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Seismic Vibration Control of Building using Base Isolation Technique with Friction Dampers

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Abstract - *Studies on the methods to mitigate the effects of earthquake on structures has gained up pace since the last four decades with the invention of base isolation techniques and then the energy dissipating seismic devices. Here in this work an effort has been made to study the effects of Lead Rubber Bearing (LRB) as base isolator and Friction Dampers as energy dissipating devices when installed individually and when as a dual combination in the eight storey 'C' shaped building considered by the use of ETABS software. The building is assumed to be located in earthquake zone 4 and the method of seismic analysis chosen is linear Response Spectrum analysis. The response parameters that are studied in this work are time period, base shear, storey displacement and storey drifts. The results show that these devices have improved seismic resistance of the building by decreasing the responses of the structure when included as individually and when as a combined control strategy. The improved results are in comparison with the conventional model.*

Key Words**:** Base Isolation, Friction Damper, Seismic Analysis, Response Spectrum Analysis, ETABS V17

1. INTRODUCTION

For controlling earthquake vibrations, Base isolation technique and Friction dampers are being used in this study. Base isolation system decouples the superstructure from substructure and hence reduces the effect of earthquake on the structure whereas friction dampers increase the stiffness of the structure and hence makes the structure earthquake resistant. Till now there have been studies conducted on the behavior of the Concrete framed structure upon the incorporation of either base isolation systems or the friction dampers as the passive earthquake energy dissipating devices in order to mitigate the earthquake effects on the structures. An attempt has been made in this work to check the effectiveness of these devices as a combined control strategy for the structure.

1.1 Base Isolation

Base isolation, also known as seismic base isolation or base isolation system 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. Base isolation system is the frequently adopted earthquake resistance system. It reduces the effect of ground motion and thus leads to nullify the effect of earthquake to on the structure. Base isolation has become popular in last couple of decades in its implementations in buildings and bridges. Base isolation has become a traditional concept for structural design of buildings and bridges in high risk areas. The isolation system decouples the structure from the horizontal components of the ground motion and reduces the possibility of resonance as shown in Figure 1.This decoupling is achieved by increasing the flexibility of the system, together with appropriate damping by providing isolator at the basement level of the structure.

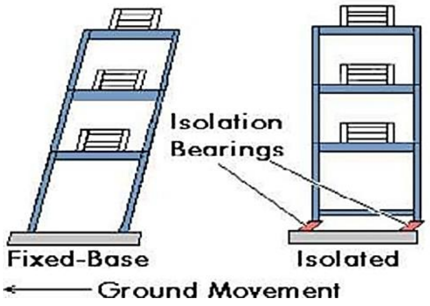

Figure 1: Typical explanation of base isolation system

1.2 Lead-Plug Rubber Bearing

Lead-plug rubber bearings were invented in New Zealand in 1975. The mechanism of lead-plug rubber bearings is very similar to that of low-damping natural rubber bearings. As show in Figure 2, there are three main pieces of equipment, layers of steel plates, rubber layers and lead core, respectively. Same as the steel shims in natural rubber bearings, the layers of steel provide vertical stiffness and the layers of rubber supply the device with high lateral flexibility. Lead core is the device that will supply extra stiffness to the isolators and appropriate damping to the system. Owing to current well-developed technologies, it is possible to manufacture lead-plug rubber bearings with high stiffness and enormous shear deformation. Innovations in materials and design related technologies such as analysis software and construction methods have enabled the concept of isolation become a reality.

