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FE-MODELLING OF DYNAMIC BEHAVIOR OF SEISMIC ELASTOMERIC ISOLATORS

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ABSTRACT

In this work, the behavior of the elastomeric material, used in the manufacture of isolators, was characterized. Data obtained from experimental uniaxial compression and tension tests were used to determine the parameters of the different hyperelastic models that are available in several commercial software of Finite Element analysis. Simulation of the test is compared with the experimental data. The constitutive models that best represent the behavior of the hyperelastic materials, were used in order to simulate the behavior of the isolator subjected to lateral and cyclic load; a good agreement is observed between numerical and experimental results. It is found that the Polynomial hyperelastic model, for the rubber used, presents a better approximation regarding the behavior of the elastomeric isolator.

Keywords: Hyperelasticity; Elastomeric isolator; Finite Element Analysis; Experimental testing

1. INTRODUCTION

Earthquakes are natural disasters that induce forces and deformations causing damages in structures, which in turn produce human and material losses. One option to improve the behavior of structures to protect them is to separate the movement of structure from ground introducing flexible elements between the structure and the foundation; these elements are defined as seismic isolators.
One of the most used seismic isolation system consists of alternating layers of steel and rubber joined through vulcanization. One type is the laminated-Rubber Bearings (RB) which takes advantage of the properties of the elastomer that can undergo large deformations and then return to their initial state when is discharged. Elastomer materials, like rubber, neoprene or another material, can experience large elastic strains and deformations with small volume change; these properties are named as hyperelasticity (Kumar and Rao, 2016).
The use of elastomeric materials has increased the interest to find models that permit to predict their behavior while subjected to seismic load. Several hyperelastic constitutive models have been developed and incorporated in most of the commercial softwares of Finite Element Analysis (FEA). Data required for each model are obtained from experimental tests; the selection of the model depends on the available data to determine the parameters that characterize the mechanical behavior of this type of material (Aidy *et al*. 2010; Ramírez Gallo, 2008).
In this paper, simple tension and uniaxial compression experimental tests were performed in order to calculate the parameters of different hyperelastic models. Then, the behavior of RB for horizontal seismic loading is simulated. Experimental test validates the best hyperelastic models used in numerical simulation.

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2. EXPERIMENTAL TESTS OF THE ELASTOMERIC MATERIAL

Hyperelasticity can be expressed in terms of energy deformation per unit volume (Estrada, et al. 2013). This approach is based on most of the different mathematical models. These equations are presented in theTable 1.

Table 1. Mathematical equation by different hyperelastic models.

Mooney-Rivlin:	$W=\sum_{i,j=1}^{N} c_{i,j}\left(\overline{I_1}-3\right)^i\left(\overline{I_2}-3\right)^j+\frac{1}{d}(J-1)^2$
Polynomial	$W=\sum_{i+j=1}^{N} c_{i,j}\left(\overline{I_1}-3\right)^i\left(\overline{I_2}-3\right)^j+\sum_{k=1}^{N}\frac{1}{d_k}(J-1)^{2k}$
Yeoh:	$W=\sum_{i=1}^{N} c_{i,0}\left(\overline{I_1}-3\right)^i+\sum_{k=1}^{N}\frac{1}{d_k}(J-1)^{2K}$
Ogden:	$W=\sum_{i=1}^{N}\frac{\mu_i}{\alpha_i}\left(\overline{\lambda_1}^{\alpha_i}+\overline{\lambda_2}^{\alpha_i}+\overline{\lambda_3}^{\alpha_i}-3\right)+\sum_{i=1}^{N}\frac{1}{d_i}(J-1)^{2i}$

where W is the strain energy density function, $\overline{I_1}$ and $\overline{I_2}$ are stretch invariants and depend of two principal strains; respectively, c , λ , α y μ are material constants for each model.

2.1 Tension strain state

The geometry of the specimen, as well as the conditions and stresses of the test were taken from the ASTM D638-14 standard referring to tensile tests of plastics. Figure 1 shows the geometry of the bone specimen.

