SEISMIC ANALYSIS OF MULTI-STOREY REINFORCED CONCRETE BUILDINGS HAVING TORSIONAL IRREGULARITY

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Abstract

Damage reports on recent earthquakes have indicated that torsional motions often cause significant damage to buildings, at times leading to their collapse. The objective of this work aimed a better understanding of the torsional behavior of building systems. In this analysis both symmetric and asymmetric structures with plan irregularity are compared. Symmetric structures have centre of mass coinciding with the centre of rigidity and the torsion effect in such structures occurs out of accidental eccentricity whereas in asymmetric structures have irregular distribution of mass and stiffness and its centre of mass and centre of rigidity do not coincide and hence causes the torsional effect on the structures which is one of the most important factor influencing the seismic damage of the structure. To assess the torsional effect on the structures in the present study 5 types of structures having same different perimeter area are considered and strengthened by introduction of shear wall cores. A simple linear comparison based on eccentricity is also carried out for the structures. Structures with asymmetric distribution of mass and stiffness undergoes torsional motions during earthquake. The performance of the structures is assessed as per the procedure prescribe in IS 1893:2002. Equivalent static and response spectrum methods are considered for the analysis of the structure. The analysis of the structural models is carried out using ETABS 2015 software.

Keywords: *Shear wall, Displacement, Drift, Equivalent static method, Response spectrum method*

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1. INTRODUCTION

During earthquake ground motions, structures much of the time will encounter torsional vibration in addition to lateral oscillations. A significant torsional reaction hotspot is due to asymmetrical distribution of mass or horizontal load opposing components in the plan of the structure which is usually refers to eccentricity of mass or rigidity. Distinctive sorts of torsional reaction can take place in regular structures if there should arise an occurrence of irregular ground movement along the base of the structure or inelastic performance of opposing component or loss of strength of such a component. This research focuses mainly on the latter case that can also occur during moderate earthquake movement. In the event of extreme or moderate earthquakes, most of the structures work inelastically. In view of this inelastic performance, horizontal coupled torsional shakings of the structure may be altogether superior than anticipated by linear-elastic analysis. When one of the horizontal opposing components yields, the position of the focal point of rigidity will change and this can cause a critical change in eccentricity of the whole structure.

The torsional irregularity is an imperative parameter which measures the stretch out of torsion impact on the structures. It can be interpreted as the proportion of highest drift to the mean drift of the individual story. Torsional irregularity should be considered when maximum story drift at one side of the structure transverse to a axis is more than 1.2 times the mean of the story drift at the two closures of the structure. $\Delta 1$ and $\Delta 2$ are the story drift (or inter-story drifts) at the two closures of the structure. Relative eccentricity is generally considered the main factor influencing the torsional effects.

2. LITERATURE REVIEW

Rahila Thaskeen, Shinu Shajee (2016) [1]: The objective of their work aimed at enhanced understanding of the torsional behavior of building systems. In the analysis both symmetric and asymmetric structures with plan irregularity were compared. To assess the torsional effect on the structures they modeled 4 types of structures having same outer perimeter area and strengthened by introduction of shear wall cores. A simple linear comparison based on eccentricity is also carried out for G+12 and G+17 structures. The analysis of the structural models is carried out using ETABS software. From their investigation on reviews they concluded that the eccentricity shows the tendency of a structure for torsional effects. Model IV (C-shaped structure) had the maximum tendency for torsional effects with higher value of eccentricity. The highest torsional irregularity ratio was found maximum for model IV which was the C shape structure and it is seen that the rigidity centre of model IV is intense at outside the structure. The drift and displacement values yielded values, indicating the dependence of the stiffness and mass concentration on the structure. Strengthened model yielded shorter-period which permitted smaller drift limits and longer-period structures that is the ideal symmetric structure allowed larger drift limits.