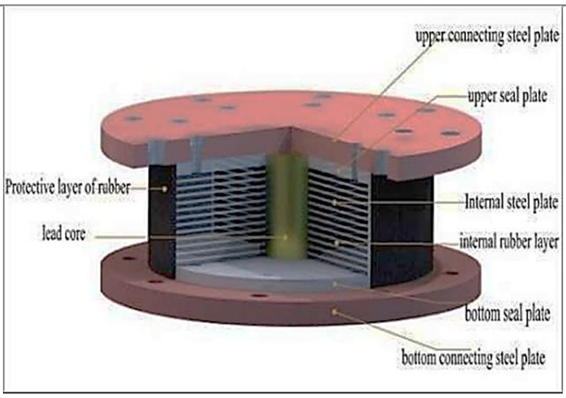

Figure 2: Typical lead rubber bearing

1.3 Friction Dampers

Earthquake cause ground vibration due to the sudden release of energy. This energy can be absorbed by using the vibration control device called friction damper. The friction dampers are designed to have moving parts that will slide over each other during a strong earthquake. When the parts slide over each other, they create a friction which uses some of the energy from earthquake that goes into the building. This Friction damper increases the stiffness of the building as a result vibration of the building is reduced. The structural response to the seismic excitation has reduced by applying friction dampers based on different construction techniques. Friction dampers come under passive seismic control system does not require any external energy source to operate and is activated by the earthquake input motion only. The friction surfaces of these systems are clamped with pre-stressing bolts. Since the amount of energy dissipated is proportional to displacement these systems are referred as displacement dependent systems. Contact surfaces of these systems used are lead–bronze against stainless steel or Teflon against stainless steel. Below Figure 3 depicts various types of Friction damper images.

Figure 3: Friction Damper

1.4 Objectives

1. To perform Response Spectrum Analysis on an irregular “C” shaped concrete framed structure using ETABS software.
2. To design the Lead Rubber Bearing as a base isolation system for the considered multi-storey building and to study the seismic behaviour of the structure upon incorporation of LRB to it.
3. To study the seismic response parameters of the considered structure with the incorporation of just Friction Dampers to it.
4. To carry out seismic analysis by introducing both LRB and Friction Dampers as a dual system in the considered structure and study the response parameters.
5. To conduct comparative study on all the four cases, reinforced concrete framed structure, framed structure with LRB, framed structure with Friction dampers, framed structure with LRB and Friction dampers, by considering time period, base shear, storey displacement and storey drifts as the response parameters.

2. LITERATURE REVIEW

Mohammued Irfan Faraaz et.al (2016) the study is performed to compare the effectiveness of base isolation over the fixed based building and fixed based building with shear wall. For this study, 10 storied R.C frame building is considered and Time History analysis is carried out for Bhuj earthquake using ETABS 2015 software. The Lead Rubber Bearing is designed as per UBC 97 code and the same was used for analysis of base isolation system. The results obtained from the analysis were time period, deflection and base shear. The models selected for analysis were fixed based building, fixed based building with shear wall and base isolated building. The installation of isolator in building at base level significantly increases the time period of the structure, which means it reduces the possibility of resonance of the structure giving rise to better seismic performance of the building.

Aparna Bhoyar et.al (2019) the paper mainly emphasized use of one such device friction damper for response control of structures. In this paper the comparison of reinforced concrete building connected with and without damper for G+5, G+10, G+15 storied building for seismic zone IV is considered. Analysis is done using equivalent static method, response spectrum method and time history method in finite element software package, ETABS version 16.2. For seismic load combination IS 1893:2016 is used. The model analysis is carried out by all four methods of analysis and results are discussed in terms of storey displacement, storey drift, base shear, bending moment and axial forces. From result obtained it is concluded that storey drift and displacement in friction damper building is reduced whereas base shear is less in building without damper.

