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Seismic Performance of Strengthening Measures for Open Ground Storey Buildings

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Abstract
In cities constructions of multi-storeyed buildings with open ground storey has become a common practice. These types of buildings are having no infill walls in ground storey but all upper storeys infilled with masonry walls making it a soft storey. Past earthquakes have shown that such buildings are vulnerable to damage or even collapse during a strong earthquake. Devastating performance of such buildings during earthquakes discouraged construction of such buildings. While damage and collapse due to soft storey are most often observed in buildings they can also be developed in other types of structures. In this paper performance of open ground storey building with lateral load resisting systems approved by Bureau of Indian standards have been studied. A 10 storeyed RCC building having open ground storey is used for analysis. The building is analysed for three models with Moment frame system(Model1),Moment frame system with shear walls(Model2),Moment frame system with bracings(Model3). All the models are having same plan aspect ratio and slenderness ratio. The structural members have same dimensions and properties in all models provided as per Indian code of practice for ductile design and detailing of reinforced concrete structures subjected to seismic forces. The models are analysed by using response spectrum method using ETABS software. Comparision of the analysis results is done for all the models for storey displacements, drifts, storey shears, overturning moments and lateral stiffness.
Keywords: stiffness, displacement, drift, overturning moment, base shear, torsion

1. Introduction

Multi-storeyed buildings require open taller ground storey for parking of vehicles and/or for retail shopping, large space for meeting room or a banking hall. Due to this functional requirement, the ground storey has lesser strength and stiffness as compared to upper storeys, which are stiffened by masonry infill walls. This characteristic of building construction creates weak or soft storey problems in multi-storeyed buildings. Increased flexibility of first storey results in extreme deflections, which in turn leads to concentration of forces at the second storey connections accompanied by large plastic deformations. In addition, columns in the soft storey dissipate most of the energy developed during the earthquake. In this process, plastic hinges are formed at the ends of columns of the soft storey. Which transform the soft storey into a mechanism in such cases the collapse is unavoidable therefore the soft storeys deserve a special consideration in analysis and design.

As per IS 1893 (Part 1):2016,RC moment resisting frame buildings, which have open storey due to discontinuation of unreinforced masonry infill walls, are flexible. In such buildings suitable measures shall be adopted which increase both strength and stiffness to the required level in the open storey. Shear wall is an effective lateral load resisting system having high in plane stiffness and strength to the required level in the open storey. The measures shall be taken along both plan directions. The said increase may be achieved by providing measures like a) RC structural walls or b) braced frames in select bays of building

When RC structural walls are provided they shall be a) founded on properly designed foundations b) continuous preferably over full height of building c) connected preferably to the moment resisting frame of the building.RC structural walls in buildings located in seismic zones III, IV and V shall be designed to comply with all requirements of IS 13920

In multi-storeyed buildings, bracing system is provided between columns to increase stiffness, strength and energy dissipation to resist lateral loads. It offers resistance to lateral forces by bracing action of inclined members. The braces simulate forces in the associated beams and columns so that all work as one like a truss with all members subjected to stresses that are for the most part axial. This axial reaction results in less moments and in turn smaller sizes of beam and column sections compared to moment resisting frames. It is easy to install, economical and occupies less space. It is a highly efficient and economical method of resisting lateral loads due to earthquake in a framed structure. It is provided in peripheral bays and on two parallel sides of building. The two main types of bracings are concentric and eccentric and commonly used shapes of bracings are X, V, K, inverted V and inverted K

In this paper attempt has been made to compare the performance of shear walls and X type bracings during earthquake based on different parameters by providing them in the same bays in a model with moment resisting frames.

