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FINITE ELEMENT MODELLING OF ELASTOMERIC BEARINGS

BY

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Abstract. The paper presents the numerical modelling of elastomeric bearings used in seismic base isolation, with the finite element method in the ANSYS Workbench software.

The aim of this paper is to determine the horizontal stiffness of simple elastomeric bearings and elastomeric bearings with holes subjected to the same vertical force and horizontal displacement. The tested elastomeric bearings have 100 ×100 mm plane dimensions and a height of 79 mm. The vertical force applied to the bearings had a value of 1,000 N and the horizontal displacement was 24 mm.

The hyperelastic and viscoelastic properties of elastomers were defined using the Ogden model and Prony series.

The hysteresis curves of the bearings, using the displacements and reactions resulted from the program, were plotted. The horizontal stiffness of elastomeric

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bearings with holes was by approximately 50% lower compared to the simple elastomeric bearing.

Key words: elastomeric bearings with holes; horizontal stiffness; Ogden model; Prony series.

1. Introduction

The elastomers are polymers consisting of long flexible chains which are able to withstand very large deformations. Hyperelastic material models based on the potential energy of deformation, such as Neo-Hookean, Mooney-Rivlin, Polinomial, Gent, Arruda-Boyce, Ogden, Yeoh, are necessary to use in order to model these materials.

In finite element analysis of elastomeric bearings the following hypotheses are assume: the material is elastic, isotropic, incompressible or nearly incompressible (the Poisson's ratio is 0.5) and the simulation include nonlinear geometric effects (Kelly *et al*., 2011).

The elastomers are materials that have properties similar to viscoelastic materials. Thus, in the computing software, it must be defined both the hyperelastic and viscoelastic properties of the elastomers in order to obtain a hysteretic behaviour of the bearing.

The coefficients of hyperelastic models can be obtained in Ansys software by introducing the experimental results (stress-strain curve) and applying the Curve Fitting option which compare the experimental results with the nonlinear material models predefined in program (Bhashyam, 2002). Based on these comparisons, the material model, which is most suitable for the elastomer behaviour, is chosen.

The viscoelasticity is implemented in the Ansys finite element software by Prony series which is very useful for calculating the material deformations whose stiffness changes depending on load, time and temperature (Imaoka, 2008).

The aim of this paper is to study the behaviour under compression and shear of simple elastomeric bearings and elastomeric bearings with nine holes in order to compare their horizontal stiffness. The elastomeric bearings were modelled in Ansys Workbench software.

2. Description of Elastomeric Bearings

The elastomeric bearing dimensions are presented in Fig. 1.

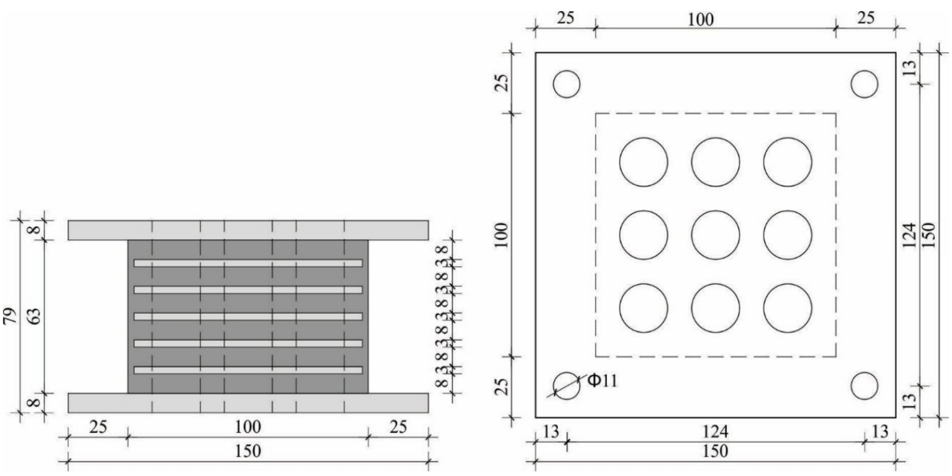

Fig. 1 – The dimensions of elastomeric bearings with nine holes.

The simple elastomeric bearings and elastomeric bearings with nine holes with diameters of 20 mm, modelled in Ansys, are presented in Fig. 2.

