SEISMIC ANALYSIS OF HYBRID STRUCTURAL CONTROL SYSTEM IN RC BUILDING

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Abstract - *Present study addresses to investigate effect of lead rubber bearing (LRB) isolation system in combinations with fluid viscous damper as an energy dissipation device in high rise RC building to study the effect of seismic isolation on structural response/behaviour under seismic loading. The effect of change in building height as 60m, 105m and 150m and location of isolators (at base and one-fifth of the building height) have also been investigated. For that fluid viscous damper (FVD) as an energy dissipation device and lead rubber bearing (LRB) as a base isolator and inter storey isolator were considered. The first case was the fixed-base (FB) building, the other three cases were the single use of FVD, LRB at base and at one-fifth of the height of building and the last two cases were included the upgrading of the building with the combination of FVD with LRB base isolation and inter storey isolation systems. The effectiveness of the lead rubber bearing (LRB) isolation systems together with the fluid viscous dampers (FVD) was investigated. They were modelled using a finite element program, and evaluated by the nonlinear time history analyses in which three ground motion records s 2001 Bhuj, 1940 and EL Centro were adopted. Time history Analysis was carried using ETABS software. This study includes comparisons of the seismic response parameters such as time periods, storey displacement, storey drift and storey shear and storey overturning moment for the different proposed structural control systems.*

Key Words: Base isolation, Inter-storey isolation, Lead rubber bearing, Fluid viscous damper, Time history analysis

1. INTRODUCTION

Civil engineering structures located in environments where earthquakes or large wind forces are common will be subjected to serious vibrations during their lifetime. These vibrations can range from harmless to severe with later resulting in serious structure damage and potential structural failure. In such area design of the structure should be done in such a way that we get proper safety of our structure in a hazard condition and to ensure the functional performance of flexible structures against such undesirable vibrations, various design alternatives have been developed, ranging from alternative structural systems to modern control systems with the use of various types of protective devices. Present study aims to investigate effect of lead rubber bearing (LRB) isolation system in combinations with viscous damper as an energy dissipation device in high rise RC building.

1.1 STRUCTURAL CONTROL

Structural control means to improve performance of structure in order to minimize structural damage.
The structural control system is also known as earthquake protective systems. Control systems which develop controllable forces to dissipate energy in a structure by increasing/modifying stiffness or/and damping to improve structural dynamic properties.
Control systems are also force actuation devices integrated with sensors, controllers and real-time information processing.
It is the fact that the earthquake can be accepted as the most devastating disaster because it causes many injuries, fatalities, and severe damage to the public buildings and bridges.
In the last three decades, there has been great deal of interest in the use of control systems to mitigate the effects of dynamic environmental hazards like earthquake and strong winds on the civil engineering structures.

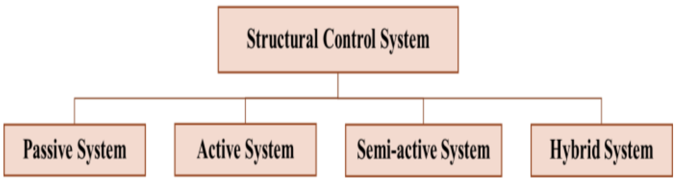

Fig -1: Structural Control Systems

1.2 BASE ISOLATION

The principle of Seismic Isolation is to introduce flexibility at the base of a structure in the horizontal plane, while at the same time introducing the damping elements to restrict the amplitude of the motion caused by the Earthquake. The system operates by decoupling the structure from the horizontal components of earthquake ground motion by interposing a layer of low horizontal stiffness between structure and foundation.

The flexible pads are called base-isolators, whereas the structures protected by means of these devices are called base-isolated buildings. If the flexible pads are properly chosen, the forces induced by ground shaking can be a few times smaller than that experienced by the building built directly on ground, namely a fixed base building.

1.3 INTER-STOREY ISOLATION

Inter-Storey isolation is a technique similar to base isolation, where a low-stiffness layer separates the upper structure from the lower contents. In the case of inter-Storey isolation, one or more stories of the structure are located below the isolation layer (substructure). By reducing the stiffness of the isolation layer, the overall structure's fundamental natural frequency decreases.

The isolation layer effectively absorbs energy from the earthquake and acts as a "filter" and prevent flux of energy transmitted by separating the superstructure from the substructure. An Inter-Story Isolation System (ISI) is an advantageous solution for mixed-use buildings, in which different occupancies along the elevation give rise to different architectural plans and structural grid layouts.

1.4 LEAD RUBBER BEARING (LRB)

Laminated Rubber Bearings are able to supply the required displacements and provides lateral flexibility for isolation Combining these with a lead-plug insert which provides hysteretic energy dissipation, reduces earthquake forces and provides wind resistance and the damping required for a successful seismic isolation system can be incorporated. LRB are usually made of alternating layers of steel plates which provides vertical stiffness to carry vertical loads and natural rubber layers with a critical hole into which the lead core is press fitted. Top and bottom flange plates are integral with bearing and connect structure above and below bearing. When subjected to lateral shear forces, the lead core deforms almost in pure shear, yields at low level of shear stresses, approximately 8 to 10 MPa at normal (20°C) temperature, and produces rather stable hysteretic deformation behaviour over a number of cycles.

