COMPARISON OF SEISMIC PERFORMANCE OF VARIOUS MID RISE BUILDINGS WITH DIFFERENT PLAN CONFIGURATIONS

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Abstract

Most of the structures are vulnerable to lateral loads, especially to seismic loads which are dynamic in nature and highly unpredictable. The vulnerability increases if the buildings are asymmetric and located in urban areas where multi-storey construction is in demand. The current research is undertaken to analyze the multi storey buildings with various plan configuration that are commonly found in urban areas assuming them to be in seismic zone IV. The surface area of the building plan configurations considered are kept constant to ensure that the overall cost of buildings remains same. The buildings are analysed using finite element software ETABS. The models are analysed using equivalent static method and response spectrum method. Relevant Indian standard codes are used while modelling and analyzing. The parameters considered for comparison are fundamental time period, base shear, storey drift and lateral displacement. The number of modes is decided based on the values of modal mass participation factor and rotational frequencies. Finally, the plan configuration which is most vulnerable and the least vulnerable to seismic loads are predicted.

Key Words*:Building plan configuration, ETABS,Fundamental time period, Base shear, Storey drift, Lateral displacement.*

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1. INTRODUCTION

In the past few decades, major portion of urban infrastructure in India are delineated by buildings with complex and irregular configuration, as the focus is on aesthetic appeal and utilization of limited space. Buildings with such irregular configuration, due to their eccentricities in the centre of mass and centre of stiffness, aggravate the vulnerability of the structures response to seismic excitations. The damages incurred could be diverse from minor non structural damages to complete collapse, which necessitates the effective mitigation of this disastrous effect on human life.

Delhi being the only major city classified under seismic zone IV by IS 1893 (Part1): 2002, which houses over 25 million people as of 2015, is having 80% of its infrastructure which will not withstand an earthquake tremor. The condition will be the same in other major cities as well if they experience an earthquake. Moreover, the number of mid rise and high rise buildings has increased as the horizontal expansions have reached a degree of saturation emphasising the need to grow vertically [3].

The seismic ground motion can affect a building in any direction. The seismic forces developed as a result will be distributed along the building height. Therefore, the building should be designed adequately ensuring compatibility between architectural and structural aspects of design, taking into consideration the seismic design philosophies.

Most of the buildings constructed nowadays tend to have plan irregular configurations. The possible reason for undesired seismic behaviour of buildings with plan irregular configurations is the concentration of stress in a few lateral load resisting members of the structure. This is caused by localised deformations [13] combined with torsion.

Usually for architecture space planning flexibility, Moment resisting frames are adopted which resists the earthquake forces primarily by flexure [10]. Each type of plan configuration behaves differently to a seismic excitation even if it is designed as special moment resisting frame. Thus awareness is required amongst architects and engineers to select a plan configuration which undergoes minimal damage during an earthquake, avoiding economic risk during construction by providing seismic damage control measures.

1.1 Asymmetric Plan Of Buildings

The structural irregularity of a building could be classified broadly as plan (Horizontal)irregularity and vertical irregularity as shown in Figure1.

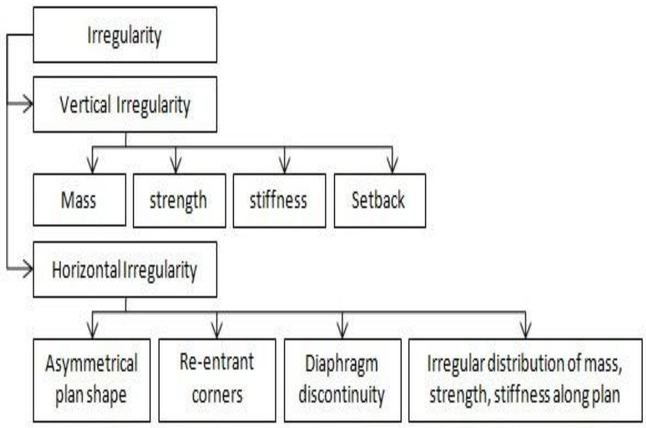

Fig-1: Flow chart showing different types of structural irregularities

A plan asymmetry in building would result in the seismic response to be both translational and rotational in nature. This is caused due to the non coinciding centres of mass and/or stiffness. The plan asymmetry could cause severe damages to structure especially at locations where the lateral flexibility is high. The Indian code IS 1893 (Part 1): 2002 prescribes the irregularity limits for buildings with re-entrant corner, tensional irregularity and diaphragm discontinuity as shown inTable1.1 [16].

Table-1: Plan irregularity limits

Irregularity	Limit	Description
Re-entrant Corners	$R_i \leq 15\%$	R_i – Projection limit of re-entrant corner.
Torsional irregularity	$d_{max} \leq 1.2 d_{avg}$	d_{max} – Maximum drift computed at a particular storey level. d_{avg} – Average of drifts computed at both sides of a structure.
Diaphragm Discontinuity	$O_a > 50\%$; $S_{dst} > 50\%$	O_a– Open area in diaphragm. S_{dst}–Diaphragm stiffness.

