EVALUATION OF LAMINATED HOLLOW CIRCULAR ELASTOMERIC RUBBER BEARING

J. Sunaryati[1], Azlan Adnan[2] and M.Z. Ramli[3]

[1] *Dept. of Civil Engineering , Engineering Faculty, Universitas Andalas. Indonesia*
[2] *Professor, Faculty of Civil Engineering, Universiti Teknologi Malaysia*
[3]*Faculty of Civil Engineering, Universiti Teknologi Malaysia*
Email: sunaryati_jati@yahoo.com, azelan@fka.utm.my,

ABSTRACT :
This paper evaluates the behavior and performance of laminated hollow circular elastomeric rubber bearings (HRB) and compares them to solid circular elastomeric rubber bearing (SRB). This research intend to develop new model of elastomeric rubber bearing to obtain more lengthens flexibility of fundamental period of elastomeric rubber bearing; the hollow base isolator. Finite element models were constructed and analyzed to find the mechanical behavior of the rubber bearing. Then, the confirmation towards specification for design, manufacturing and testing of isolation devices must be established. The study included experimental investigation of the hollow rubber bearing under cyclic loading test to evaluate the lateral stiffness and equivalent damping ratio of the isolator. Results from this limited study showed that steel stress and strain in SRB greater than steel stress in HRB but still below from allowable stress design value. On the other hand, stress of rubber in SRB is less than rubber stressed in HRB but still below from allowable design stress of rubber. Results from cyclic loading test showed that even though HRB has effective stiffness less than SRB, but HRB has damping ratio better than SRB. It is because event thought HRB has dissipated energy less than SRB, but the elastic strain energy of SRB more solid than HRB that make the damping ratio of SRB less than HRB.

KEYWORDS:
Elastomeric rubber bearing, solid rubber bearing, hollow rubber bearing, flexibility, cyclic loading test.

1. INTRODUCTION

Currently, base isolation techniques were actively adopted in the construction of building, bridges, and other structures. The basic principles of base isolation are to reduce the input earthquake energy with soft bearing, and to restrain excessive displacement by damping. Code provisions for base isolated buildings and bridges have been developed in many countries and utilized for actual structures such as in Armenia, Chile, China, Indonesia, Malaysia, Italy, Japan, New Zealand, the United States and Uzbekistan.

The isolation system reduces the effect of the horizontal components of the ground acceleration by interposing structural elements with low horizontal stiffness between the structure and the foundation. This gives the structure a fundamental frequency that is much lower than both its fixed-base frequency and the predominant frequencies of the ground motion. The isolation system does not absorb the earthquake energy, but deflects it through the dynamics of the system.

Most recent examples of isolated buildings use elastomeric rubber bearings with steel reinforcing layers as the load-carrying component of the system. Because of the reinforcing steel plates, these bearings are very stiff in the vertical direction but soft in the horizontal direction, thereby producing the isolation effect. These bearings are easy to manufacture, have no moving parts, are unaffected by time, and resist environmental degradation.

In seismic protection it is beneficial to have different stiffness in two plane directions to provide a better protection of dynamic characteristic structures. Therefore a special design of base isolators with hollow is investigated, where the diameter of the hole is 20% of the outer diameter.

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.

$$k_v = \frac{P}{\delta} = \frac{E_c A}{nt} \tag{1}$$

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.

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

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

$$S = \frac{\Phi}{4t} \tag{3}$$

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

$$k_h = \frac{F}{\Delta} = \frac{GA}{nt} \tag{4}$$

where F is the horizontal load, Δ is the horizontal displacement, and G is the shear modulus of elastomer. Considering an elastomeric bearing design G_{eff} = 0.7 MPa, and K = 2000 MPa..

Since elastomeric bearings experience large deformations and the elastomer behaves nonlinearly, the Finite Element Modeling (FEM) must include geometric and material nonlinearities in order to obtain the reliable results. The elastomer and its material properties are usually 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 computer software.

