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Seismic Behaviour of RCC Frames under Passive Dampers

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Abstract—*The basic principle of passive damping is based on minimization of seismic forces by shifting the natural vibration period of the structure out of hazardous resonance range and also the energy dissipation. In the present study, an approach towards earthquake resistant structural design is described. As example, 8-storey two dimensional (2-D) frame is analyzed. Two dimensional non-linear static analysis on R.C. structural frame with fixed base and passively damping system as earthquake resistance alternative. Effects of passive damping systems such as base isolation consisting High Density Rubber Bearing (HDRB) & Lead Rubber Bearing (LRB), Friction Pendulum System (FPS) & viscous damper (VD) are studied.*

The main objective here is to make a comparison between earthquake resistant structure with conventional fixed base structure, rather than comparing seismic resistance alternatives within themselves. In the analysis parameters like storey shear, max. storey drifts, max. storey displacement etc. are compared and discussed. Also the performance level of structural frames is analyzed.

Keywords: *Base isolation, nonlinear static analysis, 2-D frame, Pushover analysis, Etab's 9.7.4, passive Dampers.*

1. INTRODUCTION

Now-a-days space scarcity for living is rising. To cope with the demands of the consumer, construction industries try to build high rise structures. But these high rise structures face another disastrous force in the form of earthquake and wind. To make these structures safer and serviceable, the new trends of earthquake resisting structure come in the picture. To reduce this seismic damage, various types of structural control technology have been developed to resolve the safety and functionality issues for the structure under the exciting forces. There are four damping systems developed for the structural control. These damping system include,

1. Active control system
2. Passive control system
3. Semi-Active control system
4. Hybrid control system

1.1 Principal of Passive Control System

The principal function of passive control system is to reduce energy dissipation demand of the structure. A passive system is a system which does not require external power supply for its operation and uses the motion of the structure itself to generate controlling forces. The control system and the structure do not behave as independent dynamic systems but rather interact with each other. Fig. 1.1 & 1.2 shows flow chart of the structural systems.

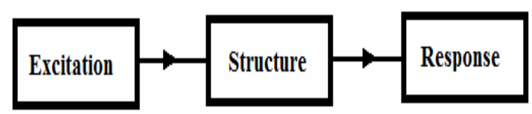

Fig. Error! No text of specified style in document.**.1: Conventional structural system**

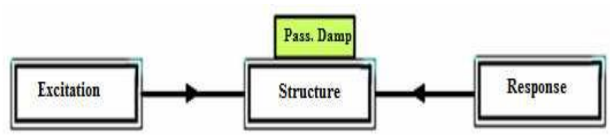

Fig. Error! No text of specified style in document..2: Passive control system

1.2 Advantages of Passive control system:

- It is relatively inexpensive.
- Requires no external power.
- Inherently stable.
- Works even in major seismic events.

1.3 Disadvantages of Passive control system

- Not as reliable as active or semi-active control system in seismic event.
- Effectiveness is limited.
- It does not make any real time changes in the system.

1.4 Purpose of Pushover Analysis

The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating its strength and deformation demands in design of earthquakes by means of static inelastic analysis and comparing these demands to available capacities at the performance levels of interest. The evaluation is based on an assessment of important performance parameters, including global drift, inter-storey drift, inelastic element deformations between elements, and element connection forces. The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic range of structural behaviour. The pushover is expected to provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis. Performance point can be obtained by super-imposing capacity spectrum and demand spectrum and the intersection point of these two curves is performance point. Fig 1.3 shows superimposing demand spectrum and capacity spectrum.

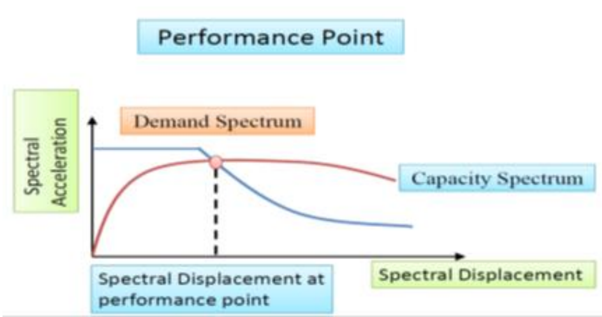

Fig. Error! No text of specified style in document..3: Performance point of the structure using capacity spectrum method

Hinge assignment [As per ATC 40]

