ANALYTICAL INVESTIGATION OF CFRP BASE ISOLATOR

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Abstract - *Base isolator is a device that provides resistance to earthquake by decoupling the structure from the ground and reducing the structures natural frequency. It reduces the amount of the lateral forces that are transferred to the structure, inter-story drift and floor acceleration. Conventionally, steel plates are used as reinforcing material in base isolator. However, steel reinforcement has some disadvantages which make it unsuitable for use in smaller and less important buildings. This problem can be overcome by using CFRP, an alternative to steel, which has stiffness comparable to that of steel but is lighter and less expensive to manufacture.*

The work deals with analytical study and comparison of elastomeric base isolators with steel and CFRP laminates as reinforcement using ANSYS 14.5. A parametric study of base isolator with CFRP laminates was carried out by varying the ply orientations for fixed horizontal displacement.

Key Words: Base isolation, CFRP, High damping rubber, nonlinear static analysis

1. INTRODUCTION

Seismic isolation is achieved by providing suitable devices called base isolation devices between the superstructure and the foundation. The principle of base isolation is to reduce the structures natural frequency by using devices with low horizontal stiffness at the base to decouple the structure from the ground. It shifts the fundamental lateral period, dissipates the energy in damping, and reduces the amount of the lateral forces that are transferred to the structure, inter-story drift, and the floor acceleration[1]. The basic feature of a base isolation system is that the superstructure vibrates almost like a rigid body due to the combination of the flexibility and energy dissipation mechanisms of the components of the base isolation system as shown in Fig-1.

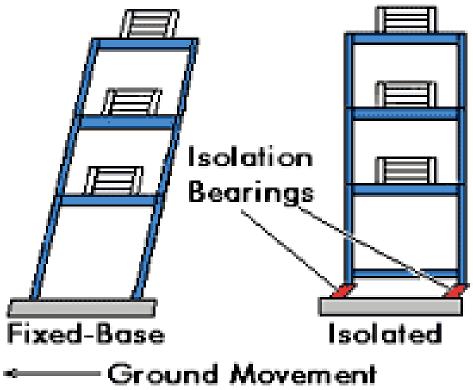


Fig-1: Comparison of a fixed base and base isolated building

Conventionally, steel plates are used as reinforcing material. Its function is to provide vertical stiffness to the isolator to take the weight of the structure. Bearings using steel as reinforcing material are known as steel-reinforced elastomeric bearings (SREI). Thin sheets of steel are interspersed in between layers of rubber. However, steel-reinforcement has some disadvantages. Steel is heavy and makes up for most of the weight of the isolator. Further, thick end-plates are needed on both ends of the isolators which adds to the total cost. The process of bonding steel with the rubber involves placing steel plates between rubber layers and heating them under pressure for several hours. The entire process is complicated and expensive. All these make conventional isolators unsuitable for use in smaller and less important buildings, particularly in developing and under-developed countries. This problem can be overcome by using an alternative to steel, which has stiffness comparable to that of steel but is lighter and less expensive to manufacture.

Many fiber materials whose stiffness is comparable to steel are now available. Seismic isolators can be designed using layers of rubber, bonded with thin layers of bidirectional fiber fabric. Replacing steel with CFRP laminates, isolators of much lesser weight can be manufactured. Bearings with fiber reinforcement and elastomeric damping material are called fiber-reinforced elastomeric isolator (FREI) bearings. Additional benefits are obtained in the form of considerable reduction in the manufacturing costs resulting from a lesser labour – intensive process. It is also possible to reduce the costs further by replacing the current bonding process by microwave heating in an autoclave which is cheaper. Fiber-reinforced isolators can be easily cut to required shape and size which is not possible with steel reinforced isolators. Another benefit of using fiber reinforcement is that it stretches under loading and is very flexible in bending. The tension in the cords, acting on the curvature of the reinforcing sheet causes individual strands to slip resulting in frictional damping. This provides additional damping in the isolator. The Orientation of the fibers is of fibers is of great importance. The behavior of the FREI isolator changes with ply orientation

2. ANALYSIS MODELS

The isolators are modelled through ANSYS 14.5. The isolators are totally constraint at its base and only half of the isolator are modelled as it exhibits symmetric behaviour. To impose this symmetric behaviour on the half isolator all the point located on radius where it has been cut (Z = 0) have the rotation around X and Y and the translation along Z blocked. The nodes at the top surface are coupled in Y direction and X direction and vertical and horizontal loads are applied to the first node on the top surface.

