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INVESTIGATION OF DYNAMIC PROPERTIES OF ELASTOMERIC BEARING COMPONENTS VIA MODAL ANALYSIS

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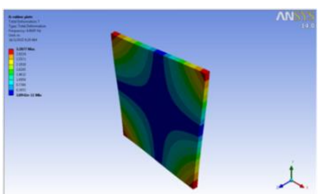
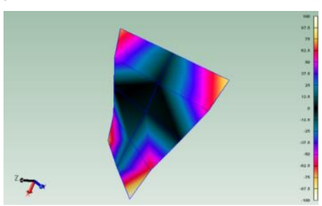
Graphical abstract





Abstract

Elastomeric bearing is a significant device in structures such as in bridges and buildings. It is used to isolate the ground structure (substructure) and the above ground structure (superstructure) from seismic loads such as earthquake load. Understanding the dynamic behavior of the elastomeric bearing in terms of natural frequencies, mode shapes and damping are increasingly important especially in improving the design and the failure limit of the elastomeric bearing. Modal analysis is one of the methods used to determine the dynamic properties of any materials. Hence, the main objective of this research is to determine the dynamic properties of elastomeric bearing components in terms of natural frequencies, mode shapes, and damping via numerical and experimental modal analysis. This method had been successfully performed in investigating the dynamic behavior of rubber and steel shim plate.

Keywords: Vibration, natural frequencies, mode shapes, experimental modal analysis, finite element modal analysis, elastomeric bearing

1.0 INTRODUCTION

Elastomeric bearing is a device to isolate a structure from seismic load such as harmonic load, periodic load, impulse or pulse load, and transient load. It is a combination of rubber layer and steel shim plate that are laminated together alternately. Elastomeric bearing is also known as laminated rubber bearing (LRB). Rubber layer is an almost incompressible material that gives high horizontal flexibility while steel shim plate is a solid material that gives high vertical stiffness [1,12]. Therefore, elastomeric bearing provides a very high vertical stiffness, while still maintaining high flexibility in horizontal direction which is required to lengthen the time period of a structure in seismic isolation applications. This behavior is required in isolation of civil engineering structure.

The importance of elastomeric bearing in seismic isolated structure has led many researchers in trying to understand the behavior and to improve the design of elastomeric bearing. The key point in the design of an effective base isolation system is the understanding of the isolator characteristics [2]. On top of that, there are a few researchers that focused on the stability of elastomeric bearing when subjected to vertical and horizontal load [3,4,11], the influence of shape factor to elastomeric bearing mechanical properties [5,6], the effect of the temperature to elastomeric bearing [7], the buckling load capacity of elastomeric bearing [2] and the instability of elastomeric bearing affected by cavitation [10]. There is no research that had been done on determining the dynamic properties of elastomeric bearing's components which are rubber and steel shim plate. By knowing the dynamic properties of rubber and steel shim plate, an effective base isolation system can be designed. Thus, the main objective of this research is to determine the dynamic properties of elastomeric bearing components; rubber and steel shim plate in terms of natural frequencies, mode shapes, and damping via numerical and experimental modal analysis.

2.0 MODAL ANALYSIS

Modal analysis is a process to determine the inherent dynamic properties of a system in the form of natural frequencies, mode shapes, and damping. On top of that, modal analysis allows the verification and adjusting the mathematical model of the structure. There are two types of modal analysis which are; numerical modal analysis and experimental modal analysis. Experimental modal analysis is also known as modal testing, meanwhile the numerical modal analysis is known as finite element analysis [8]. As far as this research concerns, both finite element and experimental modal analysis are used to determine the dynamic properties of rubber and steel shim plate from elastomeric bearing. All the materials were assumed to be linear. Any nonlinearity was ignored even if it is defined. The dimension for both rubber and steel shim plate is the same which is 200mm width and 230mm in length but the thickness is different. The thickness for rubber plate is 10mm whereas the thickness for steel shim plate is 3mm. Table 1 shows the details of the rubber and steel plate used for this research [9].