2. LITERATURE REVIEW

S Monish, S Karuna [2015], studied the effect of plan irregularities such as diaphragm discontinuity and re-entrant corners. Seven models each having 20 storeys was analyzed using the finite element software ETABS. Both static and dynamic analyses were carried out. The first model was a symmetrical square shaped model, three diaphragm discontinuous models with H, C, + shaped opening and the last three models having re- entrant corners with 40%, 60%, 80% projection in X direction and40% projection in Y direction kept constant. The authors, from the results concluded that the model with re-entrant corner with 80%projection was the most vulnerable model.

Arvindreddy, R.J.Fernandes [2015], studied the effect of regular and irregular framed structures with 15 storeys when subjected to Earthquake forces. The structures were analysed using Time history method, equivalent static method, response spectrum method and pushover method using ETABS software. A total of six models with symmetry, re-entrant corner, diaphragm discontinuity, irregular mass, torsion and stiffness were created. The earthquake was found to be more enhanced in stiffness irregular structure. So in overall it can be concluded that structure built-in with stiffness irregularity will be on non conservative side.

Shreyasvi C, B. Shivakumaraswamy [2015], taking into consideration those Buildings with re - entrant corner that are commonly encountered, have focused on studying the response of the building with a re-entrant corner located in seismic zones listed in the codes. Two building models with ground and four upper stories were considered; one of the building models had a re - entrant corner and another had regular plan configuration. Re-entrant corner projections were varied as 42.85%, 23.2% and 50%. The modal time periods obtained from response spectrum analysis implicates that the regular buildings have longer time periods than buildings with re-entrant corner. Re - entrant buildings underwent larger displacements and drifts when compared with regular buildings.

Mohod M. V [2015], aimed at studying and understanding the critical behaviour of plan irregular structures which were subjected to seismic excitation. Lateral displacement, storey drift, base shear, storey displacement were the key parameters to ascertain the performance point of the 9 models that were modelled in ETABS software for the research. The plan irregularities adopted were as follows- Regular Square Shape, T-Shape, Plus (+) Shape, E-Shape, L-Shape, Square with Core, H-Shape, C-Shape and Rectangle with core. Among the models L-shaped and C-shaped models showed larger drift than other plan irregular models.

Ahmed J and Raza S. A [2014], for the study on seismic analysis of buildings with plan irregularity selected models with rectangular shape, Y shape and diaphragm discontinuity. Using the software ETABS both static and dynamic analysis methods were performed. The models had 10 storeys. Base shear and displacement were assessed. The base shear for rectangular model was greater than other two models, while the point displacement was greater for diaphragm discontinuous model due to the opening at the centre. Finally the research was concluded with the statement that rectangular model is vulnerable to seismic effect than the diaphragm discontinuous model and 'Y' shaped model.

3. ANALYTICAL PROGRAM

Earthquake manifests as ground shaking which is caused by the sudden release of strain energy within the crust of the earth [1]. All the studies and investigations in the field of earthquake engineering repeatedly reaffirm that building with asymmetry suffers excessive damage than their asymmetric counterparts [9]. To contribute to earthquake engineering field a study is undertaken in this research to reckon a plan asymmetric model that does not perform adequately during an earthquake. Based on various studies carried out in the area of performance of asymmetric models during earthquake; eight models are adopted for the analysis. The models are analysed using the aid of finite element software ETABS taking into consideration the code provisions for the modelling. The analysis was performed using equivalent static analysis and response spectrum analysis. The parameters for comparison were modal mass participation factor, lateral displacement, storey drift and base shear. The models were validated to check the adequacy of software generated models.

3.1 Modelling

- Eight models with one symmetric model and remaining seven being asymmetric were created. All the models were having sixteen storeys (Ground +15). The building is located in seismic zone IV on a site with medium soil.
- All the models do not have slab at plinth level. At plinth level beams were provided connecting all columns to provide lateral stiffness and reduce the effect of soft storey.
- The wall loads were applied as superimposed dead load. The wall loads were not provided in the ground floor. No balconies were provided for the purpose of simplicity.
- For columns M30 grade concrete was used while M25 was used for beams and slabs.
- Sizes of every structural member remain constant and the size of column is not varied with the building height.
- Preliminary sizes of structural members were assumed by experience.
- For analysis purpose, the beams were assumed to be rectangular so as to distribute slightly larger moment in columns. Seismic loads will be considered acting in the horizontal direction (along either of the two Principal directions) and not along the vertical direction, since it was considered to be least significant.