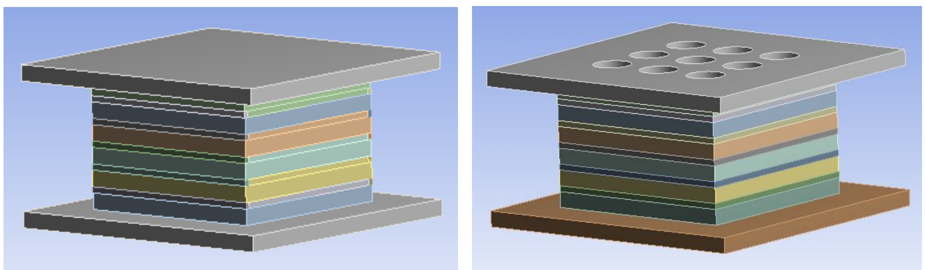

Fig. 2 – Simple elastomeric bearing and elastomeric bearing with holes.

3. Numerical Analysis with Finite Element Method

The elastomeric bearings were modelled with the finite element method in Ansys Workbench software using the *Static Structural* analysis type.

According to SR EN 1337-3, the elastomeric bearings may be designed with or without steel plates at the bottom and the top of the bearing.

The steel is modelled as linear elastic and isotropic material and the elastomer as a nonlinear elastic material.

In *Engineering Data*, the *Structural Steel* was chosen from the material library with the predefined properties: the Young's modulus E = 2e + 11 Pa, the Poisson's ratio υ = 0.3 and the shear modulus G = 7.6923e + 10 Pa. The Ogden I model was chosen for the *Elastomer Sample* and the parameters of the model, determined from experimental tests, were introduced in the software.

The Ogden model with parameters introduced manually, obtained from experimental tests, is used in order to obtain precise results for finite element modelling of elastomeric bearings with large deformations (Oanea *et al.*, 2014).

The viscoelastic properties of elastomers have been introduced in Ansys software by using the *Prony Shear Relaxation* function, which defines the material behaviour under shear. This command includes two parameters, namely relative modulus and relaxation time.

The parameters introduced in Ansys were:

a) for Ogden model: MU_1 = 1.8 MPa, α_1 = 2, D_1 = 0,0004 MPa – 1;

b) for Prony Shear Relaxation: 0.35, 0.4; 0.35, 0.2.

The contact between the elastomer and the steel plates were defined bonded.

For nonlinear analysis, the model meshing should be as fine as possible in order to observe the nonlinearity effects in the case of large deformations (Ansys, 2009). The elastomeric bearings were discretized with Solid 186 finite element (*3-D 8-Node Structural Solid*), of 5 mm size (all nodes on the adjacent surfaces have been in contact) and have been modelled with the elastomer layers equal to the metal plates (95 mm) in order to reduce the number of finite elements and the runtime analysis. A number of 47,840 nodes and 7,581 elements resulted in the case of simple elastomeric bearings and 39,738 nodes and 5469 elements were obtained for elastomeric bearings with nine holes with diameters of 20 mm (Fig. 3).

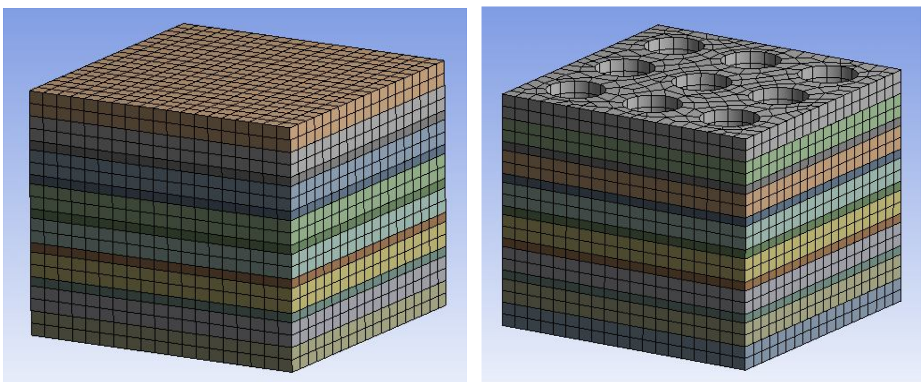

Fig. 3 – Meshig the elastomeric bearings.

The bearing was recessed at the bottom (*Fixed Support*). A vertical force of 1,000 N and a horizontal displacement of 24 mm (0.5 of elastomeric layers height) were applied at the top of the bearing, in eleven steps of loading (Fig. 4).