Table 1 Details of rubber and steel plate [9]

Materials	Dimension [mm]	Thickness [mm]	Poisson's Ratio	Young's Modulus [Pa]	Density [kg/m³]
Steel Shim	200x230	3	0.3	2.1e11	7850
Rubber	200x230	10	0.49	5e7	1100

3.0 FINITE ELEMENT MODAL ANALYSIS

In the finite element modal analysis, free vibration equation of motion for single degree of freedom system without damping can be written as [8]:

$$[\mathbf{M}]\{\ddot{x}\} + [\mathbf{K}]\{x\} = \{0\} \qquad \text{(Eq 1)}$$

Free vibration solution is mathematically non trivial solution. It should take the form as:

$$\{x\} = \{X\} \sin \omega t \qquad \text{(Eq. 2)}$$

Substitute (2) into (1), will change it into a simple algebraic matrix equation:

$$([\mathbf{K}] - \omega^2 [\mathbf{M}]) \{X\} = \{0\} \qquad \text{(Eq. 3)}$$

In equation (3), {X} cannot be 0, so:

$$|[\mathbf{K}] - \omega^2 [\mathbf{M}]| = \{0\} \qquad \text{(Eq. 4)}$$

ω^2 is the eigenvalue that determines the natural frequency of the system and {X} is the eigenvector that determines the mode shape of the system.

Rubber and steel shim plate were modeled and analyzed using ANSYS workbench 14.0. Modal analysis was chosen as the type of analysis used to analyze this plate. For steel shim plate, it was assigned to be linear elastic material properties (Young's modulus 210 GPa; Poisson's ratio of 0.3; Density of 7850 kg/m^3). Rubber is a hyperplastic material with low shear modulus and very high bulk modulus. The Poison's ratio of rubber is close to 0.5 and is considered almost incompressible. The Young's modulus of 50 MPa, Poisson's ratio of 0.49 and density of 1100 kg/m^3 were assigned for the material properties of rubber plate. The materials were meshed using SOLID 185 element and the meshing size was 2.5 mm.