Table-2: General building data

General building Data	
Property	
Floors	G+15
Beam size, b_b*D_b (m)	0.3x0.45
Slab size, L_s*B_s(m)	4x4
column size, b_c*D_c (m)	0.3x0.9
Beam length, L_b(m)	4
Wall thickness, t_w(m)	0.2
Storey Height (regular), h_r(m)	3
Foundation depth, h_b(m)	2
Storey Height (ground floor), h_g (m)	4
Parapet Height, h_p(m)	1.2
slabs depth, D_s (m)	0.15
Height of the building, H (m)	49
Brick density, $\int_b$(KN/m^3)	19
RCC density, $\int_c$(KN/m^3)	25
Concrete grade, f_{ck}(column) MPa	30
Concrete grade, f_{ck}(beams, slabs) MPa	25
Steel HYSD, f_yMPa	500
Live load- slab, W_{LS} (KN/m^2)	3
Live load- terrace, W_{LT} (KN/m^2)	2
Floor Finish, W_{SS} (KN/m^2)	1
Floor Finish - terrace, W_{ST} (KN/m^2)	2

Table-3:IS Code data

IS code data	
Property	
Location	Delhi
Earthquake load	IS1893 (Part1): 2002
zone factor Z	0.24
Importance factor I	1
Reduction factor R	5
soil type	II
Live load contributed to seismic weight	25%

Table- 4: Storey data

Name	Height mm	Elevation mm
Story17	3	51
Story16	3	48
Story15	3	45
Story14	3	42
Story13	3	39
Story12	3	36
Story11	3	33
Story10	3	30
Story9	3	27
Story8	3	24
Story7	3	21
Story6	3	18
Story5	3	15
Story4	3	12
Story3	3	9
Story2	4	6
Story1	2	2
Base	0	0

3.2 Model Geometry

a) Model 1: Rectangular shaped. This model will be represented as M1.
b) Model 2: Plus shaped. The percentage projection in X and Y direction is 67%. This model will represented as M2.
c) Model 3: L shaped. The percentage projection is 57 % in X direction and 50% in Y direction. This model will be represented as M3.
d) Model 4: rectangle with diaphragm opening. The percentage opening is 29%. This model will be represented as M4.
e) Model 5: T shaped. The percentage projection is 57% in X direction and 50% in Y direction. This model will be represented as M5.
f) Model 6: I shaped. The percentage projection is 67% in X direction. This model will be represented as M6.
g) Model 7:Z shaped. The percentage projection is 57 % in X direction. This model will be represented as M7.
h) Model 8: U Shaped. The percentage projection is 67% in Y direction. This model will be represented as M8.

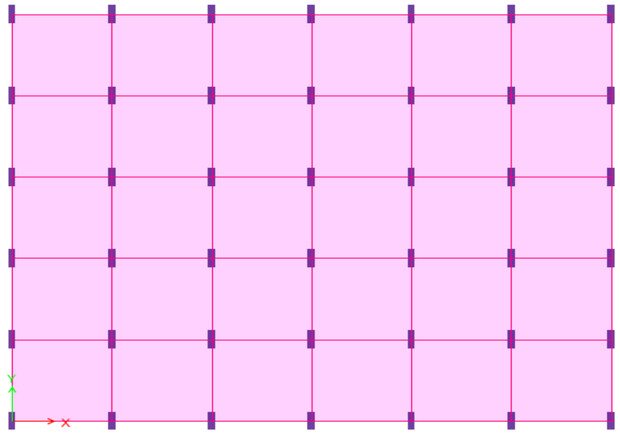

Fig- 2: Model 1(Rectangular Shaped)

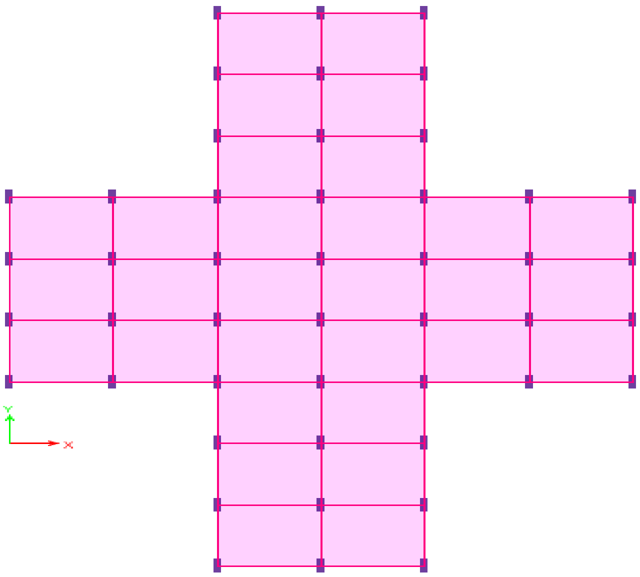

Fig- 3: Model 2(Plus Shaped)

