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FINITE ELEMENT PARAMETRIC STUDY OF CFRP REINFORCED ELASTOMERIC BASE ISOLATOR

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Abstract - *Elastomeric base isolators are the seismic isolation device installed in a structure in between its superstructure and foundation in order to resist the earthquake by decoupling the structure from the ground. The basic principle of base isolation is to reduce the natural frequency of the* structure by using devices with low horizontal stiffness in between the *superstructure and foundation. Elastomeric bearings are the one in which reinforcement is placed in between the rubber layers in other words reinforcement is sandwiched in between the rubber layer. Conventionally, steel plates are used as reinforcing material and its function is to provide vertical stiffness to the isolator so that it can bear the weight of the structure. However steel has some disadvantages which make it unsuitable to use as reinforcement in isolator and this problem can be overcome by using CFRP as an alternative to steel since it has stiffness comparable to that of steel.This work deals with the analytical study of bonded circular CFRP reinforced elastomeric base isolator by varying parameters viz; Height, Diameter and Ply Orientation. The isolators are fixed at base and loaded with vertical pressure and varying horizontal cyclic oscillation (sac loading) to mimic seismic condition in an experimental setup. The hysteresis loop between shear force and horizontal displacement is plotted. The plot obtained is analysed to obtain the effective stiffness (K^h_{eff}) and damping ratio (β).The result will help us to understand the performance of isolator when its parameter is varied.*

Key Words: Base isolator,Elastomer, CFRP, dampers, seismic loading, stiffness, damping ratio.

1. INTRODUCTION

The seismic isolation given for structures has gained worldwide acceptance, since it is an approach to aseismic design. Base isolation is a device provided to achieve seismic isolation. Base isolation is one of the most important concepts of earthquake engineering. Base isolation device is provided in between the superstructure and the foundation i.e. the separation or decoupling of the structure from its foundation. The basic principle of base isolation is to reduce the natural frequency of the structure by using devices with low horizontal stiffness in between the superstructure and foundation. The basic feature of a base isolation system is that due to the combination of the flexibility and energy dissipation mechanisms of the components of the base isolation system as shown in Fig.1.1, the superstructure vibrates almost like a rigid body [4].

There are six major types of base isolation devices like Elastomeric Bearings, High Damping Bearings, Lead Rubber Bearings, Flat Slider Bearings, Curved Slider Bearings or Pendulum Bearings, Ball & Roller Bearings. In this paper Elastomeric Bearings are chosen as base isolation device. Elastomeric bearings are the one in which reinforcement is placed in between the rubber layers in other words reinforcement is sandwiched in between the rubber layer. Bearings using steel is known as Steel Reinforced Elastomeric Base Isolator (SREI). Steel is heavy and it requires thick end plates on both the ends of the isolator which adds to the total cost of the isolator. Thin sheets of steel are interspersed in between the rubber layers and they are bonded by heating them under pressure for several hours which is an expensive and complicated process. In order to overcome this problem an alternative to steel, which has got stiffness comparable to steel but is lighter and less expensive to manufacture [4].

Now a day, many fibers are used as an alternative to steel. Bearings with fiber as reinforcement and elastomeric damping material are fiber reinforced elastomeric isolator (FREI). In this paper Carbon Fiber Reinforced Polymer (CFRP) is used as an alternative to steel reinforcement in base isolator.

1.1 Geometrical Modeling

The geometric modeling module of ANSYS is used here. The shape of the CFRP reinforced elastomeric isolator is circular, semi-circular portion (symmetric design) is considered for the simplicity of solving. The detailed geometry used in the current study is explained below.

1.2 Influence of Height

Here five different heights are chosen to find out the influence of height in the isolator. In the current design the diameter of isolator, D_1 is 305mm.