2. Literature Review

Suchita Hirde and Ganga Tepugade [1] have studied the seismic performance of open ground storey buildings. Experience in the past earthquake has shown that a building with discontinuity in the stiffness and mass subjected to concentration of forces and deformations at the point of discontinuity which may lead to failure of members at the junction and collapse of building. The conclusions of the study are i) it is observed that plastic hinges are developed in columns of ground level soft storey, which is not acceptable criteria for safe design. ii) After retrofitting of models with shear walls plastic hinges are not formed in any of the columns. iii) Provision of shear walls results in reduction in lateral displacement. iv) After retrofitting base shear carrying capacity is increased

F.Hejazil, et al. [2] have worked on the effect of soft storey on structural response of high-rise buildings. The lateral strength of the building is related to the stiffness, which is the sum of stiffness's of columns, shear walls, bracings at each storey. Therefore, the low strength in the lowest floor causing the failure occurs especially during earthquake. Usually the most economical way of retrofitting soft storey buildings is by adding proper bracings in various arrangements to soft storeys to reduce the soft storey effect on seismic response of buildings. It was found that location and numbering of bracing is an important factor for the soft storey structures to displace during earthquake. The horizontal and vertical movements of building were reduced during earthquake. Therefore, the result shows that use of bracings effectively reduces effect of soft storey on structural response in earthquake excitation.

J. Tanijaya [3] have compared the seismic performance of concentrically and eccentrically braced frames to examine the lateral resistance, plastic hinge mechanism, and ductility factor of CBF and EBF and concluded that i)The increase in lateral resistance resulting from the use of CBF is more than that for EBF as compared to MRF. ii) The plastic hinge mechanism for CBF is marked by the formation of plastic hinges on bracing while EBF is marked by the formation of plastic hinges on the links, then beams and columns.

P.B.Lamb,Dr.R.S.Londhe [4] have performed parametric study on multi-storey building with soft first storey considering the factors that influence the mass, strength, stiffness and deformability of structure. The conclusions of the study are i)Shear walls and cross bracings are found to be very effective in reducing the stiffness irregularity and bending moments in the columns ii)The use of cross bracings significantly increases the first storey stiffness. It considerably reduces the lateral displacement and shows a smooth drift profile iii) Shear walls are found to be most effective in reducing the stiffness irregularity, storey drift and strength demand in the first storey

3. Structural Modelling

3.1 Building Plan

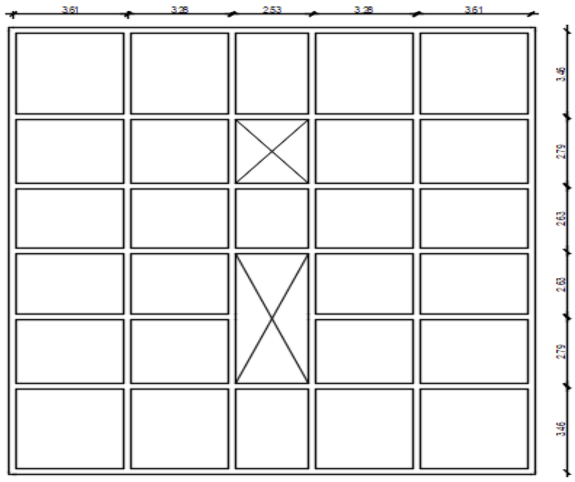


Figure.1 Floor Plan

3.1.1. Building Details

i) Building: 10-storey building having open ground storey
ii) Foundation soil: type 1 (rock or hard soil)
iii) Height: ground storey: 4.0m, other storeys: 3m
iv) Wall thickness: 150mm for external walls and 110mm for internal walls, density 19kN/m^3