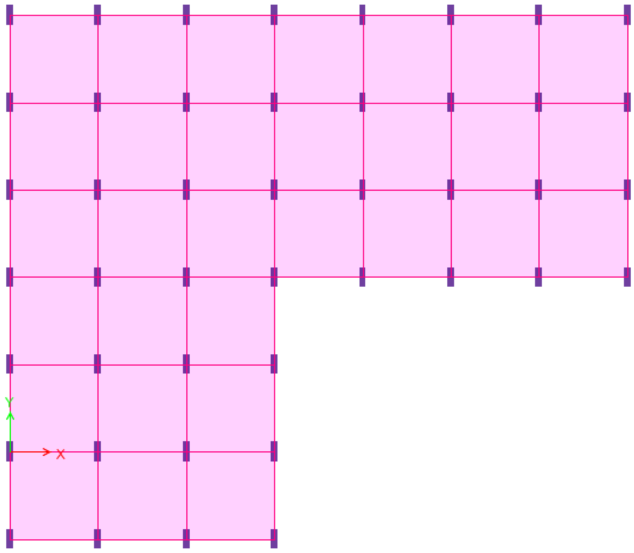

Fig- 4: Model 3: L Shaped

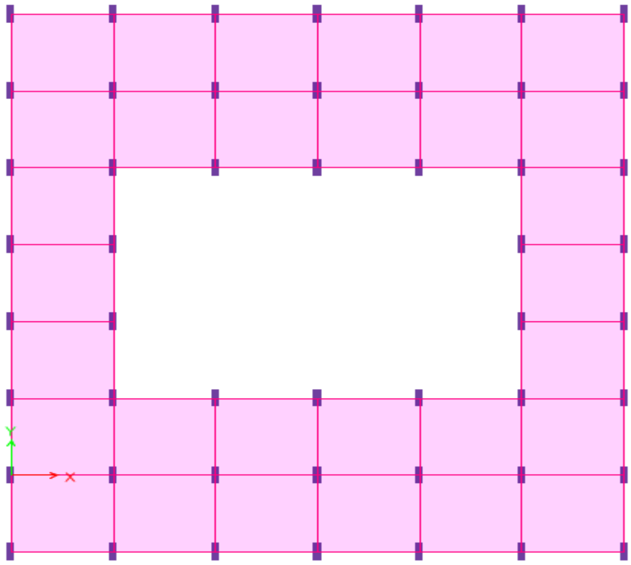

Fig- 5: Model 4: Rectangle with Opening

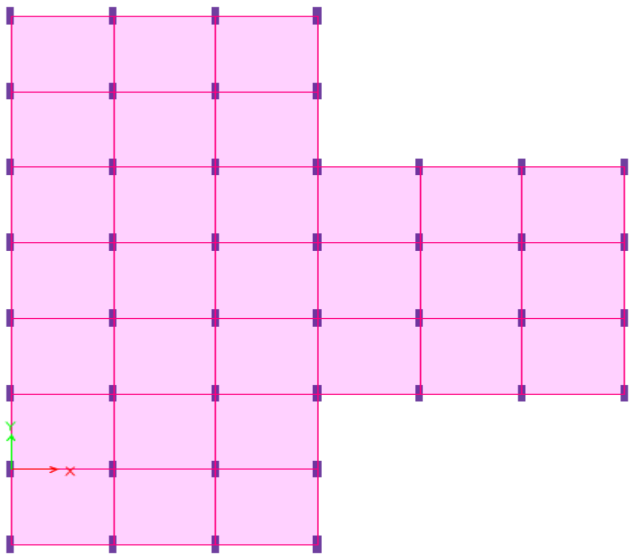

Fig- 6: Model 5: T Shaped

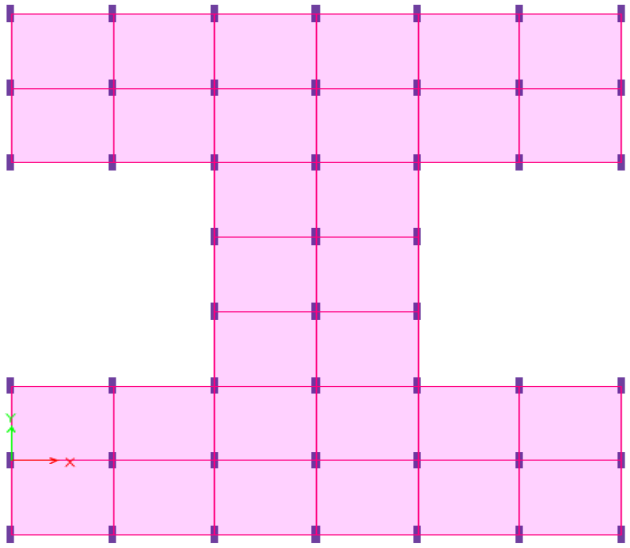

Fig- 7: Model 6(I Shaped)