P.S. Pajgade, Vipin Guptha (2015) [2] explains that the torsion is the most basic element prompting significant harm or completes collapse of building; therefore it is necessary that symmetric buildings should also be analyzed for torsion. As result the buildings should be designed by considering the design eccentricity and accidental eccentricity. They observed that the irregular profile buildings got larger forces and displacement as compared to regular one. Structures are never consummately consistent and thus the architects routinely need to assess the feasible level of irregularity and the impact of this irregularity on a structure during an earthquake.

Arvindreddy and R.J.Fernandes (2015) [3] presented a review about the Seismic analysis of RC regular and irregular frame structures. They considered 2 types of reinforced concrete structures with regular and irregular 15 story structures and analyzed for static and dynamic methods. For time history examination past seismic earth ground movement record is taken to think about reaction of the considerable number of structures. They have considered six models for analysis. One is of general structure and remaining are unpredictable structural models. From their investigation on reviews they concluded that, the static analysis strategy demonstrate lesser story displacements when compared with response spectrum analysis. This variation may be because of nonlinear distribution of force. In diaphragm irregularity, story displacement and story drift observed to be less when compared with normal structures in both static and response spectrum analysis.

O. A. Mohamed and O. A. Abbass (2015) [4]: explains review about the Consideration of torsional irregularity in Modal Response Spectrum Analysis. The motivation behind their work is to determine the impacts of torsional irregularity on seismic reaction as per ASCE 7–10, when MRSA is utilized for count of seismic forces and drifts. They discussed about why torsional irregularity must be represented, notwithstanding when MRSA is utilized. From their investigation on reviews they concluded that the torsional irregularity of building diaphragm or floor frameworks prompts increased structural reactions including bending moments and drift and should be represented in the computational model to maintain a strategic distance from structural failures and building pounding effects.

Turgut Ozturk , Zubeyde Ozturk and Onur Ozturk (2015) [5] : presented a review about the seismic behavior analysis of multi-story reinforced concrete buildings having torsional irregularity. The purpose of their work is to understanding of the characteristics of an earthquake and correct determination of the behavior of buildings under earthquake excitation turn out to be the most important requirement to build earthquake resistant buildings. In their study torsional effects that occur during earthquake excitations are analyzed in multi-story reinforced concrete buildings. In that manner the behavior of reinforced concrete structures under earthquake loads are examined and by the way the behaviors of structures having torsional irregularities are enlightened and clarified. From the results they explains that the torsional irregularity can occur in the buildings that have regular geometrical shape and regular rigidity distribution. The reason of this irregularity which is called hidden torsional irregularity, is due to lack of rigidity along the extern axes. In certain cases, torsional irregularity can be lowered or totally removed as a result of decrease shear wall rigidity at central zone. torsional irregularity is more related to the rigidity distribution than the geometrical plan of the building. For this reason, determination of the load carrying system of a structure is the most important issue at the planning stage of the project. It is essential that shear wall locations and cross-sectional areas must be properly selected, and the shear walls must be symmetrical in the plan in order to prevent torsional irregularity.

3. OBJECTIVES

(i) To determine optimum position of shear walls by taking irregular building plan.
(ii) To determine the structural response under wind and seismic loading using shear walls with the same cross sectional area in different models.
(iii) To find parameters like storey displacements, base shear, and relative storey drifts.
(iv) To study the structural response for torsional irregularities.
(v) To understand the behavior of irregular building subjected to lateral loading with the help of time period, frequency, modal mass participating ratio and the magnitudes of stress resultants.

4. MODELING

The analysis of 15 storey building is carried out using ETABS 15.2.2 software situated in zone IV. Lateral displacement, storey drift, storey shear, storey accelerations, eccentricity, and torsional irregularity is compared for all models.

4.1 Model Types

Building frame with the following geometrical types are considered for analysis under zone IV for seismic and gravity loading in each case.

Model 1: Structure having only columns and beams without shear walls and lift core walls.
Model 2: Structure consists of columns ,beams, lift core walls and without shear walls.
Model 3: Structure having columns and beams, lift core walls and shear walls with different positions.
Model 4: Structure having columns and beams, lift core walls and shear walls with different positions.
Model 5: Structure having columns and beams, lift core walls and shear walls with different positions.