The dimensions of the models are given in the Table 1 and Table 2.

Table-1: Dimensions of FREI base isolator

Diameter	305 mm
No. of rubber layers	8
Thickness of rubber layer	12.5 mm
Thickness of CFRP layer	3 mm
Total height of isolator	121 mm
No. of layers of CFRP	7
Thickness of fiber layers in each CFRP layer	.3mm
Ply orientation	0/90˚

Table-2: Dimensions of SREI base isolator

Diameter	305 mm
No. of rubber layers	8
Thickness of rubber layer	12.5 mm
Thickness of steel layer	3 mm
Total height of isolator	121 mm

2.1. MATERIAL PROPERTY

Rubber is a hyperelastic material and the material property is defined by strain energy functions. The Polynomial 2-P function is used here and the material parameters were obtained as follows [2]:

$C_{10} = 0.797$ $C_{01} = -0.05910$ $C_{20} = 0.01609$

$C_{02} = 1.103 \text{ x } 10\text{-}3$ $C_{11} = -0.00529$

Steel is modeled as linearly elastic material with $E=2x10^5$ MPa and v = 0.3.

CFRP fibers have orthotropic material property and are modeled as linearly elastic with the following material constants[3].

$E_x = 44000$MPa $E_y = 44000$MPa

$E_z = 10000$MPa $\nu_{xy} = 0.3$

$\nu_{yz} = 0.25$ $\nu_{zx} = 0.25$

$G_{xy} = 10000$MPa $G_{yz} = 5000$MPa

$G_{zx} = 5000$MPa.

3. MODELLING

The elements used are SOLID 185 for the rubber layer and steel layer. The element has 8 nodes; each node has three degrees of freedom that are the translations. It has two degenerated forms to allow irregular shapes. SOLID 185-Layered was used as the element for CFRP layer. Element has plasticity, stress efficiency, large deflection and large strain capabilities. Element is defined by 8 nodes and the orthotropic material directions.