Table-1: Height Parameters

Notation	No: of Layers		Height(mm)
	Rubber	CFRP	
H_1 D_1	12	13	141
H_2 D_1	16	17	187
H_3 D_1	20	21	233
H_4 D_1	24	25	279
H_5 D_1	28	29	325

The notations H_1, H_2, H_3, H_4, H_5 represent isolators with height 141mm, 187mm, 233mm, 279mm, 325mm.Where, the height is varied by varying the layers of rubber and CFRP present in the isolator.

1.3 Influence of Diameter

Here five different diameters are chosen to find out the influence of diameter in the isolator. In the current design the height of the isolator, H_1 is 141mm with 12 layers of rubber and 13 layers of CFRP.

Table-2: Diameter Parameters

Notation	Height(mm)	Diameter(mm)
H_1 D_1	144	305
H_1 D_2	144	274.5
H_1 D_3	144	244
H_1 D_4	144	335.5
H_1 D_5	144	366

The notations D_1, D_2, D_3, D_4, D_5 represent isolators with diameter 305mm, 274.5mm, 244mm, 335.5mm, 366mm.

1.4 Influence of Ply Orientation

Here eight different ply orientations of CFRP laminates are chosen to find out the influence of ply orientation in the isolator. In the current design the height of the isolator, H1 is 141mm and diameter is 305mm with 12 layers of rubber and 13 layers of CFRP.

Table-3: Ply Orientation Parameters

PLY C_1	
Notation	No: of CFRP Laminates
L_1	3
L_2	5
L_3	7
L_4	9
PLY C_2	
L_5	3
L_6	5
L_7	7
L_8	9

Two combinations of ply orientation Ply C_1 and Ply C_2 is considered.Where,C1 and C2 represent ply combination $0^0/45^0/-45^0/0^0$ and $0^0/45^0/90^0/0^0$.The notations L_1,L_2,L_3,L_4,L_5,L_6,L_7,L_8 represent number of CFRP laminates. Using ANSYS, total eight isolators by changing ply orientation of CFRP laminates were created.

2. BOUNDARY CONDITION

The isolator is fixed at its bottom and a vertical pressure of 6.9MPa [2] is applied at the top of the isolator and a varying horizontal cyclic oscillation to mimic seismic condition in an experimental setup is applied.

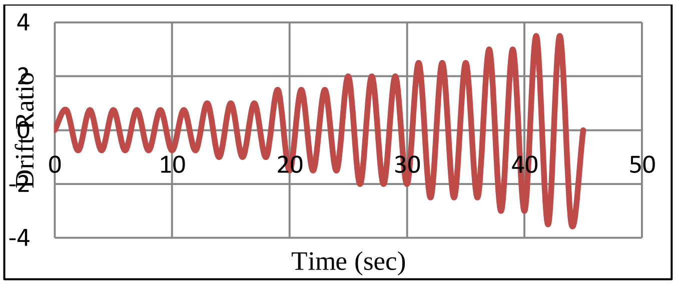

Figure-1: Cyclic Displacement Loading

This cyclic loading history is developed by referring to a loading protocol and the recommended loading (deformation) history to be applied in this program consists of stepwise increasing deformation cycles as illustrated in the figure 1. The yield deformation δ_y is obtained by extrapolating the deformation of the specimen at 75% of its yield force Q_y during preliminary test. The yield deformation δ_y, as the reference for increasing the amplitude of cycles. The history contains six cycles (amplitude < δ_y) followed by the three cycles each of amplitude δ_y, $2\delta_y$, and $3\delta_y$ followed by pairs of cycles whose amplitude increases in increment of δ_y until severe cyclic deterioration occurs.The drift ratio = Q/ δ_y, where Q is $0.75Q_y$.

3. MESHING

For the current study, bonded circular isolator is chosen. SOLID186, a 20-node layered structural solid was used to model the CFRP (reinforcement), the end plates and the rubber. Contact elements between CFRP and rubber were modeled using 3-D surface-to-surface contact elements CONTA174 and TARGE170. To reduce the computational time coarse mesh of optimum size 10mm is used. Figure 4.3, Figure 4.4 and Figure 4.5 shown below are the mesh modeling generated in ANSYS by varying height, diameter and ply orientation.