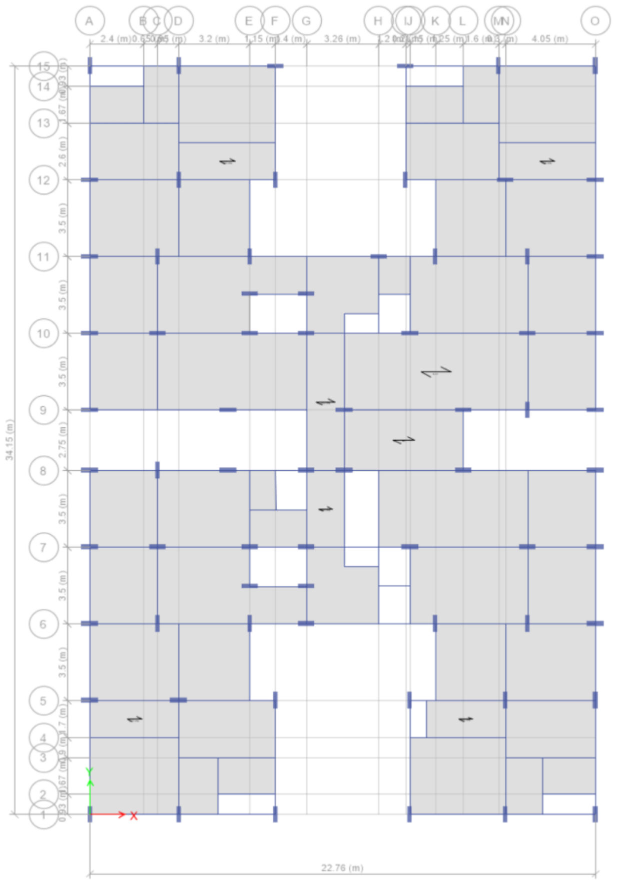

Fig.4.1 Plan view of model 1

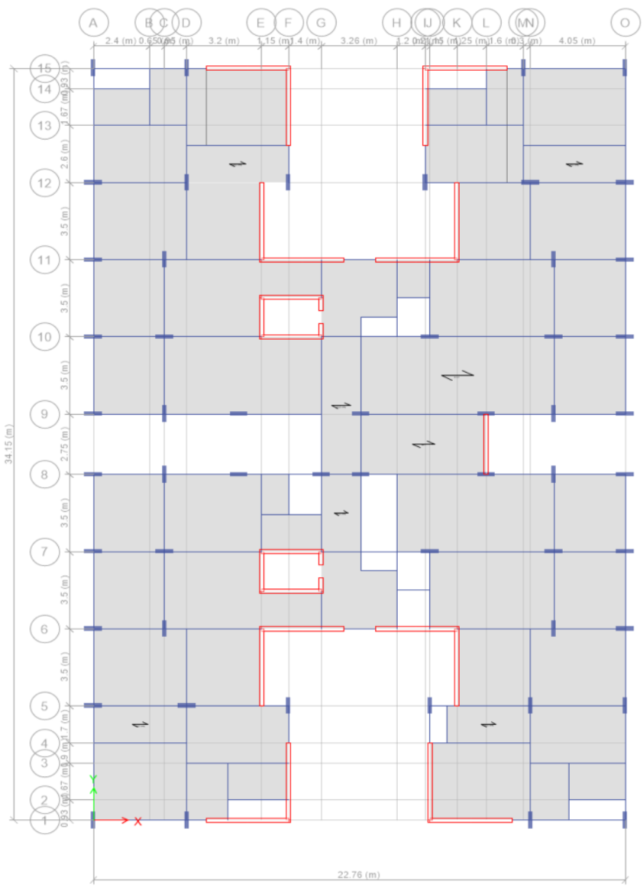

Fig.4.3 Plan view of model 3

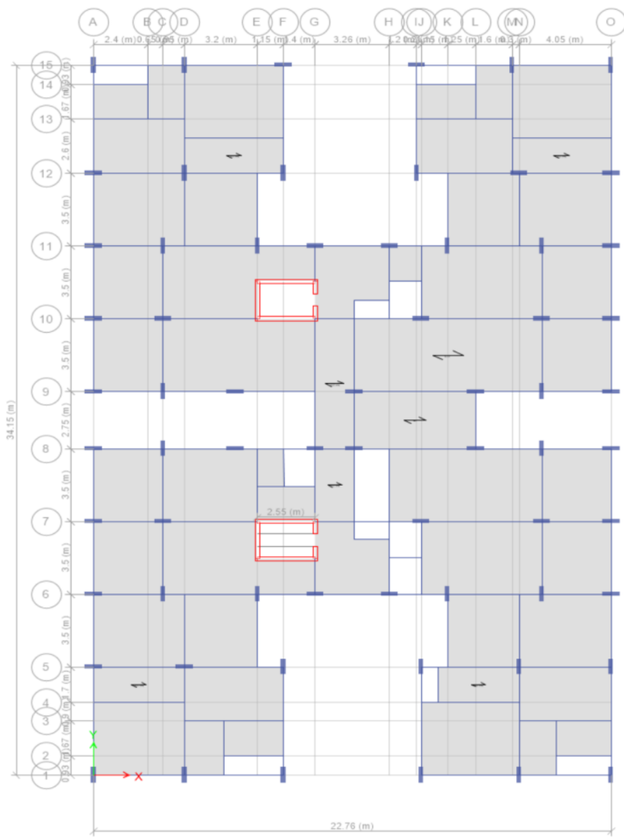

Fig.4.2 Plan view of model 2

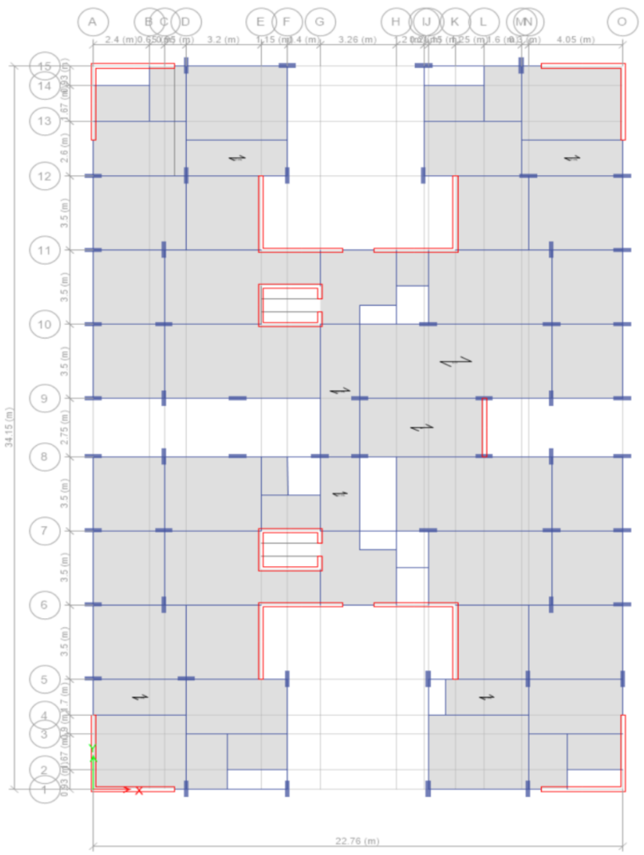

Fig.4.4 Plan view of model 4

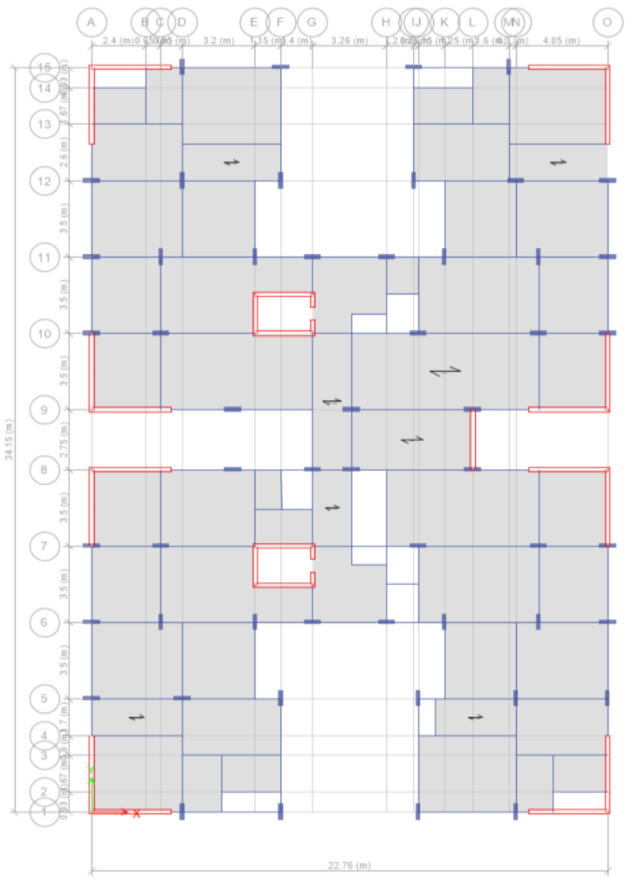

Fig.4.5 Plan view of model 5

4.2 Model Data

Following are the material properties considered for the modeling of the proposed structure frames:

Table 4.1 Material and geometrical property

Depth of foundation	3m
Floor to floor height	3m
Building dimension	22.76m x 34.15m
Type of steel	Fe-500
Grade of concrete	M-30
Column size	200mmx750mm