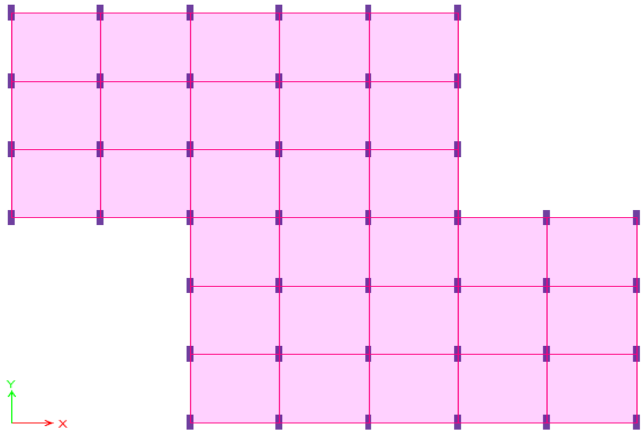

Fig - 8: Model 7(Z Shaped)

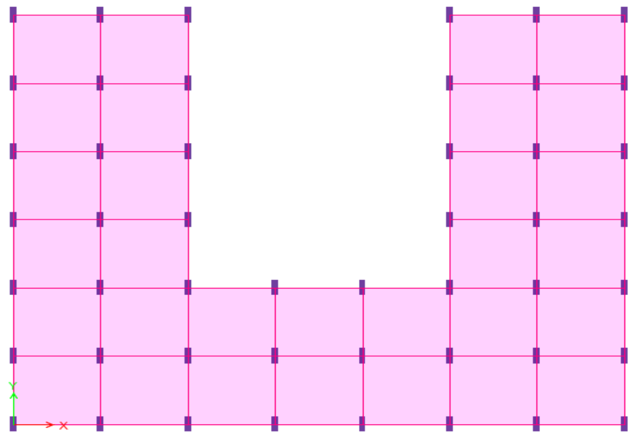

Fig- 9: Model 8(U Shaped)

3.3 Analysis Of The Building

As the structural models are created, the seismic forces that will be induced on the building can be determined by adopting various analysis techniques, whose degree of accuracy and the type of analytical approach vary. A building could be analyzed during linear methods and non linear methods. In the current research linear methods of analyses are adopted. The two linear methods namely equivalent lateral force method and response spectrum methods is briefly explained as below:

a) Equivalent static method of analysis:
In this the analysis will be based on the assumption that the lateral (horizontal) force acting on the building is equivalent to the dynamic force. The method is conservative and useful for analyzing simple symmetric building. The base shear that would be calculated using code provisions will be distributed along the building height. The analysis can be performed by defining parameters like fundamental time period of vibration, soil conditions, mode shape for the time period chosen and factors necessary for determining the horizontal seismic coefficient using clause 6.4 of IS 1893 (Part 1): 2002.

b) Response spectrum methods of analysis:
If the building is assumed to be affected by time period apart from fundamental time period then response spectrum methods are adopted. The response spectra will be used which is given in clause 6.4.5 of IS 1893 (Part 1): 2002 which depends on the three different soil sites. This method is recommended for irregular buildings which are framed and the height is greater than 12m in seismic zones IV and V. Apart from the parameters mentioned in equivalent static method, the other parameter to be determined is the modes determined by performing a modal analysis. The number of modes is selected based on clause 7.8.4.3 of IS 1893 (Part 1): 2002. After this is established the peak response would be computed using Square Root of Some of Squares (SRSS) Sum of Absolute of Modal Response Values (ABS) and the Complete Quadratic Combination (CQC). Once the methods are applied the base shear (V_{BR}) obtained from Response spectrum methods need to be scaled in accordance with the once determined using Equivalent static method (V_{EQ}) as the building asymmetry governs the scaling factor (V_{EQ} / V_{BR}) so obtained.

4. SEISMIC WEIGHT

The seismic weight of the whole building is the sum of the seismic weights of all the floors. The seismic weight of each floor is its full dead load plus appropriate amount of imposed live load.

5. MODESHAPES AND MODAL PARTICIPATION MASS FACTORS

When the inertia forces are induced on a building caused by synchronous harmonic motion, they get balanced by the restoring forces within the building. The structural configurations developed for such a process results in mode shapes or Eigen vector which is determined as a non-trivial solution for a Eigen value problem in MDOF systems.

The modal participation mass factor of a mode of vibration is the amount by which that particular mode contributes to the overall vibration of the structure under horizontal and vertical earthquake ground motions as defined by code [6]. The values of modal participation mass factors obtained for a building using dynamic analysis procedures will be used to determine the modal mass which is significant in determining the number of modes to be used in analysis of the building as given in clause 7.8.4.2 of IS 1893 (Part 1): 2002. This criterion will be checked in the research.

