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CONDITIONS REGARDING THE USE OF ELASTOMERIC BEARINGS IN BASE ISOLATION

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Abstract: *In recent years, base isolation has become one of the most used methods for the seismic protection of buildings and bridges. Base isolation systems are used in new structures as well as to secure old buildings.*
Base isolation consists of installing a system of mechanisms with the purpose of "bearings" which provides the separation of the structure from the infrastructure so that the seismic forces transmitted to the superstructure are reduced. There are many types of supports, such as: supports with balls, with rollers placed on two directions, springs, elastomers etc. The elastomeric bearings reinforced with metal plates are among the most common.
Elastomeric bearings are characterized by high vertical stiffness and low horizontal stiffness which increase the fundamental period of the seismic isolated system. The use of elastomeric bearings requires a good knowledge of their characteristics in order to increase operational safety.
This paper presents the research on some elastomeric bearings with different characteristics carried out in the laboratories of the Faculty of Civil Engineering and Building Services from "Gheorghe Asachi" Technical University of Iasi.

Key words: *structural safety, elastomer characteristics, experimental tests, seismic action.*

1. Introduction

Base isolation consists of installing a system of bearings which provides the separation of the structure from the infrastructure so that the seismic forces transmitted to the superstructure are reduced.

The current interest for seismic base isolation system has greatly increased. The study of these systems behaviour is of major importance because this method provides safety and comfort.

There are many types of bearings used in base isolation, such as: supports with balls, with rollers placed on two directions, springs, elastomeric bearings etc. The elastomeric bearings reinforced with metal plates are among the most common. The idea of introducing metal plates as reinforcement in elastomeric bearings belongs to the French engineer Eugène Freyssinet [2].

This paper presents some conditions on the design of elastomeric bearings and a series of experimental tests on the

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mechanical properties of elastomers and elastomeric bearings with different characteristics.

2. Observations on the design of elastomeric bearings

Specific requirements on the elastomeric bearings are specified in design codes, such as: Romanian design code P100-1-2013 (Section 11), European codes SR EN 1998-1:2004 (Section 10), SR EN 1337-3:2005 (Section 3) and SR EN 15129:2010, Italian code Ordinanza 3274:2003 (Section 10), American codes UBC 1997 and FEMA 356:2000 (Section 9), etc.

The parameters which influence the size and behaviour of elastomeric bearings are: the load bearing capacity, the vertical stiffness and the horizontal stiffness.

The studies conducted so far have shown that a correlation between vertical and horizontal stiffness must be achieved to prevent the vertical oscillation discomfort and swinging phenomenon of the seismic isolation system.

The ratio between vertical and horizontal stiffness of the bearing is indicated to satisfy the condition [12]:

$$\frac{K_V}{K_H} \geq 150. \tag{1}$$

where: K_V is the vertical stiffness of the bearing, K_H is the horizontal stiffness of the bearing.

Usually, in base isolation design, the number of bearings required to take over the vertical loads is determined and the horizontal stiffness required by the system to obtain a high fundamental period, which is the key element to achieve the seismic base isolation, is taken into account [3].

The correlation between vertical and horizontal stiffness is sometimes difficult to implement in terms of relationship (1).

In addition, increasing the lateral flexibility can lead to high bearings that may cause stability loss. In such situations, multi-stage elastomeric bearings may be used, which provide a stable behaviour at large lateral displacement compared with conventional bearings with an equal volume of elastomer.

The elastomeric bearings design involves determining the diameter (bearing sides), the number of layers, the total thickness of elastomeric layers from bearing, the shear modulus of elastomer, the area and the total height of the bearing.

The bearings design is performed starting from the limitation of compression normal stress, thus obtaining the required dimensions. Then, the shape factor of the bearing S_2 (the ratio between the bearing diameter and total height of elastomeric layers from the bearing) is selected and the bearing height is obtained.

The values of bearing shape factor are selected greater than 4 to avoid buckling of the bearing. The diameter (bearing sides) must be three times larger than the total height of the bearing to prevent instability [1].

The isolation system design is achieved by an equivalent linear or simplified calculation depending on the fulfilled conditions provided in norms (P100, EC8). Under these conditions, the base isolation design is an iterative process.

Thus, based on the design spectrum, the required displacement from the bearings level is determined and checked with the capable displacement. If this is exceeded, the bearings are resized and the design process repeated.

The displacement must be restricted so that the bearing can carry the vertical loads. The limit imposed for horizontal displacement of the bearing is equal to 0.7 times the total height of elastomeric layers.

The failure of elastomeric bearings may be caused by the fatigue phenomenon of the elastomer, breakage or failure of reinforcement plates, detachment between the outer metal plates and bearing or buckling of the bearing [8].

