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Comparison in Seismic Behaviour between Base Isolated Building and Conventional Building by Analytical Method

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Abstract:
There has been a great loss of life and property due to the occurrence of earthquakes in the past. The poorly constructed buildings are likely to collapse during earthquakes. There is a need to reduce the seismic demand on these buildings so that they can perform better during future earthquakes. This need can be fulfilled using the concept of base isolation. In seismic base isolation, the superstructure is decoupled from the potentially damaging ground motion. In order to predict the response of the structure during earthquake, accurate evaluation of structural properties and precise modelling of the isolation devices has to be done. A case study has been taken up to compare the response of base isolated building with that of a conventionally designed earthquake resistant building. The finite element software SAP2000 has been used for modelling and analysis. Non-linear static pushover analysis and non-linear time history analysis have been performed to study the response of base isolated building as well as fixed base conventionally designed building.

Keywords: *Base Isolation of buildings, Storey Drift, Push-over analysis, time history analysis, base shear*

1. Introduction

1.1. General
It is being realized that the structures can be effectively protected from the earthquakes by using structural control techniques. Structural control measures mitigate earthquake forces and also control vibrations due to wind and other dynamic forces. In recent years, some additional factors have come up due to which the control of structural response is required. Some of these factors are: (a) higher safety levels, (b) higher structures' flexibility, (c) economic concerns, and (d) stringent performance levels. Therefore, since 1980s the research in this field has increased several methods have developed to improve the performance of the structures during earthquake.

1.2. Base Isolation
Base isolation is a technique that decouples the building from its foundation. Base isolation deflects the seismic energy and also absorbs the seismic energy. Base of the structure is made flexible and thus energy is deflected. The hysteretic nature of the force deformation curve of the base isolators is responsible for absorbing the energy.

1.3. Characteristics of well-designed Base Isolation
Basic characteristics of a well-designed base isolation are:
- Provide desired flexibility to increase period of vibration, consequently reducing force response
- Dissipation of energy to control excessive displacement
- Remain rigid under low load levels like minor earthquakes and winds

1.4. Suitability of Seismic Base Isolation
The structures can be considered suitable for seismic base isolation, if these conditions are fulfilled (Deb 2004):
- The subsoil doesn't produce predominance of long-period ground motion.
- Horizontal displacements of 200mm or more at the base are permitted at the site of the structure
- Lateral loads due to wind and other non-earthquake components are less than approximated 10% of the total weight of the structure.

2. Objectives of the Study

- to study the design considerations of the LLRB isolators and the base isolated buildings
- to compare the linear response of the base isolated buildings with that of the conventional buildings
- to compare the nonlinear response of the base isolated buildings with that of the conventional buildings

3. Analytical Modeling and Assumptions

The base isolated structure is to be designed such that it fulfils two objectives: resist moderate level earthquakes without damage to structural components and resist major earthquakes without undergoing collapse although there is some structural and non-structural damage. Thus the isolation system must remain stable under vertical loads and it should withstand the forces and displacements that are associated with maximum considered earthquake. In addition, the superstructure should essentially remain elastic when subjected to design basis earthquake. Following assumptions are made to arrive at practically feasible design procedures:

- centreline modelling is done
- for concrete members, gross uncracked sections are considered
- floor diaphragms are considered rigid
- for the purpose of dynamic analysis, the support conditions are considered rigid

To do the analysis, a multi storey SMRF building was designed in Zone-IV with total nine storeys (including ground floor). Ground storey is 1.5m high and rest storeys are of 3.2m height. Thickness of base slab, external and internal walls are 200mm, 230mm and 110mm respectively. Two different size of columns are used, 500mm X 500mm upto six storeys (including ground floor) after which cross section is reduced to 400mm X 400mm, with M40 grade of concrete. Beams are of uniform cross section, 300mm X 500mm, with M30 grade of concrete. Live load is 3.0 kN/m^2 on floors and 1.5 kN/m^2 on roof. Plan and elevation of the building are shown below:

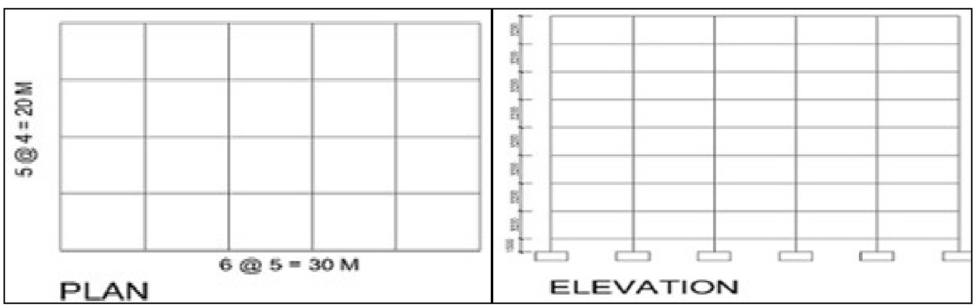

Figure 1: Plan and Elevation of model

4. Design Parameters of Isolators

As per vertical reaction of different supports, three different isolators were designed to get accurate results. Details of which are as follows:

Design Parameters	
Time period of base isolated structure (sec)	2.5
Design Displacement (mm)	142

ISOLATOR ID	R (kN)	K_{eff} (kN/m)	F_y (kN)	K_u (kN/m)	K_d (kN/m)	ξ_{eff} (%)
ISO 1	3452.61	2220.84	85.64	16783.53	1678.353	13.77
ISO 2	2498.87	1607.36	61.98	12147.29	1214.729	14.30
ISO 3	1621.22	1042.83	40.21	7880.94	788.094	14.60

Table 1: Properties of different isolators

	ISO 1	ISO 2	ISO 3
Bearing Diameter (mm)	900	800	650
Lead plug diameter (mm)	100	85	70
Rubber layer thickness (mm)	12	12	12
Number of rubber layers	24	25	25
Shim thickness (mm)	3	3	3
End plate thickness (mm)	25	17.5	17.5
Bearing height (mm)	410	410	410

Table 2: Geometric design properties

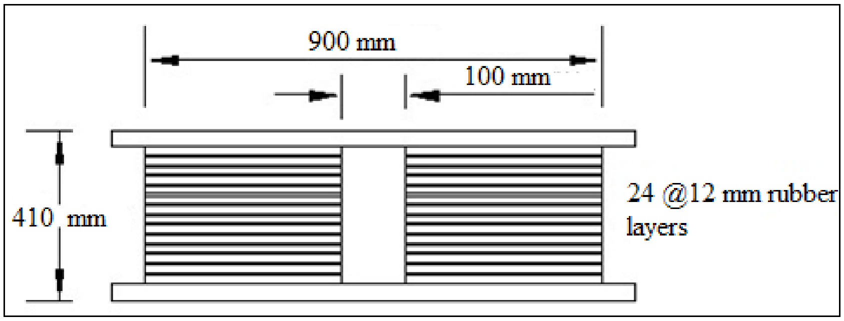

Figure 2: Geometric Properties of isolator 1

5. Linear Analysis Results

The results are in terms of Base Shear, percentage of reinforcement reduction and storey drift.

5.1. Base Shear

	FIXED BASE	BASE ISOLATED
Z	0.24	0.24
I	1	1
R	5	2
S_a/g -x	2.5	0.544
S_a/g - y	2.5	0.544
Damping	5%	15%
Base shear V_{Bx}	3744.282 kN	1422.828 kN
Base shear V_{By}	3744.282 kN	1422.828 KN

Table 3: Base Shear Calculation

Mode	Period	UX	UY
	Sec	Unitless	Unitless
1	2.715237	0.97168	0
2	2.682838	0	0.9747
3	2.563017	0	0
4	0.777307	0.0257	0
5	0.760631	0	0.0230
6	0.695976	0	0
7	0.395149	0.00222	0
8	0.383889	0	0.00188
9	0.349616	0	0
10	0.254764	0.00029	0

Table 4: Modal Participation Mass Ratio for Base Isolated Building

5.2. Percentage of Reinforcement Reduction

Storey level(m)	**Longitudinal Reinforcement (mm^2)**					
	Fixed Base		Isolated		% Saving	
	Columns	Beams	Columns	Beams	Columns	Beams
27.1	45578	47525	38592	47255	15%	1%
23.9	69288	104458	38400	71296	45%	32%
20.7	89424	146755	38400	74161	57%	49%
17.5	103408	169097	38400	60692	63%	64%
14.3	60742	186373	60000	86323	1%	54%
11.1	60322	202093	60000	97900	1%	52%
7.9	70846	217556	60000	80662	15%	63%
4.7	125764	216042	60000	101570	52%	53%
1.5	129178	150601	70170	74029	46%	51%
TOTAL	754550	1440500	463962	693888	39%	52%