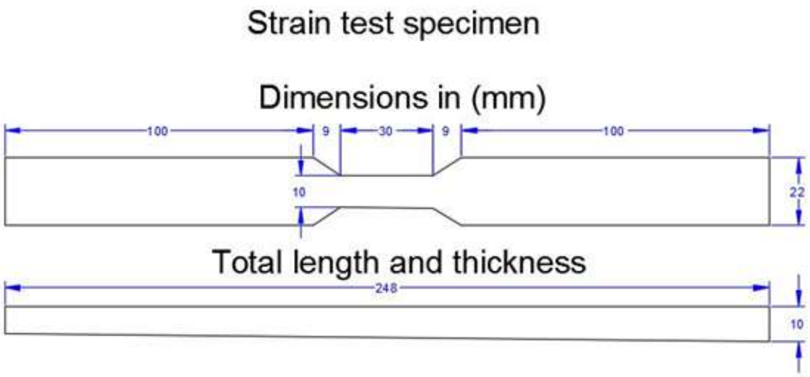

Figure 1. Dimensions for tension test

The stress response simulation was performed by using FEA for several specified hyperelastic constitutive models. The parameters used in the different models are Young's Module E = 2,552 MPa and Poisson's ratio ν = 0.50. Figure 2 compares the experimental results versus analytical models.

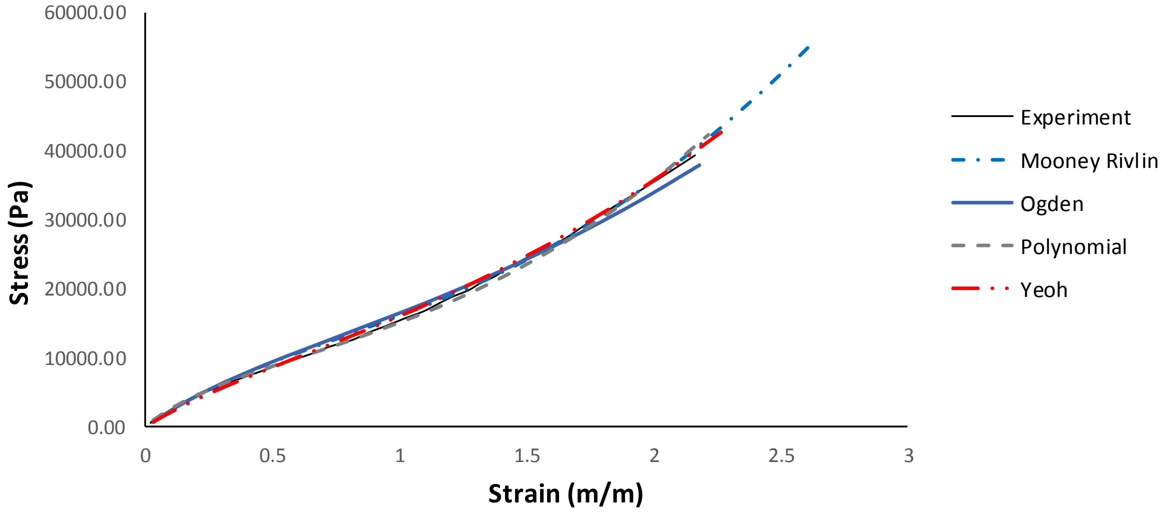

Figure 2. Experiment vs analytic results in tension

Figure 3 compares experimental test specimen vs. FEM simulation in tension obtained with commercial software.

Figure 3. Test specimen before and after in experimental test and with ANSYS simulation

The values of the constants, associated to each model, were obtained by fitting the analytical vs. experimental data using the method of least square. Table 2 shows the values of the constants corresponding to each model analyzed. The subscripts are the same as those requested by the ANSYS software.

Table 2. Values obtained of the constants by setting experimental tension test vs FEA.

Hyperelastic models	Number of parameters	Value of the constants
1.- Mooney-Rivlin	3	C_{10}=5, C_{01}=0.005, C_{11}=0.06, d=20
2.- Polynomial	2	C_{10}=1.3, C_{01}=1.3, d=0.04
3.- Yeoh	2	C_1=3.5, C_2=0.25, d=0.0005
4.- Ogden	2	μ_1=5, a_1=1, μ_2=1, a_2=4 d_1=0.005 d_2=0

2.2 Uniaxial compression strain state

For the compression test the loading and dimensions of the test piece were based on the ASTM D695-15 standard. Figure 4 shows the experimental test and simulation using FEA. Figure 5 shows the comparison between the experimental vs. compression simulation test.

