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Finite Element Analysis of Elastomeric Bearing

Febymol K B[1], Rohini G Nair[2]
[1, 2]Department of Civil Engineering, Ilahia College of Engineering & Technology, Mulavoor, Kerala, India-686673

Abstract— *Base isolation is a mechanism that provides earthquake resistance to the new structure. The base isolation system decouples the building from the horizontal ground motion induced by earthquake, and offers very stiff vertical components to the base level of the superstructure in connection to substructure.*

The work deals with modeling and finite element analysis of elastomeric bearing with and without holes in ANSYS 14.5. It also include a comparison of different geometry and a parametric study on the influence of number of layers on stiffness of bearing.

Keywords—*Base isolation; elastomeric bearing; stiffness comparison*

I. Introduction

Base isolation is one of the most popular means of protecting a structure against earthquake forces. It is a collection of structural elements which should substantially decouple a superstructure from its substructure resting on a shaking ground thus protecting a building or non-building structure's integrity. Seismic isolation systems are more effective when applied to high stiffness, low-rise buildings, owing to their abilities to alter the characteristic of the building from rigid to flexible. Figure 1 shows the behavior of a fixed base and an isolated building during an earthquake.

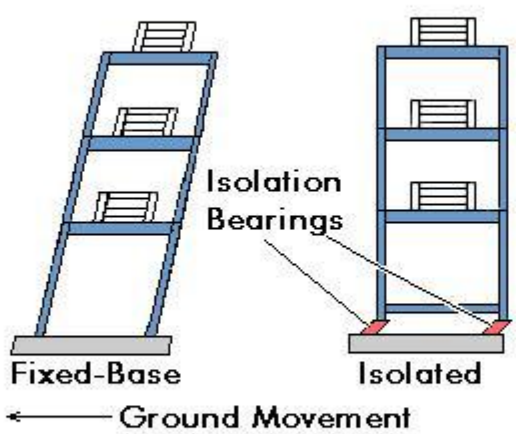

Fig. 1. Basic principle of base isolation.

The aim of this study is to analyze simple elastomeric bearing and bearing with four holes having different diameters in order to compare their horizontal stiffness. In this paper the numerical modeling of elastomeric bearings is implemented using ANSYS 14.5. A comparison of square, rectangular and circular bearings was done based on vertical stress. It also includes a parametric study on the influence of number of layers on the vertical stress and horizontal stiffness of the bearing. The size of the bearing can be fixed based on the maximum support reaction and horizontal displacement. So a three storey building is modeled in ETABS 2015 and the maximum support reaction is obtained as 1200 kN. All the models were analyzed by applying a vertical load of 1200 kN and a horizontal displacement of 50 mm.

II. Analysis Model

A. Design of Bearing

Because of the displacement dependence, the design process of elastomeric bearing is iterative, as shown in forms of flow chart in figure 2.

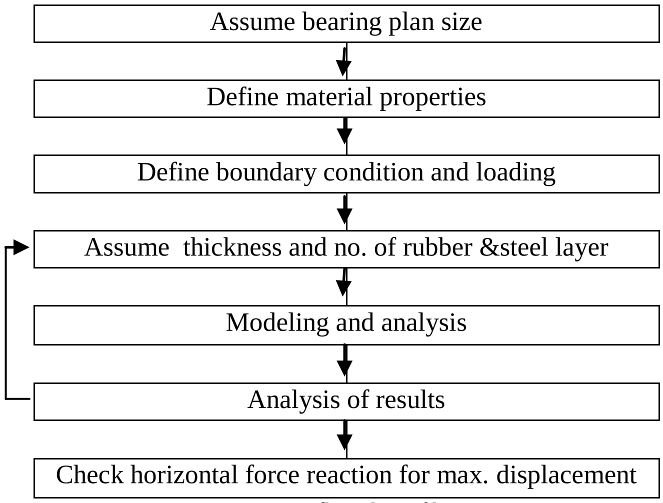

Fig. 2. Design flow chart of bearing.

B. Dimensions of Bearing

The elastomeric bearings were modeled with the finite element method in Ansys APDL software using the Static Structural analysis type. The dimensions of the model are given in table I.

TABLE I. Dimensions of the bearing.

