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Seismic Response Analysis of RCC Frame Building using FREI

Anshul Shrivastava, Savita Maru

***Abstract:** An analysis is given for the medium-rise building with fixed base and other with base isolation device. The device hereby used for base isolation is Fiber-reinforced Elastomeric Isolator (FREI). The Fiber-reinforced Elastomeric Isolator is an isolator which uses fiber fabric material instead of steel thin plates. The main purpose of using FREI is to analyze the seismic response of medium-rise RCC frame building. As in past many research work have been carried out for low-rise building. Therefore, in this paper (G+4), (G+6), (G+8) Storey building are taken for study and analysis has been demonstrated using commercial software ETABS v17. The design of Fiber Reinforced Elastomeric Isolators is broadly based on the guidelines of ASCE 7-10. The response spectrum analysis of different storey are based on Indian Design Standard. In addition to the design of FREI, a comparison between fixed based and base isolated RCC frame building has been carried out in the form of time period, displacement, drift at various load combination. The above parameter is taken to check whether it can withstand the loads and seismic forces without any failure.*

***Keywords:** Response Spectrum Analysis, FREI, Storey Drift, Lateral Displacement.*

I. INTRODUCTION

Earthquake is the unpredictable shaking of ground caused either due to the movement of two tectonic plates or by volcanic eruption. The movement of plates causes the shaking of ground, thus releasing tremendous amount of energy. This energy travel to the large distance and destroy the habitat of human being and nature. The disaster to the human life is not because of the earthquake but due to the structure constructed by human. When the structures are not constructed according the norms of earthquake-based design or when seismic energy is too high to resist, structure collapsed, thus causing disaster to the human life. Therefore, the researchers are working on to minimize the seismic acceleration to transfer to the cantilever (vertical) structure. One of the seismic control systems is Passive Control System, which do not require any power source to mitigate the seismic excitation. Passive Control System comprises of many elastomeric bearings, one of which is Fiber-Reinforced Elastomeric Isolators (FREI). FREI is the multi-layer elastomeric bearings where the reinforcement elements were fiber reinforced material instead of conventional steel plates. The conventional isolators were heavy, which make it hard to manufacture, transport and install.

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* Correspondence Author
Anshul Shrivastava*, M.E. Student, Department of Civil Engineering, Ujjain Engineering College, Ujjain (M.P.), India. E-mail: ansh1008@yahoo.in
Dr. Savita Maru, Professor, Department of Civil Engineering, Ujjain Engineering College, Ujjain (M.P.), India. E-mail: savitamaru@yahoo.com

Indirectly all this increase the cost of the isolators up to lakhs, thus it can only be used in large projects of civil engineering. However, in developing countries where low rise buildings are mostly constructed becomes difficult to install such heavy and expensive isolators. Fiber Reinforced Elastomeric Isolators are the alternative to the above problem, since it is light in weight and low-cost isolator. It became more crucial if this method of seismic protection is to be applied to a wide range of building such as residential, school and hospital building etc. in rural and urban earthquake-prone zones. In research only low-rise building were analyzed and experiments are done according to it. Therefore, the medium -rise building is analyzed to check whether it can withstand the seismic forces.

In this paper, the seismic response behavior of RCC frame building of different storey such as (G+4), (G+6), and (G+8) are taken as fixed base structure and base isolated structure has been studied and also comparison between time period, lateral displacement, maximum storey drift and also with different load combination are being carried out.

II. DESIGNING OF FREI

The design procedure for FREI is similar to the lead rubber bearing and natural rubber bearing. It uses the same principle to calculate the effective horizontal stiffness, effective damping and vertical stiffness of an isolator. Since, the non-linear properties are very complex and tedious to calculate, therefore it has been neglected. The modelling of isolator is broadly based on ASCE 07-10. The procedure for calculating the effective stiffness and damping are as follows:

- The effective horizontal stiffness of FREI is given by equation;

$$K_{eff} = \left(\frac{W_i}{g}\right) \cdot \left(\frac{2\pi}{T_D}\right)^2$$

- Design Displacement DD;

$$D_D = \left(\frac{g}{4\pi^2}\right)\left(\frac{S_D T_D}{B_D}\right)$$

- The Damping ratio β is calculated as;

$$\beta = \frac{W_d}{2\pi * K_{eff} * (D_D)^2}$$

- Vertical Stiffness Kv;

$$K_v = \left(\frac{E_c A}{t_r}\right)$$

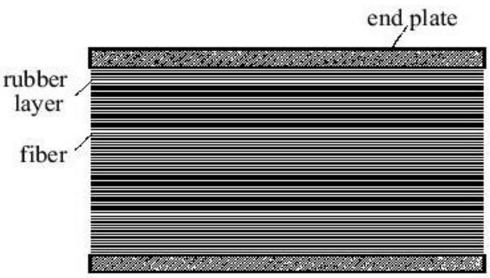

Fig. 1 Model of Fiber-Reinforced Elastomeric Isolator

The above formula provides all the necessary data to apply in software to get the desired outcomes. The fig 1 shows the cross section of FREI consisting of end plate (either rubber or thick steel plates), fiber fabric material layer and rubber layer.