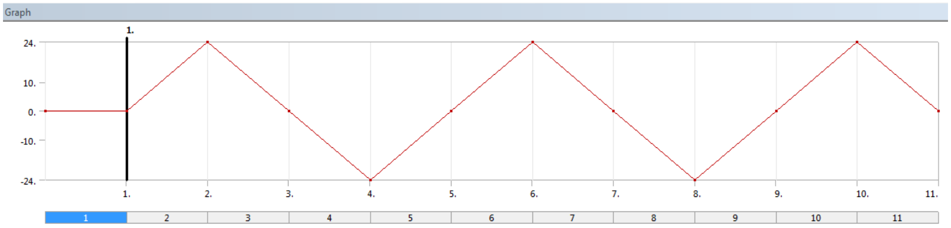

Fig. 4 – The loading graph of the imposed horizontal displacement.

The nonlinear response of the bearing requires the division of the applied force in sub steps of loading. At the end of each sub step, the stiffness matrix of the model is adjusted to reflect the nonlinear changes of the structural stiffness.

For solving the equilibrium problem and updating the model stiffness, the Ansys Workbench software uses the Newton-Raphson method by default, which is an iterative process for solving nonlinear equations.

The solution convergence depends on the ratio between the vertical and horizontal force applied to the analysed element. To avoid errors resulting from solution convergence it should be chosen the suitable type of finite element, to define correctly the mesh, the type of loading steps and the parameters of nonlinear analysis (Ansys, 2009).

The deformed shape of elastomeric bearing, meshed with finite elements, can be seen in Fig. 5. The deformations of the steel plates are small compared to elastomeric layers.

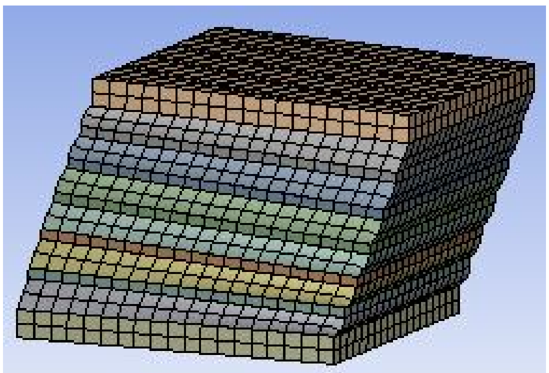

Fig. 5 – The deformed shape of simple elastomeric bearing.

The results consisted in displacements and reactions in the *y* direction. The force-displacement curves of the bearings were plotted based on this results, Figs. 6 and 7.

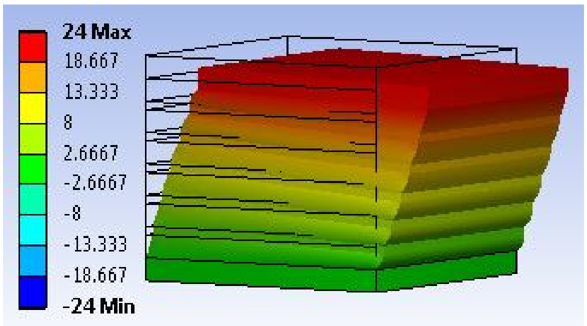

Fig. 6 – The displacement of simple elastomeric bearing.

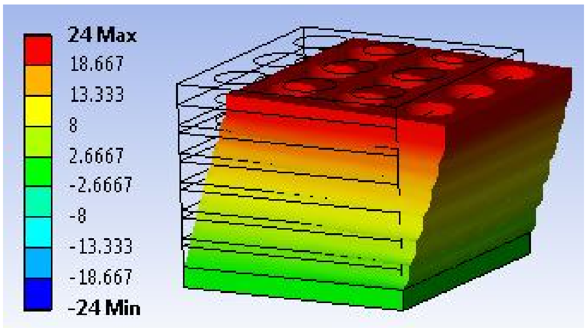

Fig. 7 – The displacement of elastomeric bearing with nine holes.

The force-displacement curves of the elastomeric bearings are presented in Fig. 8.