3.2. Model 1- Moment resisting frames system

3.2.1. Floor plan and 3D view

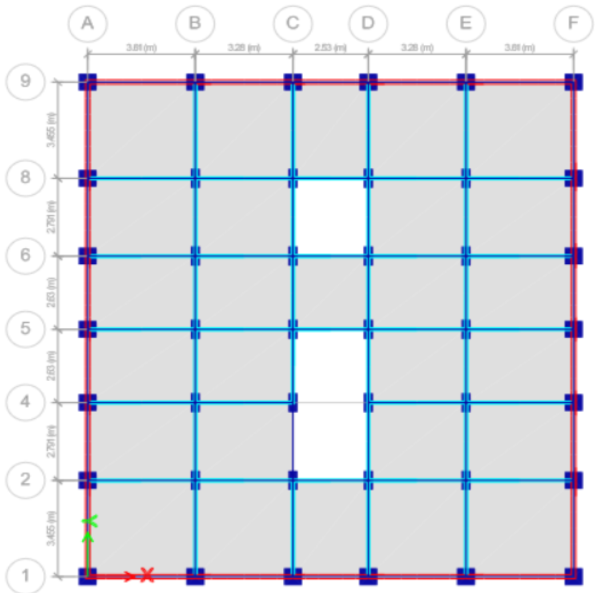


Figure.2.Floor plan

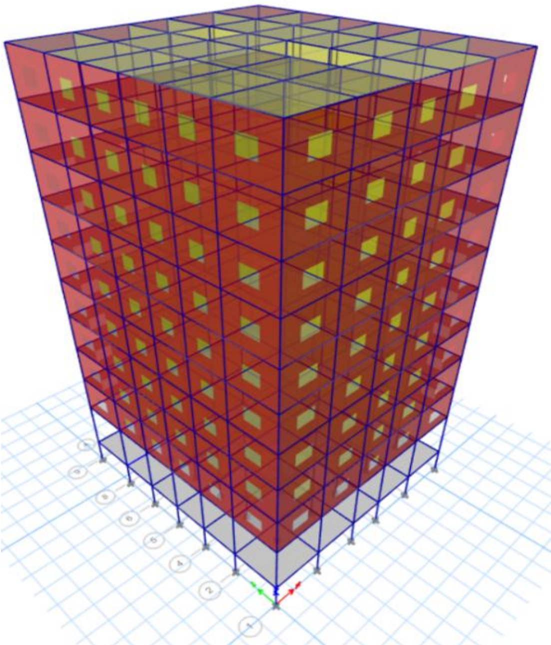


Figure.3 3D view

3.2.2. Section properties

Table 1: Frame sections

Members	Location	Floor level	Size
Columns	along periphery	base to 10FL	600mmx600mm
	in the interior	base to 1FL	450mmx850mm
		2FL to 6 FL	380mmx750mm
		7FL to 10FL	300mmx680mm
Beams	roof level	1FL to 10FL	230mmx380mm
Slab	roof level	1FL to 10FL	125mm