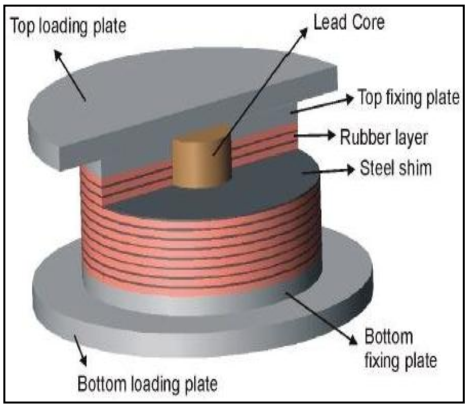

Fig -2: Lead Rubber Bearing

1.5 FLUID VISCOUS DAMPER (FVD)

In viscous damper, seismic energy is absorbed by silicone-based fluid passing through orifice between piston-cylinder arrangement. Viscous dampers are used with the objective of, but limiting the response under dynamic actions. These systems dissipate energy by forcing a fluid through an orifice similar to the shock absorbers of an automobile. Viscous dampers are used in high-rise buildings in seismic areas. It can operate over an ambient temperature ranging from 40°C to 70°C. Viscous damper reduces the vibrations induced by both strong wind and earthquake.

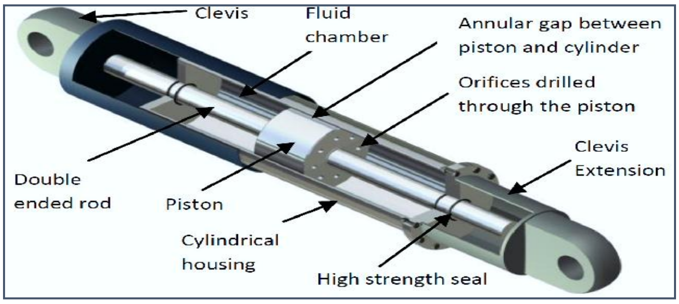

Fig -3: Fluid Viscous Damper

2. LITERATURE REVIEW

Sunagar et al. [1] were carried out this paper, 10-story reinforced concrete building with fixed base and base isolated by using lead rubber bearing, high damping rubber bearing, and friction pendulum bearing was compared and response spectrum analysis was carried out by using ETABS. George and Kuriakose [2] were carried out Comparison of seismic parameters on providing isolators at different locations along the height in both regular and vertical stiffness irregular high-rise building is presented in this study. Forcellini and Kalfas [3] have been investigated a 20-floor building has inter-story configurations at the base, at the middle and at ¾ of the building. Middle story isolation is shown to be the most effective in improving the seismic performance of the structure. Kumar and Pati [4] carried out dynamic analysis of six storied benchmark structure under seismic and wind excitation has been performed with different configuration of VE dampers placement. Deringöl and Güneyisi [5] studied the nonlinear seismic responses of five-story OMF is utilized as a case study frame. The nonlinear time history analyses using the software SAP2000 in which seven ground motion records were performed.

3. PROBLEM DESCRIPTION

Time history analysis was performed for analysis of RC buildings of different height (i.e., 60m, 105m and 150m) and different location of seismic isolator (i.e., at base and at one fifth of the building height). The effectiveness of the lead rubber bearing (LRB) isolation system together with the fluid viscous damper (FVD) was investigated. The response of RC buildings in the form of time period, storey displacement, storey drift, storey shear and storey overturning moment were analysed and compared. For analysis in which Bhuj (2001), EL Centro (1940) and Northridge (1994) earthquake ground motion records were considered for load case by using ETABS software.

Following models of different structural control systems were considered for analysis:

1. Fixed base building – FB
2. Fixed base building with fluid viscous dampers – FB+DAMPERS
3. Base isolated building – BI
4. Base isolated building with fluid viscous dampers – BI+DAMPERS
5. Inter storey isolated building – ISI
6. Inter storey isolated building with fluid viscous dampers – ISI+DAMPERS

Table -1: Properties of Fluid Viscous Damper for all buildings

Effective stiffness	109455 KN/m
Effective damping	460 KNs/m

3.1 Description of 20 Storey Building

Table -2: Description of 20 Storey Building Models

Plan area	25m x 25m
Building height	60m
Height of each Storey	3m
No of bays in X direction	5
No of bays in Y direction	5
Bay width in X direction	5m
Bay width in X direction	5m
Grade of concrete	M30
Grade of steel	Fe500
Density of infill wall	19.2 KN/m³
Slab thickness	0.150m
Live load on floors	3 KN/m²
Live load on roof	0.75 KN/m²
Floor finish	1 KN/m²
Roof finish	2.5 KN/m²
Size of beams	0.35m x 0.65m
Size of columns	
1st to 4th floors	0.85m x 0.85m
5th to 12th floors	0.75m x 0.75m
13th to 20th floors	0.65m x 0.65m

Table -3: Properties of LRB For 20 Storey Building

Properties of Seismic Isolators	Base Isolators	Inter Storey Isolators
Effective stiffness U1	2196865 KN/m	1735795 KN/m
Effective stiffness U2 & U3	924 KN/m	728 KN/m
Nonlinear stiffness U2 & U3	9741 KN/m	7670 KN/m
Yield strength U2 & U3	72 KN	57 KN
Post yield stiffness ratio U2 & U3	0.08	0.08