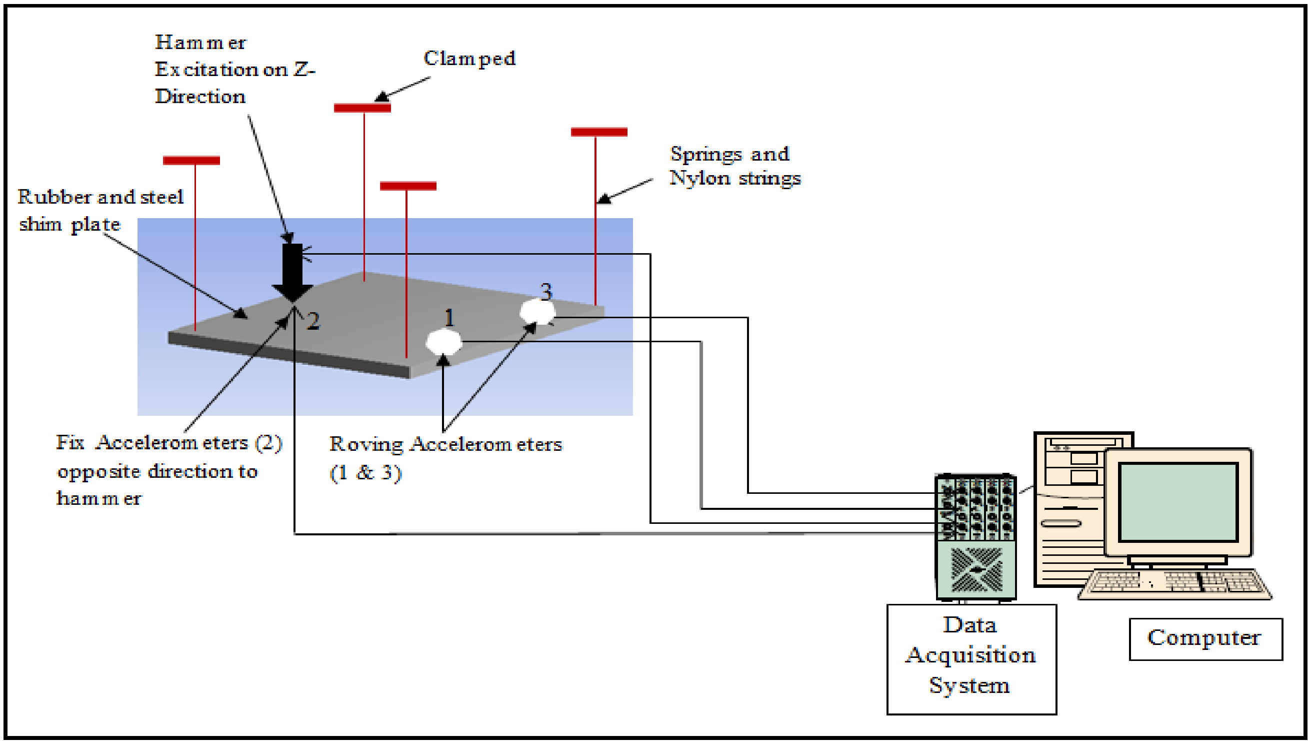


Figure 1 Full schematic diagram of experimental modal analysis

4.0 EXPERPERIMENT MODAL ANALYSIS

In the experimental modal analysis, three accelerometers and one impact hammer were used to measure the dynamic properties of the structure. The type of impact hammer used is a normal PCB Piezotronics Impact Hammer Model 086C03 with medium plastic tip. One accelerometer was fixed at one point as a reference point and two other accelerometers were roving. The force was excited by the impact hammer at one fixed point at the opposite direction of the reference point. A total of 15 points was measured and the responses were recorded by accelerometer. All of the responses were then analyzed by the analyzer to obtain the Frequency Response Function (FRF). From the FRF, the dynamic properties namely; natural frequencies, mode shapes, and damping of elastomeric bearing were determined. Figure 1 shows the full schematic diagram of the experimental analysis.

5.0 RESULTS AND DISCUSSIONS

The dynamic properties of elastomeric bearing namely; natural frequencies, mode shapes, and damping were extracted from experimental modal analysis whereas natural frequencies and mode shapes without damping were extracted from finite element modal analysis. The natural frequencies and mode shapes from both analyses were compared for the first three modes. Table 2 and 3 show the results of natural frequencies, mode shapes and relative error from the finite element and experimental modal analysis of rubber and steel shim plate. The mode shapes for both materials show a good agreement between finite element and experimental modal analysis. The first twisting deformation pattern was produce in the first mode whereas the first and the second bending deformation patterns were produce in the second and third mode for both plates. It can be seen the error of natural frequencies of finite element model of the steel shim plate and experimental data of steel shim plate have shown quite small discrepancies. However, the natural frequencies of the rubber have shown fairly large discrepancies between finite element model and experimental data as rubber is a hyperplastic material that has high nonlinearity and high damping capacity.

6.0 CONCLUSION

Modal analysis had been successfully performed to investigate the dynamic behavior of elastomeric bearing components which are rubber and steel shim plate. The results will help to enhance the understanding of elastomeric bearing and thus, improving the design of elastomeric bearing.