6. VALIDATION

To check the authenticity of ETABS analyzed models, model 1 will be validated by calculating the base shear using code provisions and then compared with ETABS generated values. If the values comply with one another, then the ETABS models will be validated. From the calculations it is concluded that $V_{B(IS)} \approx V_{B(ETABS)}$, thus validating the ETABS analyzed model, where the values for

1. Design seismic base shear, $V_{B(IS)}$ = Ah*W= 2673.544 KN.
2. Seismic base shear from static analysis using ETABS: $V_{B(ETABS)}$ = 2639 KN.

7. RESULTS AND DISCUSSIONS

7.1 Fundamental Time Period

It is the first longest modal time period of un-damped free vibration for a structure. Fundamental time period obtained from ETABS analysis and from code provisions are listed in Table.

Table- 5: Fundamental Time Period for different Cases

Models	Time period (s)					
	Program calculated (T1)		without infill (T2)		with infill (T3)	
	X	Y	X	Y	X	Y
M1	3.45	3.45	1.389	1.389	0.9	0.98
M2	3.46	2.13	1.389	1.389	0.9	0.735
M3	3.46	2.1	1.389	1.389	0.83	0.9
M4	3.49	2.14	1.389	1.389	0.9	0.83
M5	3.45	2.1	1.389	1.389	0.9	0.83
M6	3.49	2.1	1.389	1.389	0.9	0.83
M7	3.896	2.83	1.389	1.389	0.83	0.9
M8	3.47	2.14	1.389	1.389	0.83	0.9

7.2 Base Shear

Base shear is the total design lateral force along any principal direction of a structure. This is the maximum lateral force which occurs at the base of a structure.

Table-6: Base shear for Response Spectrum Analysis after applying Scale Factors

Base Shear (KN)						
Model	RSX-T1	RSY-T1	RSX-T2	RSY-T2	RSX-T3	RSY-T3
M1	1214	1557	2633	2642	4073	3734
M2	1244	1690	2742	2744	4262	5191
M3	1242	1610	2691	2691	4485	4136
M4	1340	1731	2867	2875	4430	4788
M5	1230	1502	2688	2574	4157	4290
M6	1324	1633	2795	2799	4316	4666
M7	1244	1585	2696	2686	4493	4154
M8	1263	1712	2806	2799	4664	4319

7.3 Modal Participation mass Factor

The mass participation factors in the translational direction X and Y and in rotational direction.

Table-7: Modal participation mass factor (sum of 20 modes)

Modal participation mass factor % (sum of 20 modes)			
Model	**Sum RX**	**Sum RY**	**Sum RZ**
M1	92.1	96.01	98.25
M2	92	95.91	98.25
M3	92	95.9	98.23
M4	91.8	95.8	98.27
M5	92.05	95.9	98.24
M6	91.8	95.8	98.25
M7	92	95.9	98.23
M8	92.9	95.8	98.23

7.4 Rotational Frequency

Since the Modal participation mass factor are similar for T1, T2 and T3, the rotational frequencies corresponding to T2 are only listed for the 20 modes considered. Rotational frequencies as obtained from ETABS for 20 modes are listed in table.

Table- 8: Rotational Frequency (Hz)

Mode	Rotational Frequency (Hz)							
	M1	M2	M3	M4	M5	M6	M7	M8
1	2.1	2.0	2.1	2.1	2.1	2.1	2.1	2.0
2	2.7	2.4	2.6	2.6	2.6	2.5	2.6	2.7
3	2.7	2.8	2.7	2.7	2.7	2.6	2.7	2.8
4	6.3	6.2	6.3	6.4	6.3	6.5	6.3	6.2
5	8.4	7.5	8.1	8.1	8.0	7.6	8.1	8.4
6	8.4	8.7	8.5	8.6	8.6	8.3	8.4	8.7
7	10.8	10.8	10.9	11.1	10.8	11.1	10.9	10.8
8	14.8	13.3	14.5	14.2	14.1	13.5	14.3	14.9
9	15.2	15.5	15.4	15.7	15.5	15.3	15.3	15.6
10	15.5	15.7	15.6	15.9	15.5	16.0	15.6	15.8
11	20.5	19.7	20.6	21.0	20.5	20.1	20.6	20.6
12	22.2	20.4	21.9	21.0	21.1	21.1	21.4	22.4
13	23.	24.	23.	24.	23.	23.	23.	24.

	2	0	4	0	6	5	4	1
14	25.6	25.7	25.9	26.3	25.7	26.4	25.9	25.9
15	30.7	27.0	30.4	28.9	29.1	27.6	29.7	31.0
16	31.1	31.2	31.3	32.0	31.1	32.0	31.3	31.4
17	32.8	33.8	33.1	33.9	33.3	33.4	33.1	34.1
18	36.7	35.3	37.0	37.8	36.8	36.2	37.1	37.3
19	40.6	36.9	40.3	37.9	38.3	37.9	39.2	41.1
20	42.5	42.9	42.9	43.9	42.7	43.9	42.9	43.3

7.5 Storey Drift

The displacement of one level relative to the other level above or below in a building is called storey drift. This drift is restricted by code to be below 0.004 times the storey height as given in clause 7.11 of IS 1893 (Part 1): 2002. The storey drift in X and Y directions are given in Table.