3. METHODOOGY

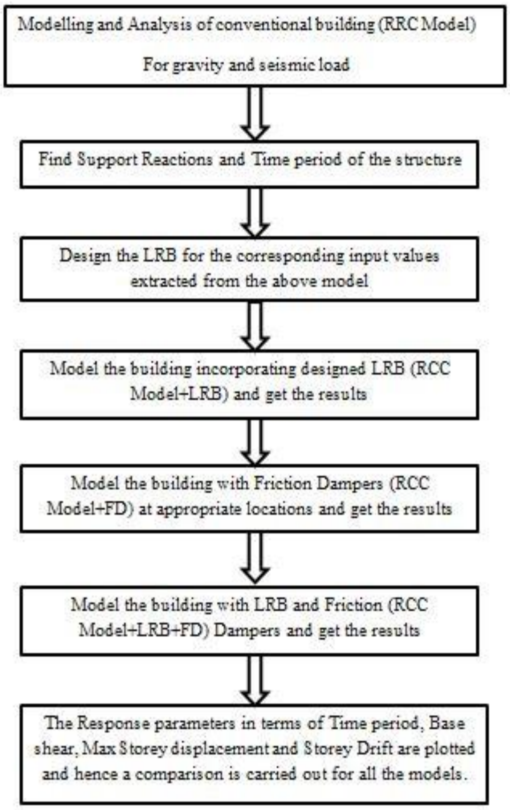

Figure 4: Flow chart of methodology

4. MODELING

Table 1: Design data for all models

No	**Design data for all the buildings**	
1	**Details of Building**	
i)	Number of stories	G+7
ii)	Type of building	Institutional
iii)	Story height	3.2 m
2	**Material Properties**	
i)	Grade of concrete	M30
ii)	Grade of steel	Fe500
3	**Member Properties**	
a	**Slab**	
i)	Grade	M30
ii)	Thickness	150 mm
b	**Beam**	
i)	Grade	M30
ii)	Size	300X450 mm
c	**Column**	
i)	Grade	M30
ii)	Size	350X450 mm
4	**Loads and Intensities**	
i)	Live Load on all the floors	4 kN/m^2
ii)	Live Load on terrace	1.5 kN/m^2
iii)	Floor Finish	1 kN/m^2
iv)	Terrace Finish	1.75 kN/m^2
v)	Wall load	14 kN/m^2
vi)	Parapet Wall load	4 kN/m^2
5	**Seismic Data from IS : 1893(Part1)-2016**	
i)	Zone factor	0.24
ii)	Importance factor	1.5
iii)	Response reduction Factor	5.0
iv)	Soil Type	Medium
6	**LRB link properties**	
	For U1	
i)	Vertical stiffness of bearing, K_v	2237015 kN/m
ii)	Effective damping of bearing, ξ_{eff}	20%
	For U2 & U3 Linear Property	
iii)	Effective horizontal stiffness, K_{eff}	2161.68 kN/m
iv)	Effective damping of bearing ξ_{eff}	20%
	For U2 & U3 Non-Linear Property	
v)	Initial Stiffness of Bearing, K_e	11660 kN/m
vi)	Yeild Force of Bearing, F_y	213.912 kN
vii)	Post yield stiffness ratio	0.1
7	**Link (Friction damper) Properties**	
i)	Mass	80 kg
ii)	Weight	0.78 kN
iii)	Effective Stiffness	108855 kN/m
iv)	Yield strength or Slip load	250 kN

For the purpose of modelling Friction Dampers, have referred Quaketek company's guidelines, which is a Canada based company known for its manufacturing of Friction dampers. The damper has been modelled as according to their guidelines.