III. MODELLING OF BUILDING

To study the seismic response of building using FREI, RCC frame buildings have been modelled using ETABS-v17. The total area of asymmetrical buildings is 1080 m^2, where each bay comprises of 6m in X direction and 4.5m in Y direction as shown in fig. 2. The height of the buildings is taken as shown in Table 1. By using the above parameter, the analytical modelling of structure is prepared and analysis are done. The soil structure interaction has been neglected and columns are considered fixed at the base. The FREI is being placed between the two-structure part in bonded conditions. The stiffness and damping properties are assigned as per the calculated data. The response spectrum method is being adopted in this study.

Table 1: Height of Storey

Storey	Height (in m)
G+4	16.7
G+6	23.3
G+8	29.9

The RCC frame building of storey G+4, G+6, G+8 are modelled with their base fixed and also with their base isolated by FREI. Total six model are analysed using ETABS v17 commercial software.

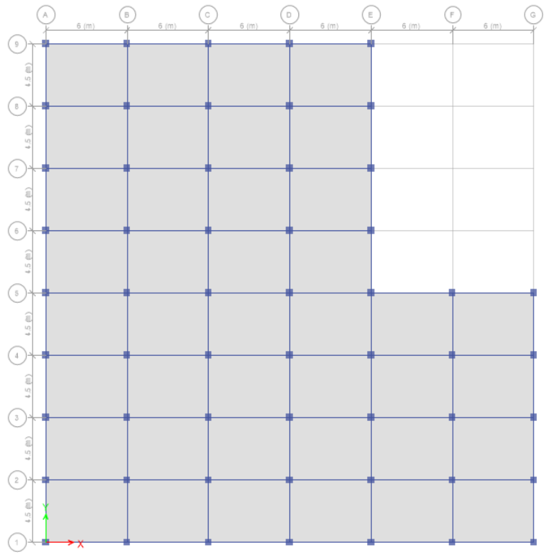

Fig. 2 Plan view of G+4, G+6, G+8 Storey

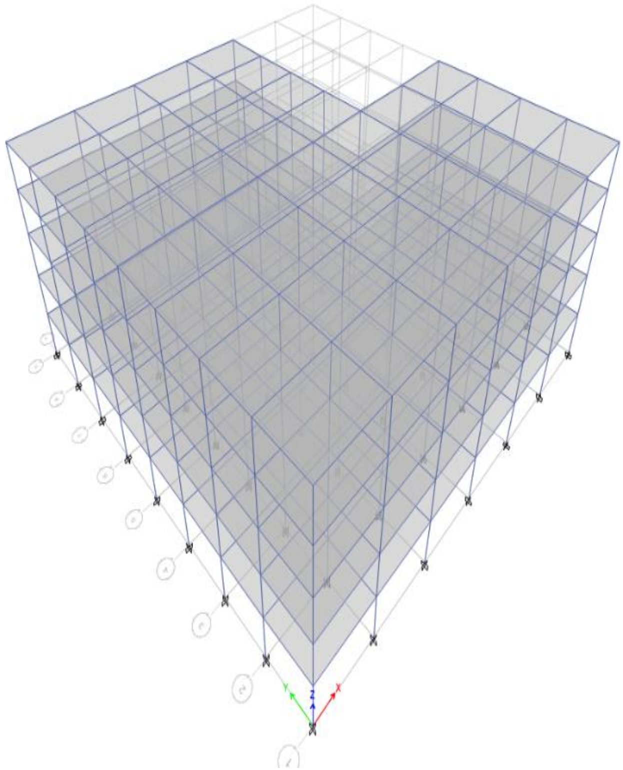

Fig. 3 Three Dimensional view of G+4 Fixed base RCC Frame Building

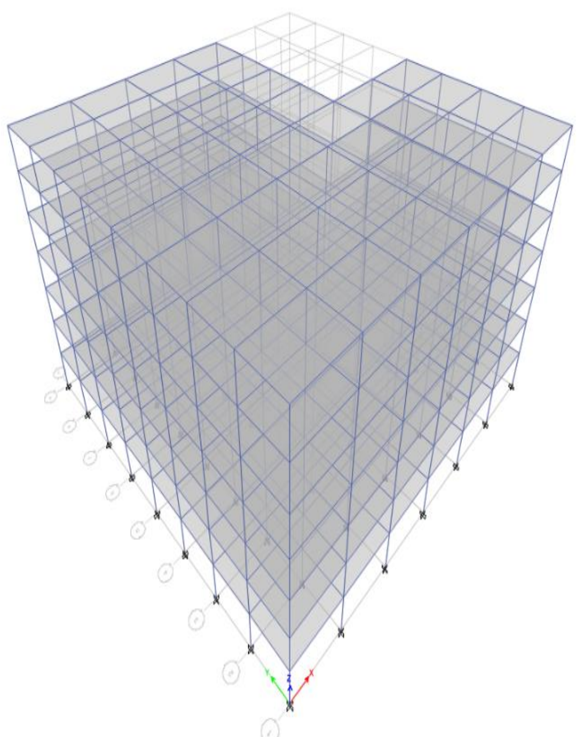

Fig. 4 Three Dimensional view of G+6 Fixed base RCC Frame Building

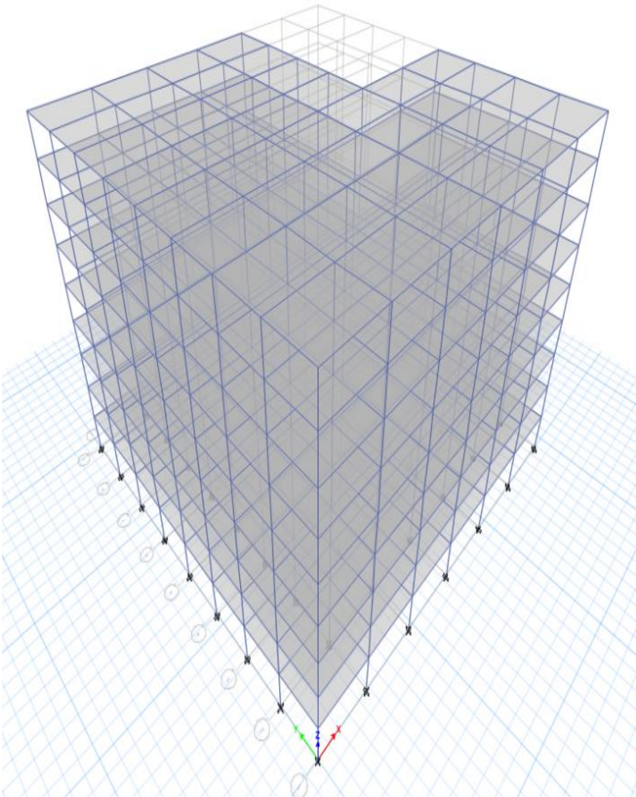

Fig. 5 Three Dimensional view of G+8 Fixed base RCC Frame Building

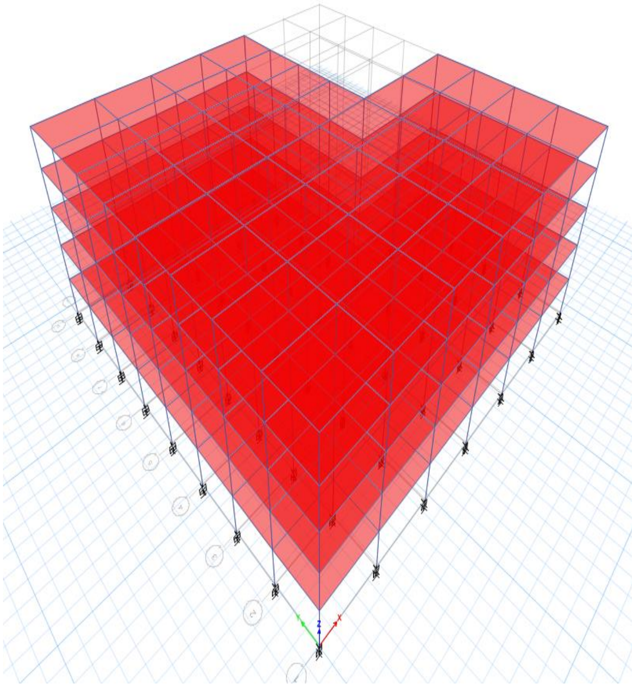

Fig. 6 Three Dimensional view of G+4 RCC Frame Building Using FREI

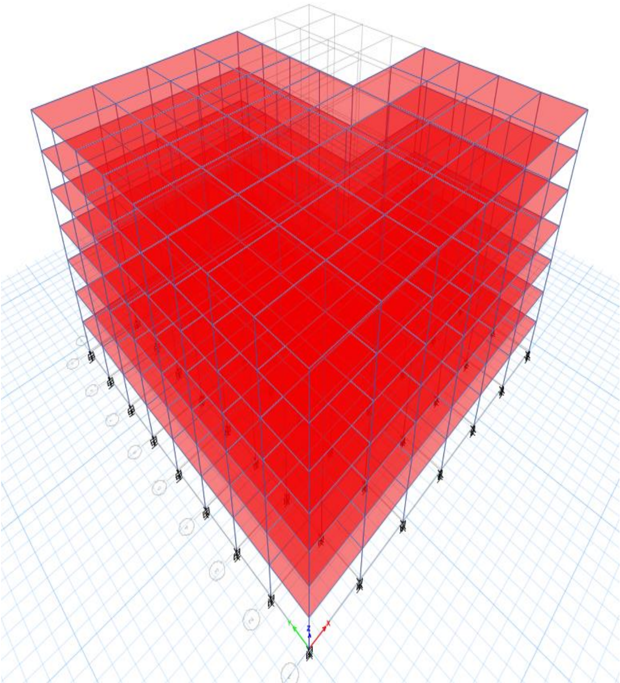

Fig. 7 Three Dimensional view of G+6 RCC Frame Building Using FREI