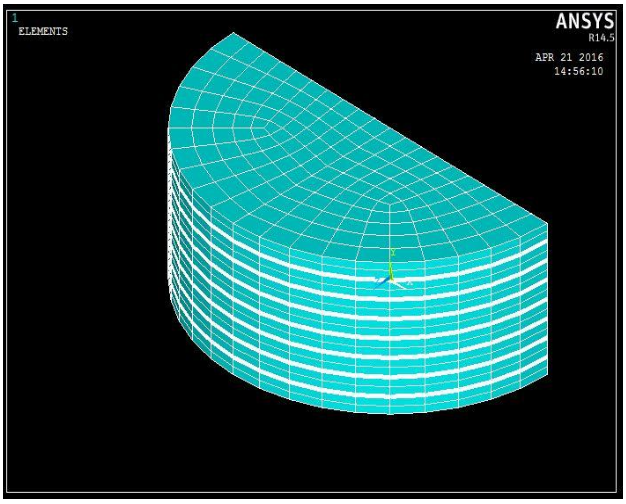


Fig-2: Model of FREI base isolator

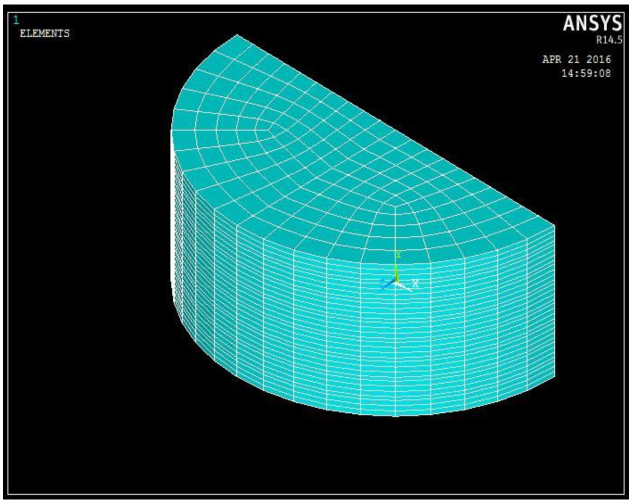


Fig-3: Model of SREI base isolator

4. COMPARITIVE STUDY OF SREI BASE ISOLATOR AND CFRP BASE ISOLATOR

Nonlinear static analysis of SREI and FREI bae isolator was carried out. Horizontal displacement values are applied incrementally. Initially, displacement corresponding to 100% shear strain is applied along with the design vertical load. Displacement values are increased until maximum shear strain is reached.

It has been found that the SREI base isolator remained stable upto 240% shear strain. Meanwhile, the FREI base isolator remained stable upto 436% shear strain.

The isolators were subject to 100% vertical load and a horizontal displacement corresponding to 500% shear strain. But it was found that the SREI material remained stable until 240mm horizontal displacement after which the elements were found to be highly distorted. Hence this is the maximum horizontal displacement that the SREI isolator with the given dimensions can take. The results are shown from Fig. 3 to 4. For FREI base isolator, the material remained stable upto 436mm horizontal displacement