3.3. Model 2-Moment frame system with shear walls
3.3.1. Floor plan and 3D view

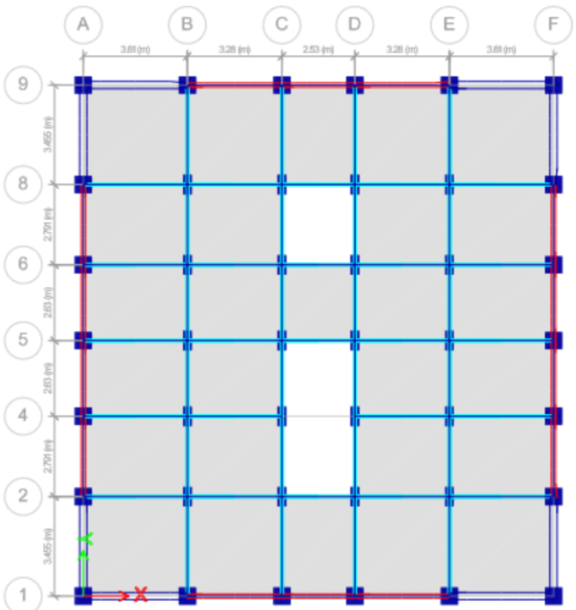


Figure.4 Floor plan

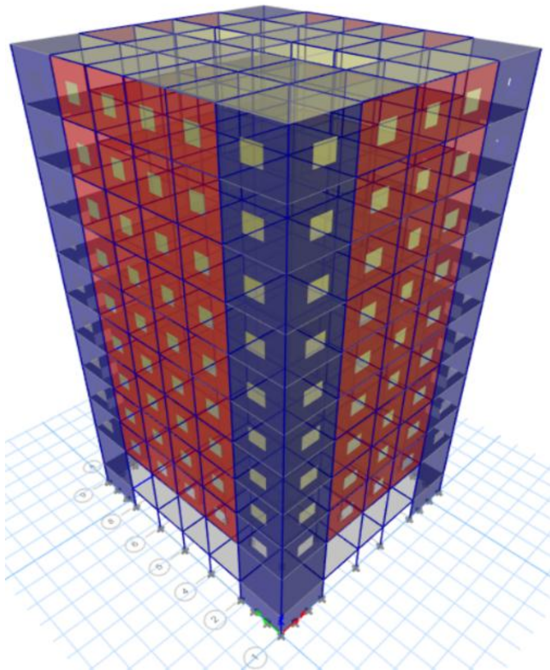


Figure.5 3D view

3.3.2. Section properties

Table 2: Shear wall sections

Members	Location	Type	Direction	Thickness
Shear walls	at corners	coupled	X	300mm
		coupled	Y	300mm

3.4. Model 3- Moment frame system with X bracings
3.4.1. Floor plan and 3D view

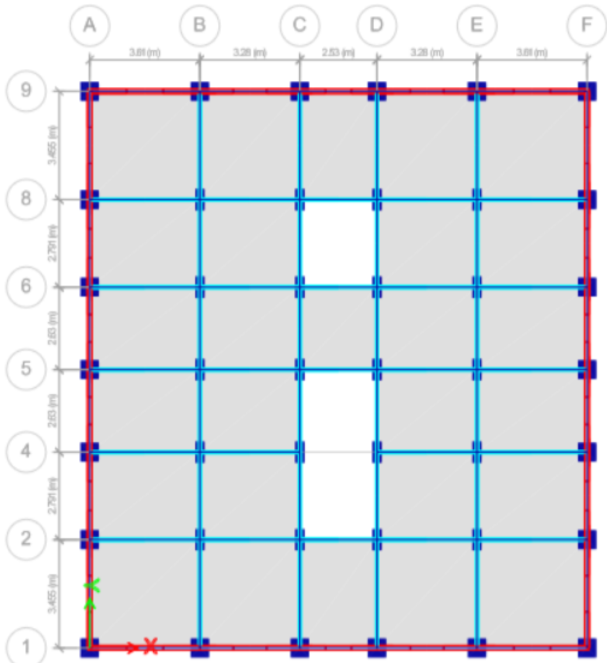


Figure.6 Floor plan

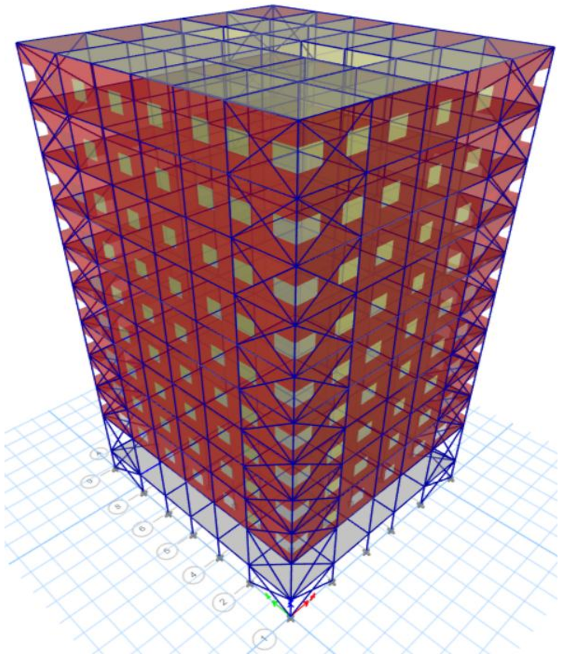


Figure.7 3D view

3.4.2. Section properties

Table 3: Bracing sections

Members	Location	Type	Direction	Thickness
Bracings	Corners bays	X	X	230X380mm
		X	Y	230X380mm