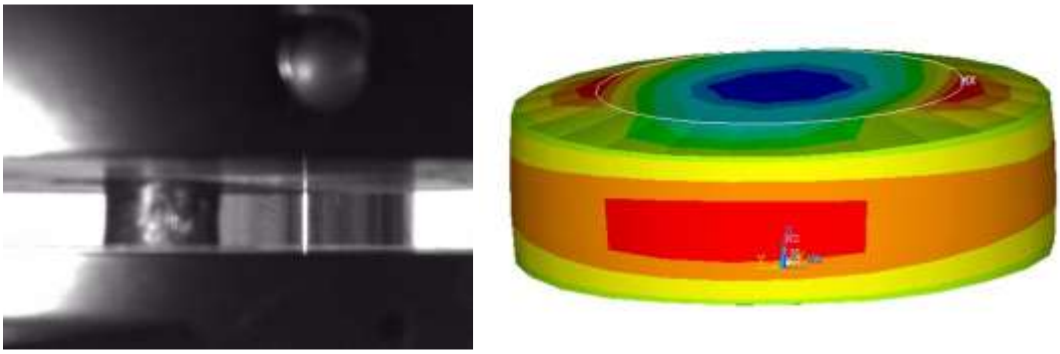

Figure 4. Comparison between experimental compression test and simulation by means of FEA

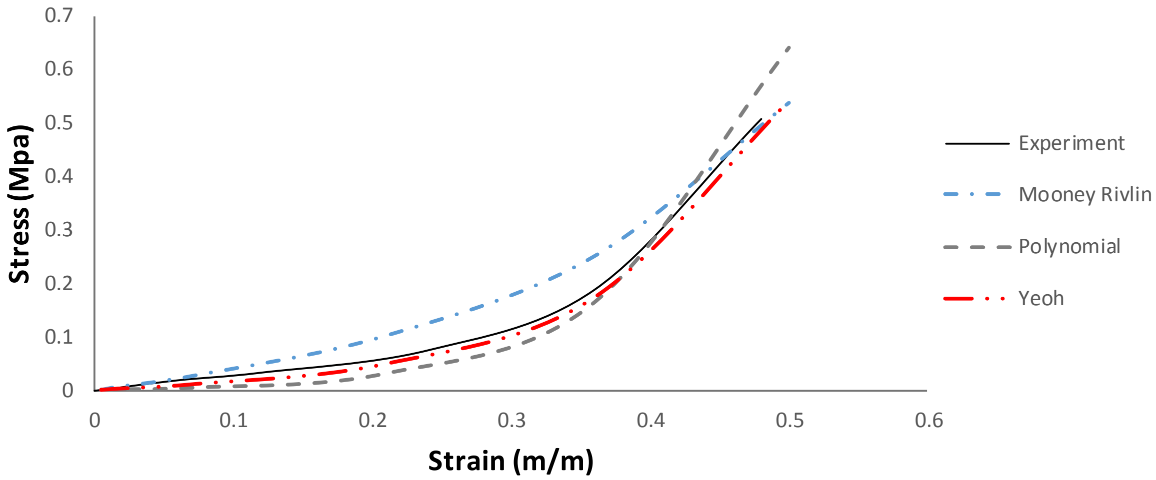

Figure 5. Compression testing vs simulation.

In compression test, Yeoh and Polynomial model presents good fit with the experimental curve. Also, both models presented good adjustment in the tension test; those models will be used to obtain the behavior of the seismic isolator. Ogden model is not presented in the Figure 4 because it is not possible to obtain a good fitting to the experimental curve with the parameters calculated for this model; also this model was omitted in the simulation of the elastomeric isolators and the Money Rivlin model since it was the one with the greatest error in the fitting with respect to the experimental curve in compression.

Table 3 shows the values of constants obtained by fitting the analytical vs. experimental data.

Table 3.Values obtained of the constants by fittering experimental compression test vs. simulation.