Default hinges are assigned to the members for analysis of the frames

Table Error! No text of specified style in document..1: Hinge Property Assignment

ELEMENT TYPE	HINGE TYPE	RELATIVE DISTANCES
Beams	M3	0 and 1
Columns	PMM	0 and 1

2. ANALYSIS OF BUILDING FRAMES WITH PASSIVE DAMPERS

For the seismic analysis, 8-storey 2-D frame is studied, for this frame; firstly linear static seismic analysis is carried out and resultant parameters are studied. After that, non-linear static analysis i.e. Pushover analysis is carried out to check the performance level of the building frames. These structures are designed according to IS 456:2000 and are located in seismic zone-III, soil type-II.

Following is the other common data for both the frames: structural dimension-3.5 m each for 3 bay structure, floor height-3m, depth of slab- 150mm, L.L.-3kN/m^2, concrete grade-M20 & steel grade-Fe415.

2.1 Structural data for 8-storey 2-D Frame:

For 8-storey 2-D frame:

Size of columns: 230mm X 350mm

Size of beams: 230mm X 450mm

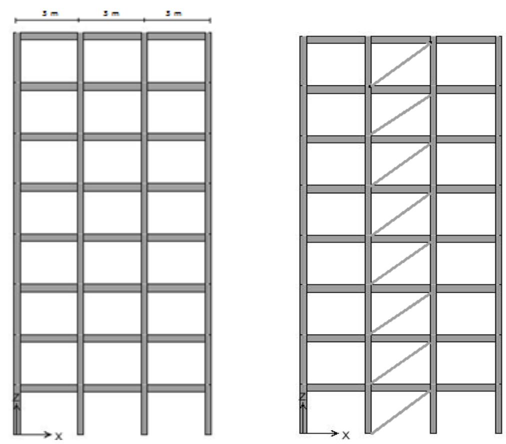

Fig. Error! No text of specified style in document.**.4 Elevation Fig.** Error! No text of specified style in document.**.5 Frame with Viscous Dampers**

- **Fixed Base Building**

For 8-storey fixed base building frames, static linear analysis carried out. For first mode, the time period in x-dir for 8-storey is 0.913 sec.

- **Alternative with High Density Rubber Bearing**

For the high density rubber bearing base isolated building frame, static linear analysis carried out. The seismic isolators in the system are defined as Nllink components 0.5 m in length placed between the fixed base and the columns. The parameters selected to define the utilized isolators in the ETAB‟s 9.7.4 program are as follows-

Nonlinear Link Type: Rubber, U1 Linear Effective Stiffness: 2812845 kN/m, U2 and U3 Linear Effective Stiffness: 2454 kN/m, U2 and U3 Nonlinear Stiffness: 2069.24 kN/m, U2 and U3 Yield Strength: 130.14 kN, U2 and U3 Post Yield Stiffness Ratio: 0.1

For first mode, the time period in x-dir for 8-storey is 1.293 sec.

- **Alternative with Lead Rubber Bearing:**

For the LRB base isolated building frame, static linear analysis carried out. The seismic isolators in the system are defined as Nllink components 0.5 m in length placed between the fixed base and the columns. The parameters selected to define the utilized isolators in the ETAB‟s 9.7.4 program are as follows-

Nonlinear Link Type: Rubber, U1 Linear Effective Stiffness: 1500000 kN/m, U2 and U3 Linear Effective Stiffness: 800 kN/m, U2 and U3 Nonlinear Stiffness: 2500 kN/m, U2 and U3 Yield Strength: 80 kN, U2 and U3 Post Yield Stiffness Ratio: 0.1

For first mode, time period in x-dir is 1.583 sec.

- **Alternative with Friction Pendulum System**

Friction pendulum isolators are defined as Nllink components 0.5m in length placed between the fixed based and the columns just like in the case of rubber isolators. The parameters selected to define the utilized isolators in the program are as follows-

Nonlinear Link Type: Friction Isolator, U1 Linear Effective Stiffness: 15000000 kN/m, U1 Nonlinear Effective Stiffness: 15000000 kN/m, U2 and U3 Linear Effective Stiffness: 750 kN/m, U2 and U3 Nonlinear Stiffness: 15000 kN/m, U2 and U3 Friction Coefficient, Slow: 0.03, U2 and U3 Friction Coefficient, Fast: 0.05, U2 and U3 Rate Parameter: 40, U2 and U3 Radius of Sliding Surface: 2.23.