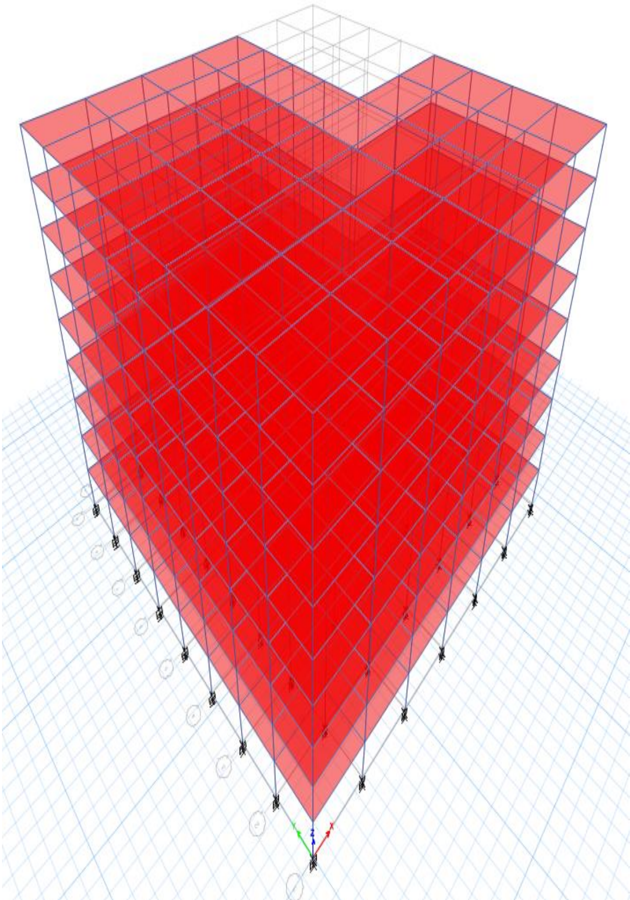

Fig. 8 Three Dimensional view of G+8 RCC Frame Building Using FREI

A. Structural Modelling

Table 2: Structural properties of Concrete

Particular	Model Data
Grade of Concrete	M-20
Weight per unit volume (kN/m^3)	25 kN/m^3
Modulus of Elasticity, E_c (MPa)	27386.12
Poison's Ratio μ	0.2
Coefficient of Thermal Expansion, $\alpha \left(\frac{1}{°C}\right)$	5.5×10^{-6}
Shear Modulus, G (MPa)	11410.89

Table 3: Structural properties of Steel

Particular	Model Data
Grade of Steel	Fe-500
Weight per unit volume (kN/m^3)	78.5 kN/m^3
Modulus of Elasticity, E_c (MPa)	2×10^5
Coefficient of Thermal Expansion, $\alpha \left(\frac{1}{°C}\right)$	5.5×10^{-6}

Table 4: Dimension of RCC Frame Building

Particular	Model Data
Slab Thickness (mm)	125
Size of Beam (mm)	250×450
Size of Column for G+4, G+6, G+8 resp. (in mm)	500×500 600×600 750×750
Floor Finishing Load (Dead Load)	1.25 kN/m^2
Live Load	2.5 kN/m^2
Wall Load (on Each Beam)	11.4 kN/m

Table 5: Seismic Parameters

Particular	Model Data
Seismic Zone	IV
Seismic Factor (Z)	0.24
Response Reduction Factor, R	5
Importance Factor, I	1
Soil Type	II
Damping Ratio	0.05

B. FREI Properties

The dimensions and various other properties such as effective horizontal Stiffness, effective vertical stiffness, design displacement and damping ratio has been calculated, to analyze the behavior of structure under seismic forces. The above parameter has been calculated by the formula given in chapter II of this paper. The modelling of FREI depends on

- The total weight of the structure.
- Fundamental Natural Time Period
