

MECHANIC BEHAVIOUR OF ELASTOMERIC HOLLOW BASE ISOLATOR USING FINITE ELEMENT MODELING

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ABSTRACT: The principle of isolating a structural system from ground motion has been understood for many years, whereas numerous successful implementations have been applied in bridges or buildings that are mounted as a bearing. One of these devices appears as the laminated steel/elastomer bearing. Structural Earthquake Engineering Research (SEER) has been developing the hollow base isolator in order to reduce the horizontal stiffness of the isolator and to increase the effectiveness of the original one. The existing advanced computer programs used a finite element method based on the mechanic behaviour of elastomeric bearing under compressions and shear loads. The previous programs assumed the isolator as an elastic material. In contrast, the isolator is made from elastomeric rubber bearing which is not an elastic material. Therefore, the previous programs should be clarified or modified to obtain more reliable results. This paper describes the aspects of this research.

Keyword: Base isolator, elastomeric rubber bearing, hollow base isolator, horizontal stiffness, vertical stiffness.

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1. INTRODUCTION

Seismic safety, since the lesson learned from San Francisco earthquake of 1906, have been improved due primarily to the acceptance of ever increasing force levels to which building must be designed. Innovation has been confirmed to the development and acceptance of structural systems that perform reasonably well, accommodate architectural demands and enable material.

The choices for lateral resistance lie among shear wall, braced frames, and moment resistance frames. Over the years, these have been retained and their details developed, and method of analysis and modeling have improved and reduced uncertainty. But the basic approach has not changed: construct a ductile and/or strong building and attach it surely to the ground.

Designed structure, if it were to remain elastic, would still encounter forces several times above its designed capacity. This situation quite different from that for vertical forces, in which safety factor insure that actual forces will not exceed 50% of designed capacity unless a serious mistake has been made.

The new concept now is generally termed as seismic isolation. Mounting building on an isolation system will prevent most of the horizontal movement of the ground from being transmitted to the building. This result in a significant reduction in floor accelerations and interstory drifts, thereby providing protection to the building (*Fig. 1 and 2*). The principle of seismic isolation is to introduce flexibility at the base of a structure in the horizontal plane, while at the same time introducing damping elements to restrict the amplitude of the motion caused by the earthquake.

Base isolation is today an accepted design alternative for earthquake hazard mitigation for structures or bridges. Typically such devices fall into two broad categories: the laminated rubber bearing systems and friction systems. The laminated rubber bearing systems shift the fundamental periods of the structure away from the frequencies of the ground motion that contain significant energy additional devices are used to provide energy dissipation. In the

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friction type systems, the maximum force transmitted to the superstructure is limited and energy dissipation is achieved through friction. In this paper, the device is focused to laminated rubber bearing or elastomeric rubber bearing.

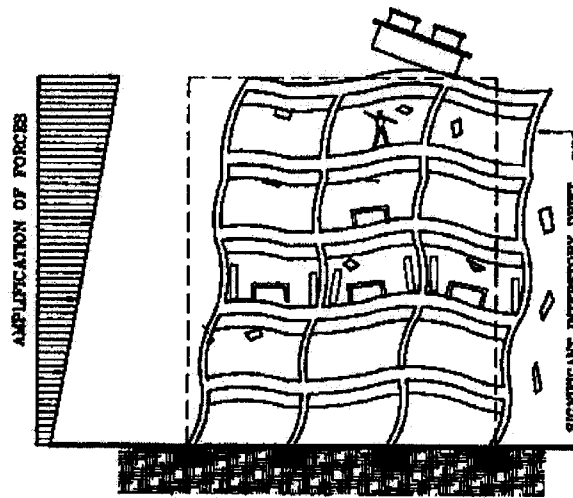


Fig. 1. Conventional Structure (Mayes,)

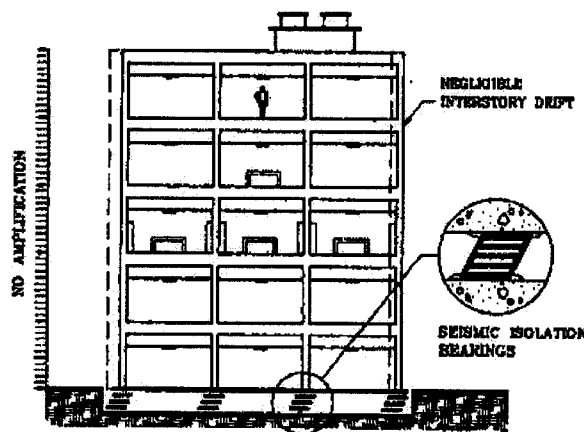


Fig. 2. Base Isolated Structure (Mayes,)

Elastomeric rubber bearings consist of thin layers of natural rubber that are vulcanized and bonded to steel plates. Natural rubber exhibits a complex mechanical behaviour, which can be described simply as combinations of viscoelastic and hysteretic behaviour. Low-damping natural rubber bearings exhibit essentially linearly elastic and linearly viscous behaviour at large shear strains.

