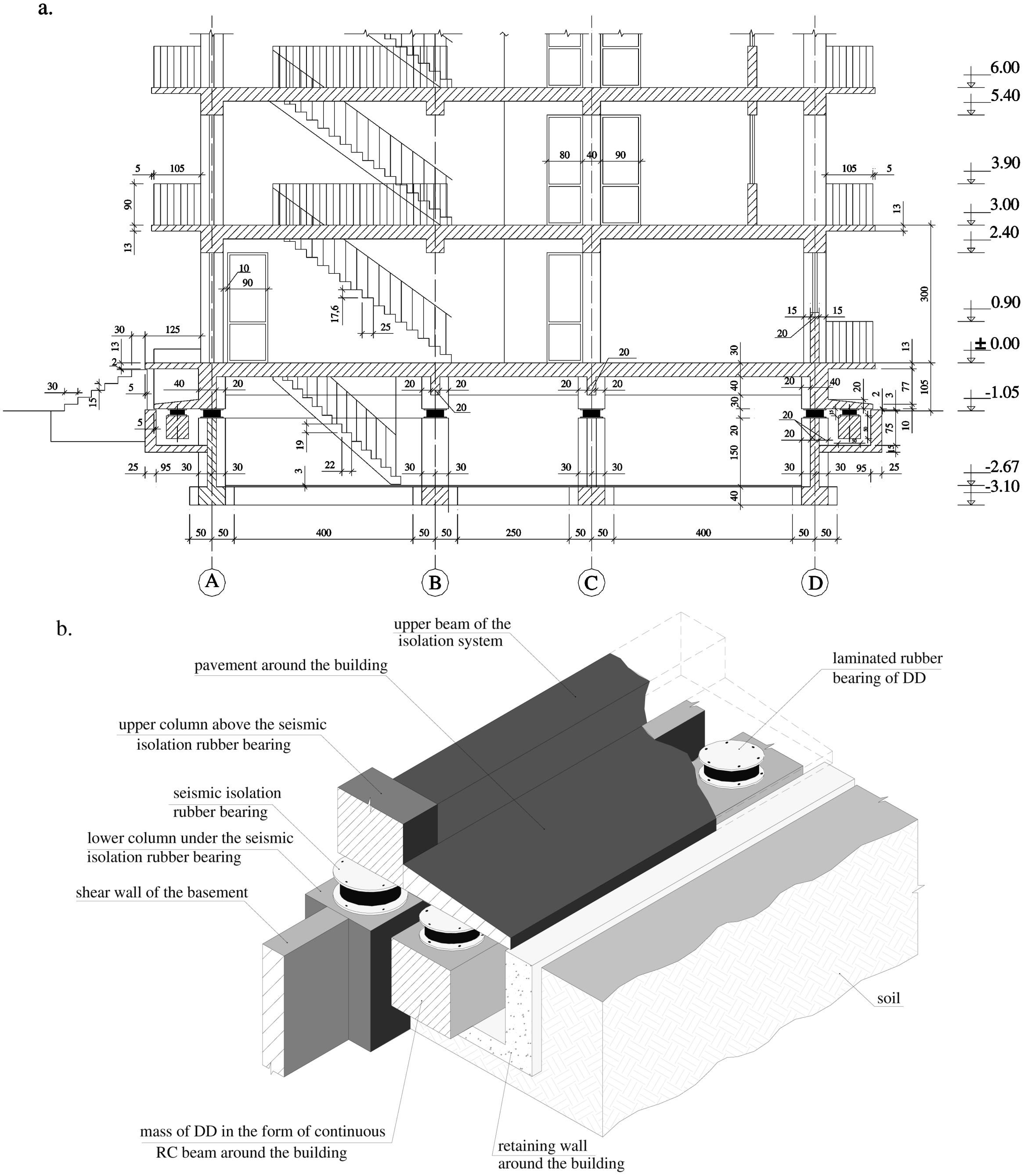

Fig. 1 Vertical elevation of the base isolated building with DD (a) and three-dimensional view of the seismic isolation system and the DD (b)

installation of the DD (Fig. 1a). The pavement was considered as a cantilever support to which the laminated rubber bearings of DD are connected with certain spacing around the whole perimeter of the