2.1. Three Dimensional Model of Elastomeric Rubber Bearings

There are two geometric types of elastomeric are designed and analyzed in this study; the conventional isolator and the elastomeric hollow rubber bearing. The dimensions of both the elastomeric can be shown in Figures 1 and 2. The modulus of elasticity of the steel is 20 x 10^6 kN/m^2 and 14 x 10^3 kN/m^2 for rubber. The poison ratio for the steel and the rubber are 0.3 and 0.6 respectively. The design parameters of both elastomeric rubber bearings can be shown at Table1.

The devices were analyzed under two directions of loading, i.e. vertical and horizontal directions. Table 2 shows the loading values for load directions. Figures 3 and 4 show the mesh of the base isolator's model.

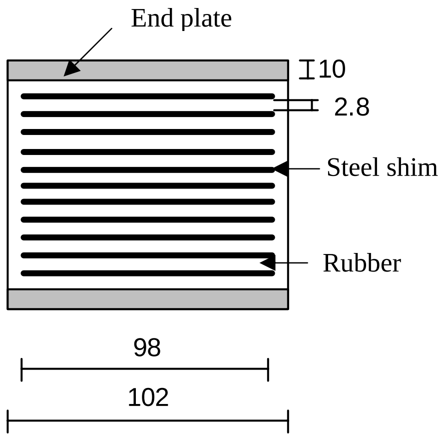

Figure 1 Solid rubber bearing (SRB)

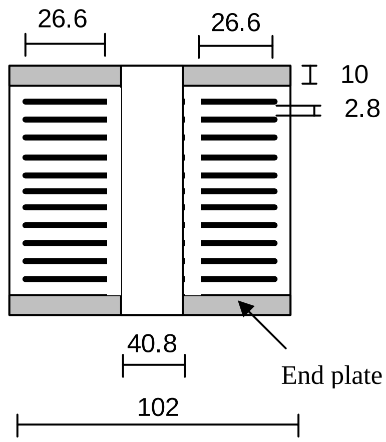

Figure 2 Hollow rubber bearing *(HRB)*

Table 1 Data The design parameter of the elastomeric rubber bearings

Parameters	Solid Rubber Bearing	Hollow Rubber Bearing
Vertical design load (kN)	25	25
Nominal shear stiffness (kN/mm)	0.082	0.078
Nominal vertical stiffness (kN/mm)	13.256	13.234
Nominal vertical natural frequency (Hz)	5.79	5.79
Safety factor	3.59	2.05
Critical load (kN)	89.82	50.2
Rollout instability (mm)	26	21

Table 2 Loading value on both directions

Load Number	Vertical Loading (P) kN	Horizontal Loading (H) kN
Load 1	5	5
Load 2	10	10
Load 3	15	15
Load 4	20	20

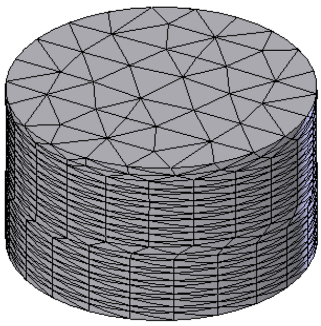

Figure 3 The mesh of solid rubber bearing

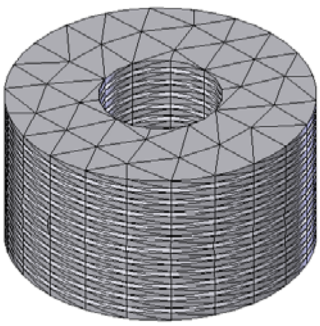

Figure 4 The mesh of hollow rubber bearing

2.2 Results from finite element models

Figure 5 shows the stresses of the bearings and Figure 6 shows the stress of the bearings. It is recognized that displacements, stresses and strains of two bearing are different even each bearing is applied in the same vertical and horizontal loadings. The graphs loading versus displacement with different direction of loadings were plotted at Figures 7 and 8 for each bearing. Summarized responses of the bearing can be shown at Table 3.