For the FPS base isolated building frame, static linear analysis carried out. For first mode, the time period in x-dir for 8-storey is 1.606 sec.

- **Alternative with Viscous Dampers:**

In this alternative; 1 VD is placed in middle bay throughout the storey (Fig. 2.1). The parameters selected to define the utilized isolators in the program are as follows: Nonlinear Link Type: Damper, U1 Nonlinear Stiffness: 500 kN/m, U1 Nonlinear Damping: 70 kN.sec/m, U1 Nonlinear Damping Exponent: 1.

In the linear static analysis carried out; the first mode period of the structure is found to be 1.122 sec for 8- in the x direction.

3. RESULTS AND DISCUSSION

In this section; the results obtained from the linear static & non-linear static analysis are examined within the framework. The natural period of the structure being 0.913 in the 8-storey fixed base situation is increased to1.606 sec level in the systems containing base isolators. When storey shear, max. Storey drift and max. Storey displacements are examined, it is seen that; this value is adequate for the structure being completely removed from the resonance range of the earthquake. It is seen that the alternative containing viscous dampers did not have that much influence on the natural period.

3.1 Linear Static Results

3.1.1 Storey Shear

Storey Shear of fixed base structure and Passively Damped structure using High Density Rubber Bearing (HDRB), Lead Rubber Bearing (LRB), Friction Pendulum System (FPS) and Viscous Damper isolators are compared. Base Shear in X direction for all cases are compared and shown in Fig. 3.1

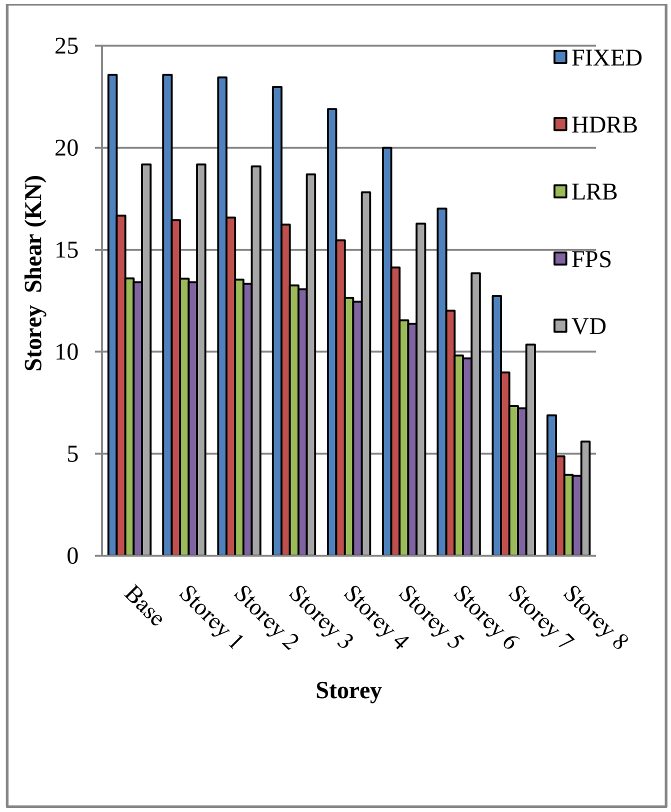

Fig. Error! No text of specified style in document.**.6: Storey shear distribution between Fixed base and passively Damped Framed Structure**

From above figure, we can conclude that, Base shear of fixed frame structure changes from 23.57 kN to 13.4035 kN by implementing FPS to structure.

3.1.2 Storey Drift

Storey Drift of fixed base structure and Passively Damped structure using High Density Rubber Bearing (HDRB), Lead Rubber Bearing (LRB), Friction Pendulum System (FPS) and Viscous Damper isolators are compared. Storey Drift in X direction for all cases are compared and shown in Fig. 3.2

From Fig. 3.2, we can conclude that, Storey Drift of fixed frame structure changes from 0.4668 mm to 1.045 mm by implementing VD to structure.