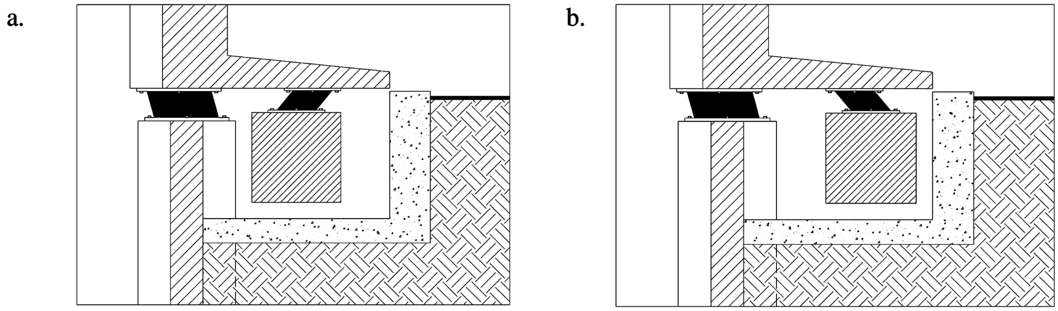

Fig. 2 DD oscillates in phase with the building (a) and in anti-phase with the building (b)

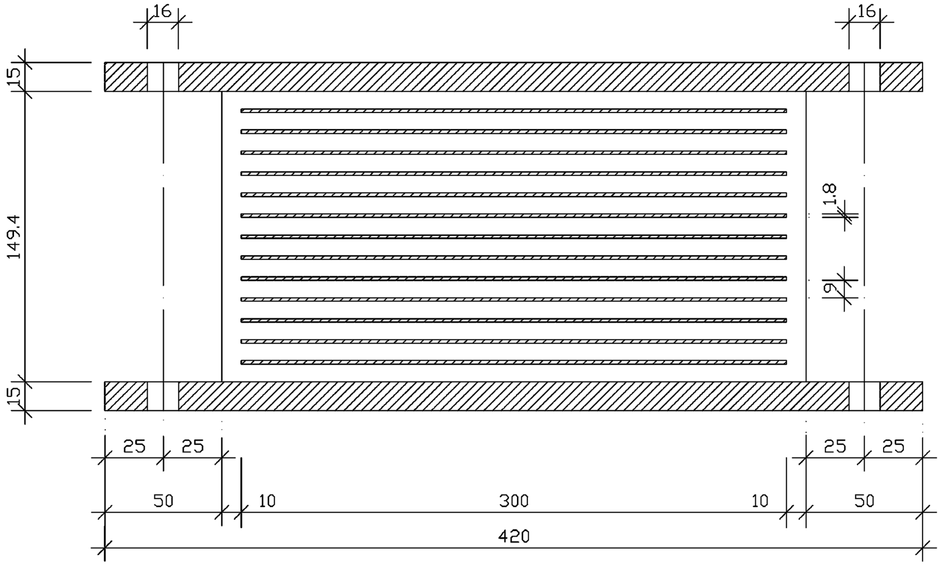

Fig. 3 The cross section of the laminated rubber bearing to be applied in the system of DD

building. The mass of DD in its turn is connected to the laminated rubber bearings and designed in the form of a continuous reinforced concrete (RC) beam also around the whole perimeter of the building (Fig. 1b).

It was suggested to choose the stiffness and the mass of DD so that the period of vibrations of DD be equal to the period of vibrations of the seismic isolated building. In this case the isolated building with DD will have two main modes of vibrations: the first one - when DD oscillates in the same phase with the building and the second one - when it oscillates in anti-phase with the building (Fig. 2). Exactly this second mode became prevailing, and due to this phenomenon reduction of horizontal displacements and forces takes place. It is obvious that the laminated rubber bearings of DD are subjected to the tension and shear forces during the seismic action.