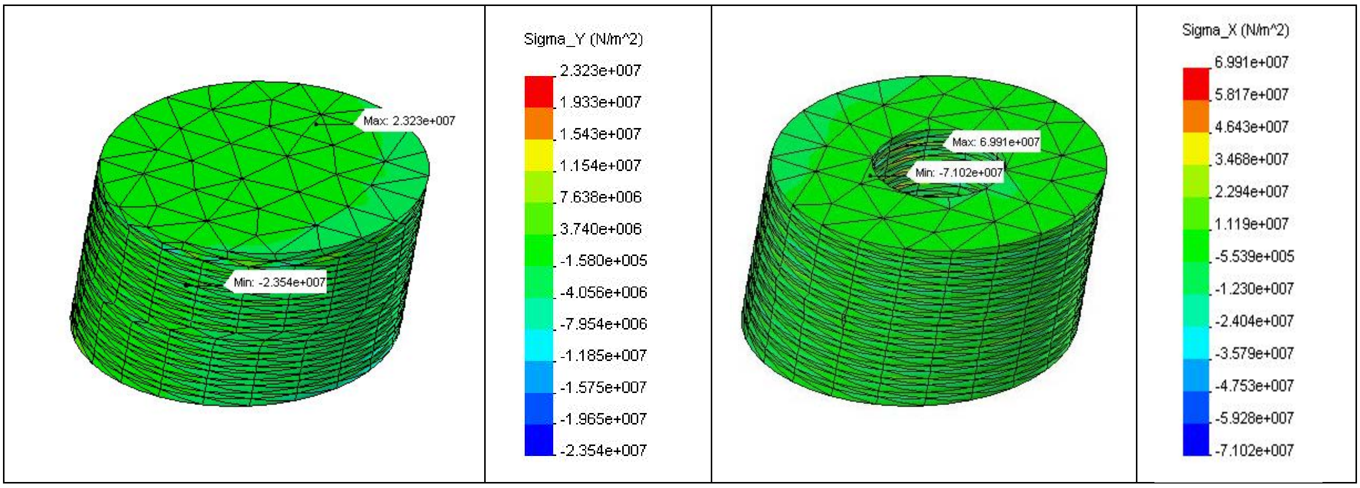

Figure 5 Stress of elastomeric rubber bearing

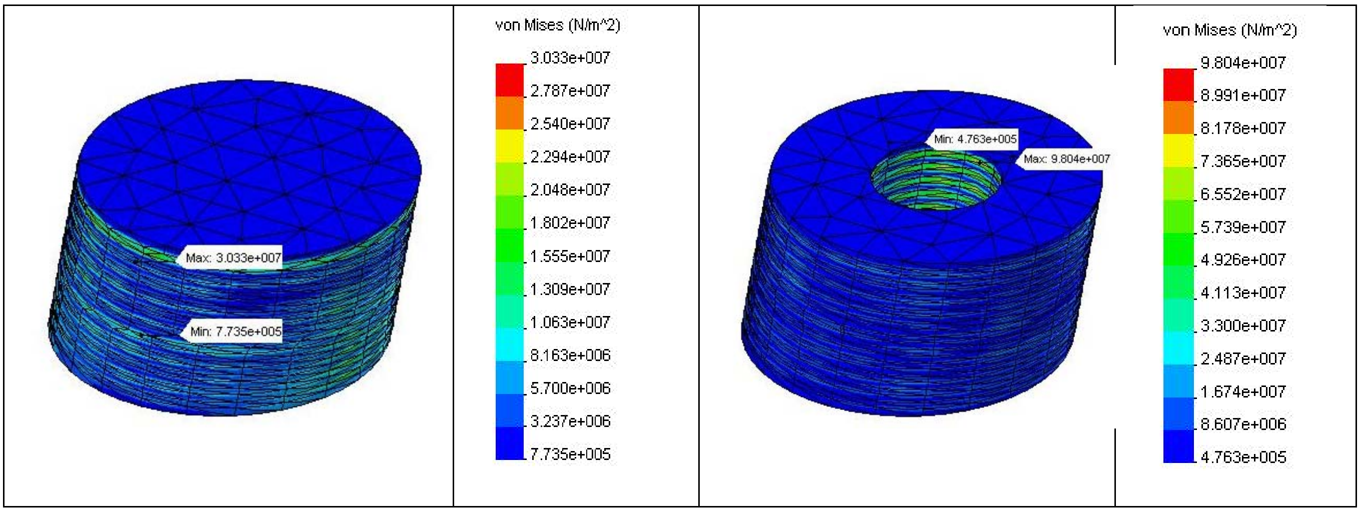

Figure 6 Strain of elastomeric rubber bearing

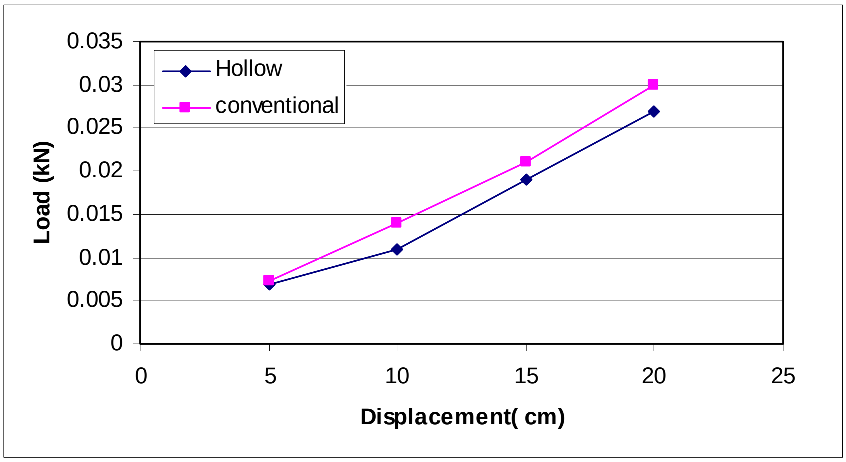

Figure 7 Horizontal loads versus displacement of the bearings

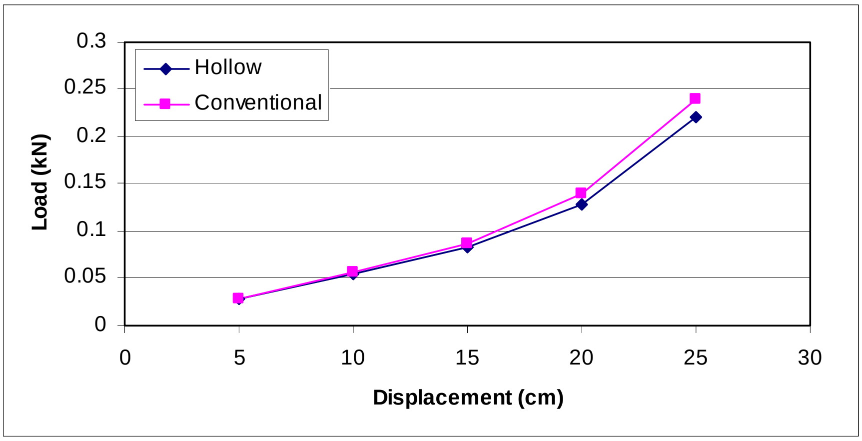

Figure 8 Vertical loads versus displacement of the bearings

Table 3 Responses of base isolator

Load (kN)	Max. Deflection (m)		Strain			Stress (MN/m^2)		
	Original	Hollow		Original	Hollow		Original	Hollow
5	0.011	0.012	Max	6.2	9.5	Max	540	770
			Min	0.000041	0.000015	Min	3.6	3.9
10	0.022	0.024	Max	12	19.1	Max	1100	1500
			Min	0.000082	0.000031	Min	7.2	7.8
15	0.033	0.037	Max	18.7	28.6	Max	1600	2300
			Min	0.00012	0.00044	Min	11	12
20	0.044	0.049	Max	24.9	38.1	Max	2100	3100
			Min	0.00016	0.00062	Min	14	16

3. EXPERIMENTAL TEST OF ELASTOMERIC RUBBER BEARINGS

To verify the numerical simulation that have been done, there is laboratory testing presented in this chapter, i.e. elastomeric rubber bearing test to obtain the mechanical properties of elastomeric rubber bearing.