Table-9: Drift (m) for Time Period T1, T2, and T3 in X direction

Drift (m) for Time Period T1, T2, T3 in X direction				
Model	T1	T2	T3	0.004H (H=4m)
M1	0.00134	0.002905	0.004494	0.016
M2	0.00132	0.002908	0.004492	0.016
M3	0.00136	0.002945	0.004909	0.016
M4	0.00129	0.002759	0.004267	0.016
M5	0.00133	0.002906	0.004491	0.016
M6	0.00130	0.002742	0.004239	0.016
M7	0.00133	0.002866	0.004779	0.016
M8	0.00135	0.002986	0.004976	0.016

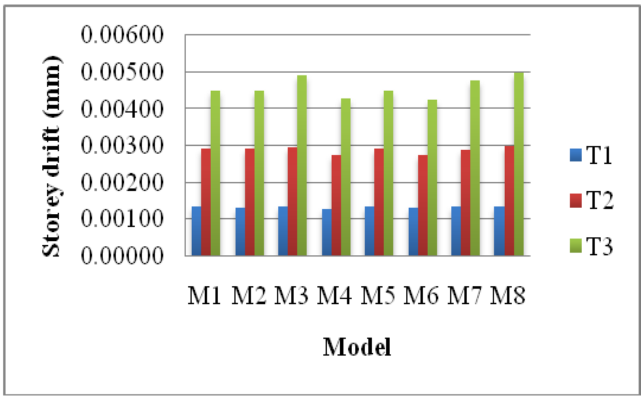

Chart-1: Maximum Storey Drift in X direction

Table- 10: Drift (m) for Time Period T1, T2, T3 in Y direction

Drift (m) for Time Period T1, T2, T3 in Y direction				
Model	T1	T2	T3	0.004H (H= 49m)
M1	0.00081	0.00138	0.00195	0.016
M2	0.00079	0.00128	0.00242	0.016
M3	0.00127	0.00210	0.00323	0.016
M4	0.00079	0.00131	0.00219	0.016
M5	0.00104	0.00171	0.00285	0.016
M6	0.00081	0.00138	0.00231	0.016
M7	0.00080	0.00137	0.00211	0.016
M8	0.00078	0.00128	0.00197	0.016

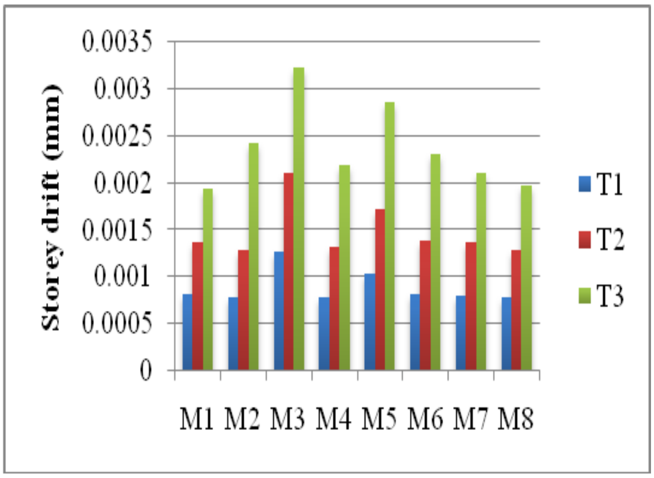

Chart- 2: Storey Drift (m) for Time Period T1, T2, T3 in Y direction

7.6 Lateral Displacement

The Lateral Displacement for X and Y directions are given in tables.

Table-11: Displacement for Time Period T1, T2, T3 in X Direction

Displacement (mm) for various time period in X direction			
Model	T1	T2	T3
M1	34.8	75.6	116.9
M2	35.8	79.1	122.1
M3	36.8	79.7	132.8
M4	34.6	74.1	114.6
M5	35.4	77.3	119.5
M6	34.2	72.1	111.5
M7	34.7	75.1	125.3
M8	39	86.5	144.2