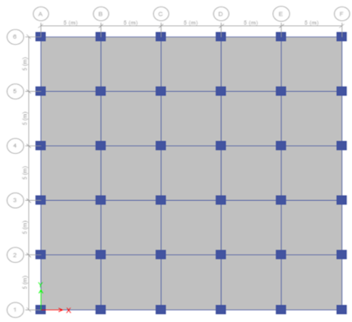

Fig -4: Plan View of 20 Storey Building models

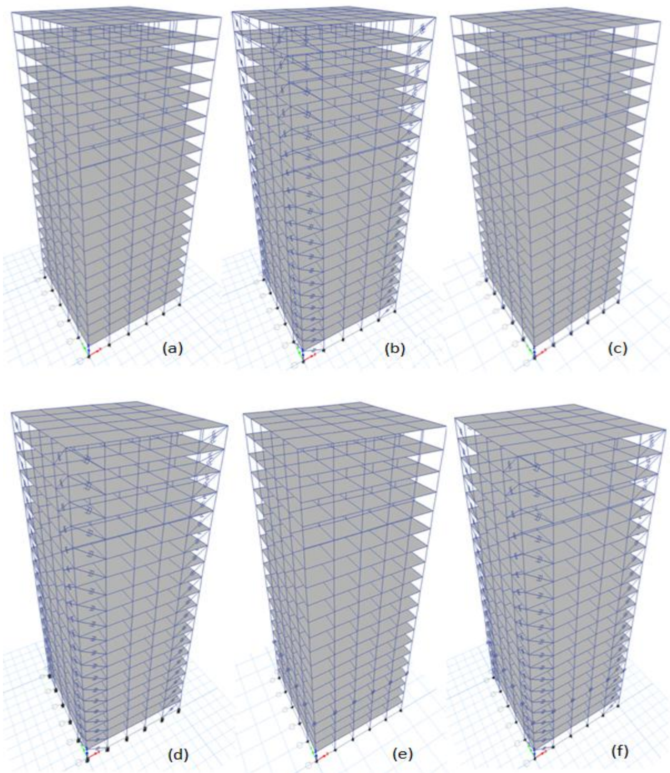

Fig -5: (a) FB, (b) FB+DAMPERS, (c) BI, (d) BI+DAMPERS, (e) ISI, (f) ISI+DAMPERS

3.1.1 TIME PERIOD

Table -4: Time Period of 20 Storey Building Models

Mode	FB	FB + FVDS	BI	BI + FVDS	ISI	ISI + FVDS
1	1.771	1.351	4.604	4.455	4.597	4.380
2	1.771	1.285	4.604	4.455	4.597	4.367
3	1.613	0.397	4.357	4.055	4.348	3.979
4	0.599	0.369	0.934	0.804	0.763	0.728
5	0.599	0.179	0.934	0.804	0.763	0.667