4. MATERIAL PROPERTIES

The fiber reinforcement was modeled as a linear orthotropic element with the following properties as available in standard literature:

E_x = 4.4 X 1010 Pa; E_y = 4.4 X 1010 Pa; E_z = 1 X 1010 Pa

$\upsilon_{xy} = 0.3$; $\upsilon_{yz} = 0.25$; $\upsilon_{zx} = 0.25$

G_{xy} = 1 X 1010 Pa; G_{yz} = 5 X 109 Pa; G_{zx} = 5 X 109 Pa

Elastomer was modeled with hyperelastic and viscoelastic parameters.

Ogden (3-terms) μ_1 = 1.89 X 106; $\mu_2 = 3600$; $\mu_3 = -30000$

$\alpha_1 = 1.3$; $\alpha_2 = 5$; $\alpha_3 = -2$

Prony Shear Response $a_1 = 0.3333$; $t_1 = 0.4$; $a_2 = 0.3333$; $t_2 = 0.2$

5. RESULT AND DISCUSSIONS

The obtained shear force is plotted against the applied horizontal displacement. The plot obtained is analysed to obtain the effective stiffness (K^h_{eff}) and damping ratio (β). The hysteresis loop were analysed and the area of the hysteresis loop in the shear force vs horizontal displacement curve gives the energy dissipated. The stiffness and damping ratio is calculated using below equations and the values are compared.

$$K^h_{eff} = \frac{Fmax - Fmin}{dmax - dmin}$$

F_{max} is maximum value of force

F_{min} is minimum value of force

d_{max} is maximum value of displacement

d_{min} is minimum value of displacement

The hysteresis loop were analysed and the area of the hysteresis loop in the shear force vs horizontal displacement curve gives the energy dissipated. The damping ratio is calculated as

$$\beta = \frac{Wd}{4\pi Ws}$$

W_d is the dissipated energy and evaluated as the area under loop
W_s is elastic energy and is written as

$$Ws = \frac{K^{h}_{eff(\Delta max)^2}}{2}$$

Δ_{max} is average of positive and negative maximum displacement and expressed as

$$\Delta_{max} = \frac{dmax + |\, dmin \,|}{2}$$

5.1 Effect of Height

In this parametric study, the height is varied by increasing the number of rubber and CFRP, the diameter, D1 is 305mm. The analysis is done and the deformation and hysteresis loop.

Table-4: Tabulation of Result by Varying Height

Notation	Height(mm)	Stiffness (KN/m)	Damping (%)	Maximum Load(KN)	Deflection (mm)
$H_1 D_1$	141	420	24.24	21	50
$H_2 D_1$	187	530	20.56	64.42	121.55
$H_3 D_1$	233	586	18.94	106.5	181.74
$H_4 D_1$	279	630	16.75	156.44	248.31
$H_5 D_1$	325	643	15.15	194.35	302.25