4. Analysis

4.1. Seismic data

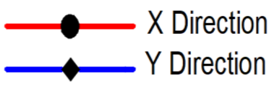
i) Seismic zone: III
ii) Zone factor=0.16
iii) Importance factor=1
iv) Response reduction factor=5
v) Damping=5%
vi) Approximate period of oscillation= 1.6sec

4.2. Analysis data

i) i)Method: Dynamic analysis using Response spectrum method using ETABS 20.0.0 software
ii) No of modes: 12
iii) Indian Standards used: IS 1893 (part1):2016, IS13920:2016
iv) Materials: Concrete M25, Reinforcement: Fe500
v) Imposed loads: Live load= 2 kN/m^2, Floor finish=1 kN/m^2
vi) Load Cases: DL, LL, ELX, ELY, Modal, RSX, RSY
vii) Load combinations:
1.2(DL+IL+/-ELX), 1.2(DL+IL+/-ELY)
1.5(DL+/-ELX), 1.5(DL+/-ELY)
0.9DL+/-1.5ELX, 0.9DL+/-1.5ELY
1.2(DL+IL+RSX), 1.2(DL+IL+RSY)
1.5(DL+RSX), 1.5(DL+RSY)
0.9DL+1.5RSX, 0.9DL+1.5RSY

5. Parametric Investigation

5.1 Seismic Parameters (Model-1)