3.1.2 STOREY DISPLACEMENT

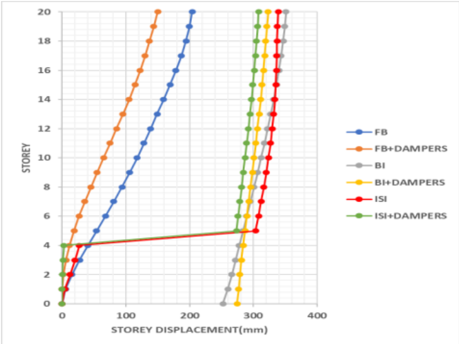

Chart -1: Storey Displacement for Bhuj Ground Motion

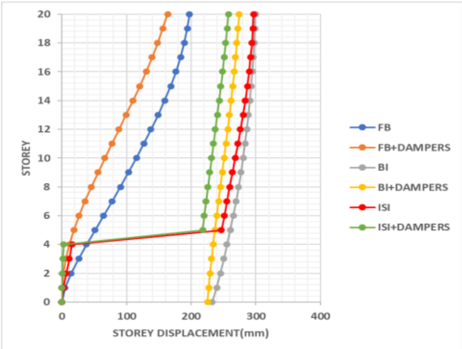

Chart -2: Storey Displacement for EL Centro Ground Motion

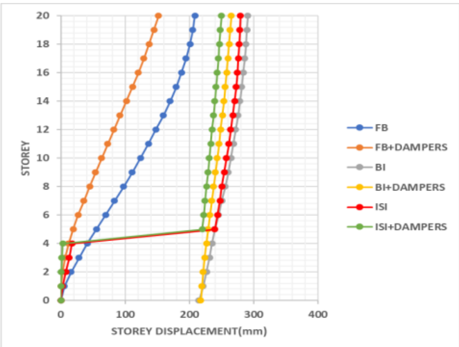

Chart -3: Storey Displacement for Northridge Ground Motion

3.1.3 STOREY DRIFT

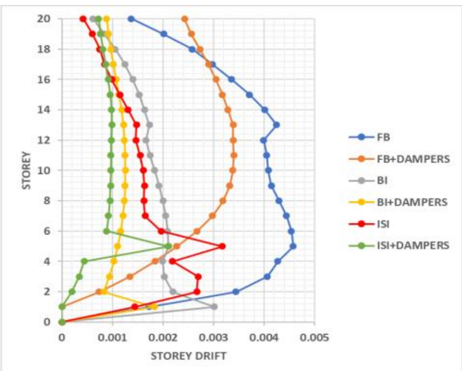

Chart -4: Storey Drift for Bhuj Ground Motion

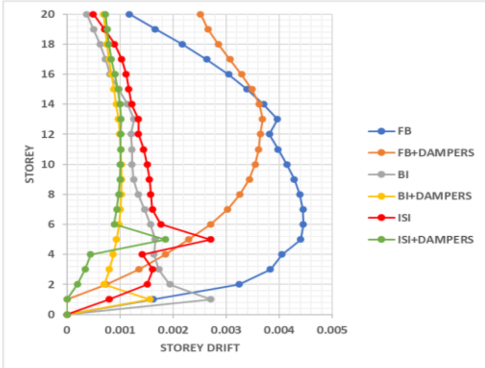

Chart -5: Storey Drift for EL Centro Ground Motion

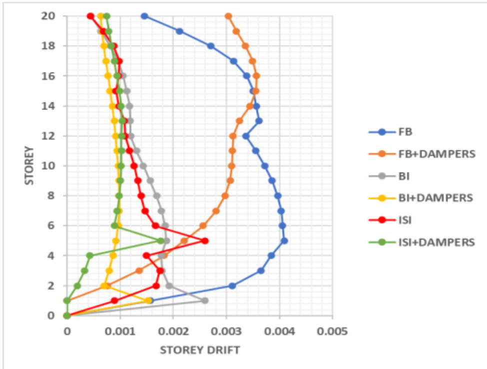

Chart -6: Storey Drift for Northridge Ground Motion

3.1.4 STOREY SHEAR

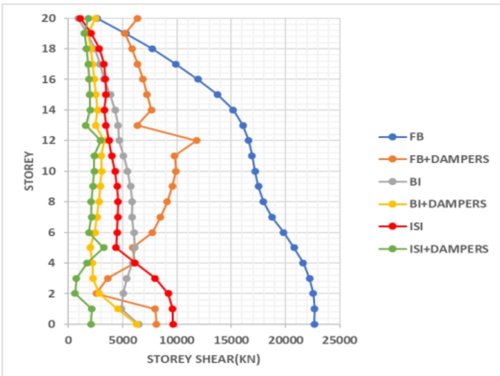

Chart -7: Storey Shear for Bhuj Ground Motion

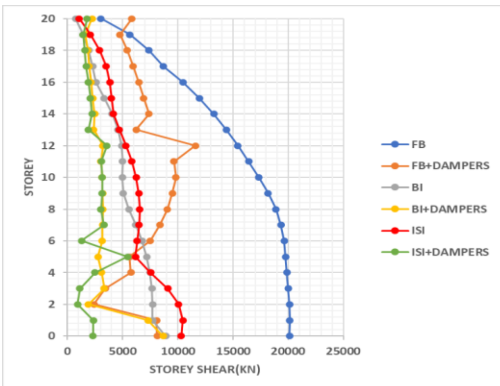

Chart -8: Storey Shear for EL Centro Ground Motion

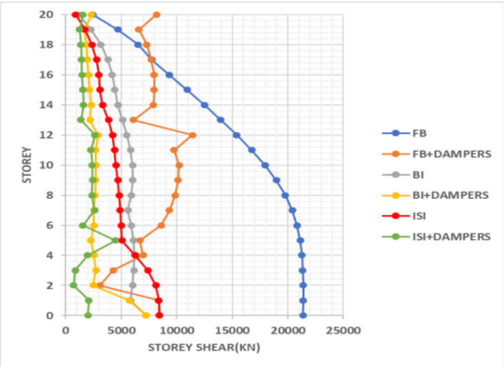

Chart -9: Storey Shear for Northridge Ground Motion

3.1.5 STOREY OVERTURNING MOMENT

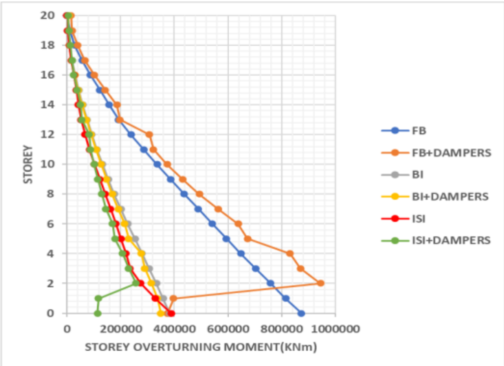

Chart -10: Storey Overturning Moment for Bhuj Ground Motion

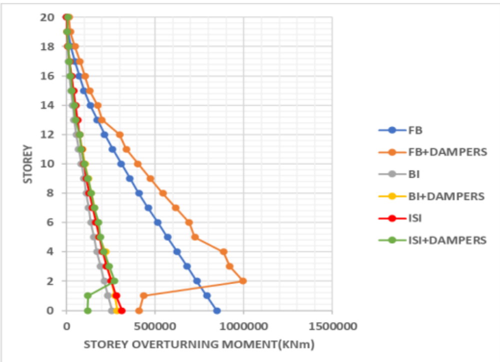

Chart -11: Storey Overturning Moment for EL Centro Ground Motion

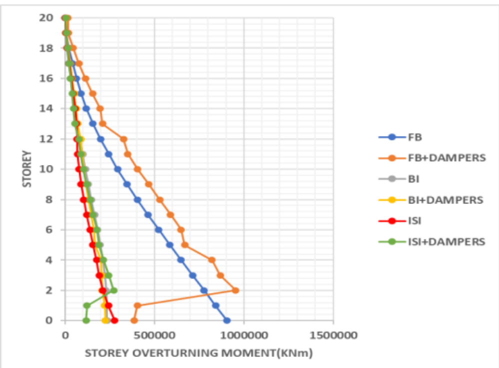

Chart -12: Storey Overturning Moment for Northridge Ground Motion

3.2 DESCRIPTION OF 35 STOREY BUILDING

Table -5: Description of 35 Storey Building Models

Plan area	25m x 25m
Building height	105m
Height of each Storey	3m
No of bays in X direction	5
No of bays in Y direction	5
Bay width in X direction	5m
Bay width in X direction	5m
Grade of concrete	M40
Grade of steel	Fe550
Density of infill wall	19.2 KN/m³
Slab thickness	0.150m
Live load on floors	3 KN/m²
Live load on roof	0.75 KN/m²
Floor finish	1 KN/m²
Roof finish	2.5 KN/m²
Size of beams	0.35m x 0.65m
Size of columns	
1st to 7th floors	1.050m x 1.050m
8th to 14th floors	0.95m x 0.95m
15th to 21th floors	0.85m x 0.85m
22th to 28th floors	0.75m x 0.75m
29th to 35th floors	0.65m x 0.65m

Table -6: Properties of LRB For 35 Storey Building

Properties of Seismic Isolators	Base Isolators	Inter Storey Isolators
Effective stiffness U1	2187825 KN/m	1808120 KN/m
Effective stiffness U2 & U3	738 KN/m	573 KN/m
Nonlinear stiffness U2 & U3	7781 KN/m	6036 KN/m
Yield strength U2 & U3	87 KN	68 KN
Post yield stiffness ratio U2 & U3	0.08	0.08