Currently under the INTAS Ref. Nr. 03-51-5547 Project "Seismic Risk Mitigation for Schools and Hospitals Exploiting Smart Materials and Intelligent Systems" the DD was designed for application in a real construction. With this purpose a detailed design of the bolted type of laminated rubber bearing was also carried out. Its cross section is given on Fig. 3.

The rubber bearing consists of two flanges of diameter of 420 mm and thickness of 15 mm. By these flanges the rubber bearing can be connected to the cantilever pavement and to the RC continuous beam - the mass of DD. The bearing has 14 rubber layers of thickness of 9 mm and 13 steel layers of thickness of 1.8 mm. The diameter of bearing is 320 mm and the diameter of steel layers is 300 mm.

The laminated rubber bearings envisaged for the DD were manufactured in Armenia by "Retine Noruyt" Co. Ltd. Within the framework of the mentioned INTAS Project these bearings were tested at the Engineering Research Center of the American University of Armenia. This paper describes the methodology of testing and the obtained results.

2. Methodology on testing of laminated rubber bearings

The goal of the testing of rubber bearings is to experimentally define their horizontal stiffness and shear modulus under the simultaneous action of the vertical and horizontal forces, as well as their vertical stiffness and elasticity modulus under the action of only vertical force.

The methodology of shear test conduction assumes carrying out of testing of the full-scale rubber bearings (Melkumyan 2001). The tests are carried out by the scheme demonstrated in Fig. 4.

The bearings are installed between rigid plates, to which vertical tension and horizontal shear forces are applied. During the shear test deformations of up to shear angle $\tan\gamma = 0.9$ should be reached not less than two times. At the second shear the values of shear angles $\tan\gamma$ and the corresponding values of tangent stresses are recorded at every step of loading and are plotted on the coordinate system (Fig. 5).

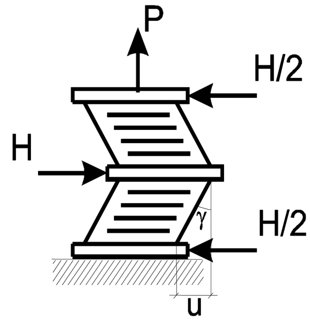

Fig. 4 Scheme of shear testing of two rubber bearings simultaneously

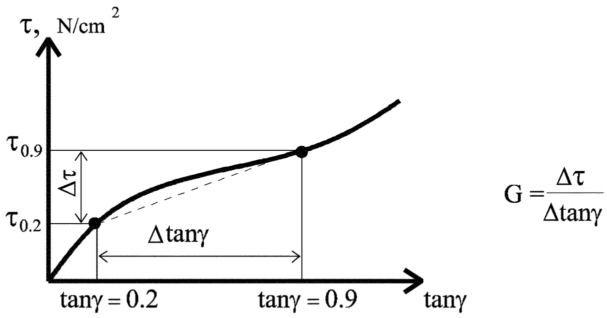

Fig. 5 Determination of the bearings' shear modulus

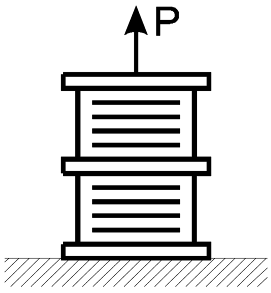

Fig. 6 Scheme of tension testing of two rubber bearings simultaneously

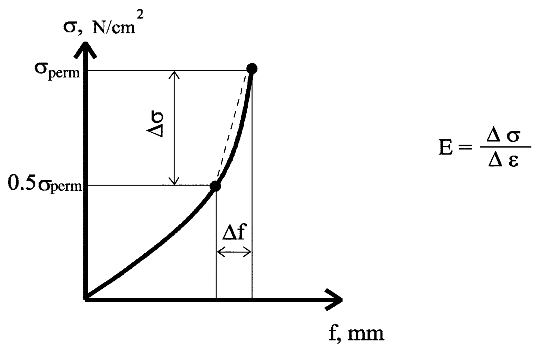

Fig. 7 Determination of the bearings' elasticity modulus

As far as the "stress -deformation" dependence has a non-linear nature, in order to determine the shear modulus **G** the range between the values tanγ= 0.26795 (γ= 15°) and tanγ= 0.57735 (γ=30°) is used. Therewith, the tangent stresses are equal to the ratio of horizontal force **H** to the loading surface of bearing **A**, i.e., τ = H/A, and the shear angle is equal to the ratio of horizontal displacement **u** to usable height of bearing **T**, i.e., tanγ= u/T. The deformations are made step-by-step, with a step of 1 mm. The loading rate should not exceed 10 kN/min and the readings are taken after 20-30 sec at every step of loading.