- Maximum Load on acting on the column
- Damping Factor
- Design Horizontal Spectral Acceleration Coefficient.

*B1. Dimensions of FREI for **G+4 Storey** Building*

1. Effective Horizontal Stiffness = 1523.10 kN/m
2. Effective Damping = 0.05
3. Effective Vertical Stiffness = 1486596 kN/m
4. Dimension of FREI = 430×430×130 mm
5. Aspect Ratio = 3.3
6. Shape Factor = 15.5

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B2. Dimensions of FREI for G+6 Storey Building

1. Effective Horizontal Stiffness = 1390 kN/m
2. Effective Damping = 0.05
3. Effective Vertical Stiffness = 22.8065 kN/m
4. Dimension of FREI = 465×465×161 mm
5. Aspect Ratio = 2.9
6. Shape Factor = 15.5

B3. Dimensions of FREI for G+8 Storey Building

1. Effective Horizontal Stiffness = 1323.53 kN/m
2. Effective Damping = 0.05
3. Effective Vertical Stiffness = 2139991.54 kN/m
4. Dimension of FREI = 500×500×192 mm
5. Aspect Ratio = 2.62
6. Shape Factor = 15.5

IV. RESULT AND DISCUSSION

The linear static analysis and linear dynamic analysis are being carried out in accordance with IS codes. The result of time period of different stories having their base fixed and base isolated are compared with Modal Analysis. The storey displacement are also being compared accordance with lateral load method and response spectrum method in X-direction and Y-direction. One more comparison is also done by taking maximum base shear of individual stories, statically and dynamically in X & Y direction. All the result is being analyzed by using commercial software of CSI-ETABS v17. Hereby, the results are displayed in form of graph or by table as shown below.