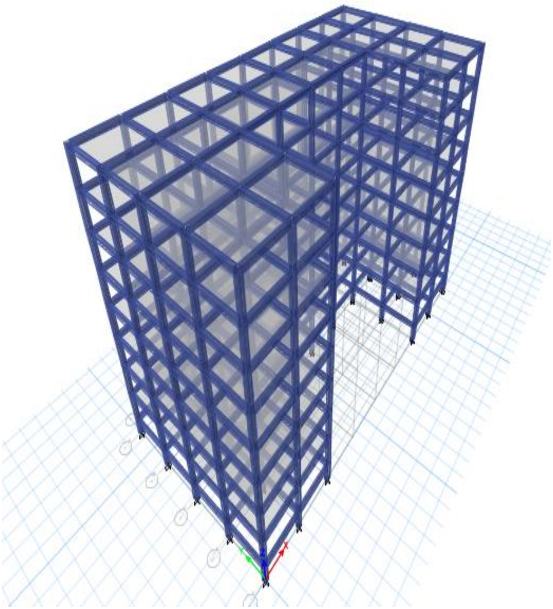

Figure 5: 3D Model of the conventional building

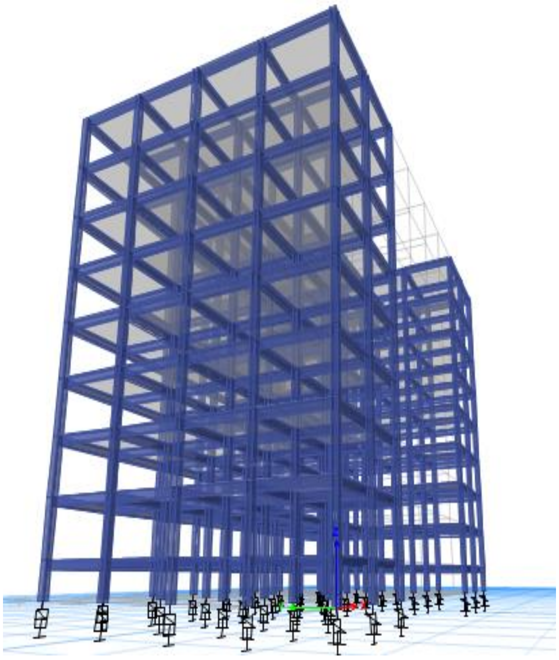

Figure 6: Building after the incorporation of LRB at the base of it

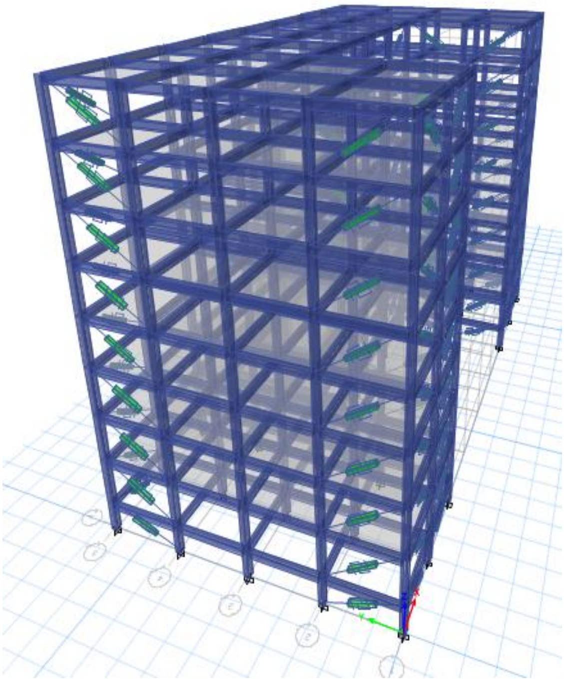

Figure 7: Building after the incorporation of Friction Dampers

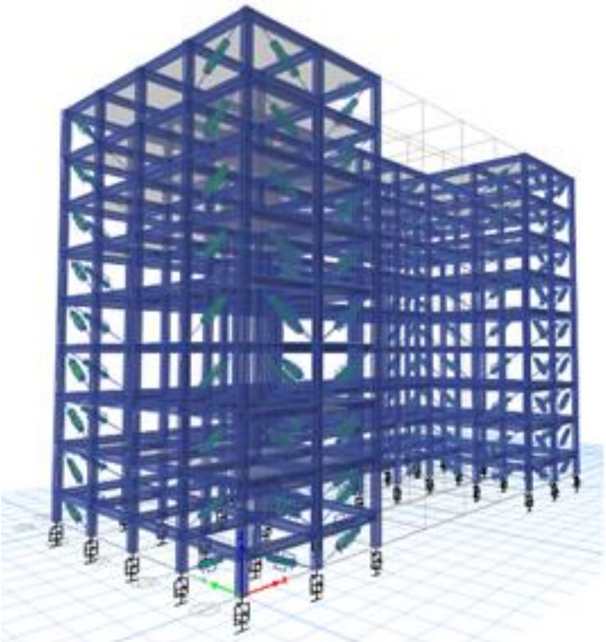

Figure 8: Building with the inclusion of LRB and Friction Damper

4.1 Load Combination

- 1.5(DL+RSx)
- 1.5(DL+RSy)

Response Spectrum Analysis Analysis results are taken for above load combination for the parameters like Time Period , Base Shear, Storey displacement, Storey drift.

5. RESULTS AND DISCUSSIONS

5.1 Time Period

The time taken by the wave to complete one cycle is called its time period. The fundamental time period for all models obtained from the modal analysis in ETABS.