Beam size	200mmx450mm
Thickness of masonry wall	200mm
Slab thickness	150mm
Live load	3 kN/m²
Floor finishes	1.5kN/m²
Wall load	11kN/m
Seismic zone, Z	IV
Importance factor, I	1
Response reduction factor, R	5
Soil type	Medium
Building height	33.5m

5. RESULTS AND DISCUSSION

Find the results for lateral displacements, storey drift, base shear, storey acceleration, natural time period, Modal mass participating ratio, eccentricity and torsional irregularity. Then the results are compared with different models to determine the effective position of shear wall system.

5.1 Maximum Lateral Displacement

The maximum lateral displacement values for all the models in zone IV for both equivalent static analysis and response spectrum analysis along X and Y direction tabulated in table.5.1 and graphical representation in Fig.5.1.

Table 5.1 Maximum lateral displacement along X and Y direction

Model	ESA Ux	ESA Uy	RSA Ux	RSA Uy
1	125.22	175.34	104.34	140.49
2	89.37	141.08	73.99	121.44
3	30.88	38.85	27.14	34.95
4	30.55	46.59	26.86	40.44
5	40.00	50.48	37.83	43.81

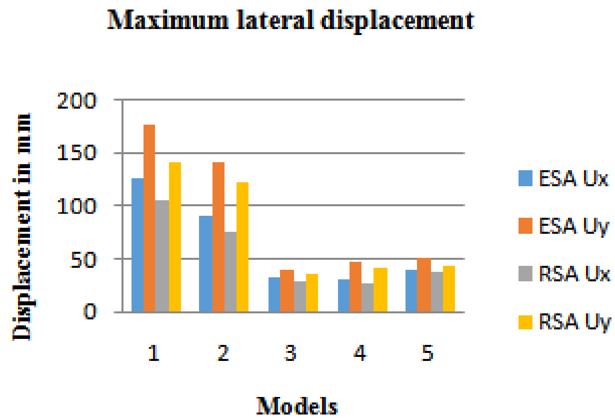

Fig 5.1 Maximum lateral displacement along X and Y direction

From table 5.1 and Fig 5.1, it is observed that the lateral displacement is reduced to large extent for model 3 and model 4, while the displacement is maximum for model 1.