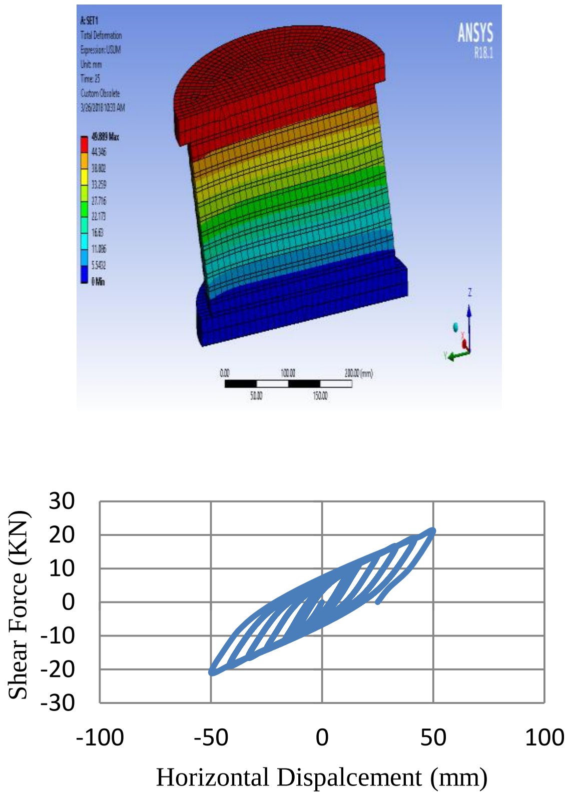

Figure-2: Deformation Model and Hysteresis Loop of H_1 D_1

5.2 Effect of Diameter

In this parametric study, the reference diameter is taken as D_1 (=305mm) and height, H_1 is 141mm.The rest of the diameter is chosen by adding and reducing 10% and 20% from the reference diameter and the height is constant.

Table-5: Tabulation of Result by Varying Diameter

Notation	Diameter (mm)	Stiffness (KN/m)	Damping (%)	Maximum Load (KN)	Deflection (mm)
H_1 D_3	244	207.68	12.50	26.235	126.32
H_1 D_2	274.5	321.23	17.04	23.85	74.25
H_1 D_1	305	420	24.24	21	50
H_1 D_4	335.5	576.74	31.41	24.567	42.60
H_1 D_5	366	683.01	38.23	24.052	34.21

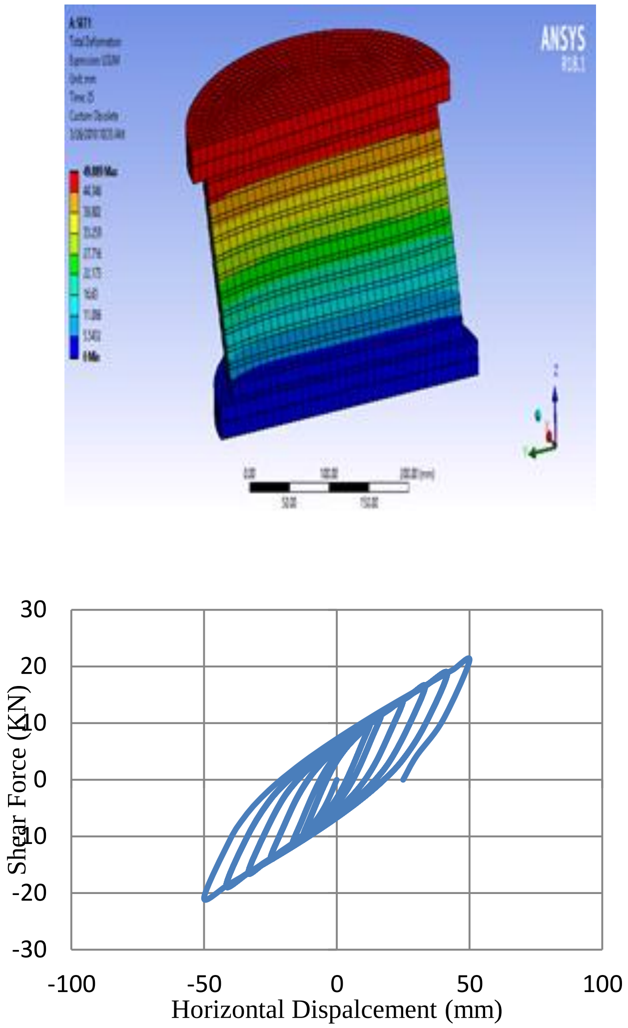

Figure-3: Deformation Model and Hysteresis Loop of H_1 D_1

5.3 Effect of Ply Orientation

In this parametric study of the isolator, two studies were conducted for general ply orientation combinations $0^0/45^0/-45^0/0$ and $0^0/45^0/90^0/0^0$ for diameter D_1 305mm with height H_1 141mm, number of rubber layer is 12 and that of CFRP is 13. These combinations give the maximum bonding strength in between the plies.