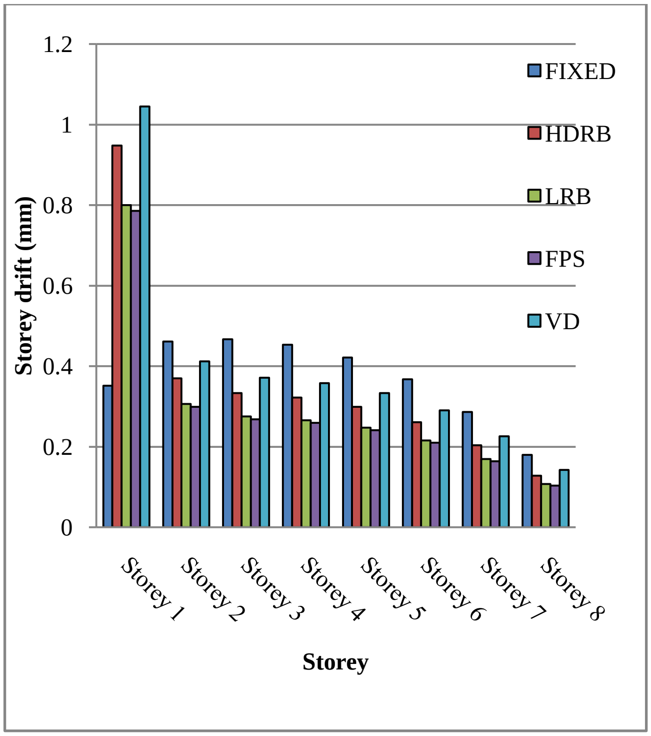

Fig. Error! No text of specified style in document.**.7: Storey Drift between Fixed base and passively Damped Framed Structure**

3.1.3 Storey Displacement:

Storey Displacement of fixed base structure and Passively Damped structure using High Density Rubber Bearing (HDRB), Lead Rubber Bearing (LRB), Friction Pendulum System (FPS) and Viscous Damper isolators are compared. Storey Displacement in X direction for all cases is compared and shown in Fig. 3.3

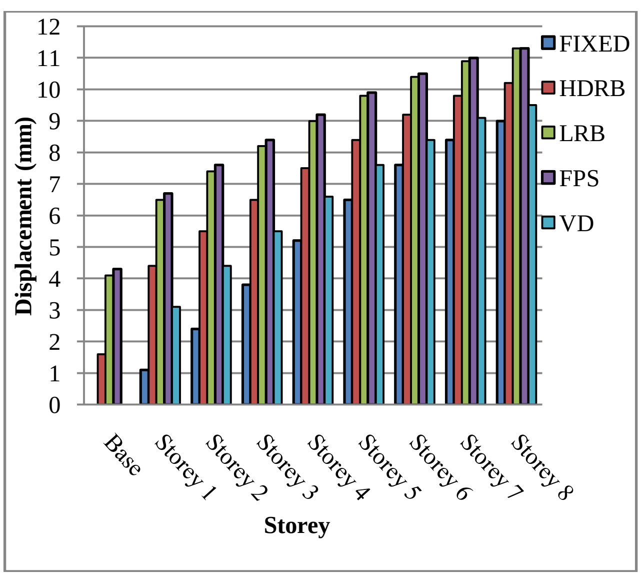

Fig. Error! No text of specified style in document.**.8: Storey Displacement between Fixed base and passively Damped Framed Structure.**

From above figure, we can conclude that, max. Storey Displacement of fixed frame structure changes from 9 mm to 11.3 mm by implementing Fps & LRB to structure.

In the base shear forces, the results of the rubber and friction pendulum alternatives are very close to each other, and they provided approximately 43% reduction in the x direction. This reduction in the forces indicates that the performance of the base isolation under the influence of earthquake is extremely good. Here VD shows negligible difference in base shear compared to fixed base.

It is seen that in all alternatives, apart from the first floor, the relative storey drifts is significantly reduced especially in the fixed - base alternative. This situation indicates that the superstructure exhibits behaviour close to rigid body behaviour in base isolation.

In the Storey displacement comparison, the results of the rubber and friction pendulum alternatives are very close to each other, and they provided approximately 25% increment in the x direction. Here use of VD doesn’t shows much increment in displacement.

3.2 Non-linear static analysis results:

As per FEMA 356 guidelines time period for first mode is used in push over analysis

Capacity spectrum curve:

C_a =Acceleration based soil coefficient

C_v =Velocity based soil coefficient

C_a =Z/2 =0.16/2 =0.08

C_v =1.0 x Ca =1.0 x 0.08 =0.08

From Fig. 3.4, we can see performance point & at the performance point base shear is 66.017 kN and roof displacement is 0.025 m.