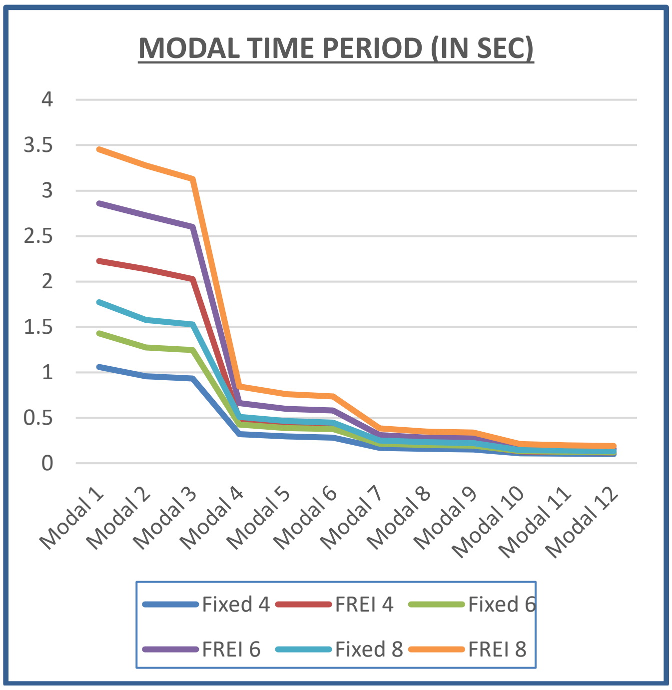

Fig. 9 - Modal Time Period for Different Modals

The modal time period of fixed base RCC building is 1.059, 1.429 and 1.772 (in sec) and of FREI structure is 2.225, 2.859 and 3.454 (in sec) for storey 5, storey 7 and storey 9 respectively.