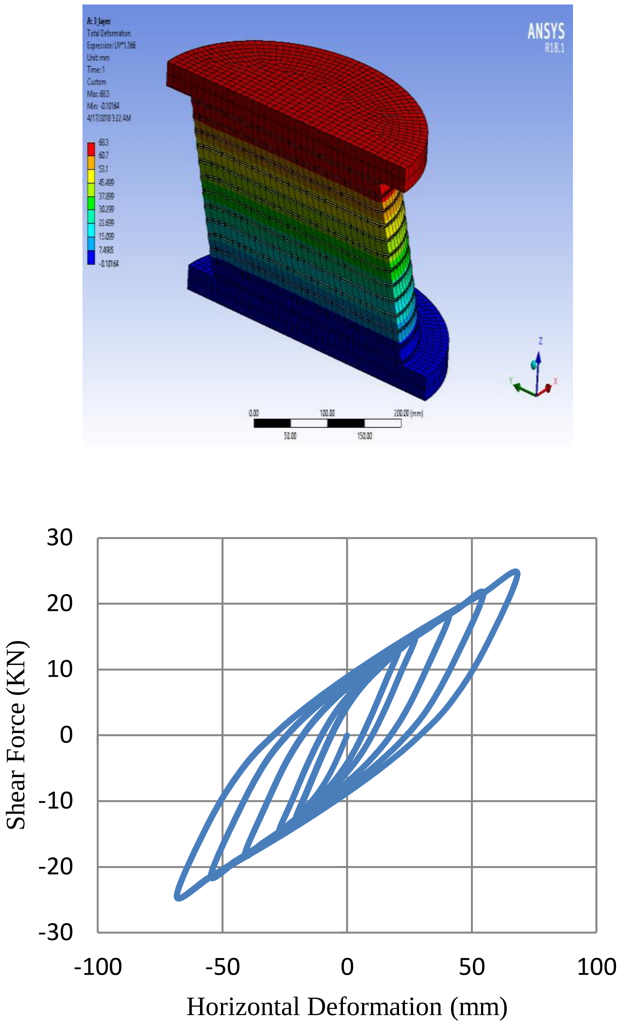

Figure-4: Deformation Model and Hysteresis Loop of L_1

5.4 Effect of C-FREI over Conventional Steel Reinforced Isolator

Table- 6: Dimensions of Bonded Circular CFRP Reinforced and Steel Reinforced Isolator

Diameter	305mm
Total Height,H1	141mm
Thickness of Reinforcement	3mm
Number of Reinfocement Layer (CFRP and Steel)	13nos
Thickness of Rubber Layer	8.5mm
Number of Rubber Layer	12nos
Bonded End Plate Diameter	305mm
Bondrd End Plate Thickness (Top and Bottom)	15mm

The dimensions used for this study is given above. Both CFRP reinforced and steel reinforced elastomeric isolator is analysed and the hysteresis loop and the result obtained is shown below:

Table-7: Tabulation of Comparison Result

Reinforcement	Stiffness (KN/m)	Damping (%)	Maximum Load(KN)
CFRP	420	24.25	21
Steel	635	19.12	26.23