5.2 Maximum Storey Drift

The maximum storey drift values for all the models in zone IV for both equivalent static analysis and response spectrum analysis along X and Y direction tabulated in table.5.2 and graphical representation in Fig.5.2.

Table 5.2 Maximum storey drift along X and Y direction

Model	ESA DriftX	ESA DriftY	RSA DriftX	RSA DriftY
1	0.0045	0.0063	0.0038	0.0051
2	0.0033	0.0052	0.0027	0.0045
3	0.0011	0.0014	0.0009	0.0012
4	0.0011	0.0016	0.0009	0.0014
5	0.0015	0.0018	0.0013	0.0015

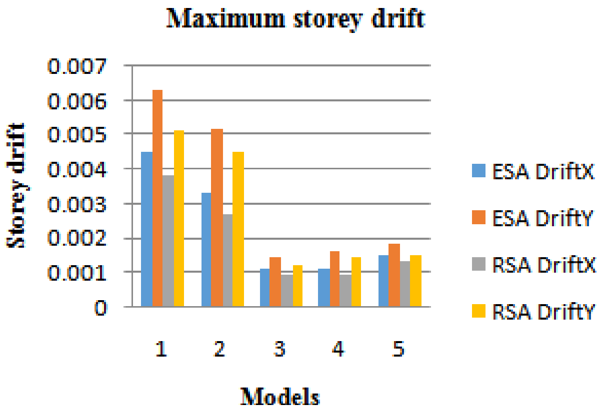

Fig 5.2 Maximum storey drift along X and Y direction

From table 5.2 and Fig 5.2, it is observed that the storey drift reduced to large extent for model 3 and model 4, while the drift is maximum for model 1.

5.3 Base Shear

The maximum base shear for different models under seismic zone IV is carried out as shown in table 5.3. For better result the graph of base shear versus models is plotted as shown in Fig.5.3

Table 5.3 Maximum base shear for different models

Model	Base shear (kN)
1	6377
2	6595
3	7409
4	7422
5	7415

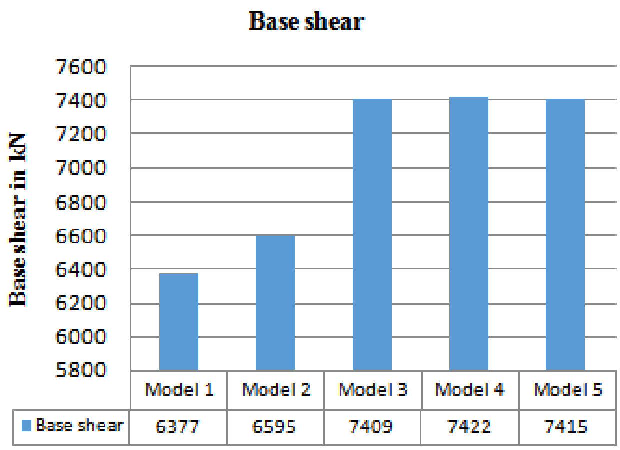

Fig. 5.3 Maximum base shear in different models

From table 5.3 and Fig.5.3, it is observed that, It is observed that the model 1 base shear is minimum and model 4 base shear is maximum. If the building has higher value of base shear it indicates that the building is stiff under earthquake ground motions and similarly the lesser value of base shear indicates that the building is flexible under earthquake ground motion. So, as per analysis point of view the building should be stiff under seismic forces.