3.2.1 TIME PERIOD

Table -7: Time Period of 35 Storey Building Models

Mode	FB	FB + FVDS	BI	BI + FVDS	ISI	ISI + FVDS
1	2.918	2.373	7.094	6.915	7.092	6.855
2	2.918	2.373	7.094	6.914	7.092	6.854
3	2.532	0.700	6.667	6.200	6.665	6.133
4	0.998	0.700	1.603	1.466	1.311	1.204
5	0.998	0.336	1.603	1.465	1.311	1.204

3.2.2 STOREY DISPLACEMENT

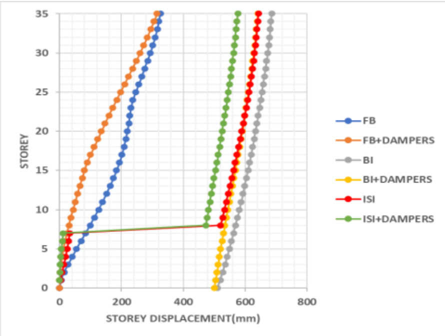

Chart -13: Storey Displacement for Bhuj Ground Motion

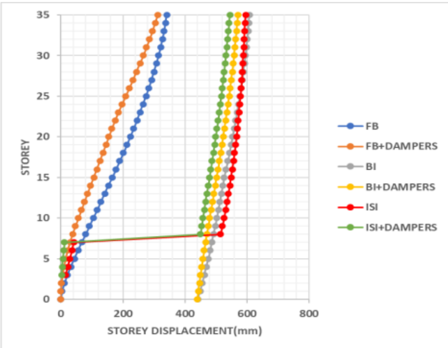

Chart -14: Storey Displacement for EL Centro Ground Motion

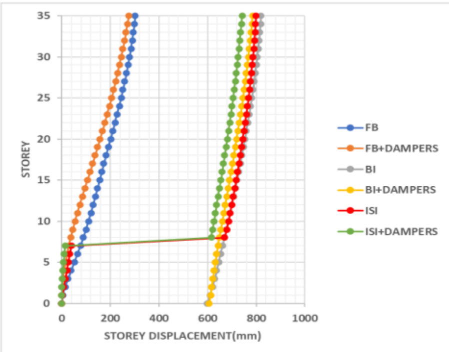

Chart -15: Storey Displacement for Northridge Ground Motion

3.2.3 STOREY DRIFT

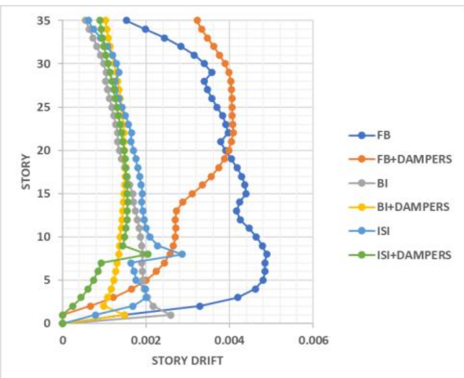

Chart -16: Storey Drift for Bhuj Ground Motion

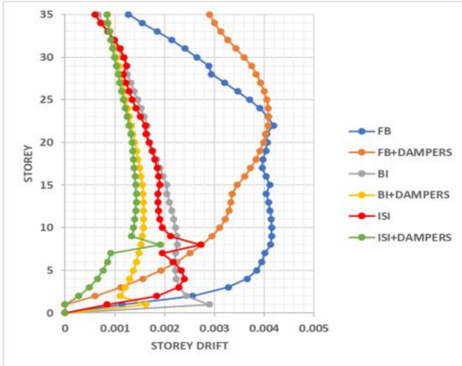

Chart -17: Storey Drift for EL Centro Ground Motion

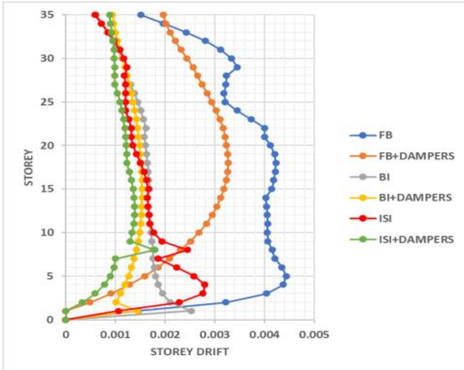

Chart -18: Storey Drift for Northridge Ground Motion

3.2.4 STOREY SHEAR

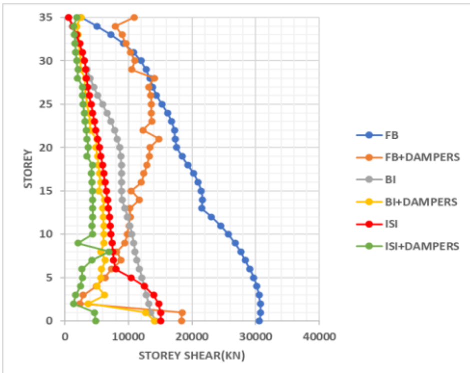

Chart -19: Storey Shear for Bhuj Ground Motion

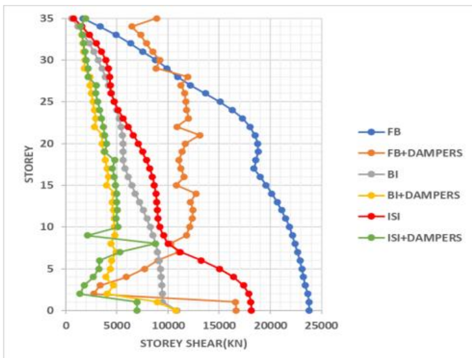

Chart -20: Storey Shear for EL Centro Ground Motion

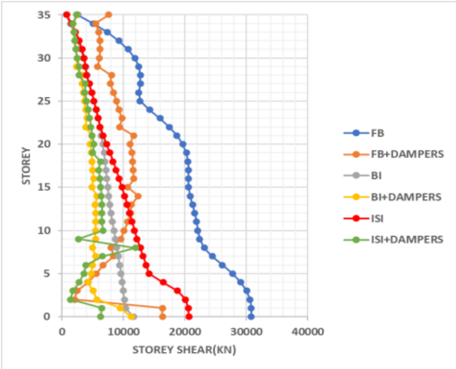

Chart -21: Storey Shear for Northridge Ground Motion

3.2.5 STOREY OVERTURNING MOMENT

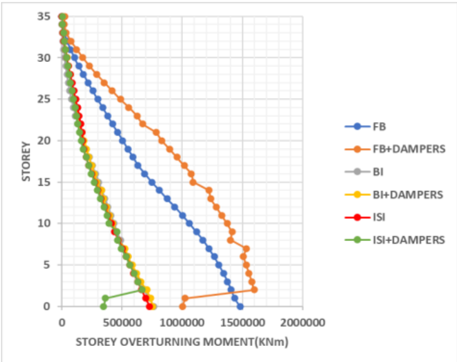

Chart -22: Storey Overturning Moment for Bhuj Ground Motion

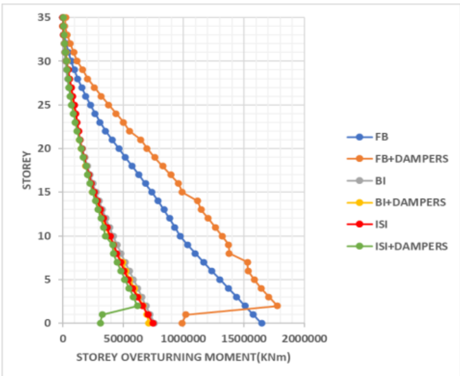

Chart -23: Storey Overturning Moment for EL Centro Ground Motion