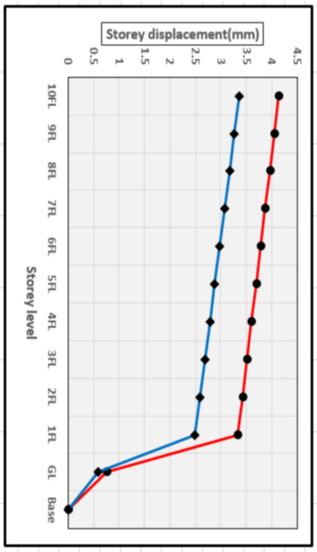


Figure.8 Storey displacements

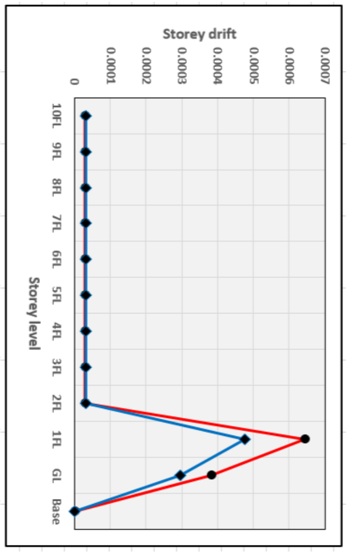


Figure.9 Storey drif

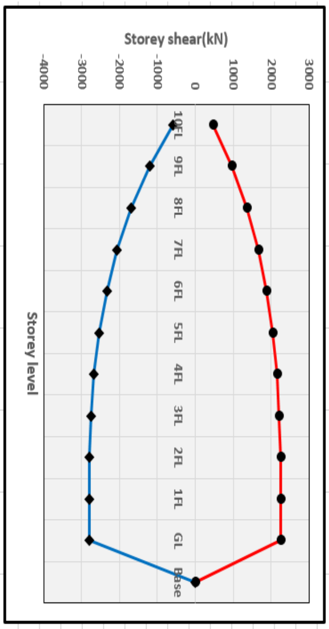


Figure.10 Storey shears

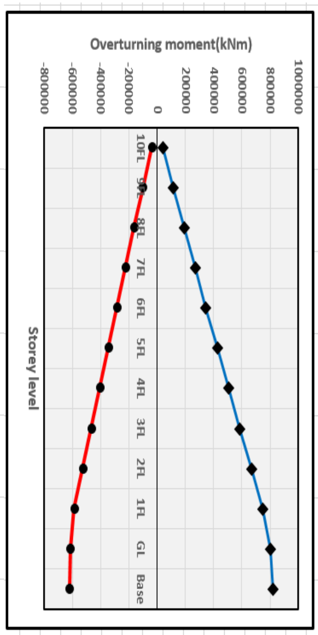


Figure.11 Overturning moments

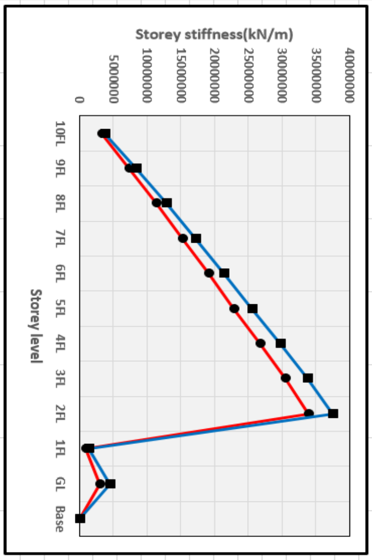


Figure.12 Lateral storey stiffness

5.2. Seismic Parameters (Model-2)

X Direction
Y Direction

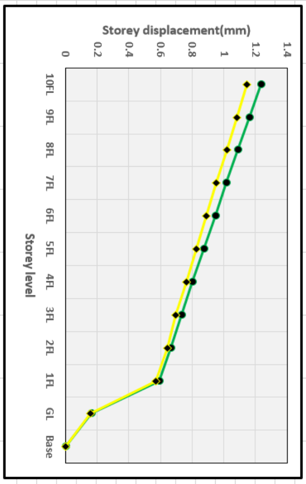


Figure.13 Storey displacements

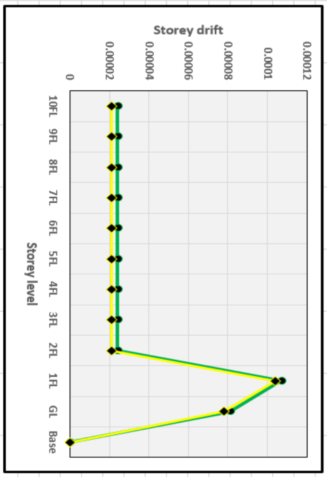


Figure.14 Storey drifts

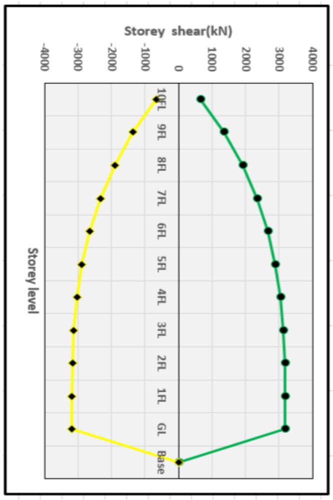


Figure.15 Storey shears

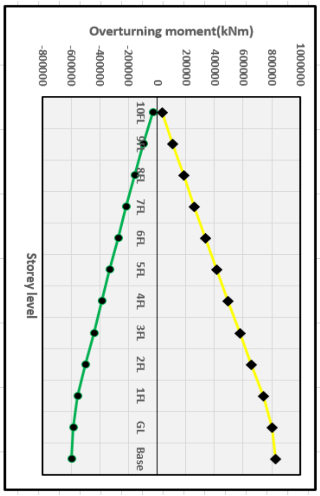


Figure.16 Overturning moments

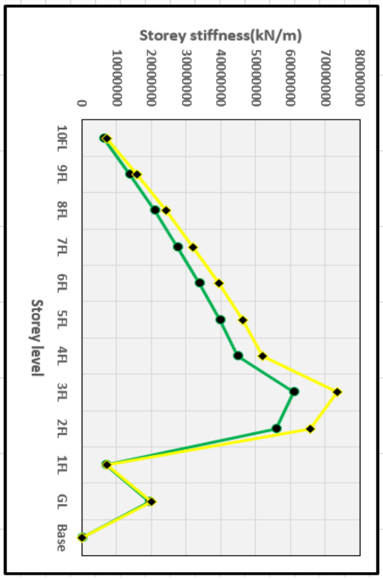


Figure.17 Lateral storey stiffness

5.3. Seismic Parameters (Model-3)

X Direction
Y Direction

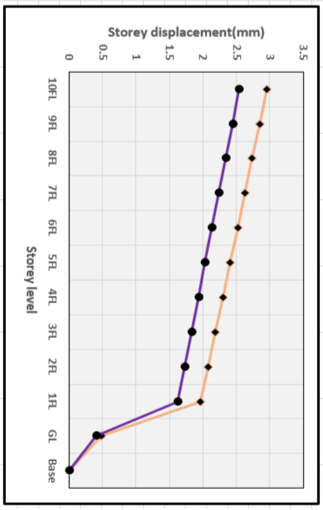