Table 5: Steel reduction percentage in fixed building and base isolated building

5.3. Storey Drift

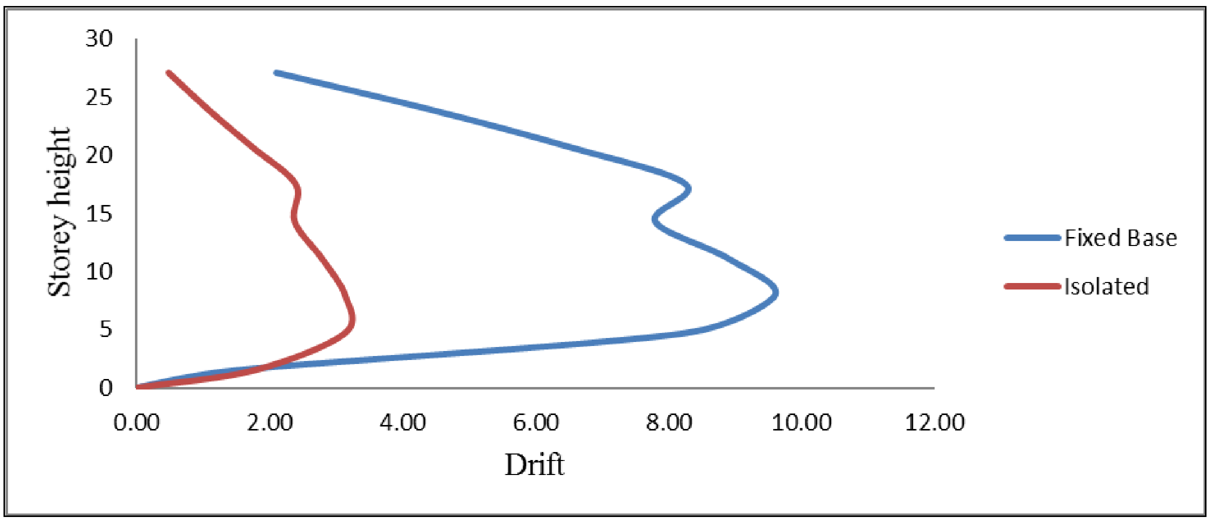

Figure 3: Storey drift in Longitudinal direction

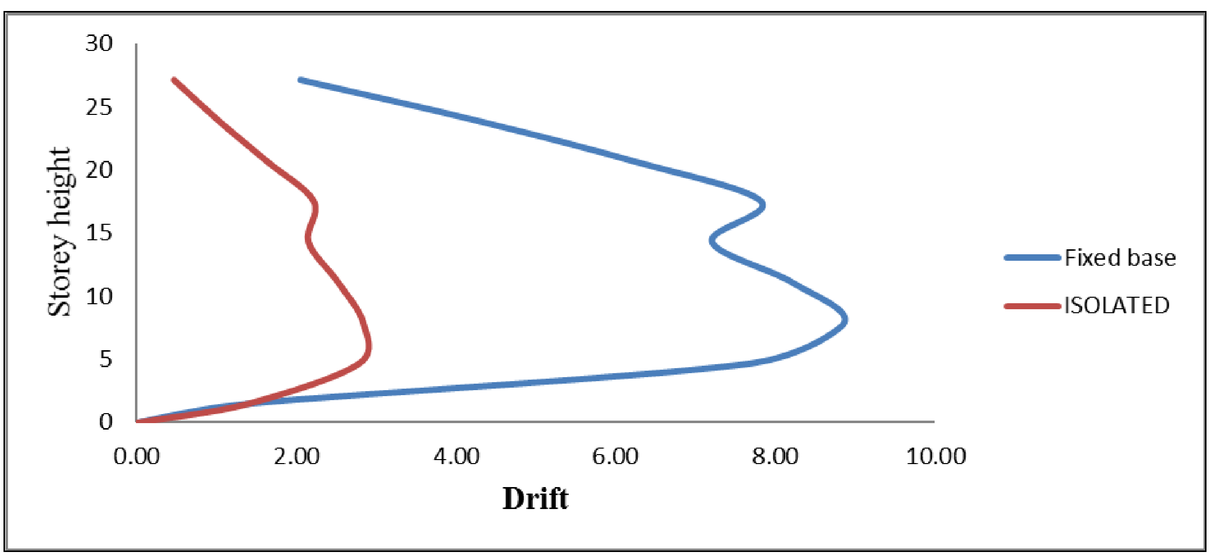

Figure 4: Storey drift in transverse direction

6. Non-Linear Analysis and Results

6.1. Non-linear Static Analysis/ Pushover Analysis

Non-linear static pushover analysis has been carried out for the fixed base and the base isolated structures in both directions using the finite element software SAP2000. Non-linearity in the beams has been considered as per FEMA 356. For beams, M_3 plastic hinges have been provided at both ends. For the columns, P-M_2-M_3 plastic hinges have been provided. The non-linear behaviour of the isolators has been modelled by providing the bilinear curve for the link element. The performance point has been calculated as per ASCE/SEI 41:

$$\text{Performance point} = C_0 C_1 C_2 C_3 S_a \frac{T_e^2}{4\pi^2} g$$

where, S_a is the spectral acceleration at the effective fundamental period and damping ratio of the building in the direction under consideration. C_0 is a factor that relates the spectral displacement of an equivalent single degree of freedom (SDOF) system to the roof displacement of the building multi degree of freedom (MDOF) system. C_1 is a factor that relates the expected maximum inelastic displacements to displacements calculated for linear elastic response. C_2 is a modification factor that represents the effect of pinched hysteresis shape, strength deterioration and cyclic stiffness degradation on the maximum displacement response. T_e is the effective fundamental time period of the building in the considered direction.

6.2. Non-linear Static Analysis or Pushover Analysis results

Building Type	Performance Level				
		IO	LS	C	Target Displacement
Fixed Base	X direction	124.86	256.38	319.68	144
Isolated		167.12	310.59	376.24	179
Fixed Base	Y direction	127.10	263.13	321.04	131
Isolated		165.53	314.80	381.40	172