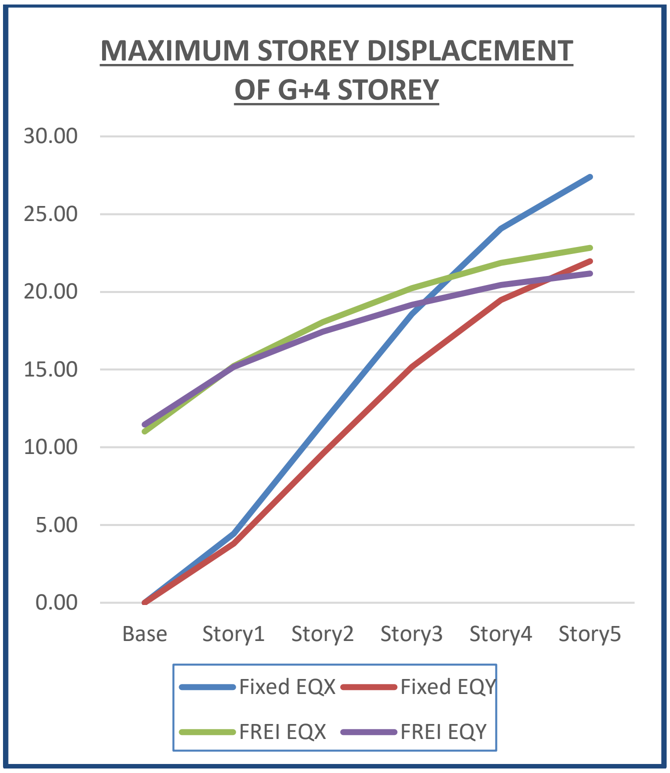

Fig. 10 Static Storey Displacement of G+4 Storey in X & Y Direction

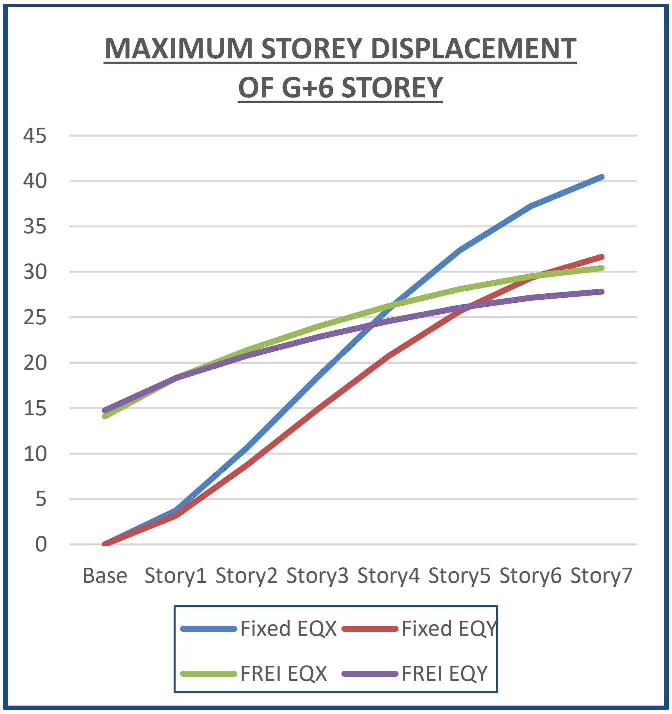

Fig. 11 Static Storey Displacement of G+6 Storey in X & Y Direction

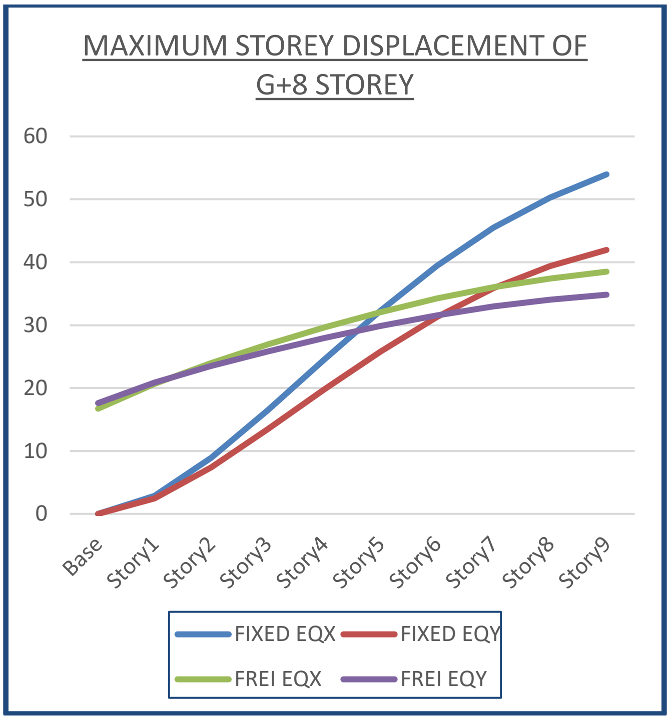

Fig. 12 Static Storey Displacement of G+ 8 Storeys in X & Y Direction

It can be clearly seen from the linear static analysis that the displacement in top of the building is reduced in X & Y direction, when the FREI comes in act. The results also show us that the variation in displacement from base to top also been reduced while using FREI as an isolator in the RCC frame building. The discussion done above is applicable for all stories such as G+ 4, G+ 6, G+ 8 storeys while applying lateral load method.