Hyperelastic models	Number of parameters	Value of the constants
1.- Mooney-Rivlin	2	C_{10}=25, C_{01}=25, d=0.0005
2.- Polinomial	2	C_{10}=1.4, C_{01}=3.7, d=20
3.- Yeoh	2	C_1=20, C_2=20, d=0.0005

As seen in Table 2 and Table 3, the values of the parameters obtained by tension and compression are different for all the models. The question is, what model should be used to simulate the behavior of the seismic isolator, and what values should be given to the constants? Should those obtained from tension or compression test? The most accurate representation of the hyperelastic properties will be obtained from the parameters of each model determined through the combination of the mechanical tests in multiple states (tension, compression, shear, etc). However, Iwabe et al. (2000) studied the effect of tension in rubber because tensile forces affect more the performance of the RB. In order to verify this hypothesis, the values of the constants are calculated by fittering the behavior of the isolators, with the two constitutive hyperelastic models, versus experimental test for cyclic load.

3. COMPARISON OF THE SIMULATION VS. EXPERIMENTAL TEST

To verify that the behavior of the parameters in Yeoh and Polynomial models, for hyperelactic material, experimental cyclic load tests for three isolations were realized. Table 4 shows the geometric properties of the RB isolator.

Table 4. Captions of tables; first letter capitalized, period at end, and centrally aligned.

Number of specimen	Diameter (mm)	Height of each specimen (in)	Number of plates of steel	Thickness (mm)	Thickness of neoprene (mm)
Isolator 1	150	1.5	3	6	10.05
Isolator 2	150	2.5	4	6	13.17
isolator 3	150	3.5	5	6	14.73

Steel used in the isolator was A36 with $E=2x10^6\ Kg/cm^2$.
Figure 6, 7 and 8 shows the comparison between cyclic loading versus simulation using FEA for the three isolators listed in Table 4.
Table 5 shows the value of the constants obtained by fitting with the experimental cyclic loading

Table 5. Values obtained of the constants by setting experimental cyclic loading vs simulation.

Hyperelastic models	Number of parameters	Value of the constants
2.- Polynomial	2	C_{10}=1.3, C_{01}=1.3, d=0.04
3.- Yeoh	2	C_1=5, C_2=0.2, d=20