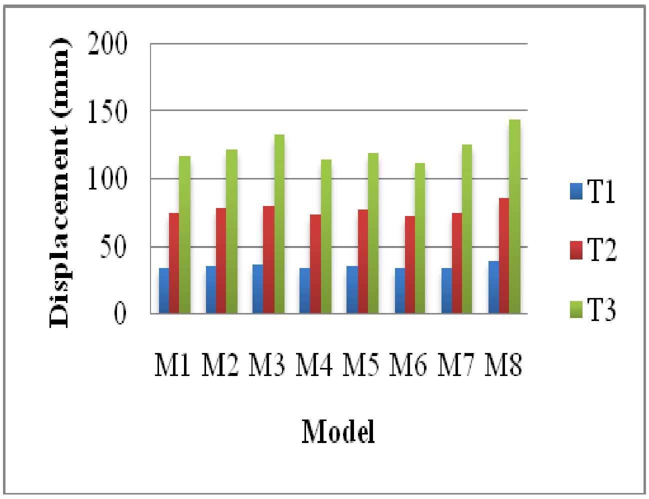

Chart-3:Maximum Lateral Displacement in X Direction

Table-12: Displacement for Time Period T1, T2, T3 in Y Direction

displacement (mm) for various time period in Y direction			
Model	T1	T2	T3
M1	28.2	47.8	67.6
M2	27	43.9	83.1
M3	42.7	70.9	109
M4	27.7	46.1	76.8
M5	35.2	58.1	96.8
M6	28.8	49.4	82.3
M7	28.1	47.7	73.6
M8	27	44.3	68.2

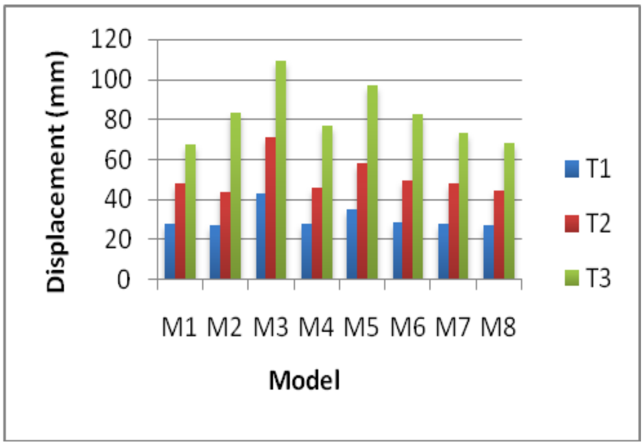

Chart-4:Maximum Lateral Displacement in Y Direction

COMPARATIVE STUDY

- Time period T2 is around 1.5 times greater than T3 while T1 is around 4 timesgreater in X direction than T3 and around 2.5 times greater in Y direction.
- For T1, base shear of M5 is 1.3% more in X direction and 3.53% less in Ydirection compared to M1. For M4 the base shear is increasing by 10.37% in X direction and 11.17% in Y direction as compared to M1.
- For T2, base shear of M5 is 2.1% more in X direction and 2.58% less in Ydirection compared to M1. For M4 the base shear is increasing by 8.8% bothin X and Y directions as compared to M1.
- For T3, base shear of M5 is 2% more in X direction but in Y direction base shear of M3 and M5 is 10.76% and 14.89% more respectively compared to M1.
- Modal participation mass factor for all the models are greater than 90%in translational direction and rotational direction. The values are similar for all models; translational X has approximately 92%, translational Y has approximately 96%, rotational direction has approximately 98%.The frequency is beyond 33Hz for modes above 18.
- M4 has the least storey drift in X direction compared to all the other models. However the drifts of all the models are well within permissible limits.
- M8 has the least storey drift in Y direction compared to all the other models. However the drifts of all the models are well within permissible limits.
- For all the three cases of time periods i.e. T1, T2 and T3, the lateral displacement of M6 is found to be lesser by 1.75%, 4.85% and 4.84% respectively than M1 in X direction.
- M8 has the highest value of lateral displacement in X direction by 10.7%, 12.6%and 18.9% respectively for T1, T2 and T3.
- On the contrary, M8 is having least value of lateral displacement in Y direction.
- For all the three cases of time periods i.e. T1, T2 and T3, the lateral displacement of M3 is found to be higher by 33.95%, 32.5% and 38% respectively than M1 in Y direction.

CONCLUSIONS

The seismic analyses of eight models with varying plan configurations are performed using the aid of ETABS. The models are analysed by Equivalent static method and response spectrum methods. After the analysis and interpretation of results in the form of base shear, mass participation factor, frequency, drift and lateral displacement, the conclusions extracted are:

[1]. From the results it is evident that equivalent static method gives a higher base shear when compared to response spectrum method.
[2]. Even though the surface area of the building plan configuration is kept constant in each floor, the base shear is not same in any of the buildings as the seismic weight varies with change in building plan configuration.
[3]. From the studies it is again observed that there is huge variation in program calculated time period and the time period calculated using IS 1893 (Part 1):2002, once again emphasising that more clarity is required in calculating the time period for buildings with different plan configuration.
[4]. The base shear in T shaped building was least among all the models and the base shear obtained for rectangular shaped with opening was having the highest.
[5]. The buildings; rectangular shape with opening and I shaped, performs consistently better than buildings with L shape and T shape.

[6]. From the above points it can be arrived at a broader conclusion that buildings with plan configuration which are symmetrical in both X and Y directions perform better than plan configuration which are unsymmetrical in one or both directions.

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