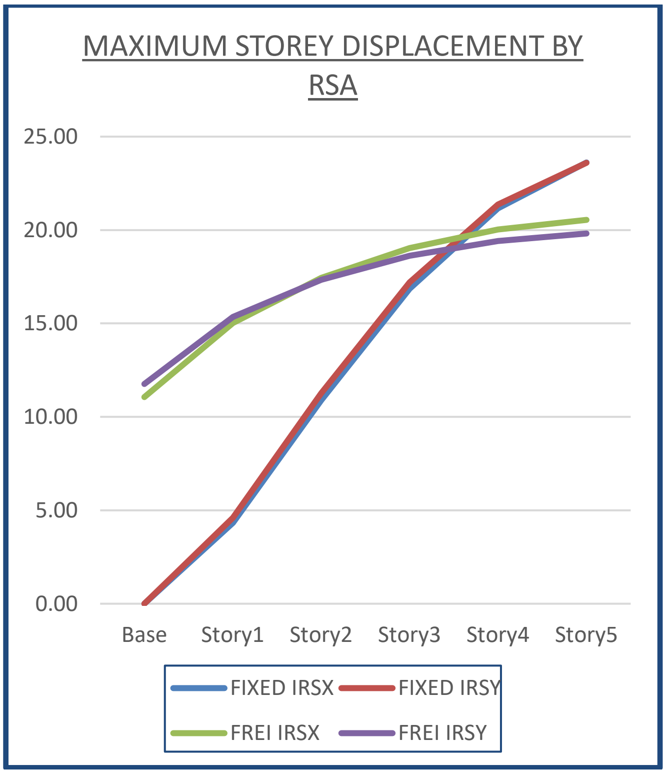

Fig. 13 Response Spectrum Storey Displacement of G+4 Storey in X & Y Direction

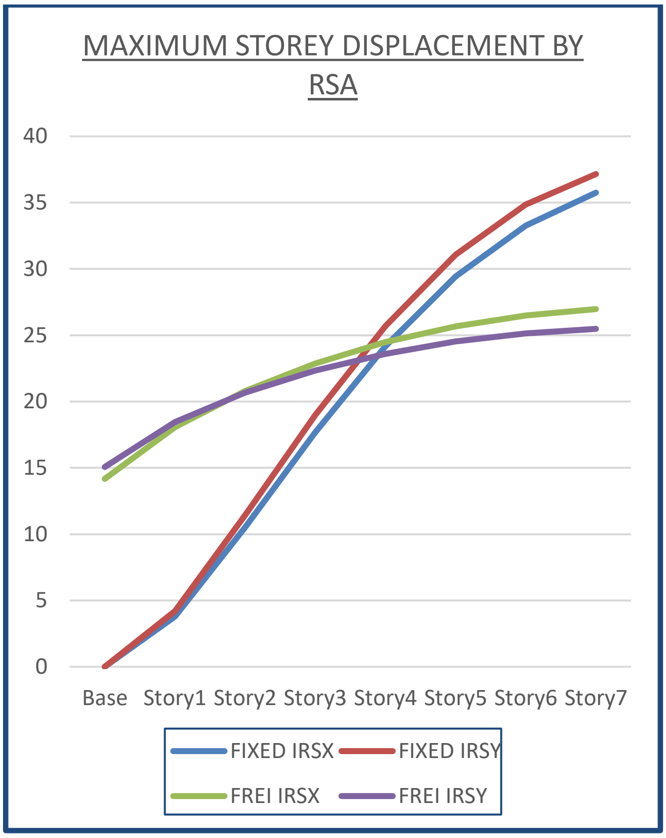

Fig. 14 Response Spectrum Storey Displacement of G+6 Storey in X & Y Direction

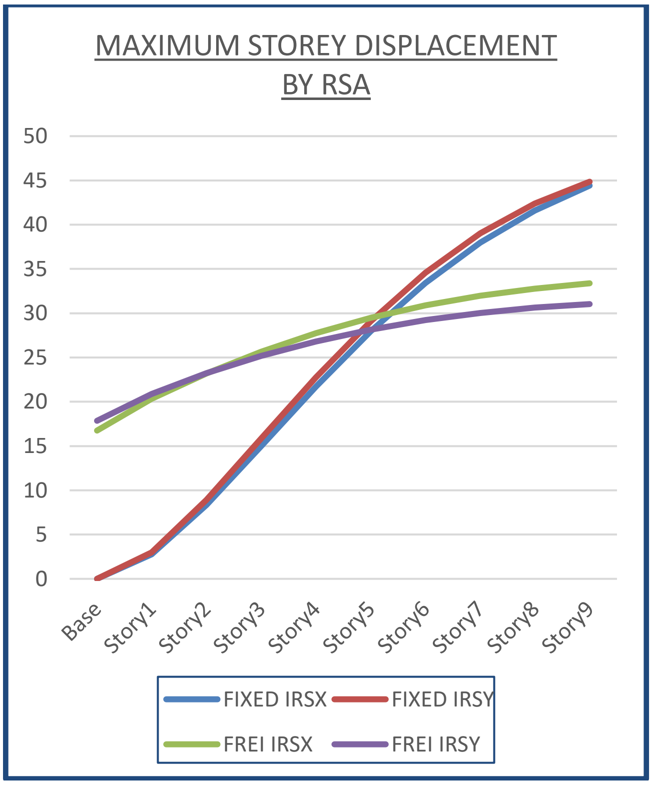

Fig. 15 Response Spectrum Storey Displacement of G+8 Storey in X & Y Direction

Similarly, In Response Spectrum analysis, the displacement in top of the building is reduced in X & Y direction, when the FREI comes in act.

The results also show us that the variation in displacement from base to top also been reduced while using FREI as an isolator in the RCC frame building. The above parameter shown in form of graph are in range, in accordance with the Indian Standard.