The diameters of the elastomeric bearings used in base isolation have values between 200 and 1200 mm depending on the vertical load bearing capacity. The thickness of the elastomeric layers is usually between 8 and 20 mm and the thickness of metal plates is 2-3 mm.

3. Experimental research to determine the mechanical characteristics of elastomers

The experimental tests, performed in the laboratories of the Faculty of Civil Engineering and Building Services of Iasi, were carried out on elastomeric specimens with different compositions and hardness: natural rubber/butadiene rubber (NR/ BR), chloroprene/neoprene rubber (CR), natural rubber (NR), natural rubber/butadiene rubber/styrene butadiene rubber and polyamide/polyethylene fibres (NR/ BR/ SBR+ PA/ PE fibres), Figure 1.

Fig. 1. *The elastomer specimens* [8]

The materials were provided by S.C. FREYROM S.A., which services in the fields of: civil engineering, roads, bridges and rehabilitation of historical monuments.

The laboratory tests on elastomers consisted in the determination of: hardness, elastic moduli and their dynamic modulus.

3.1. The elastomers hardness

The determination of hardness was performed with Zwick/Roell 3114..17 device, Figure 2, according to SR ISO 7619-1:2011 [13].

Fig. 2. *The Shore hardness tester* [4]

The measurement of elastomer hardness depends on several factors, such as: the viscoelastic properties of the elastomer, the elastic modulus, the thickness of the test sample and the pressure exerted on elastomer.

The hardness values, obtained for the four elastomer samples, are shown in Table 1:

The elastomers hardness Table 1

Elastomer type	CR	NR	BR	SBR
Hardness [Shore A]	64	65	63	65

3.2. The compression modulus of elastomers

The aim of this study was to define the relationship between the compression and shear modulus, shape factor and hardness of the elastomers analysing the difference between the compression modulus experimentally determined according

ASTM D 395-03 [9] and theoretically determined with the relationships proposed by Rocard (eq. 2), Gent and Lindley (eq. 3) and Derham (eq. 4), [4]:

$$E_{c1} = 3 \cdot G\left[\frac{1+k_1 \cdot S^2}{1+k_2 \cdot S^2} + 2 \cdot S^2\right]. \quad (2)$$

$$E_{c2} = E_0(1+2kS^2). \quad (3)$$

$$E_{c3} = \frac{H^{1.9}}{6700}\left[\frac{1+9 \cdot S^2}{1+4 \cdot S^2} + 2 \cdot S^2\right]\text{ksi}. \quad (4)$$

where: E_c is the compression modulus of the elastomer;
G - the shear modulus of the elastomer;
k_1=4.8, k_2=4 - their values depend on the variation of the shape factor;
S - the shape factor;
E_0 - is Young's modulus, E_0=3G for unfilled, low-damping elastomers and E_0=4G for high-damping elastomers with carbon black filler;
H – the elastomer hardness
ksi - the kilo pound per square inch, 1 ksi = 10^3 psi ≈ 6.89475 MPa.

The results indicated experimental values of the compression modulus, $E_{c,exp}$, close to theoretical values (Table 2), [4].

The compression modulus Table 2

Elastomer type	E_{c1} [MPa]	E_{c2} [MPa]	E_{c3} [MPa]	$E_{c,exp}$ [MPa]
CR	6.82	7.40	6.35	7.55
NR	7.03	7.75	6.54	7.72
BR	6.60	7.04	6.16	6.53
SBR	7.03	7.75	6.54	7.72

In conclusion, many relationships were developed to determine the compression modulus, however it is necessary to carry out experimental tests according to the test standards to verify the characteristics of the elastomers [4].

The compression test on elastomers was carried out in four cases to analyse the influence of metal plates: first, the elastomeric samples were bonded with epoxy adhesive to metal plates, second, the elastomeric samples were fixed without adhesive on two metal plates, third, the samples have not been provided with plates and fourth, a thin layer of lubricant was applied between the elastomeric layer and the test machine platens, Figure 3, [5].

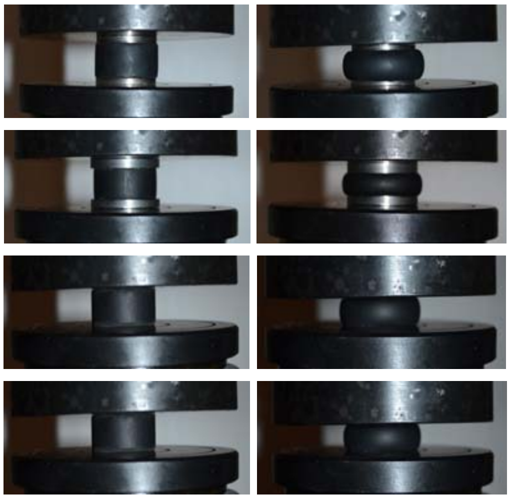

Fig. 3. *The compression test of elastomers*

The stress-strain curves of the elastomer samples are shown in Figures 4 up to 7 [5].