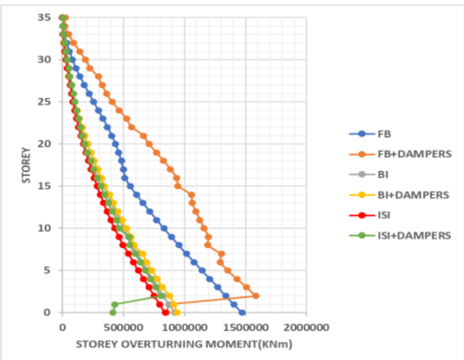

Chart -24: Storey Overturning Moment for Northridge Ground Motion

3.3 Description of 50 Storey Building Models

Table -8: Description of 50 Storey Building Models

Plan area	25m x 25m
Building height	150m
Height of each Storey	3m
No of bays in X direction	5
No of bays in Y direction	5
Bay width in X direction	5m
Bay width in X direction	5m
Grade of concrete	M50
Grade of steel	Fe550
Density of infill wall	19.2 KN/m³
Slab thickness	0.150m
Live load on floors	3 KN/m²
Live load on roof	0.75 KN/m²
Floor finish	1 KN/m²
Roof finish	2.5 KN/m²
Size of beams	0.4m x 0.7m
Size of columns	
1st to 10th floors	1.2m x 1.2m
11th to 20th floors	1.1m x 1.1m
21th to 30th floors	1.0m x 1.0m
31th to 40th floors	0.9m x 0.9m
41th to 50th floors	0.8m x 0.8m

Table -9: Properties of LRB For 50 Storey Building

Properties of Seismic Isolators	Base Isolators	Inter Storey Isolators
Effective stiffness U1	2211015 KN/m	1871404 KN/m
Effective stiffness U2 & U3	695 KN/m	536 KN/m
Nonlinear stiffness U2 & U3	7325 KN/m	5648 KN/m
Yield strength U2 & U3	104 KN	81KN
Post yield stiffness ratio U2 & U3	0.08	0.08

3.3.1 TIME PERIOD

Table -10: Time Period of 50 Storey Building Models

Mode	FB	FB + FVDS	BI + FVDS	BI + FVDS	ISI	ISI + FVDS
1	3.804	3.373	9.266	9.118	9.197	9.008
2	3.804	3.373	9.266	9.117	9.197	9.007
3	3.051	1.007	8.624	8.119	8.546	8.015
4	1.269	1.007	2.173	2.061	1.789	1.685
5	1.269	0.497	2.173	2.061	1.789	1.685