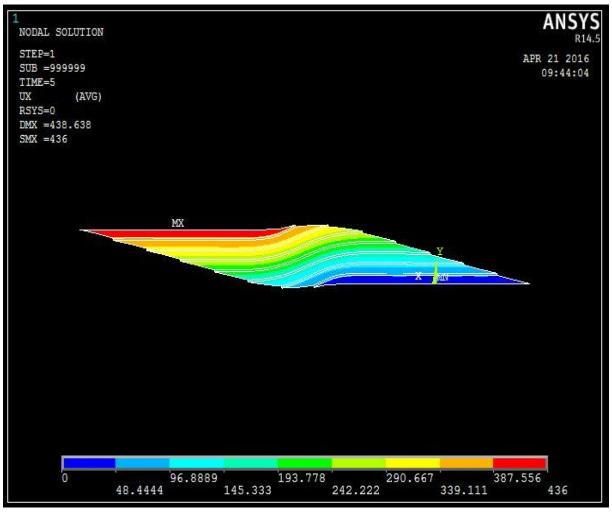


Fig-4: Max. Horizontal displacement of FREI isolator

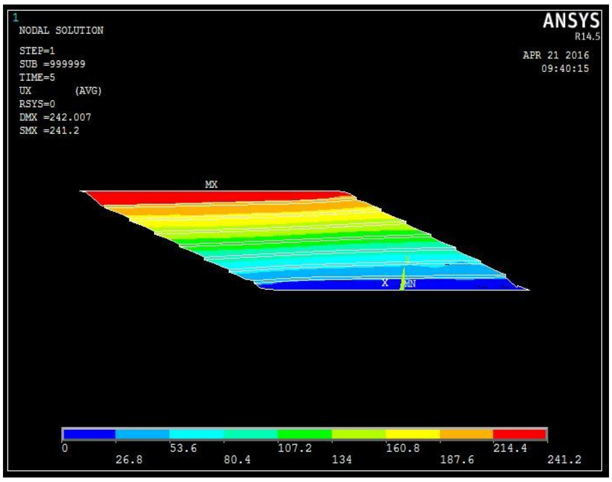


Fig-5: Max. Horizontal displacement of SREI isolator

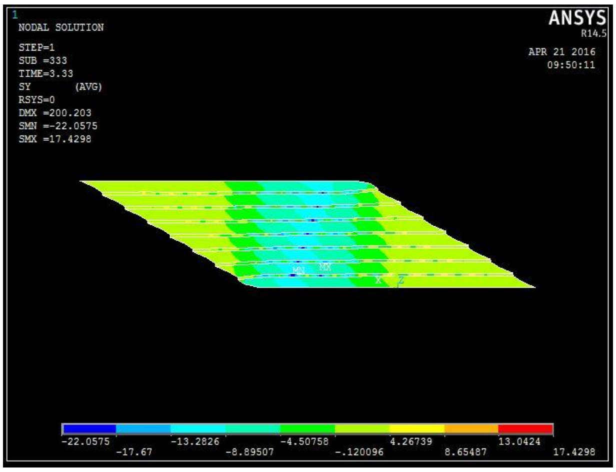
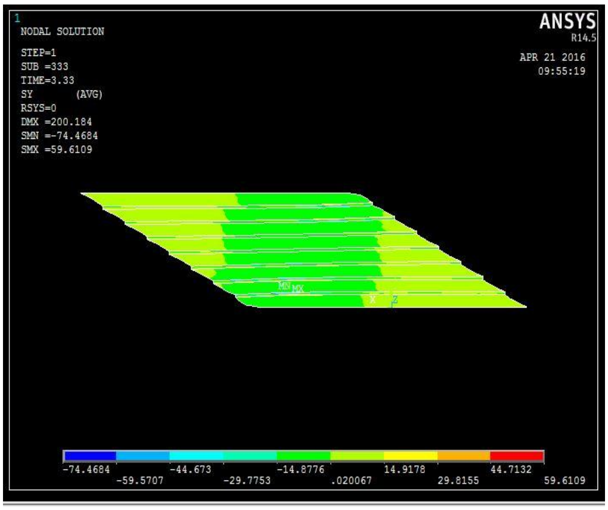


Fig-6: Axial stress (σ_y) in FREI isolator



```
1
NODAL SOLUTION
STEP=1
SUB =333
TIME=3.33
SY       (AVG)
RSYS=0
DMX =200.184
SMN =-74.4684
SMX =59.6109
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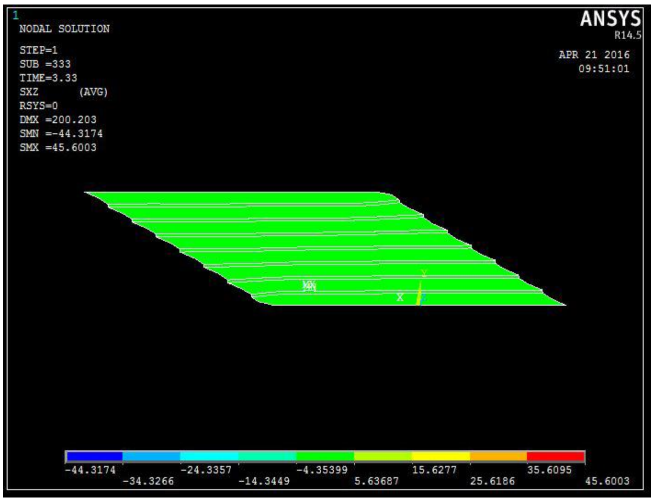
Fig-7: Axial stress (σ_y) in SREI isolator



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1
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STEP=1
SUB =333
TIME=3.33
SXZ      (AVG)
RSYS=0
DMX =200.203
SMN =-44.3174
SMX =45.6003
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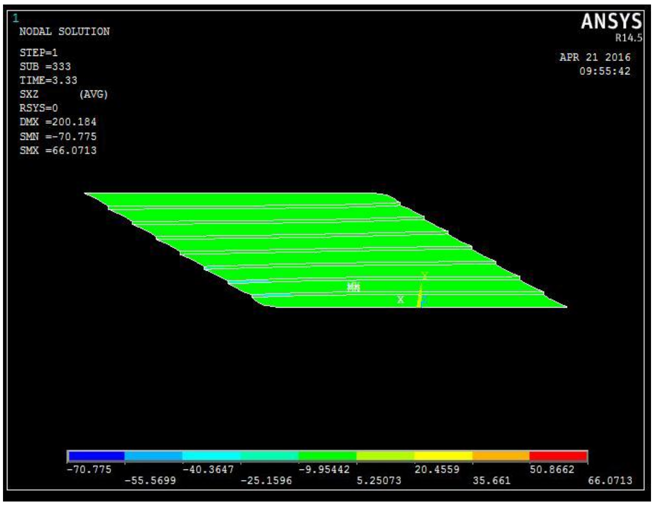
Fig-8: Shear stress in FREI isolator



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1
NODAL SOLUTION
STEP=1
SUB =333
TIME=3.33
SXZ      (AVG)
RSYS=0
DMX =200.184
SMN =-70.775
SMX =66.0713
```