5.4 Storey Acceleration

The maximum storey acceleration values for all the models in zone IV for response spectrum analysis along X and Y direction tabulated in table.5.4 and graphical representation in Fig.5.4

Table 5.4 Maximum storey acceleration along X and Y direction

Model	RSA X	RSA Y
1	3002.37	2997.83
2	3036.83	4301
3	2726.16	2982.41
4	2667.95	2965.61
5	2915.48	3062.38

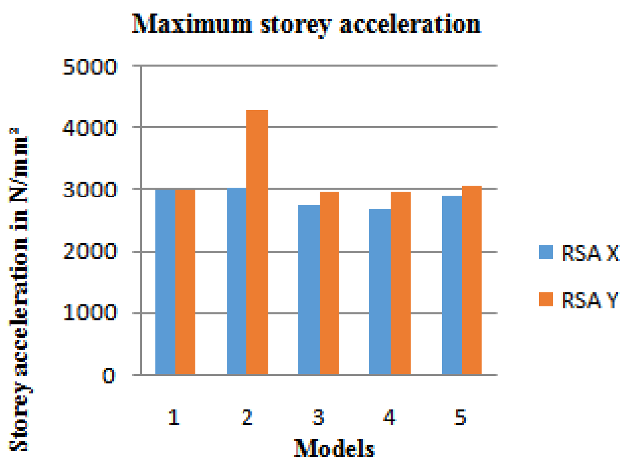

Fig. 5.4 Maximum storey acceleration for different models

From table 5.4 and Fig 5.4, it is observed that the storey acceleration reduced for model 3 and model 4, while the storey acceleration is maximum for model 2.

5.5 Eccentricity in X and Y Direction

The eccentricity values for all the models in zone IV for response spectrum analysis along X and Y direction tabulated in table.5.5 and graphical representation in Fig.5.5.

Table 5.5 Maximum storey acceleration along X and Y direction

Model	RSA X	RSA Y
1	235.1	647.4
2	273	114.4
3	65	27.1
4	49.7	43
5	98.1	49.2

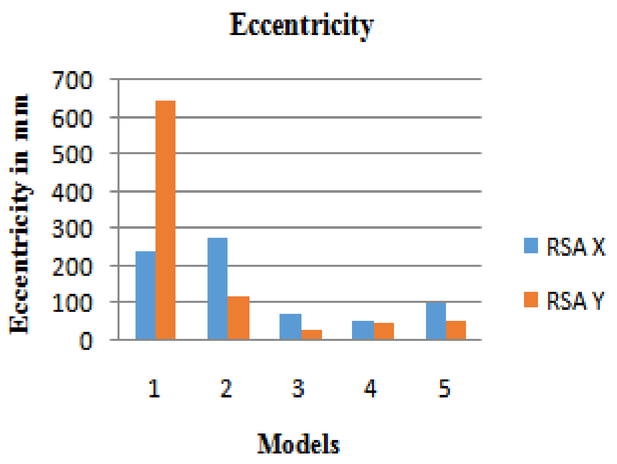

Fig. 5.5 Maximum eccentricity for different models

From table 5.5 and Fig 5.5, it is observed that the eccentricity values are reduced in larger extent for model 3 and model 4, while the eccentricity value is maximum for model 1.

5.6 Natural Time Period and Modal Participation Factor

Natural time period value depends on the building flexibility and mass, more the flexibility, the longer is the T, and more the mass, the longer is the T. In general, taller building are more flexible and have larger mass, and therefore have longer T. Table 5.6, 5.7, 5.8, 5.9 and 5.10 shows the natural time period of all the models. It can be observed that model 1 has longer time period and model 3, model 4, and model 5 has shorter time period, this is because the model 1 which has no core walls and shear wall, behaves flexible under earthquake ground motions. In model 3, model 4, model 5 the introduction of core wall and shear wall makes the structure more rigid under earthquake ground motions hence has shorter time period T.

Modal Mass Participating Ratio is a measure of energy contained with each resonant mode since it represents the amount of system mass participating in a particular mode.
For a particular structure, with a mass matrix, normalized mode shapes and a ground motion influence coefficient, participation of each mode can be obtained as the effective mass participation factor. Table 5.6, 5.7, 5.8, 5.9 and 5.10 shows the modal mass participating ratio of all the models.