3.3.2 STOREY DISPLACEMENT

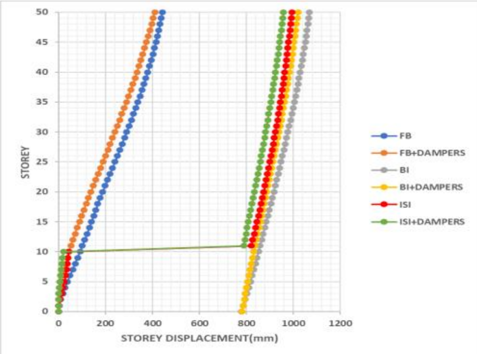

Chart -25: Storey Displacement for Bhuj Ground Motion

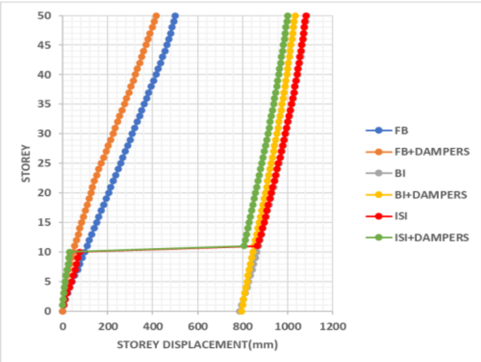

Chart -26: Storey Displacement for EL Centro Ground Motion

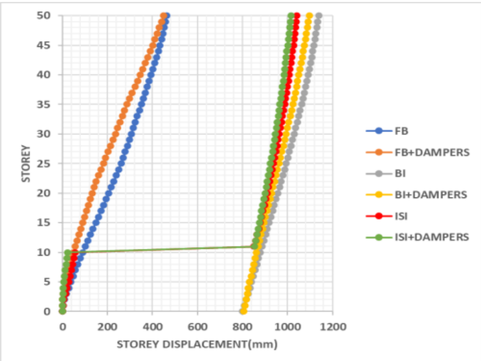

Chart -27: Storey Displacement for Northridge Ground Motion

3.3.3 STOREY DRIFT

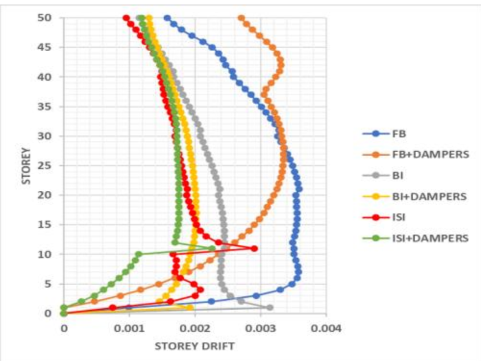

Chart -28: Storey Drift for Bhuj Ground Motion

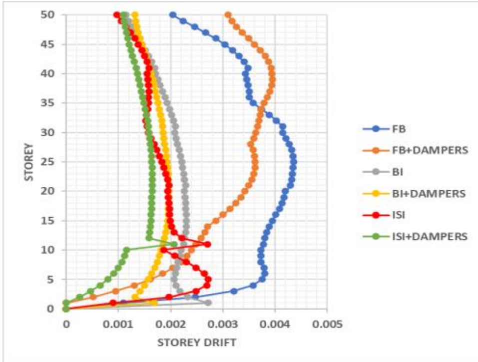

Chart -29: Storey Drift for EL Centro Ground Motion

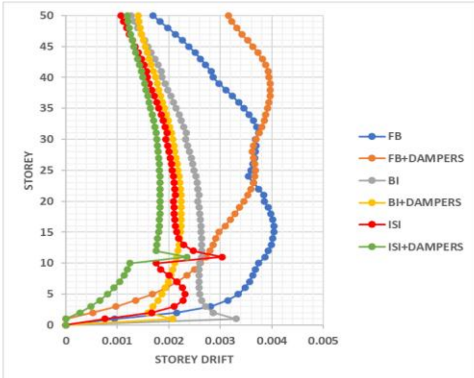

Chart -30: Storey Drift for Northridge Ground Motion

3.3.4 STOREY SHEAR

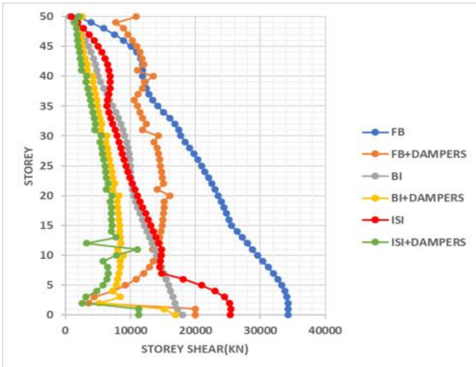

Chart -31: Storey Shear for Bhuj Ground Motion

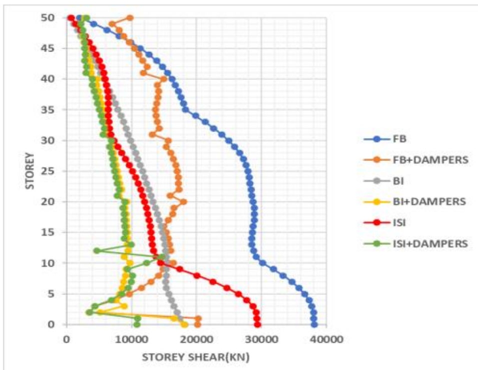

Chart -32: Storey Shear for EL Centro Ground Motion

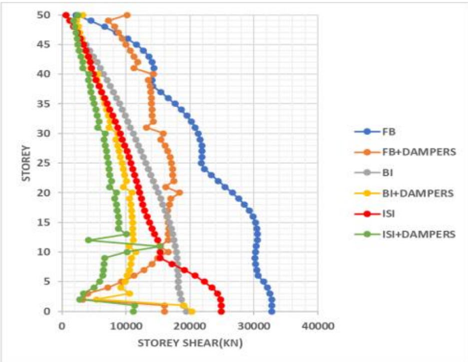

Chart -33: Storey Shear for Northridge Ground Motion

3.3.5 STOREY OVERTURNING MOMENT

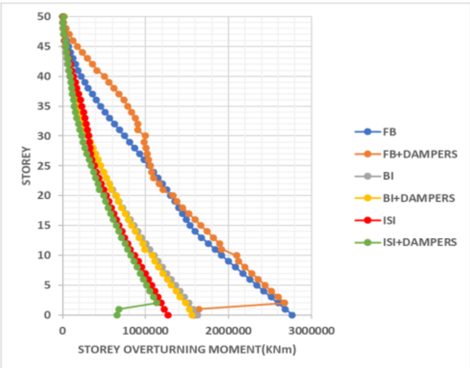

Chart -34: Storey Overturning Moment for Bhuj Ground Motion

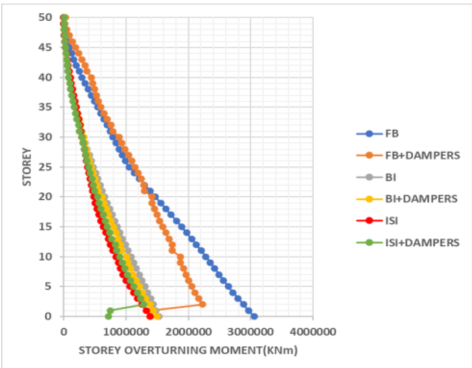

Chart -35: Storey Overturning Moment for EL Centro Ground Motion

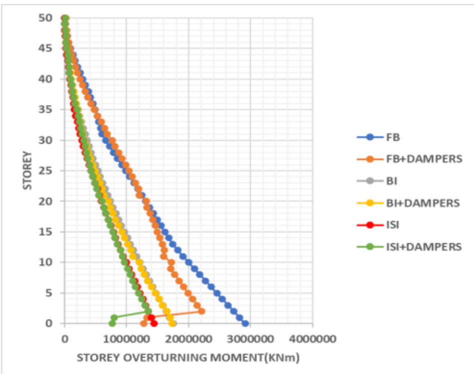

Chart -36: Storey Overturning Moment for Northridge Ground motion

4. DISCUSSION

Time period of building increased with utilization LRB in BI and ISI structures. Time period of BI structure was slightly more than ISI structure. Time period of the building decreased by use of FVD in FB, BI+DAMPERS and ISI+DAMPERS structures.

4.1 DISCUSSION OF 20 STOREY BUILDING

Table -11: Discussion of 20 Storey Building Models

Model	FB + FVDS	BI	BI + FVDS	ISI	ISI + FVDS
Maximum Storey Displacement	-24%	+55%	+42%	+50%	+11%
Maximum Storey Drift	-19%	-37%	-63%	-37%	-57%
Maximum Storey Shear	-46%	-64%	-65%	-56%	-80%
Maximum Storey Moment	-8%	-66%	-69%	-63%	-70%

4.2 DISCUSSION OF 35 STOREY BUILDING

Table -12: Discussion of 35 Storey Building Models

Model	FB + FVDS	BI	BI + FVDS	ISI	ISI + FVDS
Maximum Storey Displacement	-7%	+120%	+108%	+112%	+94%
Maximum Storey Drift	-15%	-41%	-65%	-38%	-58%
Maximum Storey Shear	-39%	-57%	-58%	-36%	-67%
Maximum Storey Moment	-8%	-47%	-48%	-50%	-54%

4.3 DISCUSSION OF 50 STOREY BUILDING

Table -13: Discussion of 50 Storey Building Models

Model	FB + FVDS	BI	BI + FVDS	ISI	ISI + FVDS
Maximum Storey Displacement	-9%	+135%	+125%	+122%	+112%
Maximum Storey Drift	-6%	-32%	-48%	-23%	-44%
Maximum Storey Shear	-45%	-47%	-49%	-25%	-61%
Maximum Storey Moment	-18%	-44%	-46%	-53%	-57%

5. COST COMPARISONS

5.1 COST COMPARISON FOR 20 STOREY BUILDING