Size of bearing	380 × 380 mm
No. of rubber layers	30
Thickness of rubber layers	12 mm
Thickness of steel plate	10 mm

C. Material Property

Rubber is a hyperelastic material and the material property is defined by strain energy function (W).

$$W=C_{10}(I_1-3)+C_{01}(I_2-3)+C_{20}(I_1-3)^2+C_{02}(I_2-3)^2+C_{11}(I_1-3)(I_2-3)$$

The polynomial 2-P function is used here and the material parameters were obtained as follows [3]:

$C_{10} = 0.797$
$C_{01} = -0.0591$
$C_{20} = 0.01609$
$C_{02} = -0.00529$
$C_{11} = 1.103$ e-3

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Steel is modeled as linearly elastic and isotropic material with E= 2×10^5 MPa and μ=0.3.

D. Modeling

The elements used are, SOLID 185 for rubber layers and SHELL 181 for steel layers. Contact is given by the coupling of coinciding nodes. The isolator is totally constraint at its base. The load and displacement are applied to the top nodes of the bearing.

III. Performance Comparison of Bearing With and Without Holes

To study the effect of holes on the stiffness, bearings were modeled without hole and with four holes having different diameters. Bearings were analyzed by applying a vertical load of 1200 kN and a horizontal displacement of 50 mm. Different analysis cases are as shown in table II.

TABLE II. Analysis cases.

Analysis case	1	2	3	4	5
Diameter of hole	-	15	20	25	30

The model of bearing without hole and with 15 mm hole is given in figure 3 and 4 respectively.

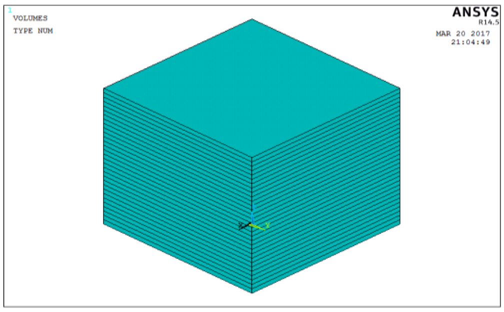

Fig. 3. Model of bearing without hole.

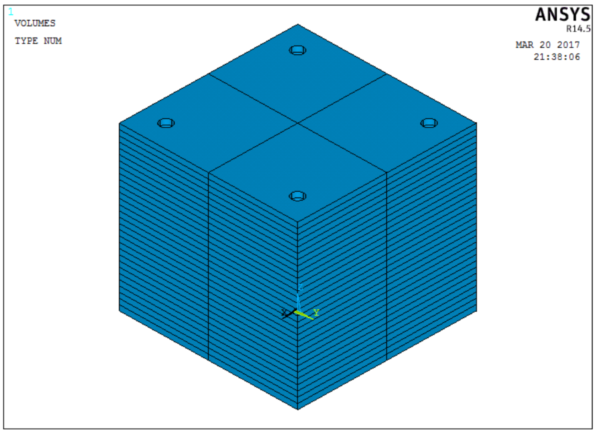

Fig. 4. Model of bearing with 15 mm hole.

Deflected shape of bearing without hole is given in figure 5.

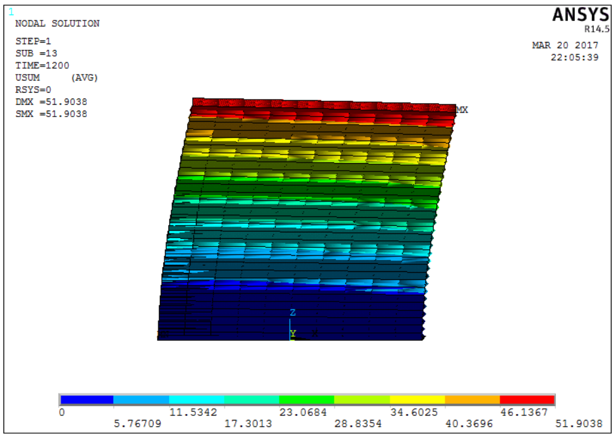

Fig. 5. Deflected shape of bearing without hole.

Table III shows the value of horizontal force reaction (F_x) and deflection for bearings with and without holes and their corresponding horizontal stiffness.