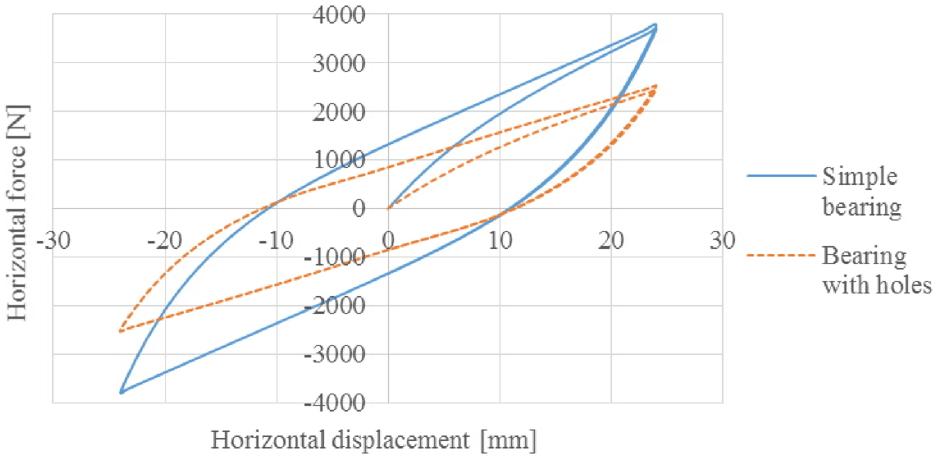

Fig. 8 – The force-displacement curves of the bearings.

The effective stiffness of elastomeric bearings can be determined using the force-displacement curve (Fig. 9).

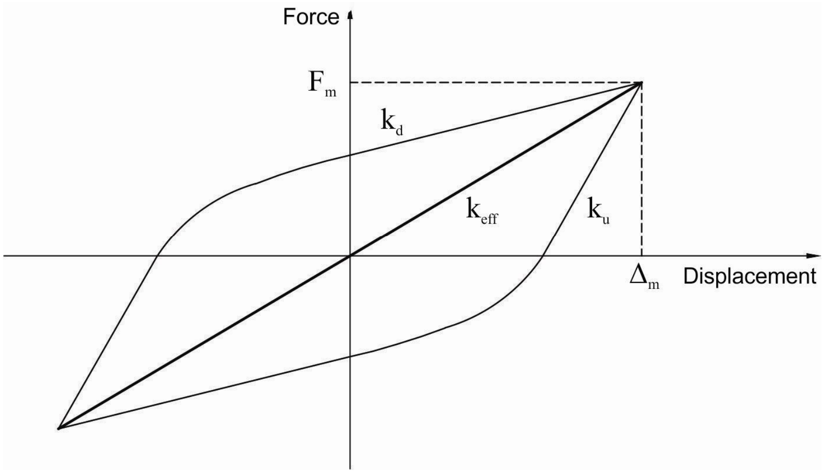

Fig. 9 – The effective stiffness of elastomeric bearings (Kelly, 2001).

The effective stiffness of simple elastomeric bearings resulted 157.64 N/mm and the effective stiffness of elastomeric bearings with nine holes resulted 105.15 N/mm.

4. Conclusions

This paper presents the numerical modelling of two elastomeric bearings, simple and with nine holes with diameters of 20 mm, subjected to compression and shear.

The effective stiffness of elastomeric bearings with nine holes was by approximately 50% lower compared to the simple elastomeric bearing.

In conclusion, a higher lateral flexibility of elastomeric bearings can be obtained by removing a portion of the loading area, by making holes with constant section in the bearing.

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MODELAREA NUMERICĂ CU ELEMENT FINIT A REAZEMELOR DIN ELASTOMERI

(Rezumat)

Se prezintă modelarea numerică a reazemelor din elastomeri, utilizate la izolarea seismică a bazei, în programul de calcul cu element finit ANSYS Workbench.

Scopul lucrării este de a determina rigiditățile orizontale ale unor reazeme din elastomeri simplu şi cu găuri, supuse la aceleaşi forțe verticale şi deplasări orizontale. Reazemele din elastomeri testate au dimensiunile în plan de 100 ×100 mm şi înălțimi de 79 mm. Forța verticală aplicată reazemelor a fost de 1 000 N şi deplasarea orizontală de 24 mm.

Au fost definite atât proprietățile hiperelastice, cât şi cele vâscoelastice ale elastomerilor, cu ajutorul modelului Ogden şi seriei Prony.

Rezultatele au constat în deplasări şi reacțiuni şi pe baza acestora s-au trasat curbele histerezis ale reazemelor. În cazul reazemului din elastomeri cu găuri s-a obținut o rigiditate orizontală cu aproximativ 50% mai mică comparativ cu cea a reazemului din elastomeri simplu.