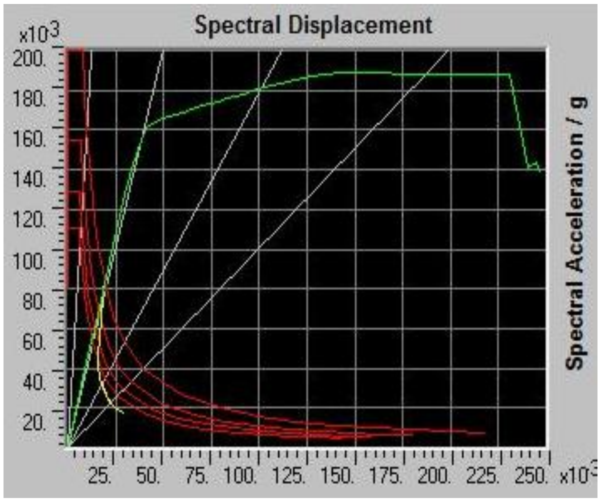

Fig. Error! No text of specified style in document..9: Capacity spectrum curve for Fixed Building frame

From Fig. 3.5 we can see performance point &at the performance point base shear is 51.905 kN and roof displacement is 0.034 m.

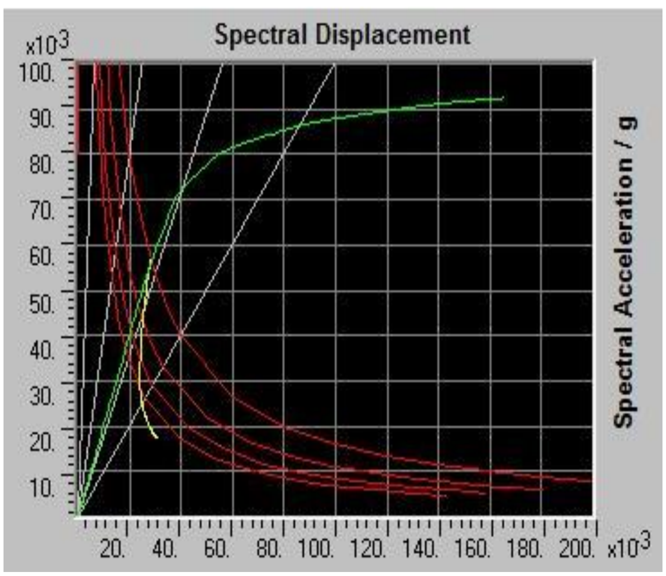

Fig. Error! No text of specified style in document.**.10: Capacity spectrum curve for HDRB frame**

From Fig. 3.6, we can see performance point & at the performance point base shear is 52.459 kN and roof displacement is 0.034 m.

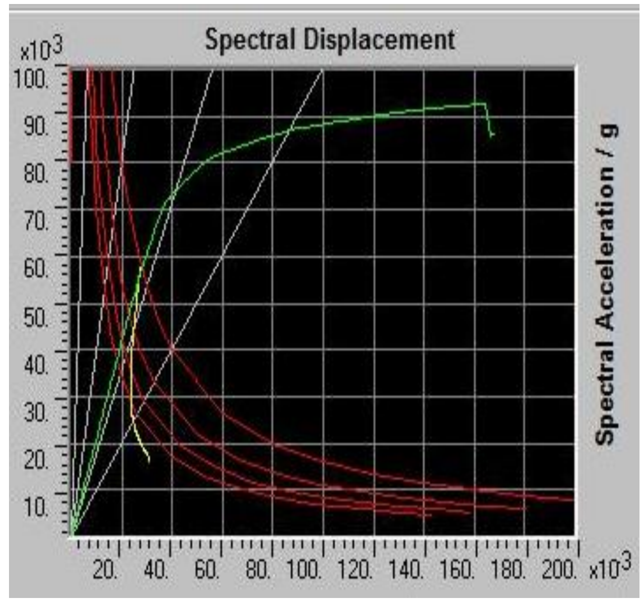

Fig. Error! No text of specified style in document..11: Capacity spectrum curve for LRB frame