Fig-9: Shear stress in SREI isolator

The fig 10 and 11 shows the comparison of axial stress and shear stress values for both the isolators at 200% shear strain. Hence CFRP can be used as an efficient replacement to steel in elastomeric bearings.

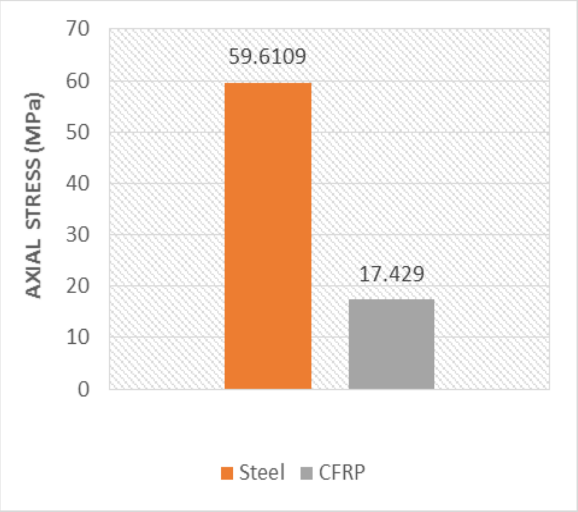

Fig-10: Axial stress

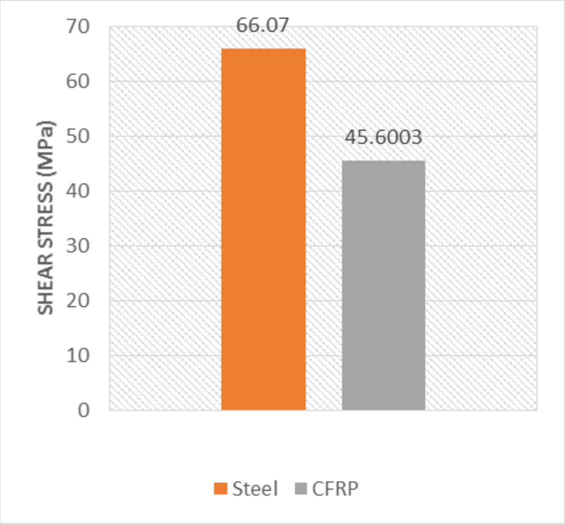

Fig-11. Shear stress

5. SIGNIFICANCE OF PLY ORIENTATION

Each individual layer of CFRP laminate exhibits orthotropic property, ie, the material property differs along three mutually perpendicular directions. But, when taken as a whole, it behaves as an isotropic material. This is due to the ply orientation[4] Fig 12 shows the ply orientation pattern.