Table 6: Pushover Analysis results

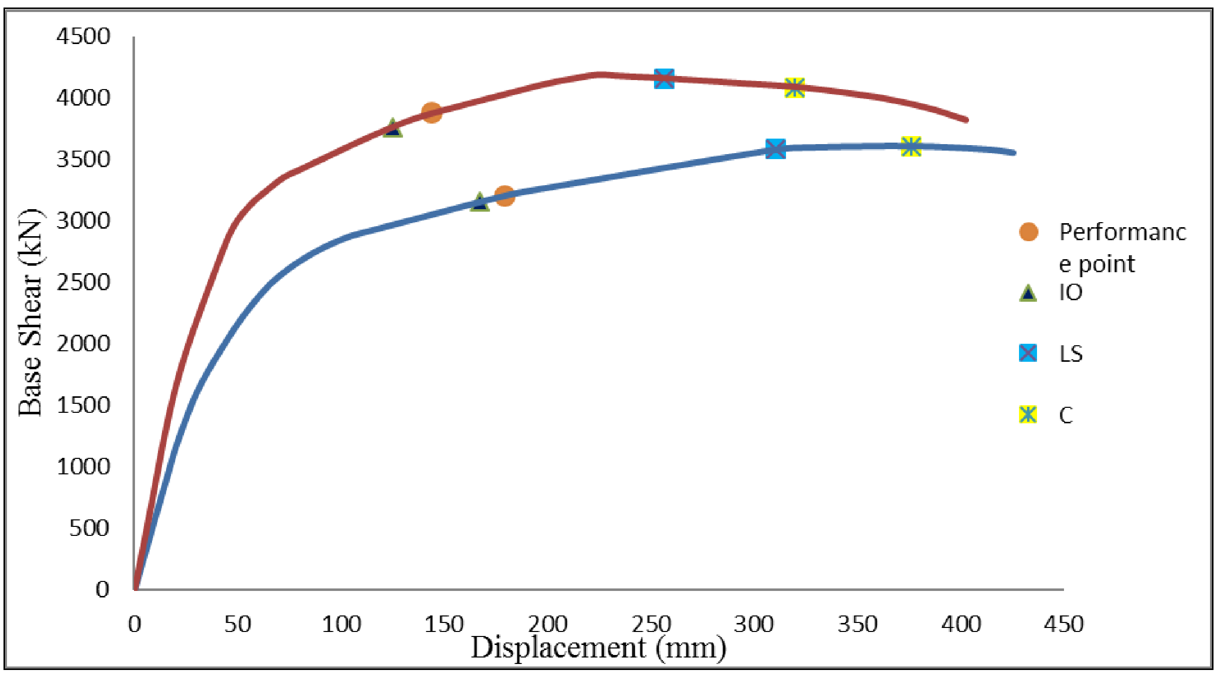

Figure 5: Pushover curve for the building with base slab in longitudinal direction

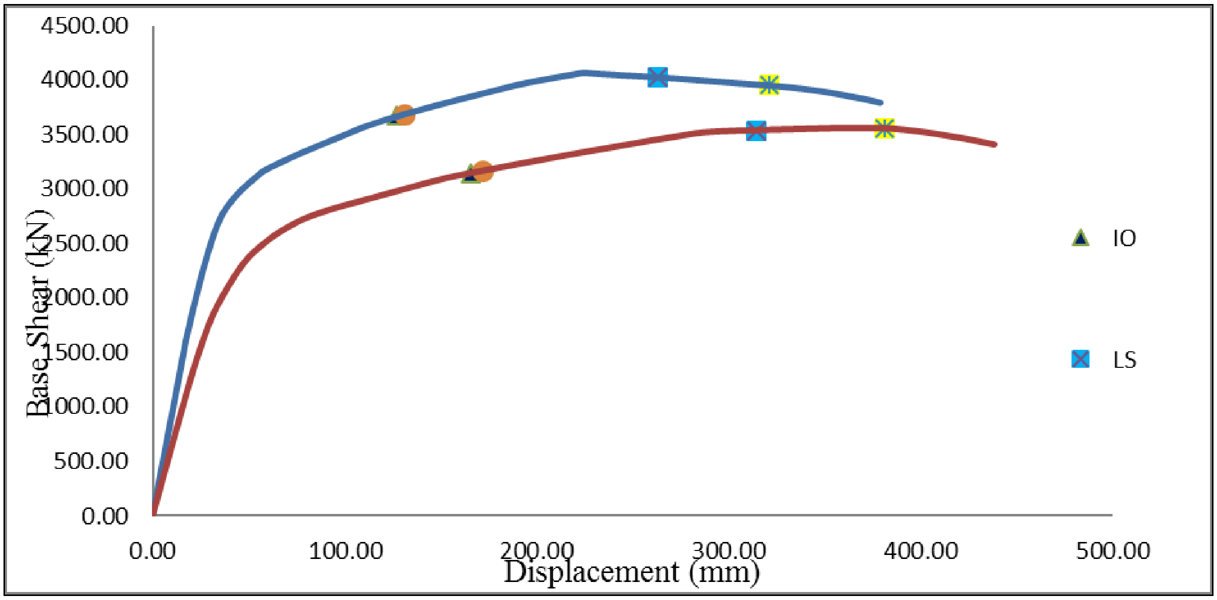

Figure 6: Pushover curve for the building with base slab in transverse direction

6.3. Non-Linear Time History Analysis Results

The Time history considered is compatible with IS-1893 response spectrum. Linear scaling has been done for PGA=0.24g.