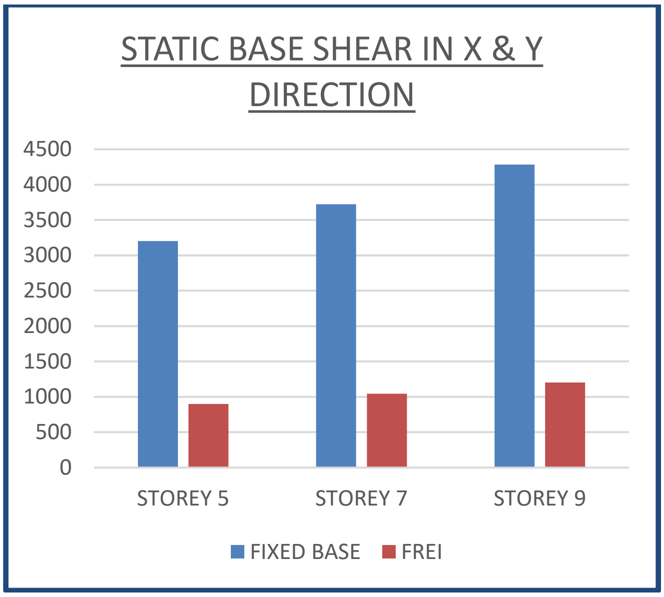

Fig. 16 Static Base Shear of All Storey in X & Y Direction

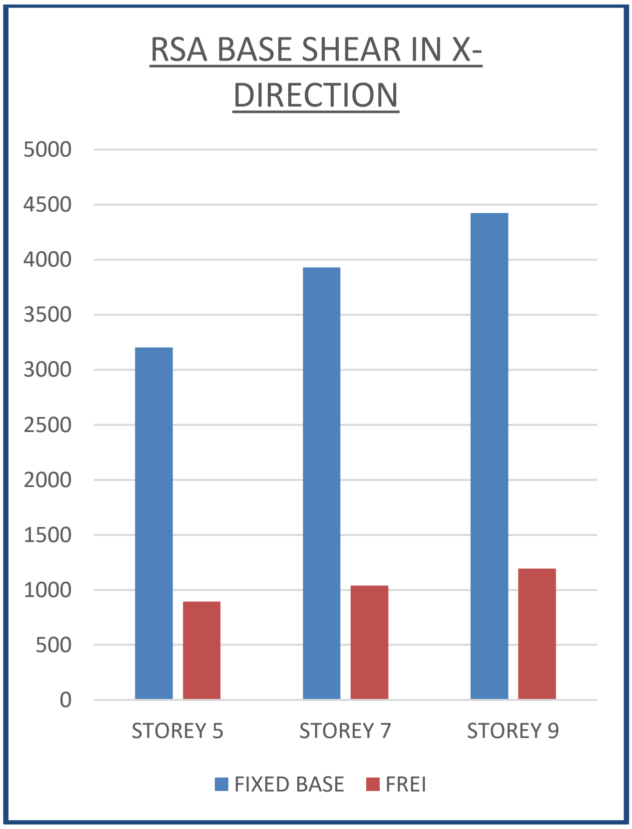

Fig. 17 Response Spectrum Base Shear of All Storey in X-Direction

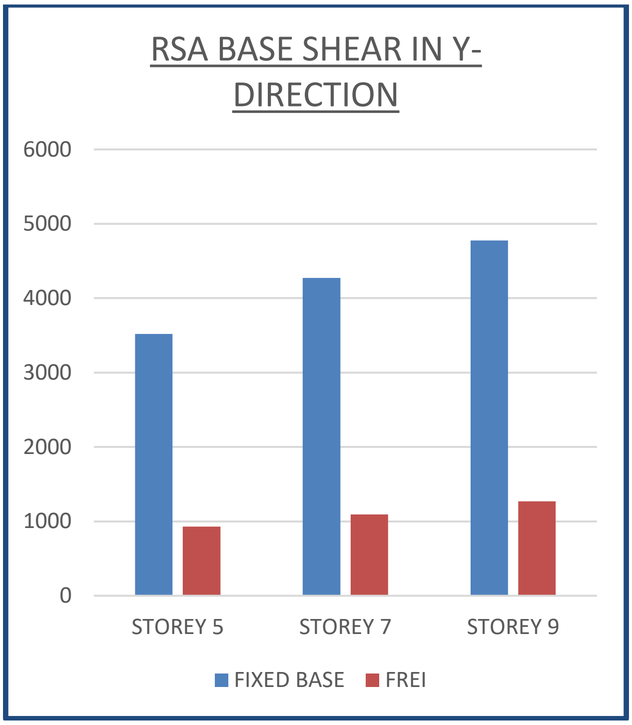

Fig. 18 Response Spectrum Base Shear of All Storey in Y-Direction

The maximum base shear of all storey by both methods i.e., Lateral Load Method and Response Spectrum Method are represented in graph form. It shows that there is tremendous lose in maximum base shear of fixed base and FREI base. About 70% base shear has been reduced, which is the good outcome for FREI bearing.

V. CONCLUSION

The study describes the behavior of fiber-reinforced elastomeric isolators on structural system under the execution of dynamic load, from which various conclusion can be drawn based on results:

- Time period of all the modals have been increased after the installation of FREI in the Structure System. Maximum increase in time period is observe about 52.4% in G+4 Storey, 50% in G+6 Storey, and 51.3% in G+8 Storey building. Thus, the frequency of structure will reduce and comfort the humans, living inside the isolated building.
- Static analysis of RCC frame building gives the storey displacement in X & Y direction, which can be concluded as, the variation in base to top storey is reduced under permissible limits as mention Indian Standard Code. It means that, their will be highly reduction in shear crack when the seismic force act on it.
- The Response Spectrum Analysis shows the storey displacement in X-direction reduces about 59.84% in G+4 Storey, 64.19% in G+6 Storey, and 62.54% in G+8 Storey, while considering the whole storey of the buildings. Thus, increasing the flexural rigidity of the structure in X- Direction.

- Similarly, Response Spectrum Analysis shows the storey displacement in Y-direction reduces about 65.87% in G+4 Storey, 72% in G+6 Storey, and 70.62% in G+8 Storey, while considering the whole storey of the buildings. Thus, increasing the flexural rigidity of the structure in Y-Direction.
- Maximum Base Shear of static analysis in X & Y-Direction is fall down up to 71% Approx. all the stories.
- The analysis of base shear was done by response spectrum analysis, when FREI is mounted on structure and comparison is done with Fixed Base Structure. It is being observed that there is a reduction of about 72% in the base shear by using response spectrum as per Indian Standard in X- direction.
- Similarly, there is a decrement in base Shear of about 73.5% in Y direction, by taking response spectra as per IS code.

The above conclusion can simply be stated as, that the FREI can be the better option in developing countries because of its similar properties as conventional isolators. Also because of FREI is light in weight and manufacturing cost is ten times low as conventional once.

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AUTHORS PROFILE

Anshul Shrivastava M.E. in Computer Aided Structure Design & Drafting, Department of Civil Engineering, Ujjain Engineering College, Ujjain (M.P.) India.

Dr. Savita Maru, Professor, Department of Civil Engineering, Ujjain Engineering College, Ujjain (M.P.) India. Member of The Institution of Engineers (India), The Indian Society for Technical Education (ISTE) Life Member, Indian Association of Structural Engineers Fellow, Institute for Steel Development and Growth (INSDAG) Life Membership.