2. FINITE ELEMENT MODELING

Elastomeric rubber bearings have finite vertical stiffness that affects the vertical response of the isolated structure. The vertical stiffness, k_v , of an elastomeric rubber bearing can be obtained using the following formula.

$$k_v = \frac{P}{\delta} = \frac{E_c A}{nt} \quad (1)$$

where P is the vertical load, δ is the vertical displacement, A is the cross sectional area of the bearing, n is the number of elastomeric layers, t is the thickness of each layers and E_c is the compression modulus of elastomer. Although some approximations using empirical method have been proposed for calculating the compressions modulus, the most acceptable expressions for circular bearings is proposed by Kelly (1993) as follow.

$$E_c = \left(\frac{1}{6G_{eff}S^2} + \frac{4}{3K} \right)^{-1} \quad (2)$$

where K is the bulk modulus (typically assumed to have a value of 2000 MPa) and S is the shape factor, which is defined as the ratio of the loaded area to the bonded perimeter of a single rubber layer. For a circular bearing of bonded diameter Φ and rubber layer thickness t , the shape factor is given by

$$S = \frac{\Phi}{4t} \quad (3)$$

A similar approach leads to the horizontal stiffness, k_h , is expressed as

$$k_h = \frac{F}{\Delta} = \frac{GA}{nt} \quad (4)$$

where F is the horizontal load, Δ is the horizontal displacement, and G is the shear modulus of elastomer. Ratio of vertical to horizontal stiffness is k_h/k_v .

Seismic elastomeric bearings are generally designed with large shape factor, typically 12 to 20. Considering an elastomeric bearing design with $S = 15$, $G_{eff} = 1$ MPa, and $K = 2000$ MPa, the ratio of vertical stiffness to effective horizontal stiffness is approximately equal to 700. Thus, the vertical period of vibration of a structure on elastomeric isolation will be about 26 times less than the horizontal period on the order of 0.1 second. The value of vertical period provides potential for amplification of the vertical ground acceleration by isolation system. The primary effect of this amplification is to chance the vertical load on bearings, which may need to be considered for certain design application.

Another consideration in the design of seismically isolated structure with elastomeric rubber bearings is reduction of horizontal stiffness of a bearing for the hollow isolator. Modification of the expressions for this bearing has been providing in this paper. Clearly, the equations do not reflect the observed nonlinear behaviour of elastomer, do not account for large deflections, or do not provide any information regarding the internal stresses strain within the bearing. Therefore, a more realistic mathematical model is required in order to improve the understanding regarding the actual behaviour of multi-layered isolators.

Since elastomeric bearings experience large deformations and the elastomer behaves nonlinearly, the finite element formulation (FEM) must include geometric and material nonlinearities in order to obtain the reliable results. The results of the analysis are very sensitive to the value material properties. Hence, the values that represent the elastomer and its material properties become significant problems in analyzing the isolator using FEM. It is difficult to determine these parameters experimentally; therefore in this study the parameters

are determined based on parameter analysis using software COSMOS.

2.1 Three Dimensional Model of Base Isolator

The data of base isolator for modeling were taken from Japan (Nazira, 2003) (*Table 1* and *Table 2*). The analysis of base isolator was conducted using SAP90. Two models of base isolator were analyzed in this research. The first is the conventional base isolator and the second is the base isolator with zigzag inner steel. Both of them have the same dimensions and data properties but different in steel shape of base isolator.

Table 1. Input data for modeling

Descriptions	Types of Base Isolator	
	Conventional	Hollow
No. of Layer	35 layer – 18 rubber – 17 steel	35 layer – 18 rubber – 17 steel
Thickness	Rubber – 6.7 mm Steel – 3 mm	Rubber – 6.7 mm Steel – 3 mm
No. of element	925 solid element	925 solid element
Dimensions	0.445 m x 0.445 m	0.445 m x 0.445 m

Table 2. Material properties of base isolator

Property Name	Rubber	Steel
Elastic modulus	$6.1 \times 10^6 \text{ N/m}^2$	$1.9 \times 10^{11} \text{ N/m}^2$
Poisson's ratio	0.49	29
Shear modulus	$2.9 \times 10^6 \text{ N/m}^2$	$7.5 \times 10^{10} \text{ N/m}^2$
Thermal expansion coefficient	0.00067 /Kelvin	1.8e-005 /Kelvin
Mass density	1000 kg/m ³	8000 kg/m ³
Thermal conductivity	0.14 W/(m.K)	16 W/(m.K)
Tensile strength	$1.3787 \times 10^7 \text{ N/m}^2$	$5.1702 \times 10^8 \text{ N/m}^2$
Yield strength	$9.2374 \times 10^6 \text{ N/m}^2$	$2.0681 \times 10^8 \text{ N/m}^2$

The devices were analyzed under two directions of loading, i.e. vertical and horizontal directions with two different values for each direction. *Table 3* shows the loading values for both directions. *Fig. 3* shows the position of the load on the base isolator.