3.1 Compression Test

An Elastomeric Testing Machine *(ETM)* was used for the vertical load tests. The facility consisted of a 100 kN capacity actuator with mini controller. The actuator was mechanically connected to the specimen through a reaction-loading frame. The frame had two thick circular plates with Teflon coating. The compression test on bearings was carried out under displacement control condition; the rate of displacement was kept as 0.5 mm per minute. The test was carried out up to 25 kN loads.

The compression test of *SRB* and *HRB* are shown in Figure 9 and 10 respectively. Under the displacement control condition, the vertical stiffness of rubber bearing can be determined as load per stroke. The average of vertical stiffness of bearing can be calculated as shown in Table 4. Table shows that the vertical stiffness of *SRB* from the experimental value lower than design value, while the vertical stiffness of *HRB* from experimental higher than design value.

Table 4 Vertical Stiffness of rubber bearing

	SRB	HRB
Design Model	23.107 MN/m	7.217 MN/m
Experimental	20.779 MN/m	7.589 MN/m

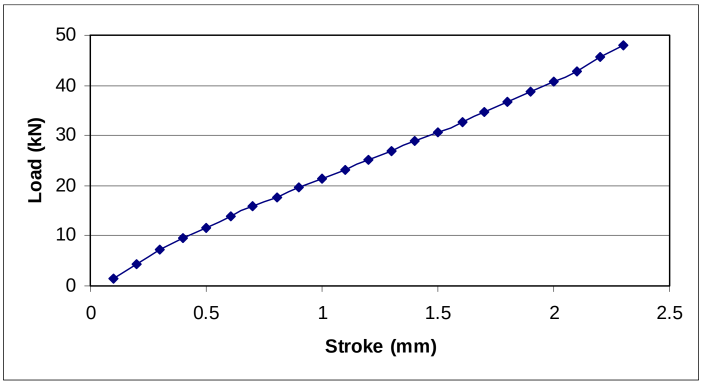

Figure 9 Load (kN) - stroke (mm) behaviour of SRB in compression load

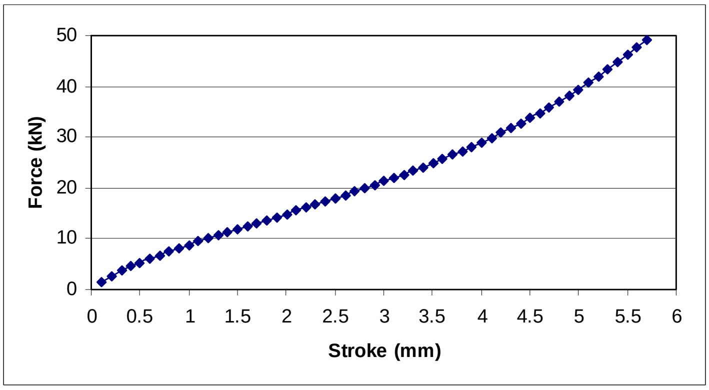

Figure 10 Load (kN) - stroke (mm) behaviour of HRB in compression load

3.2 Dynamic Test

The dynamic mechanical properties of the rubber bearing can determine by dynamic test. These are usually done to evaluate lateral stiffness and equivalent damping ratios of the isolators. In this experiment, two rubber bearings were tested in a double shear configuration simultaneously, as shown in Figure 11. The cyclic loading test in this research used the facility at Rubber Research Institute Malaysia *(RRIM)*, Sungai Buloh, Malaysia.