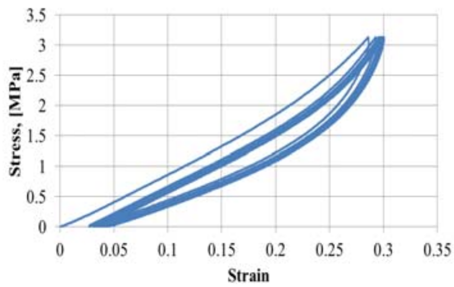

Fig. 4. *The stress-strain curves of CR*

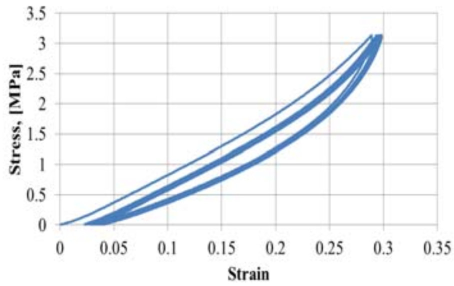

Fig. 5. *The stress-strain curves of NR*

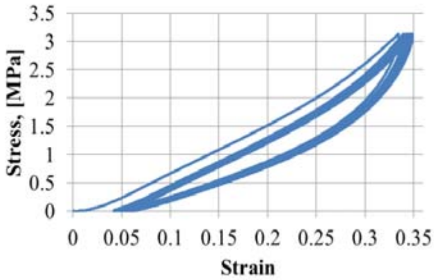

Fig. 6. *The stress-strain curves of BR*

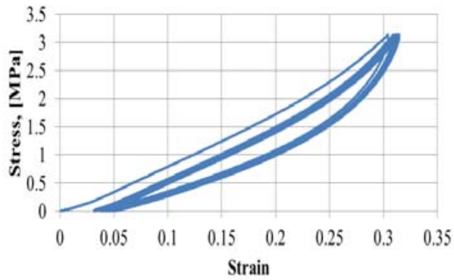

Fig. 7. *The stress-strain curves of SBR*

The compression modulus of elastomers was determined according to SR EN 1337-2006 [14].

Following laboratory tests, it was found that the highest values of the compression modulus were obtained in the case when the specimens were bonded to metal plates, thus the role of reinforcement of the elastomers used in base isolation bearings was highlighted. The NR and NR/BR/SBR+PA/PE fibres have the same hardness, but different values of the compression modulus were obtained because those materials have different fillers (PA/PE fibres) [5].

3.3. The shear modulus of elastomers

The shear moduli of elastomers were determined according to ASTM D 4014-2003, Annex A [11]. The shear test was carried out on four specimens bonded to metal plates, Figure 8.

Fig. 8. *The shear test of elastomer* [7]

The values of shear modulus are presented in Table 3:

The shear modulus Table 3

Elastomer type	CR	NR	BR	SBR
G [MPa]	0.9	0.87	1.1	0.96

The shear modulus depends on the elastomer composition and the amount of filler materials. In the case of elastomers with the same hardness, NR and NR/BR/SBR+ PA/PE fibres, the shear moduli have different values due to the different chemical composition [7].

In conclusion, the hardness is not a sufficient indicator of elastomer quality or performance, although it is easy to measure. In the scientific literature, the values of elastomer moduli in compression and shear are given only as information in terms of hardness [7].

3.4. The dynamic modulus of elastomers

According to ASTM D 945-92, the specimens made of two elastomer samples bonded between parallel metal plates were used to determine the dynamic shear modulus [10].

The method to determine the dynamic characteristics consists in compressing the elastomer specimen, allowing free vibrations and pursuing the material behaviour at different loads and frequencies, Figure 9 [6].

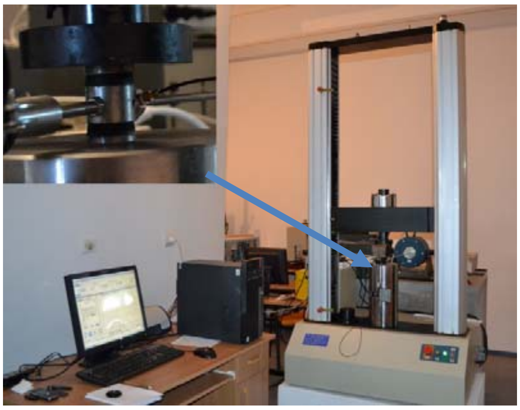

Fig. 9. *The equipment for the dynamic test*

The elastomers are viscoelastic materials and have a phase angle between the applied sinusoidal force and the resulting strain between 0 and 90°. The phase angle between the action and response occurs due to the damping characteristics of the material.