Table 2 Results of modal analysis for rubber

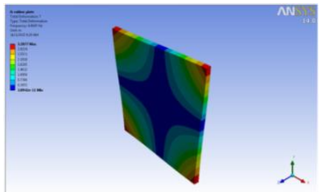
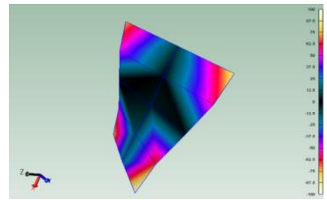
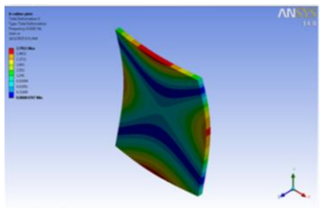
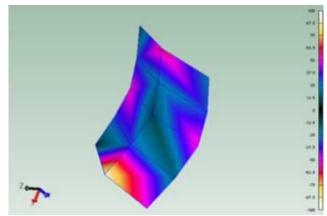
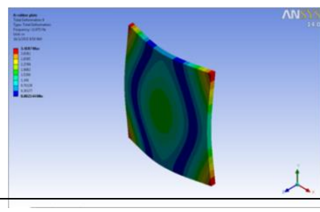
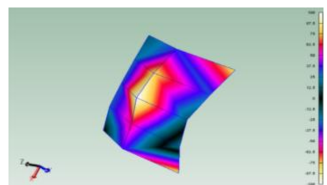
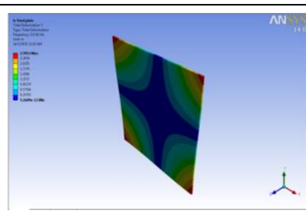
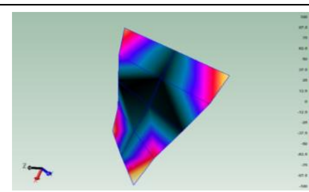
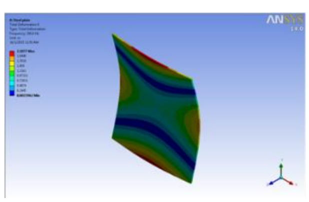
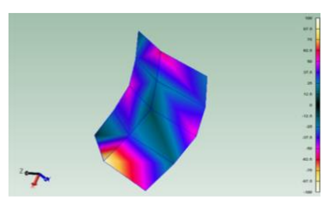
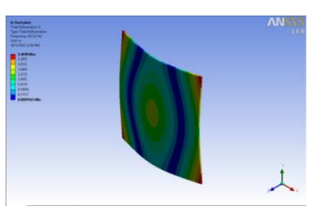
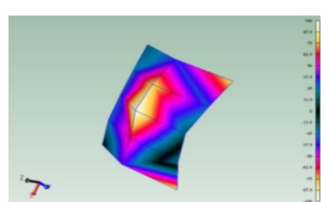
Finite Element			Experiment		Relative Error [%]
Mode No.	**Frequency (Hz)**	**Mode Shape**	**Frequency (Hz)**	**Mode Shape**	
1	27.63		21.09		23.67
2	39.68		27.06		31.80
3	63.13		42.01		33.45

Table 3 Results of modal analysis for steel shim plate

Finite Element			Experiment		Relative Error (%)
Mode No.	**Frequency (Hz)**	**Mode Shape**	**Frequency (Hz)**	**Mode Shape**	
1	217.63		260.46		19.68
2	296.6		289.36		2.44
3	422.62		411.35		2.67

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References

[1] Derham, C. J., Kelly, J. M., & Thomas, a. G. 1985. Nonlinear Natural Rubber Bearings for Seismic Isolation. *Nuclear Engineering and Design.* 84(3): 417-428.

[2] Chang, C. H. 2002. Modeling of Laminated Rubber Bearings Using an Analytical Stiffness Matrix. *International Journal of Solids and Structures.* 39(24): 6055-6078.

[3] Pinarbasi, S., & Akyuz, U. 2004. Investigation of Compressive Stiffness of Elastomeric Bearings, 6th International Congress on Advances in Civil Engineering, Bogazici University October 6–8, 2004, Istanbul, Turkey.

[4] Kumar, M. 2012. Analysis of Elastomeric Bearings in Compression. Unpublish Doctoral Dissertation, University at Buffalo, United State.

[5] Imbimbo, M., & De Luca, A. 1998. F. E. Stress Analysis of Rubber Bearings Under Axial Loads. *Computers & Structures.* 68(1-3): 31-39.

[6] Koo, G., Lee, J., Lee, H., & Yoo, B. 1999. Stability of Laminated Rubber Bearing and Its Application to Seismic Isolation. *KSME International Journal.* 13(8): 595-604.

[7] Othman, A. 2001. Property Profile of a Laminated Rubber Bearing. *Polymer Testing.* 20(2): 159-166.

[8] He, J., & Fu, Z. F. 2001. *Modal Analysis.* 1st Edition. Butterworth Heinemann.

[9] Doshin Rubber Product (M) Sdn. Bhd. 2014. E-Catalog. Retrieved March 3, 2015. from http://www.doshinrubber.com/catalog/index.php.

[10] Kelly, J. M., & Marsico, M. R. 2013. Tension Buckling in Rubber Bearings Affected by Cavitation. *Engineering Structures*. 56: 656-663.

[11] Osgooei, P. M., Tait, M. J., & Konstantinidis, D. 2014. Three Dimensional Finite Element Analysis of Circular Fiber Reinforced Elastomeric Bearings Under Compression. *Composite Structure*. 108: 191-204.

[12] Warn, G. P., & Weisman, J. 2011. Parametric Finite Element Investigation of The Critical Load Capacity of Elastomeric Strip Bearings. *Engineering Structures*. 33(12): 3509-3515.