M1: RCC Model M2: RCC Model +FD
M3: RCC Model+LRB M4: RCC Model+LRB+FD

Table 2: Time Period for different Models

Mode	M1 (sec)	M2 (sec)	M3 (sec)	M4 (sec)
1	1.93	1.252	2.798	2.398
2	1.777	1.201	2.622	2.33
3	1.695	1.029	2.608	2.168

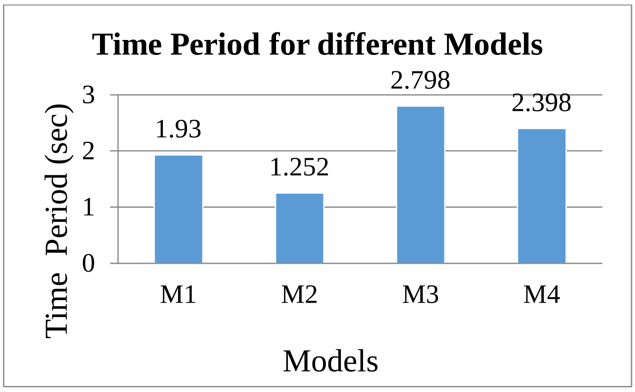

Figure 9: Time periods of all the models considering only the first mode

Table 3: Percentage variation in Time Periods calculated with respect to the Time period of conventional model considering 1st Mode results only.

Model type	Percentage variation
RCC + FD	35.12% ⬇
RCC + LRB	44.50% ⬆
RCC +LRB+ FD	24.24% ⬆

The Figure 9 shows the comparison of time period of different models in seconds. With the incorporation of LRB at base of the building, has increased time period to an extent of 44% that is from 1.93 seconds to 2.798 seconds, with only FDs reduced time period to 35% that is from 1.93 seconds to 1.252 seconds and upon the inclusion of both LRB and FDs, have resulted in increase of time period to 24% that is from 1.93 seconds to 2.398 seconds, on comparing with time period of first mode of conventional model which is fixed base and without dampers.

5.2 Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of the structure. Base shear is the total estimate of the lateral force that would act at the base of the building.The base shear values have been taken for the load combinations 1.5DL+1.5 RSX and 1.5DL +1.5RSY and the results are plotted for the same.

Table 4: Base Shear results of all the models

Models	Base Shear in X direction, (kN)	Base Shear in Y direction, (kN)
M1	3234.417	2839.98
M2	4571.989	4386.222
M3	2088.447	1956.878
M4	2352.887	2285.644

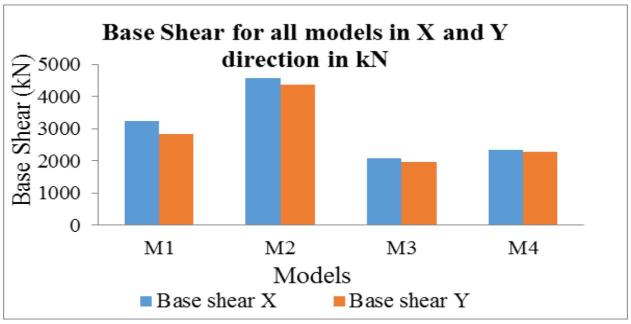

Figure 10: Base Shear of all the models in both X and Y direction

Table 5: Percentage variation in Base Shear calculated with respect to the Base Shear of conventional model

Model type	Percentage variation in X	Percentage variation in Y
RCC + FD	41.35% ⬆	54.44% ⬆
RCC + LRB	35.43% ⬇	31.09% ⬇
RCC +LRB+ FD	27.25% ⬇	19.51% ⬇

When LRBs are introduced at the base of building, it has reduced the base shear values to 35% in X and 31% in Y directions. With the inclusion of only FDs in the model, base shear values have increased to an extent of 41% in X and 54% in Y direction. But in the combined control strategy, that is LRB with FD, the base shear values decrease to 27.25% in X and 19.51% in Y direction as compared with conventional model which is clearly depicted in the Figure 10.

5.3 Storey Displacement

Displacement is the distance of element (beam, column, frame, etc.) moved from its original location.