TABLE III. Comparison of horizontal stiffness

Hole dia	F_x (N)	Deflection (mm)	Stiffness N/mm	% reduction in stiffness
0	4531.131	51.9038	87.298	
15	3654.315	53.9445	67.74	22.9
20	3998.427	54.2692	55.251	36.7
25	2133.049	53.819	39.634	54.6
30	1839.02	55.5209	33.123	62.0

From the results it is clear that as the diameter of holes increases, there is a reduction in the stiffness of the bearing. In other words, as the diameter of hole increases, the bearing become more flexible in horizontal direction. A graphical representation of this is shown in figure 6.

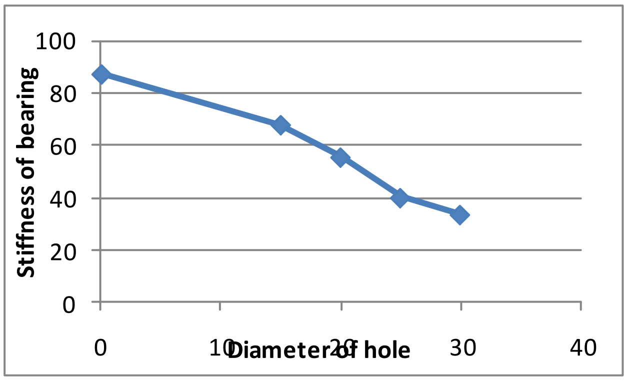

Fig. 6. Variation of stiffness with diameter of hole in the bearing.

IV. Comparison of Geometry

Comparison between square, rectangular and circular isolator is conducted on a 30 layered model. All geometries are having the same top area and are analyzed by applying a vertical load of 1200 kN and a horizontal displacement of 50 mm. Model of circular, square and rectangular bearings are shown in figure 7, 8 and 9 respectively

Diameter of circular bearing = 430 mm
Size of square bearing = 380mm ×380 mm

Size of rectangular bearing = 480mm × 300 mm

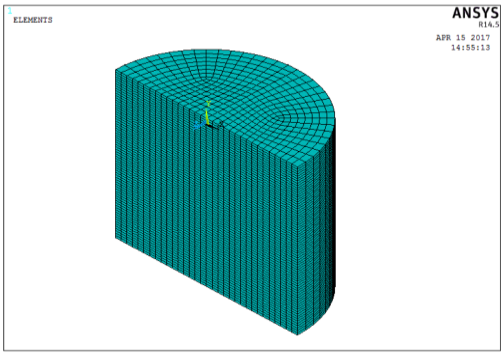

Fig. 7. Model of circular bearing.

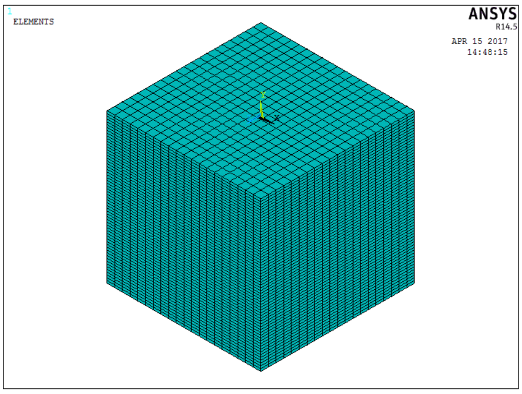

Fig. 8. Model of square bearing.

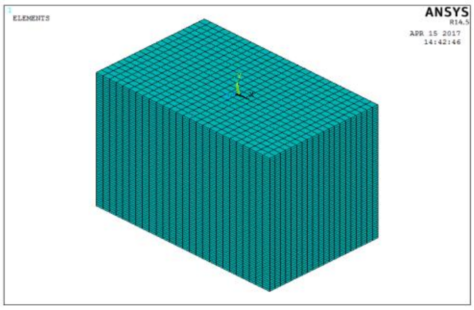

Fig. 9. Model of rectangular bearing.

A comparison of stresses of the three geometries is given in table IV.

TABLE IV. Comparison of three geometries.

Geometry	Circular	Square	Rectangular
Vertical stress S_y	-35.0528	-40.9291	-44.9758
	0.012169	2.8779	3.7749
Horizontal shear S_{xz}	-15.3112	-21.3806	-22.4299
	15.3131	21.3806	22.4299
Deflection	52.1096	52.8837	52.8858

On comparing the three geometries, circular isolators have lesser vertical stress (compressive and tensile) than that of square and rectangular isolators.

V. Parametric Study

The performance of laminated rubber bearings are influenced by the presence of laminates. Configuration refers to the number of layers and their thickness. Variation in configuration results in change in shear stiffness of the isolator.