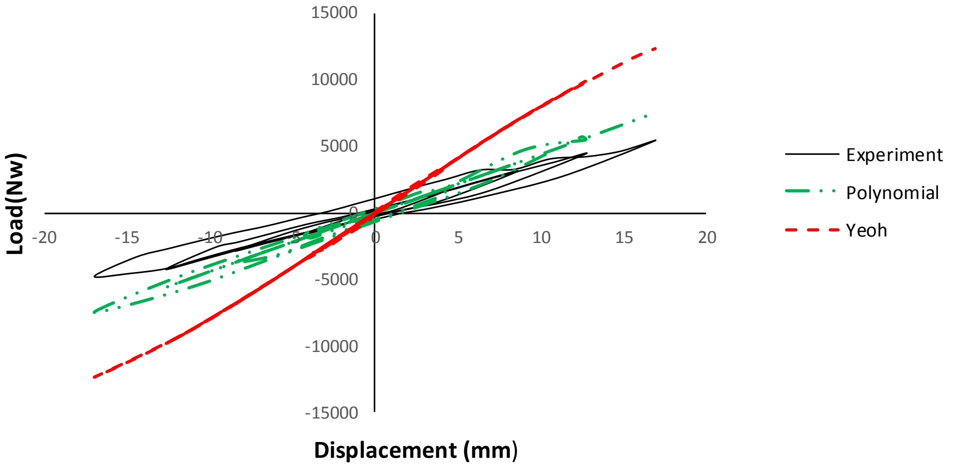

Figure 6. Cyclic loading isolator 1

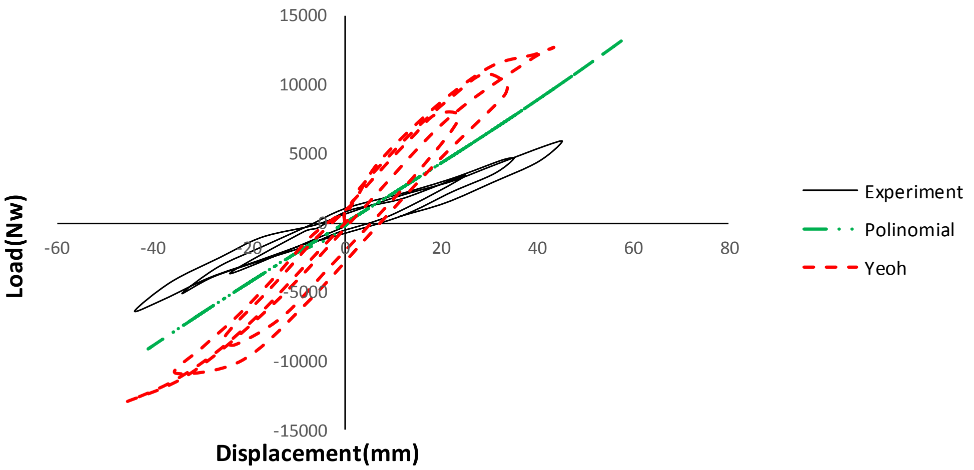

Figure 7. Cyclic loading isolator 2

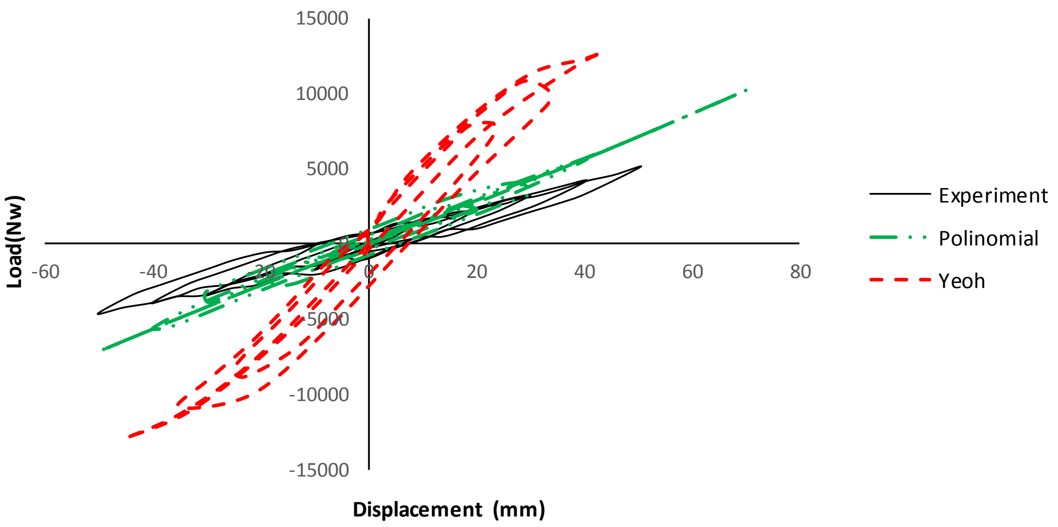

Figure 8. Cyclic loading isolator 3

The values of the constants obtained from simple tension (Table 4), for the Polynomia model, gives a good approximation with the constants obtained from the RB isolation(Table 5) to represent the horizontal displacement and stiffness of the RB isolator. However, in the case of energy, the Yeoh model show a better approach than the Polynomial model but the value of the constants obtained from the tension test are different from those obtained in the cyclic load (Table5)

An approach to the actual dynamic behavior of the isolator depends to a large extent on the correct choice of the model, this is due to the accuracy of each model, the load conditions and the characterization of the material by means of mechanical tests. When the information of all the deformation states is not available, the uniaxial tension test is used (Ramirez Gallo, 2008), and it is implemented in the different models in order to fitting with the hysteretic cycles.

4. CONCLUSIONS

In this paper, a study of the most common hyperelastic materials was performed. The values of the associated parameters were obtained by correlating analytical and experimental tension and compression tests. These parameters are used to simulate the behavior of the elastomeric material in the seismic isolator. Values of the parameters in the Polynomial model, obtained from tension tests, present a good approximation in the simulation of the behavior of the laminated-Rubber Bearings isolator. Results were verified by the experimental tests.

5. ACKNOWLEDGMENTS

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