Table 3. Loading value on both directions

Load Number	Vertical Loading (P)kN	Horizontal Loading (H)kN
Load 1	10	10
Load 2	20	20

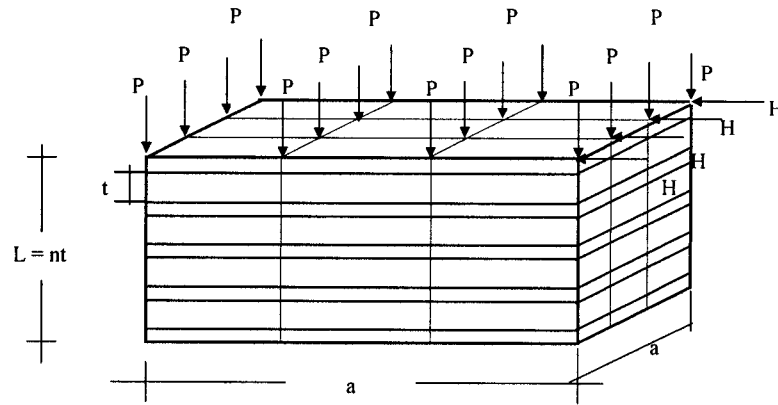


Fig. 3. The position of vertical load (P) and horizontal load (H) due to base isolator

Two types of base isolators, which were studied in this research, can be seen in the Fig. 4.

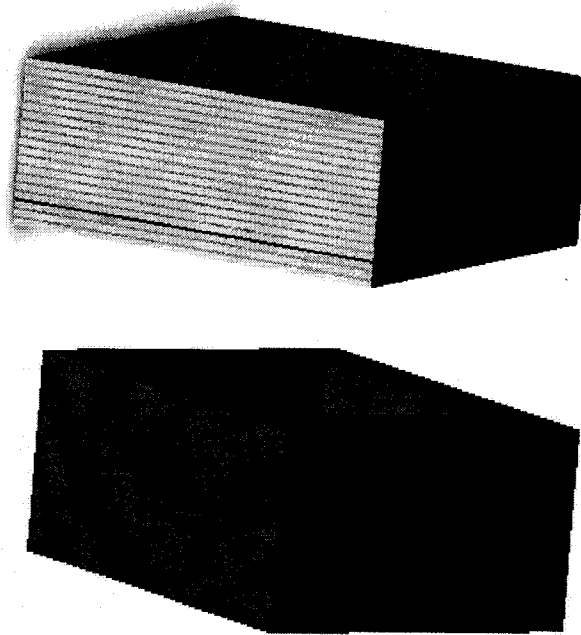


Fig. 4. (a) Conventional base isolator – no scaled (b) Hollow base isolator-no scaled

2.2 Discussion of Results

The displacement, the strain and the stress of the bearings due to load number 1 are shown in Fig.5-7. The maximum displacement, maximum and minimum strain and stress of the bearings due to load number 1 and load number 2 are shown in Table 4.

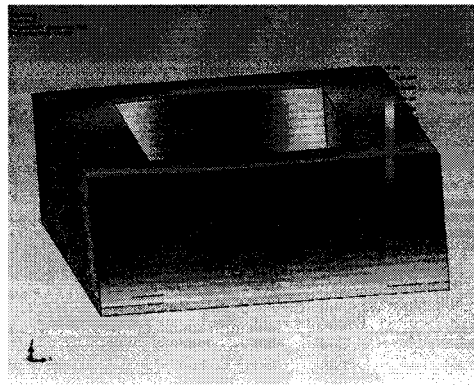
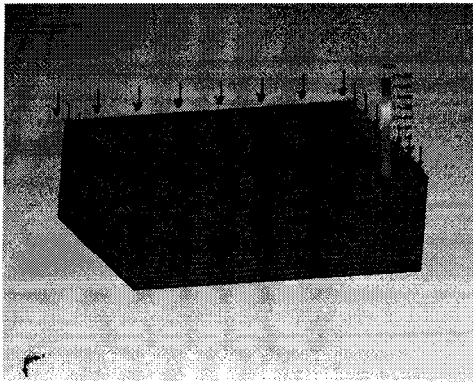