The configuration of the rubber bearing was studied using different number of rubber layers and the height was kept constant. 25, 30, 35, 40, 45 and 50 layered isolators were modeled. The models were analyzed by applying a vertical load of 1200 kN and a horizontal displacement of 50 mm. Variation of vertical stress and horizontal stiffness with number of layers were studied. The dimension of the models in which analysis was done is shown in table V.

Table V. Dimensions of models for parametric study.

No. of layers	Rubber	Steel
25	14.4	12.1
30	12	10
35	10.3	8.53
40	9	7.44
45	8	6.6
50	7.2	4.92

The circular isolator is totally constraint at its base and only half of the isolator is modeled as it exhibits symmetric behavior. The nodes at the top surface are coupled in Y direction and X direction. Vertical load and horizontal displacements are applied to the first node on the top surface.

Vertical stress diagram of the model with 25 numbers of layers is shown on figure 10.

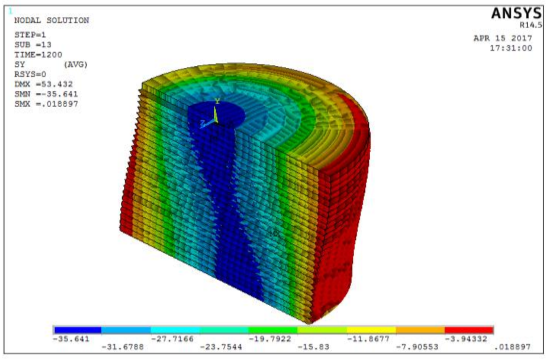

Fig. 10. Vertical stress contour plot – 25 layered.

A comparison of vertical stress and shear stress for circular isolators having different number of layers is shown in table VI.

TABLE VI. Comparison of stresses.

No. of layers	Vertical stress		Shear stress	
25	-35.641	0.018897	-13.6464	13.6502
30	-35.0528	0.012169	-15.3112	15.3131
35	-34.4791	0.00928	-16.8292	16.8305
40	-34.2896	0.007898	-18.1123	18.1131
45	-34.0961	0.05284	-19.0526	19.0531
50	-34.0257	0.202625	-19.5844	19.5848

As the number of layers increases, there is a slight decrease in the vertical stress. But the shear stress increases with increase in number of layers. A comparison of horizontal force reaction (F_x) and horizontal stiffness for circular isolator with different number of layers is given in table VII.

TABLE VII. Comparison of stiffness.

No. of layers	F_x	Deflection	Stiffness
25	2194.248	53.432	41.066
30	5530.154	52.1096	106.125
35	7520.731	51.411	146.286
40	8909.208	50.9938	174.712
45	9832.832	50.7389	193.793
50	10493.47	50.5704	207.502

The horizontal stiffness is minimum for the isolator with 25 numbers of layers and the stiffness increases with increase in the number of layers. That is, as the number of layers increases, the bearing becomes more and more stiff. The variation of stiffness with number of layers is shown in figure 11.

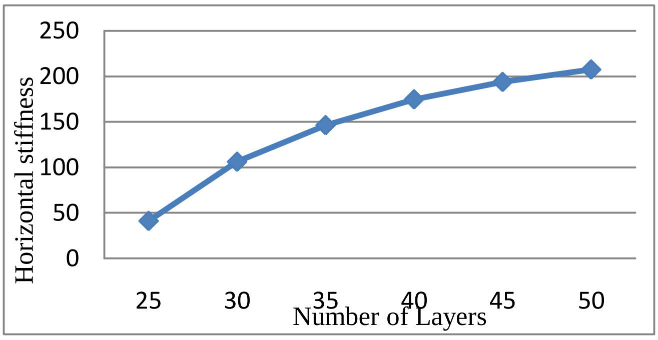

Fig. 11. Variation of stiffness with number of layers.

VI. CONCLUSIONS

Elastomeric bearings were modeled and nonlinear finite element analysis was done using ANSYS 14.5. The main conclusions were:

- As the diameter of holes increases, there is a reduction in the stiffness of the bearing.
- On comparing the circular, square and rectangular geometries, circular shape was found as the best one.
- As the number of layers increases for a constant thickness, vertical stress decreases.
- There is an increase in the horizontal shear stress with increase in number of layers.
- Horizontal stiffness increases with increase in the number of layers of the bearing.

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