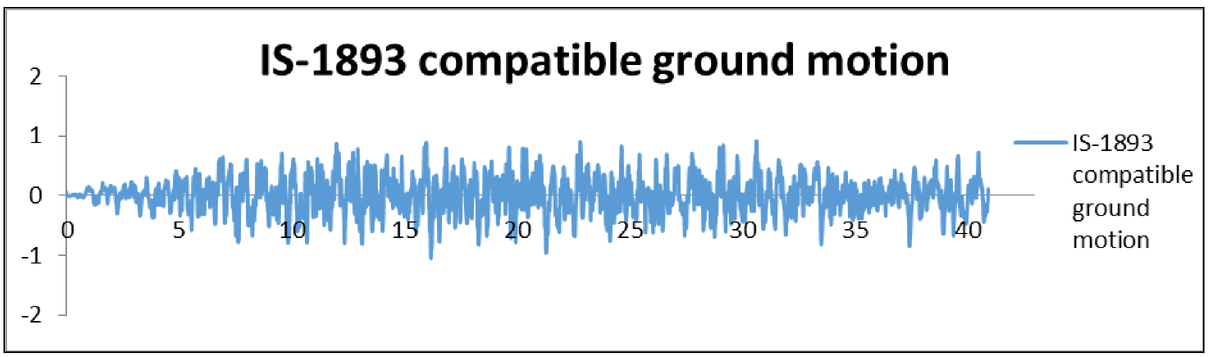

Figure 7: IS-1893 compatible ground motion

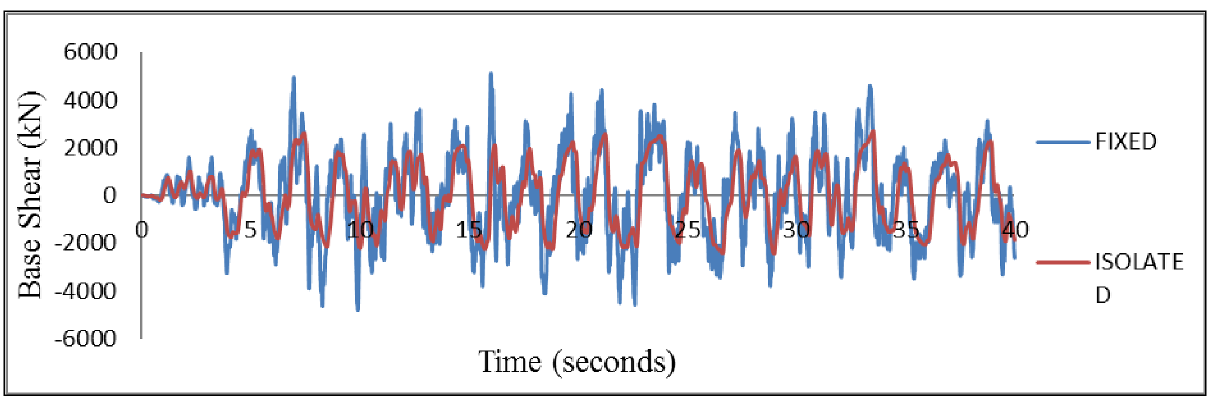

Figure 8: Comparison between fixed and isolated base shear

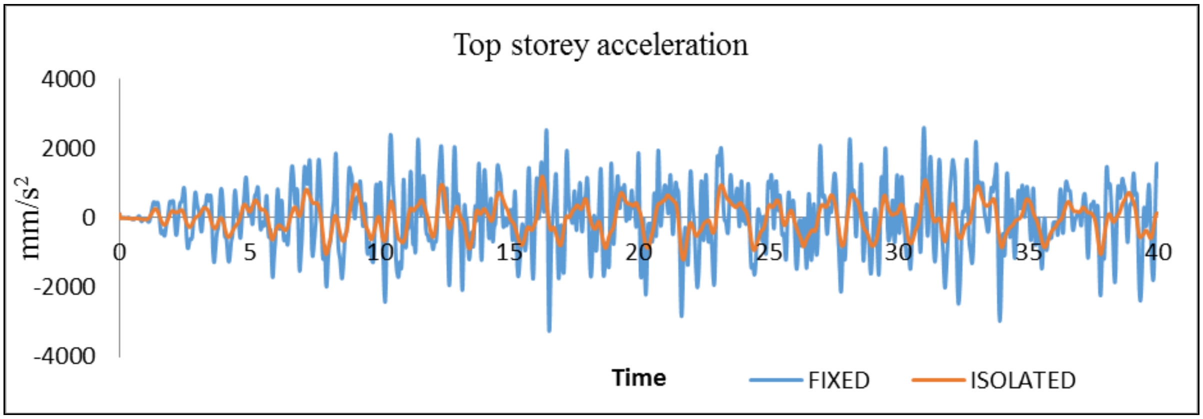

Figure 9: Comparison between top storey acceleration in fixed building and isolated building