Considering that the dynamic shear properties of the viscoelastic materials depend on the excitation frequency, the temperature of the material and environment, the amplitude of stress and strain, the most effective method for estimating these parameters is to carry out experimental tests [6].

4. Experimental research to determine the mechanical characteristics of elastomeric bearings

The experimental test consisted in measuring the compression and shear modulus and the vertical and horizontal stiffness of an elastomeric bearing.

The tested elastomeric bearings had 100x100 mm plane dimensions and consisted of 6 elastomer layers with 8 mm thickness interspersed with metal plates with 95x95 mm plane dimensions and 3 mm thickness. The outer metal plates have 8 mm thickness, Figure 10.

Fig. 10. *The elastomeric bearing*

The compression force applied on the elastomeric bearing had the value of 60 kN and the horizontal displacement was 0.7 times the elastomer layers thickness, Figure 11.

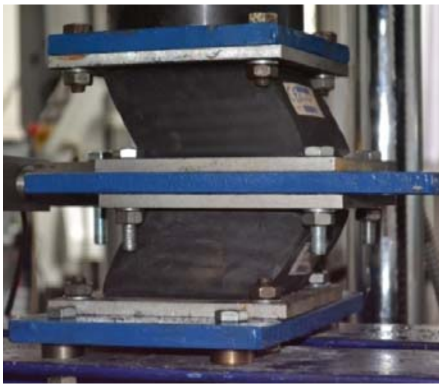

Fig. 11. *The elastomeric bearing displacement*

The force-displacement curves of the elastomeric bearings are shown in Figure 12.

The elastic moduli values and the stiffness of the elastomeric bearing are presented in Table 4.

The elastic moduli and the stiffness of the bearing Table 4

G [MPa]	K_H [N/mm]	E_c [MPa]	K_V [N/mm]
0.58	117.04	35.62	7186.95

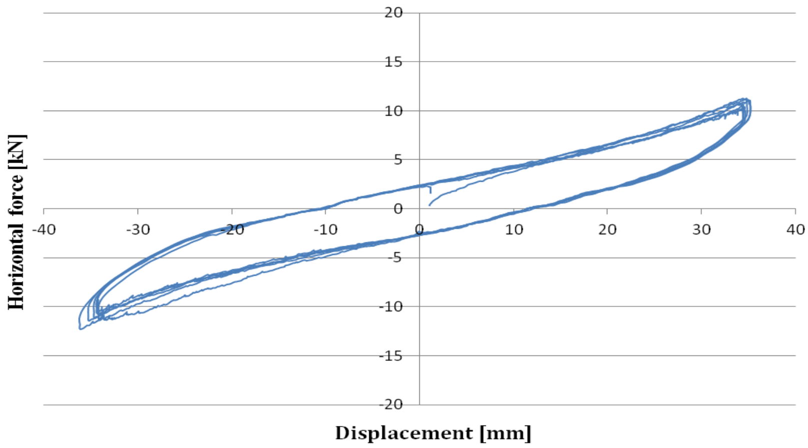

Fig. 12. *The force-displacement curves of elastomeric bearings*

5. Conclusion

This paper presents some principles and observations on base isolation design, on elastomeric bearings, for structures located in seismic areas. These observations are backed up by a series of experimental researches carried out in the laboratories of the Faculty of Civil Engineering and Building Services from "Gheorghe Asachi" Technical University of Iasi.

The experimental tests were performed on elastomers made available by the S.C. FREYROM S.A. company. Therefore, four types of elastomers were tested: natural rubber/ butadiene rubber (NR/BR), chloroprene/ neoprene rubber (CR), natural rubber (NR), natural rubber/ butadiene rubber/ styrene butadiene rubber and polyamide/ polyethylene fibres (NR/BR/SBR+PA/PE fibres).

The best compression and shear behaviour of the elastomers was obtained in the case of NR/BR/SBR+PA/PE fibres, due to the fillers which improve the mechanical properties of elastomers.

Base isolation, as a protection method to seismic actions, in addition to an analysis of elastomers, involves a careful study of the bearing location to avoid dysfunctions, such as high flexibility of the bearing, with effects on the sway of structure, the loss of lateral stability and the allowable maximum displacement which is very often neglected.

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