The tests under vertical tension loading are also conducted for the full-scale rubber bearings. The test scheme is demonstrated in Fig. 6.

Here, again, the bearings are installed between rigid plates to which vertical force is applied. Before determining the dependence "stress-deformation", the bearings are repeatedly (not less than six times) loaded up to permissible stresses by continuous increase of vertical force. The dependence "stress-deformation" is determined at the 7th loading fixing at each step of the loading the values of normal stresses **σ** and corresponding values of vertical deformations **f** (Fig. 7).

The elasticity modulus is determined by the secant in the range between the permissible stresses and one-half of the permissible stresses. Therewith, the normal stresses are equal to the ratio of vertical force **P** to the loading surface of bearing **A**, i.e., $\sigma = P/A$, and the relative deformation is equal to the ratio of deformations' difference, which corresponds to permissible stresses and one-half of permissible stresses, to the usable height of bearing **T**, i.e., $\Delta\varepsilon = \Delta f / T$. At testing under vertical load the loading is made step-by-step, with a step of 10% of the value of permissible stresses. The loading rate should not exceed 200 kN/min.

3. Testing of laminated rubber bearings

In order to test the laminated rubber bearings based on the accumulated experience (Melkumyan and Hakobyan 2003, 2005) special testing facilities were designed and manufactured (Fig. 8). The loading system was envisaged to test simultaneously two laminated rubber bearings and could produce up to 1000 kN force on the bearings in horizontal and vertical directions. It consists of four side columns, upper and lower beams, movable in the horizontal direction steel platform and horizontally immovable upper plate. The bearings were subjected to tension by vertical force through hydrojack, which was

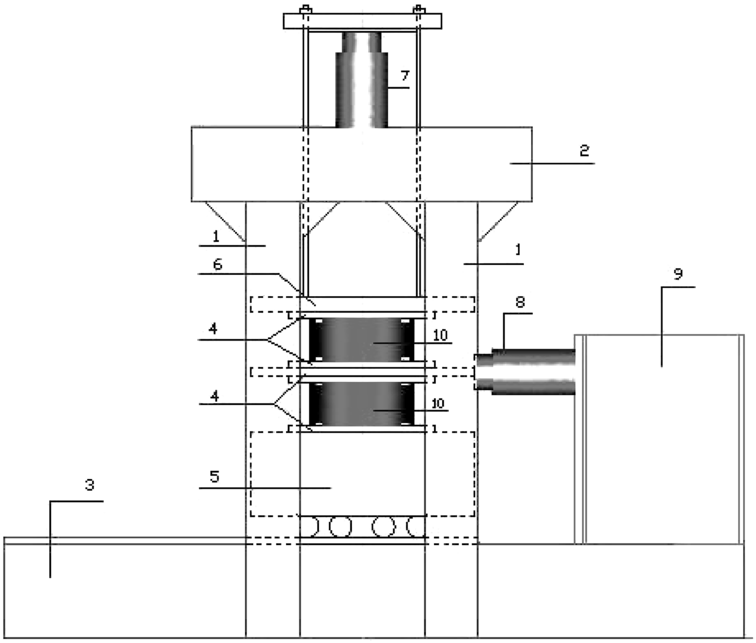

Fig. 8 Scheme of loading frame designed for testing of two laminated rubber bearings of DD 1-columns; 2-upper beam; 3-lower beam; 4-flanges; 5-movable platform (at the testing of two bearings this platform is fixed); 6-upper immovable in horizontal direction plate; 7-hydrojack for vertical loading; 8-hydrojack for horizontal loading; 9-support; 10-laminated rubber bearings