Figure 11 Cyclic test loading of rubber bearing

The hysteresis loop for 25 kN amplitude cycle and 150 % shear strain is shown in Figure 12 and Figure 13 for solid rubber bearing and hollow rubber bearing respectively. The loop shows that the load-deflection behaviour of the isolation bearings used in the study is mildly non-linear. The hysteresis loops, obtained from a series of similar tests with different frequencies are plotted in Figure 12 and 13 for solid rubber and hollow rubber bearing respectively.

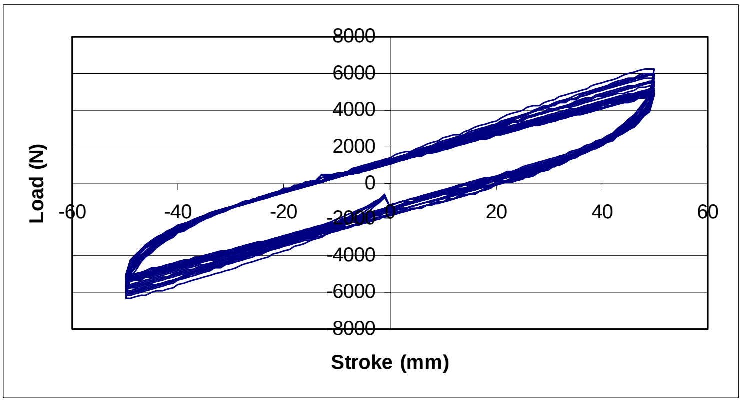

Figure 12 Load – deflection behavior of SRB in 5 cycles frequency (0.5 Hz)

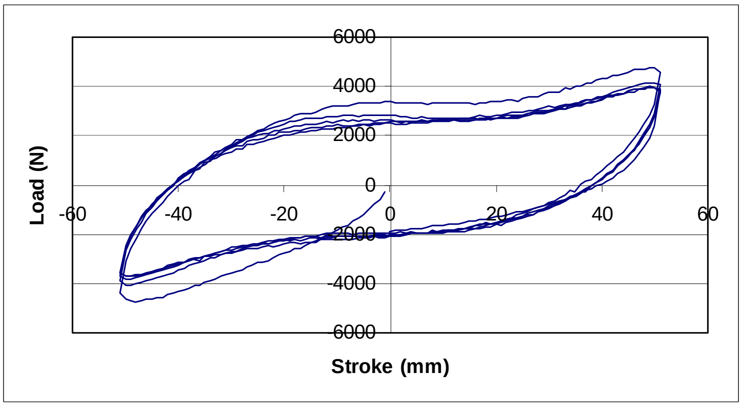

Figure 13 Load – deflection behavior of HRB in 5 cycles frequency (0.5 Hz)

Effective stiffness of *SRB* and *HRB* from the design model and experimental test are shown in Table 5. The table shows that the effective stiffness for both rubber bearings from the experimental have higher values than effective stiffness of design rubber bearing.

Table 5 Shear Stiffness of rubber bearing

	SRB	HRB
Design Model	0.0976 MN/m	0.082 MN/m
Experimental	0.123 MN/m	0.084 MN/m

4. CONCLUSIONS

By using HRB, the stiffness of the bearing are reduced almost 69% for vertical stiffness and 16% for horizontal stiffness. It made *HRB* has more possibility to have more deformation than *SRB*. It is because stiffness is a material's resistance to deformation while deformation includes bending and elongation. A material with greater stiffness will deform less under a given load than a material with lower stiffness. The lower the stiffness, the higher the period, and consequently the performances of *HRB* will be better if it used as isolator for a base isolated structure while maintain the stability of isolator.
Studies on the nonlinear mechanical behaviour (e.g. horizontal and vertical displacement, stress and strain) of the elastomeric rubber bearings were also accomplished using finite element model. From the finite element models, the results showed that the normal stress of rubber in *HRB* is 35% greater than that of *SRB*, while von Mises stress of rubber in *HRB* is 68% greater than that of *SRB*. As the same time the normal stress of steel shim in *HRB* is 54% less than that of *SRB* and von Mises stress of *HRB* is 69% less than that of *SRB*.

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