Figure.18 Storey displacements

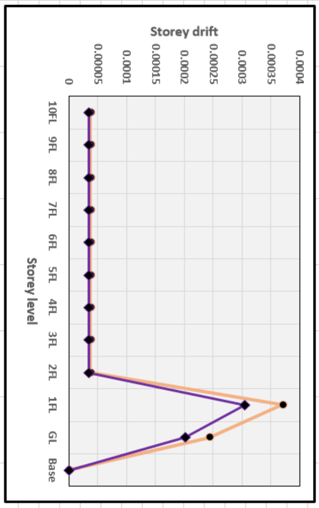


Figure.19 Storey drifts

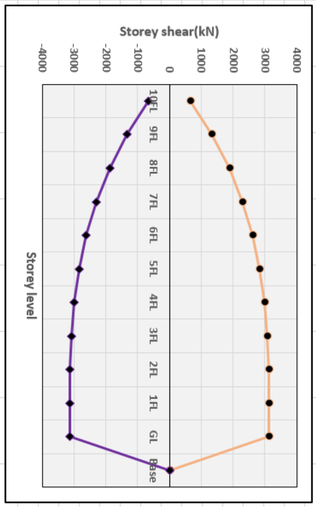


Figure. 20 Storey shears

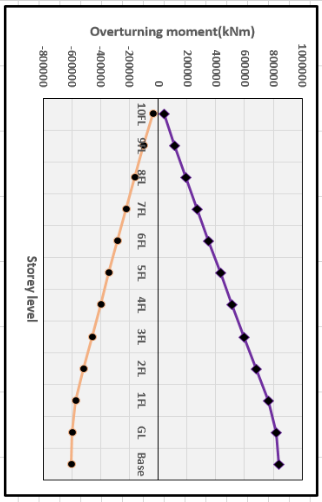


Figure.21 Overturning moments

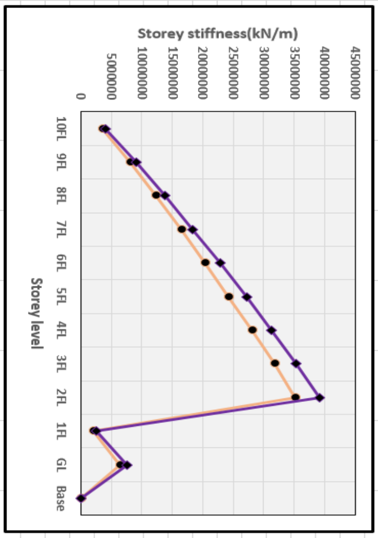


Figure.22 Lateral storey stiffness

Table.4 Comparision of seismic parameters

S. No	Parameter	direction	Model-1	Model -2	Model-3
i	Max. displacement (mm)	X	4.148	1.23	3.08
		Y	3.36	1.14	2.65
ii	Max. drift	X	6E-04	1E-04	4E-04
		Y	5E-04	1E-04	3E-04
iii	Storey shear (kN)	X	2259.62	3187.3	3262.13
		Y	-2796.63	-3187.3	-3272.79
iv	Torsion eccentricity (m)	X	0.0483	0.0079	0.0065
		Y	0.504	0.0022	0.0561
v	Overturning moment (kNm)	X	-616298.17	-588468.26	-601438
		Y	803689.0	802748.13	821102.7
vi	Lateral storey stiffness(kN/m)	X	839318.07	6963849.6	2083219.5
		Y	1387677.06	7147960.85	2528511.3