Fig.5. Displacement of base isolator

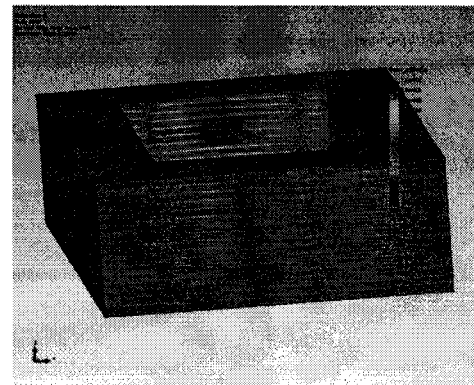
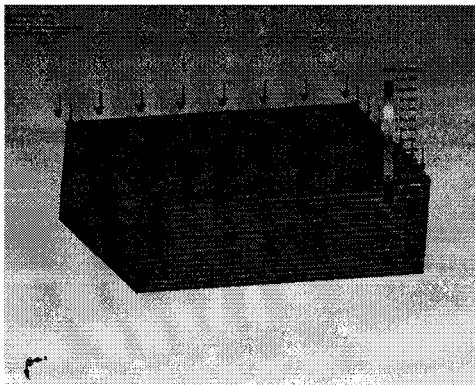


Fig.6. Strain of base isolator

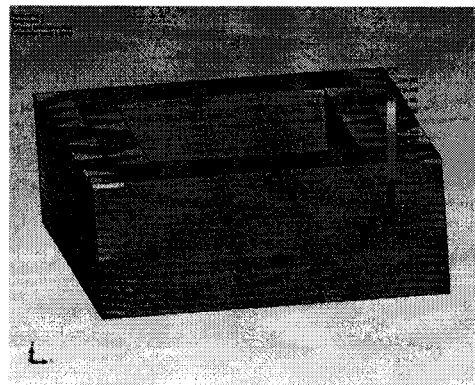
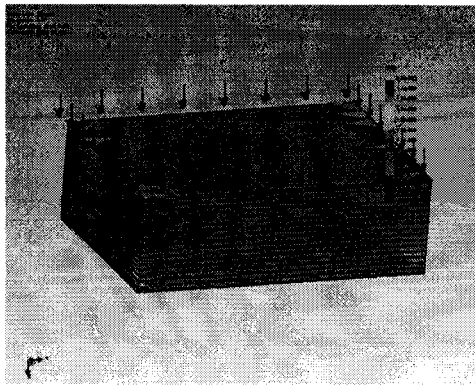


Fig. 7. Stress of base isolator

Table 4. Responses of base isolator

Load	Max. Deflection (m)		Strain			Stress (N/m ²)		
	Conventional	Hollow		Conventional	Hollow		Conventional	Hollow
10 kN	0.0030	0.00498	Max	0.0192269	0.0322226	Max	5.576x10 ⁶	2.202x10 ⁷
			Min	1.22314x10 ⁻⁷	4.41426x10 ⁻⁷	Min	-5.046x10 ⁶	-1.942x10 ⁷
20 kN	0.0060	0.00996	Max	0.0384538	0.0644453	Max	1.115x10 ⁷	4.404x10 ⁷
			Min	2.44629x10 ⁻⁷	8.82851x10 ⁻⁷	Min	-1.009x10 ⁷	-3.884x10 ⁷

Table 5 shows that for both types of Base Isolators, the Vertical Stiffness value is larger than the Horizontal Stiffness value. These results prove that the modeling is satisfied the design rules for bearing or Base Isolator that the vertical stiffness has to be greater than the horizontal stiffness. This is to ensure that the rocking and other unwanted modes can be minimized.

Table 5. Vertical and horizontal stiffness for both base isolators

Type	Description	Stiffness
Conventional	Vertical stiffness	3.23 x 10 ⁷ N/m
	Horizontal stiffness	3.35 x 10 ⁶ N/m
	Ratio	0.0108
Hollow	Vertical stiffness	3.44 x 10 ⁷ N/m
	Horizontal stiffness	2.019 x 10 ⁶ N/m
	Ratio	0.0587

The ratio of Vertical Stiffness to the Horizontal Stiffness was calculated for both Base Isolators. The ratio is calculated in order to know the efficiency of Base Isolator. It can be seen from Table 5 that the Hollow Base Isolator has larger ratio than the Conventional Base Isolator.

3. CONCLUSIONS

From the research, it can be concluded that by changing the geometries of the base isolator, the stiffness values would also change. The hollow base isolator is efficient compared to the conventional base isolator because the ratio of the stiffness of the hollow base isolator is higher than the conventional one.

4. ACKNOWLEDGMENT

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