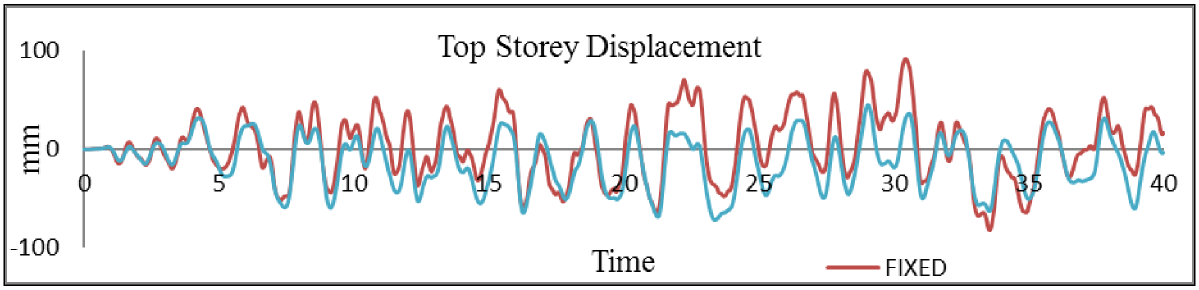

Figure 10: Comparison between top storey displacement of fixed building and isolated building

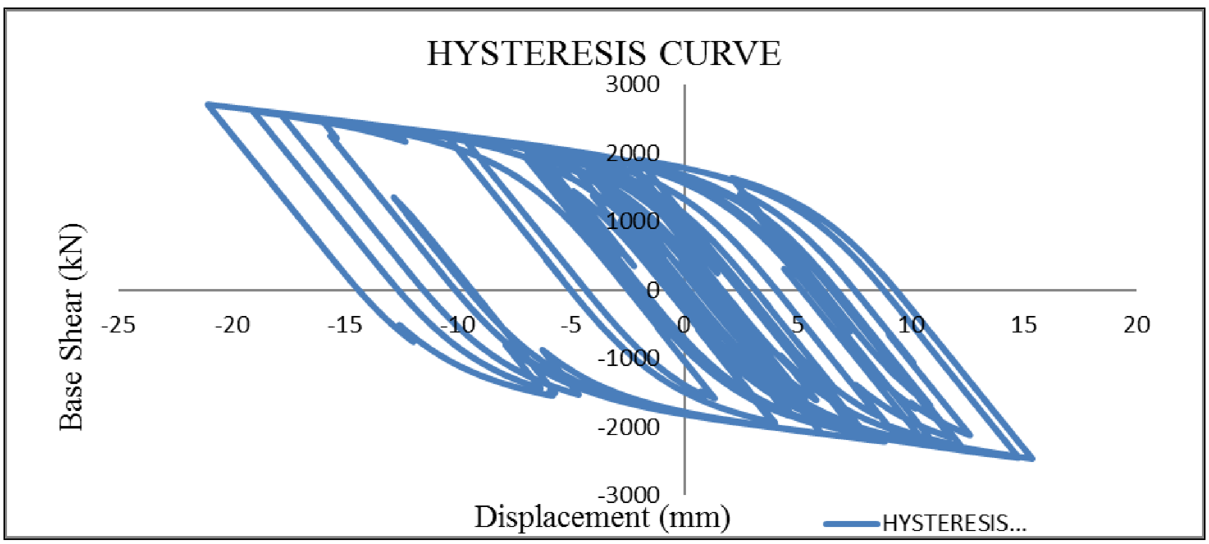

Figure 11: Hysteresis curve for base isolated building

	Fixed Base	Isolated	% Reduction
Base Shear	5110 kN	2706 kN	47%
Top acceleration	3.25 m/s2	1.2 m/s2	63%
Top Displacement	91.04 mm	64 mm	30%

Table 7: Results of Non-linear Dynamic Analysis (Peak values only)

7. Conclusion

Base isolation basically reduces the demand forces by shifting the time period of the structure. The displacement can be controlled by introducing additional damping in the structural system, which also helps in reduction of the demand forces. In this study detailed literature review has been carried out on the subject. Design considerations of base isolators as well as base isolated buildings have been presented. Detailed design of LLRB isolators has been carried out. A G+8 storey RC framed building has been considered for studying the comparative response of fixed base and base isolated buildings. 47% reduction in base shear was observed. Maximum storey drift also reduced from 0.3% to 0.1%. Pushover curves have been plotted for fixed base and isolated buildings with base sla

8. References

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