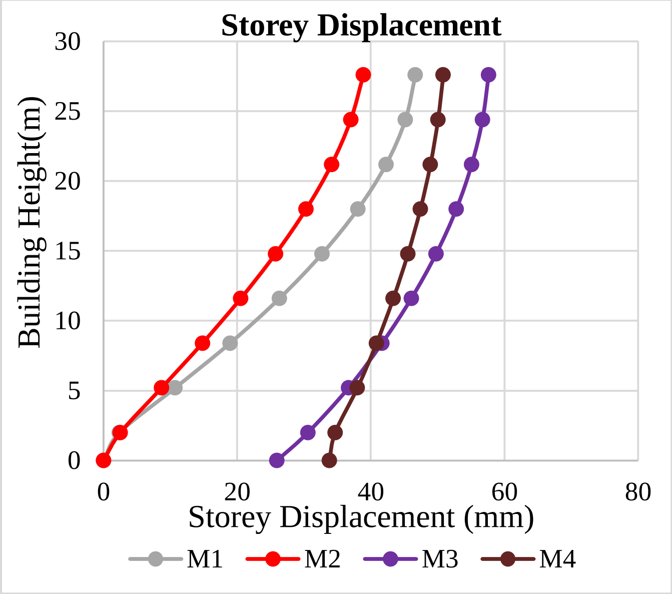

Figure 11: Storey Displacement of all the models in X direction

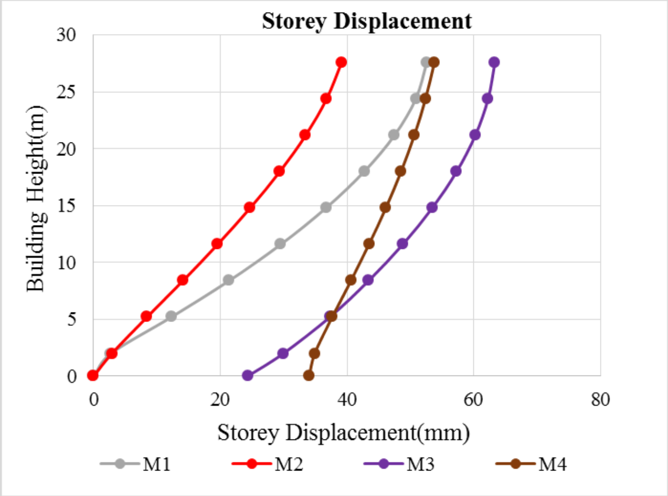

Figure 12: Storey Displacement of all the models in Y Direction

Table 6: Percentage variation in Storey Displacement calculated with respect to the Top Storey Displacement of conventional model

Model type	Percentage variation in X	Percentage variation in Y
RCC + FD	16.68% ⬇	25.56% ⬇
RCC + LRB	23.47% ⬆	20.42% ⬆
RCC +LRB+ FD	8.95% ⬆	2.27% ⬆

Figure from 11 and 12 shows the variation of lateral displacement of the building at each story in both X and Y direction. For all models the lateral displacement is maximum at top and minimum at the bottom.

The maximum storey displacement values decrease to an extent of 16.68% in X and 25.56% in Y direction that is from 46.679mm to 38.891mm in X and 52.58mm to 39.139mm in Y for the model with FDs. For the model with LRB, the maximum storey displacements increase to an extent of 23.47% in X and 20.42% in Y directions that is from 46.679mm to 57.638mm in X and 52.58mm to 63.321mm in Y. For the model with both LRB and FDs there is increase of 8.95% in X and 2.27% in Y directions that is from 46.679mm to 50.857mm in X and 52.58mm to 53.777mm in Y as compared with conventional case.

5.4 Storey Drift

Storey drift is the difference of displacements between two consecutive stories w. r. t. height of that storey.

As per IS 1893 (Part 1): 2016, the storey drift in any storey due to specified lateral force, shall not exceed 0.004 times the storey height.