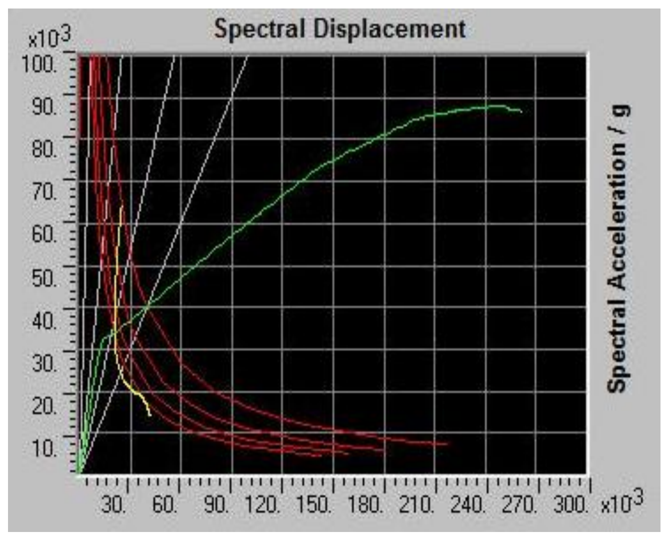

Fig. Error! No text of specified style in document..12: Capacity spectrum curve for FPS frame

From Fig. 3.7, we can see performance point & at the performance point base shear is 32.667 kN and roof displacement is 0.025 m.

From Fig. 3.8, we can see performance point & at the performance point base shear is 56.438 kN and roof displacement is 0.030 m.

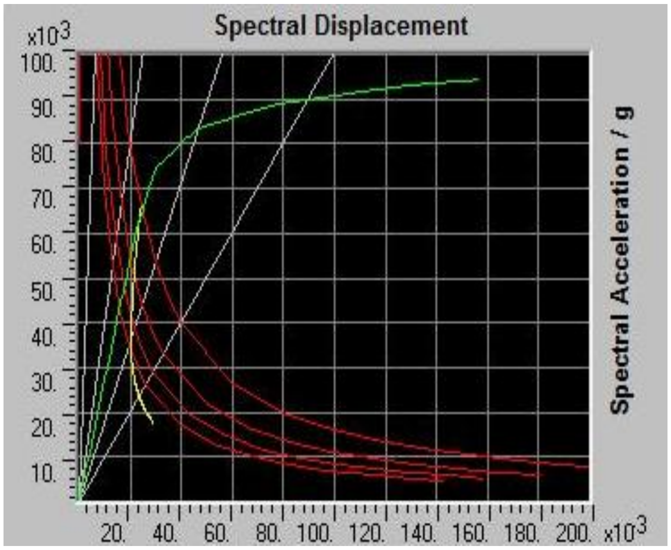

Fig. Error! No text of specified style in document.**.13: Capacity spectrum curve for VD frame**

Table Error! No text of specified style in document..2: Performance level of Frames

Type of Frame	Base Shear (KN)	Disp. (mm)	Performance level
Fixed Frame	66.016	0.025	A-B
Frame With HDRB	51.905	0.034	B-IO
Frame With LRB	52.459	0.034	B-IO
Frame With FPS	32.667	0.025	A-B
Frame With VD	56.438	0.030	B-IO

4. CONCLUSION

Basic concept of base isolation is very well studied. Base Isolators controls structural response in which the building or structure is decoupled from the horizontal component of the earthquake ground motion. A base-isolation system reduces ductility demands on a building, and minimizes its deformations. From the result, By conducting the linear static analysis, it was shown that base isolation increases the flexibility at the base of the structure which helps in energy dissipation due to the horizontal component of the earthquake and hence superstructure's seismic demand drastically reduced as compared to the conventional fixed base structure.

- Base isolation is very promising technology to protect different structures like buildings, bridges, airport terminals and most important to nuclear power plants etc. from seismic excitation.
- The variation in maximum storey displacement of stories in base isolated model is very low while compared with fixed frame model.
- The flexibility of the bearing is important to the structures under earthquake ground motion;
- Storey overturning moment and storey shear are also reduced in base isolated framed structures resulting in making the superstructure above the isolation plane as rigid and stiffer.
- Results shows that storey acceleration considerably reduced by using base isolation devices over the fixed framed conventional structure
- It shows that, Building Designed as per IS code, Performs well in the Non-linear region.
- At the Performance point, the performance level of frame is between B-IO level, which concludes that the design as per IS Code is very safe and stable.

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