Table 5.6 Natural time period and modal participation factor for model 1

Mode	Time period	Frequency	Modal mass participating ratio (%)		
			X – trans	Y - trans	Rz - Rotation
1	1.777	0.562	0.11	80.22	0.41
2	1.708	0.585	0.23	0.42	80.38
3	1.474	0.678	79.75	0.1	0.24
Sum of 12 modes			96.934	96.8736	97.06

Table 5.7 Natural time period and modal participation factor for model 2

Mode	Time period	Frequency	Modal mass participating ratio (%)		
			X – trans	Y - trans	Rz - rotation
1	1.58	0.632	0.0009	29.18	48.84
2	1.36	0.734	0.06	46.32	28.27
3	1.19	0.837	73.78	0.05	0.02
Sum of 12 modes			96.40	97.063	97.7255

Table 5.8 Natural time period and modal participation factor for model 3

Mode	Time period	Frequency	Modal mass participating ratio (%)		
			X - trans	Y - trans	Rz - Rotation
1	0.195	5.12	0.22	5.36	64.23
2	0.19	5.26	1.4	64.01	5.55
3	0.175	5.71	69.82	1.69	0.02
Sum of 12 modes			96.4639	96.4118	96.325

Table 5.9 Natural time period and modal participation factor for model 4

Mode	Time period	Frequency	Modal mass participating ratio (%)		
			X - trans	Y - trans	Rz - Rotation
1	0.064	15.62	0.04	69.61	0.07
2	0.052	19.23	71.23	0.05	0.00042
3	0.048	20.83	0.00049	0.07	68.49
Sum of 12 modes			96.5033	96.4082	96.8504

Table 5.10 Natural time period and modal participation factor for model 5

Mode	Time period	Frequency	Modal mass participating ratio (%)		
			X - trans	Y - trans	Rz - Rotation
1	0.061	16.39	0.49	68.12	0.14
2	0.05	20	68.84	0.5	0.00013
3	0.049	20.40	0.000022	0.14	67.71
sum of 12 modes			96.3649	96.5056	96.8485

5.7 Torsional Irregularity

Table 5.11 Torsional irregularity along X and Y direction

Model	ESA X	ESA Y	RSA X	RSA Y
1	1.226	1.072	1.01	1.786
2	1.014	1.22	1.001	1.157
3	1.009	1.021	1.029	1.053
4	1.006	1.001	1.027	1.006
5	1.008	1.006	1.017	1.017

Torsional irregularity should be considered when maximum story drift at one end of the structure transverse to an axis is more than 1.2 times the average of the story drift (or inter-story drifts) at the two ends of the structure. Table 5.11 shows Torsional irregularity for different types of model. It is observed that the torsional irregularity of model 1 and model 2 has exceeded the specified limit and for remaining models the torsional irregularity value has been reduced due to introduction of core walls and shear walls.

6. CONCLUSION

1 The displacement is more in model-1 compare to other models, the model 1 is building without shear wall and the other models are building with shear walls.
2 Positions of shear walls in building influenced the displacement due to seismic actions.
3 Keeping shear walls at proper places significantly minimize the displacement caused by earth quake forces.
4 In this study it is found that model 3 building shows less displacement compare to other models for both earth quake and wind forces.
5 The optimum position of shear wall in reducing displacement and drift is given by the model 3 for all types of loading.
6 The storey drift was more influenced by shear walls presence and their positions in a building.
7 The storey drift of model 1 building is more in comparison with the other models .model 3 is found to be having lesser drifts between stories.
8 In this study it was observed that the time period of building with shear walls are less compare to building without shear wall.
9 The modal mass participating ratio of models considered for this work are within permissible limits, i.e. greater than 90% seismic weight, according IS 1893[part-1] : 2002.
10 The torsional irregularity ratio of all models are within the permissible limit of $\Delta Max / \Delta Avg < 1.2$ as per IS 1893(part-1):2002.
11 Hence it can be said that the proper location of shear walls results in good, useful and efficient performance of building subjected to lateral forces i.e earth quake load.
12 Among all the models, the optimum location of shear walls to counteract ill effects of Irregularity found to be provided by model 3

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BIOGRAPHIES

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