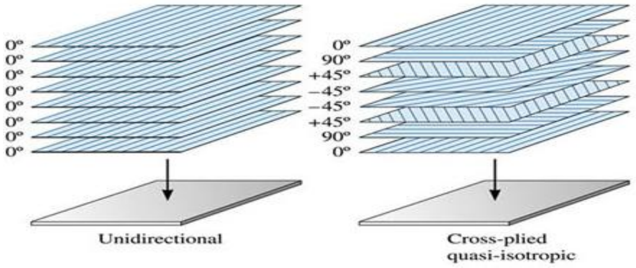

Fig-12: Ply Orientation

Owing to the orientation, 0°/90° or 0°/90°/45° or 0˚/30˚/60˚, it may become quasi isotropic. Quasi isotropic is a term applied to fiber reinforced composite material when the orientation and lamination stack up sequence is such that the resultant material behaves like an isotropic material. Quasi isotropic laminates behave like isotropic materials at the laminate level though their individual layers are orthotropic.

6. STUDIES BY CHANGING PLY ORIENTATION OF CFRP LAMINATES

Three ply orientations were studied:

1. Layers oriented at 0°/90°.
2. Layers oriented at 0˚/30˚/60˚ symmetrically from the middle layer.
3. Layers oriented at 0°/90°/45° symmetrically from the middle layer.

Non-linear static analysis was done on the FREI base isolators of above mentioned ply orientations. Fig 13 and 14 shows the comparison of results for the three ply orientations at horizontal displacement corresponding to 300% shear strain.

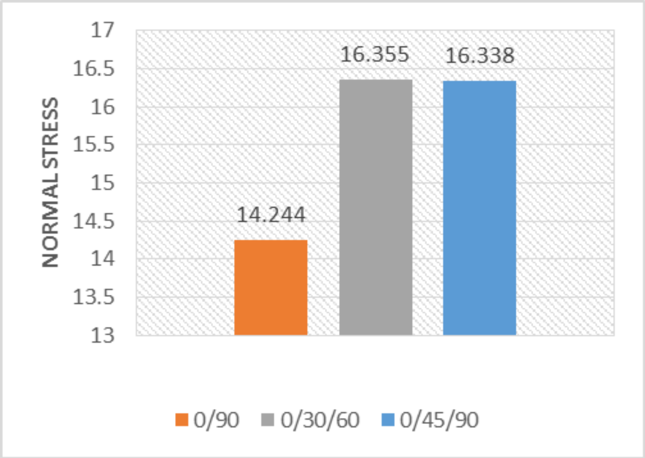

Fig-13: Normal stress comparison

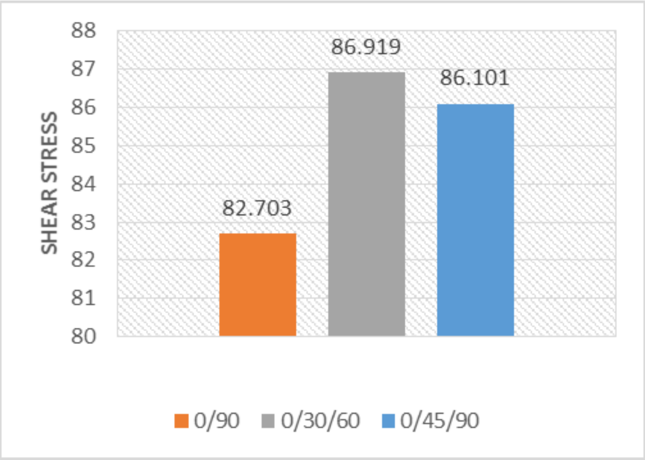

Fig-14: Shear stress comparison

The model with 0°/90° was found to perform well and it is the most efficient orientation since the stresses are less.

7. CONCLUSION

The FREI and SREI base isolators were modeled and nonlinear finite element analysis was done using ANSYS 14.5.

The main conclusions were:

- The maximum displacement that the FREI isolator can undergo without losing its stability corresponds to 436% of shear strain which much higher than that of SREI isolators.
- By replacing steel with CFRP in the multi-layer isolator it was found to behave in a similar manner and more efficient than steel plates.
- Fibre-reinforced plates can be used as an alternative to steel there by reducing the weight of the bearing and the use of isolators can be made more widespread.
- The most efficient ply orientation of the fibers in CFRP laminates was found to be 0˚ /90˚ which corresponds to minimum stresses.

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