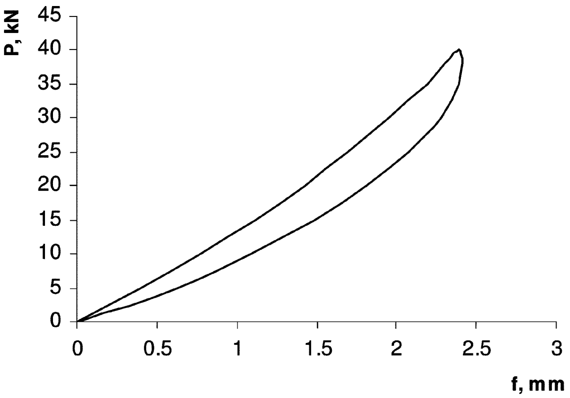

Fig. 9 "Vertical tension force - displacement" loop for laminated rubber bearings of DD

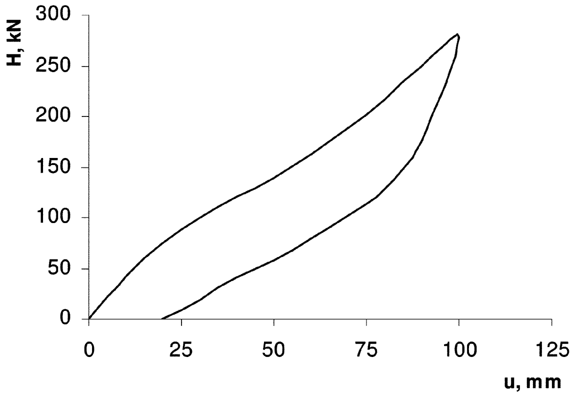

Fig. 10 “Horizontal force - displacement” loop for laminated rubber bearings of DD

Table 1 Results of testing of laminated rubber bearings of DD

Vertical tension force *P*, kN	Vertical displacement *f*, mm	Horizontal displacement *u*, mm	Horizontal shear force *H*, kN
5	0.39	10	42
10	0.77	20	75
15	1.11	30	101
20	1.43	40	121
25	1.70	50	139
30	1.96	60	163
35	2.19	70	188
40	2.39	80	216
35	2.39	90	249
30	2.30	100	278
25	2.08	90	174
20	1.81	80	129
15	1.49	70	101
10	1.10	60	79
5	0.63	50	58
0	0.02	40	41
		30	19
		20	0

located on the frame and the axis of which coincided with longitudinal axis of the frame and bearings. The horizontal actuator was positioned in such a way that its longitudinal axis was in one horizontal plane with the internal movable plate.

The tests were carried out in conformity with the above described methodology. On the Figs. 9 and 10, as an example, the relationships “vertical tension force-displacement” and “horizontal force-displacement” for one pair are given, respectively. During the displacement control shear test isolators were subject to constant vertical force of 40 kN and gradual increasing of horizontal displacement with bringing it to the maximum value of the design displacement -100 mm. The obtained results are given in the Table 1.

Based on these results the following characteristics of laminated rubber bearings were calculated: shear modulus $G = 1.684$ MPa, elasticity modulus $E = 65.4$ MPa, horizontal stiffness $K_H = 1.267$ kN/mm, vertical stiffness $V = 41.7$ kN/mm and damping factor $\xi = 9.6\%$.

4. Conclusions

Laminated rubber bearings to be applied in the system of DD of seismic isolated building were tested by specially designed and manufactured test machine. Based on the tests' results for the rubber bearings from neoprene with diameter of 320 mm and height of 149.4 mm the following conclusions were made. The shear modulus of seismic isolation rubber bearings is equal to 1.684 MPa and the elasticity modulus - 65.4 MPa. The horizontal stiffness is equal to 1.267 kN/mm and the vertical stiffness - 41.7 kN/mm. No damages were observed in rubber bearings at the design displacement. The vertical stiffness of seismic isolation bearings at compression is 328 times greater than their horizontal stiffness. The damping factor is equal to 9.6%.

Acknowledgements

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