Table -14: Cost Comparison of 20 Storey Building Models

Material/ Element	FB Building		ISI+DAMPERS Building	
	Quantity	Cost (Rs)	Quantity	Cost (Rs)
Concrete (m^3)	4347.5	1,99,98,500	3199.13	1,47,15,998
Steel (ton)	436.81	2,83,92,650	350.89	2,28,07,850
LRB isolators	-	-	36	93,60,000
FV dampers	-	-	160	56,00,000
Total cost (Rs)	**4,83,95,934**		**5,24,87,398**	

5.2 COST COMPARISON FOR 35 STOREY BUILDING

Table -15: Cost Comparison of 35 Storey Building Models

Material/ Element	FB Building		ISI+DAMPERS Building	
	Quantity	Cost (Rs)	Quantity	Cost (Rs)
Concrete (m^3)	8476.65	4,57,73,910	5887.35	3,17,91,690
Steel (ton)	828.16	7,03,93,600	778.25	6,61,51,250
LRB isolators	-	-	36	1,15,20,000
FV dampers	-	-	280	98,00,000
Total cost (Rs)	**11,61,76,814**		**11,92,69,605**	

5.3 COST COMPARISON FOR 50 STOREY BUILDING

Table -16: Cost Comparison of 50 Storey Building Models

Material/ Element	FB Building		ISI+DAMPERS Building	
	Quantity	Cost (Rs)	Quantity	Cost (Rs)
Concrete (m^3)	14395.5	8,92,52,100	10638.3	6,59,57,460
Steel (ton)	1150.47	9,77,89,950	1034.29	8,79,14,650
LRB isolators	-	-	36	1,26,00,000
FV dampers	-	-	400	1,40,00,000
Total cost (Rs)	**18,70,57,596**		**18,04,83,782**	

6. CONCLUSIONS

Following are the conclusions derived from the study:

- Maximum storey displacement of building decreased in FB+DAMPERS and increased in ISI+DAMPER, BI+DAMPERS, BI, ISI systems, respectively.
- Maximum storey drift of building decreased in FB+DAMPERS, BI, ISI, ISI+DAMPERS, BI+DAMPER systems, respectively.
- Maximum storey shear of building decreased in ISI, FB+DAMPERS, BI, BI+DAMPER, ISI+DAMPERS systems, respectively.
- Maximum Storey overturning moment of building decreased in FB+DAMPERS, BI, BI+DAMPER, ISI, ISI+DAMPERS systems, respectively.
- Time period of FB+DAMPERS building decreased while time period of ISI+DAMPERS, BI+DAMPERS, ISI, BI buildings increased, respectively.
- As height of the building increased, the reduction in the seismic parameters decreased.
- The total cost of 20 storey ISI+DAMPERS building increased 8.45% as compared to fixed base building.
- The total cost of 35 storey ISI+DAMPERS building increased 2.66% as compared to fixed base building.
- The total cost of 50 storey ISI+DAMPERS building decreased 3.51% as compared to fixed base building.
- The cost of the hybrid structural control system was slightly more than fixed base building but as the height of the building increased, the total cost of the hybrid structural control system decreased as compared to conventional fixed base building.

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