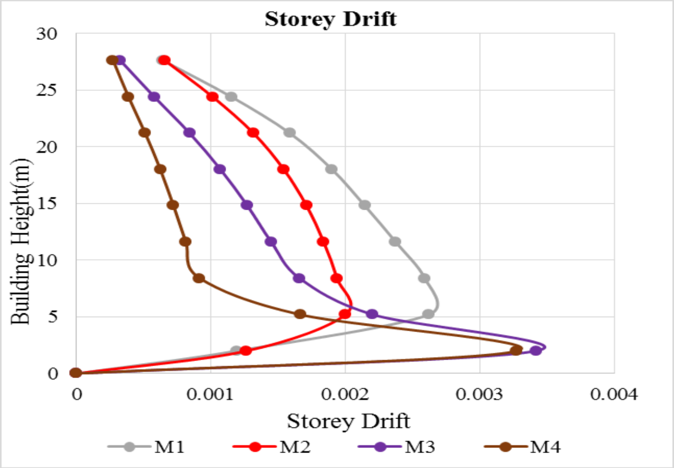

Figure 13: Storey Drift of all the models in X direction

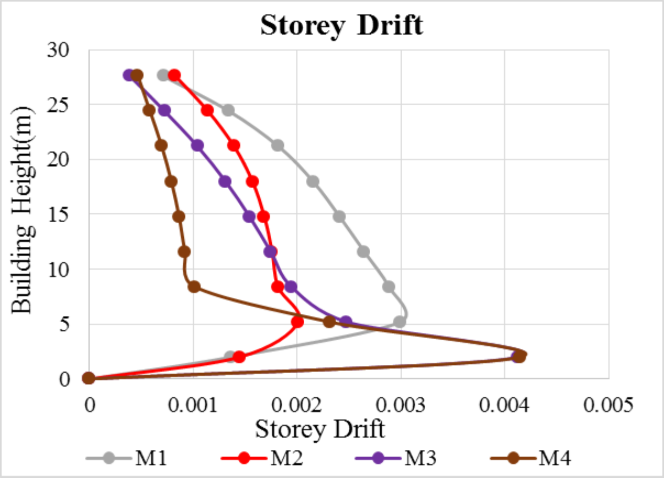

Figure 14: Storey Drift of all the models in Y direction

Table 7: Percentage variation in Storey Drifts calculated with respect to the Maximum Storey Drift of conventional model

Model type	**Percentage variation in X**	**Percentage variation in Y**
RCC + FD	25.21% ↓	37.00% ↓
RCC + LRB	35.94% ↓	32.48% ↓
RCC+LRB+ FD	64.63% ↓	64.73% ↓

It is very clear from the results and Figures 13 and 14 that for both the individual models equipped with LRB singally, with Friction Dampers alone and with both of them as a dual system has reduced the storey drift values which is a major parameter to look for in seismic analysis. The following points depict the actual decrease in storey drift values in percentages,

The storey drift values gets reduced almost to a range of 25.21% in X direction and to 37% reduction in Y direction after the incorporation of friction dampers. When LRB is introduced in the place of fixed base condition, has effectively reduced storey drift values to 35.94% at the storey2 level in X direction and to 32.48% reduction in Y direction. To an extent, the dual effect of LRB and Friction dampers has worked on the same way as above in reducing the drift values effectively, reduced almost to a range of 64% in both X and Y direction.

6. CONCLUSIONS

- The seismic control methods that are used, base isolation (LRB) and Friction Dampers (FD) have effectively reduced the response parameters caused due to earthquake.
- With the incorporation of LRB at base of the building, has increased time period to an extent of 44.50%, with only FDs reduced time period to 35.12% and upon the inclusion of both LRB and FDs, have resulted in increase of time period to 24.24% on comparing with time period of first mode of conventional model which is fixed base and without dampers.
- When LRBs are introduced at the base of building, it has reduced the base shear values of 35.43% in X and 31.09% in Y directions. With the inclusion of only FDs in the model, base shear values have increased to an extent of 41.35% in X and 54.44% in Y direction. But in the combined control strategy, that is LRB with FD, the base shear values decrease to 27.25% in X and 19.51% in Y direction as compared with conventional model.
- The maximum storey displacement values decrease to an extent of 16.68% in X and 25.56% in Y direction for the model with FDs. For the model with LRB, the maximum storey displacements increase to an extent of 23.47% in X and 20.42% in Y directions. For the model with both LRB and FDs there is increase of 8.95% in X and 2.27% in Y directions as compared with conventional case.
- In the model with LRB and in the model with both LRB and FDs, shows some little displacement at base level to an extent of 25mm in X and 34mm in Y, which is zero in case of fixed base building.
- The storey drift values significantly decrease in all the models with LRB, with FDs and even in the dual system that is with both LRB and FDs as compared with conventional building.
- The storey drift values have reduced to an extent of 25% in X and 37% in Y directions for model with FDs. Those drift values have decreased to 35% and 32% in both X and Y directions for model with LRB and to 64% in the case of model with both LRB and FDs in both X and Y directions as compared with conventional case.
- The decrease in storey drifts in the case of combined strategy, that is with LRB and FDs, is because of the seismic energy dissipation and increased stiffness of the structure due to both LRB and FDs. Hence this combined control strategy can be adopted to mitigate the effects of earthquake.

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