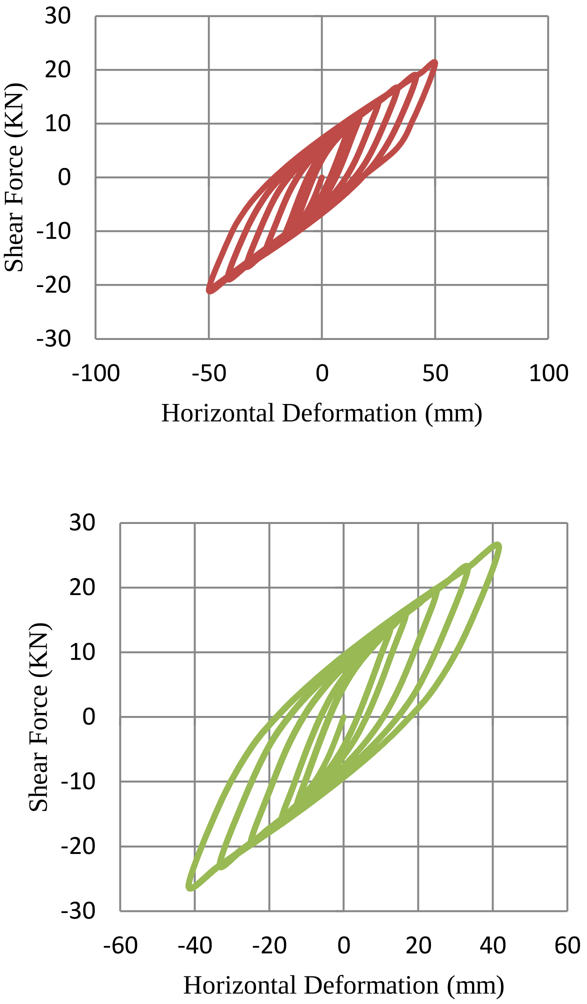

Figure-5: Hysteresis Loop of (a) CFRP (b) Steel Reinforced Elastomeric Isolator

6. CONCLUSIONS

In this study, different parametric studies were tested under varying cyclic loading conditions. The concluding remarks for each parametric study are as follows.

- The load carrying capacity is seen to be increased as the height of the isolator is increased. The variation in load carrying capacity of maximum height is found to be 9 times the minimum height.
- The maximum possible deflection is within the diameter of the isolator which means that beyond that the isolator may fail.
- The load carrying capacity is seen to be maximum for the isolator with diameter 305mm (reference diameter).
- By reducing the diameter from D1 by 10% there is a sufficient reduction in stiffness of 23.51%.
- By reducing diameter from D1 by 20% the stiffness is reduced to 50.55% which means that there is a large variation in stiffness by reducing the diameter.
- Stiffness get reduced if the diameter of the isolator is reduced. Similar way we can see the same change in damping also.
- Both stiffness and damping is increased when the diameter is increased by 10% and 20%.
- Stiffness and damping is seen to be inversely proportional to change in diameter.
- The load carrying capacity is seen to be high for seven layered CFRP ply oriented laminate.
- The stiffness is found to be increasing with the increase of the number of CFRP laminate.
- Damping is also found to be increasing up to seven layered CFRP laminate and in the nine layered the damping is found to be decreased.
- The load carrying capacity is seen to be nearly equal in layers except for three layered laminate.
- In both combinations, seven layered CFRP laminate is good. Thus we can say that it is better to provide a minimum of five layered CFRP laminate and a maximum of seven layered CFRP ply oriented laminate.
- The stiffness value of Ply C1 and Ply C2 is 648.96 KN/m and 571.81 KN/m whereas the damping is 32.65% and 27.69%.
- The damping is found to be more for the Ply C1 seven layered CFRP ply oriented laminate which is good even though the stiffness in this is higher than the other seven layered CFRP ply oriented laminate in Ply C2.
- The load carrying capacity of steel reinforced elastomeric base isolator is seen to be more than that of C-FREI.
- Damping of steel reinforced isolator is 19.12% and for C-FREI is 19.12%. So, CFRP reinforced elastomeric isolator can be improvised since it is better damping towards applied loading.
- In every result we can see that the damping percentage and deflection of C-FREI are inversely proportional i.e.: increase in damping percentage results in decrease of deflection and vice versa.
- CFRP sheets can absorb and dissipate a certain amount of energy due to their flexibility under shear forces. Not only that, they can be considered as a source of the frictional damping because of the interfacial slip between the fibers of carbon. As a result, carbon fiber-reinforced composite layers can increase the damping ratio of the elastomeric isolator.

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