*Max interstorey drifts for model 2 and 3 are less than 0.004 times storey height
*Max displacements for model 2 and 3 are calculated without scaling

5.4. Modal analysis results

(red)	Model1
(blue)	Model2
(green)	Model3

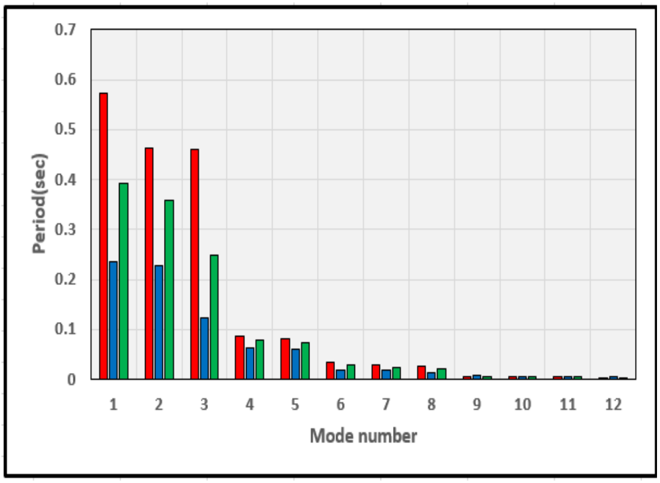


Figure.23 Time (Sec)

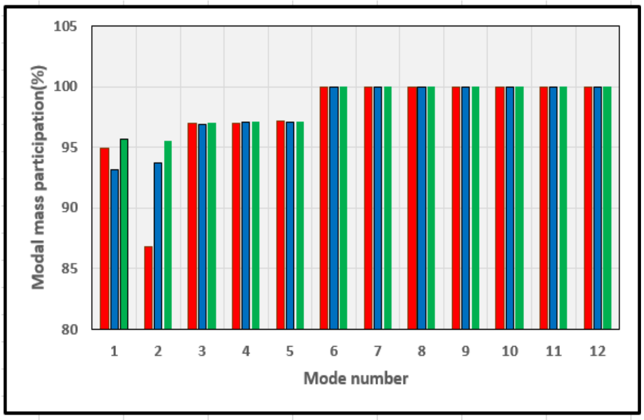


Figure.24 Model mass participation (%)

Table.5 Comparision of modal results

S.No	Analysis result	Mode No	Mode-1	Mode-2	Mode-3
i	Mode type	Model-	Tx	Ty	Rz
		Model-2	Tx	Ty	Rz
		Model-3	Tx	Ty	Rz
ii	Oscillation time (sec)	Model-	0.575	0.464	0.46
		Model-2	0.235	0.227	0.122
		Model-3	0.401	0.367	0.26
iii	Modal mass participation (%)	Model-	94.93	87.38	97.03
		Model-2	93.16	93.75	96.9
		Model-3	95.8	95.67	97.26

T-Translational, R-Rotational

i) Considering the occurrence of first three types of modes and their natural time periods the models are not torsionally irregular
ii) Considering the modal mass participations and natural periods of first three modes there is no lateral storey irregularity in principal plan directions in models
iii) Sum total of modal masses for number of modes considered is more than 90% of the total seismic mass

Conclusions

The conclusions drawn from the structural analysis results are

i) Maximum storey displacements, drifts and oscillation periods in X and Y directions for model with shear walls are smaller than those of model with bracings
ii) Storey shears and torsional eccentricities in X and Y directions for model with shear walls are smaller than those of model with bracings
iii) Overturning moments in X and Y directions for model with shear walls are smaller than those of model with bracings
iv) Lateral storey stiffnesses in X and Y directions for model with shear walls are greater than those of model with bracings

Based on the comparision of results it can be concluded that shear walls perform better than X bracings during earthquakes

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