Torsional and Seismic Behavior of Shear Wall Dominant Flat Plate Buildings

Ramya S R[1], Dr. P M Ravindra[2]

[1]M. Tech Student, Department of Civil Engineering, Bangalore Institute of Technology, Bengaluru- 560004, India.
[2]Professor & P G Co-Ordinator, Department of Civil Engineering, Bangalore Institute of Technology, Bengaluru- 560004, India.

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Abstract - *In modern construction due to various types of functional and architectural requirements asymmetric building structures are almost unavoidable. Investigations are carried out for three types of plan irregular structures created by asymmetrical varying shear wall positions, and varying aspect ratio of plan area. These structural forms are analyzed by equivalent static analysis and time history analysis. Parameters such as torsional irregularity coefficient, time period, torsional amplification factor, spectral acceleration and displacement are derived in the form of results. It is observed that positioning of shear walls with respect to geometric centroid of the plan affects both torsional and seismic behavior.*

Key Words: **Flat Plate, Torsional Irregularity, Torsional Amplification factor, Shear Wall, Aspect Ratio, Geometric Centroid.**

1. INTRODUCTION

Based on the data of previous seismic activity, seismic damage examinations and studies are carried on various modes of failure of buildings and determined that most vulnerable structures are those, which exhibits asymmetric nature. Therefore, seismic performance of asymmetric building structures has become a subject of worldwide research since last two decades. To discover the cause of seismic vulnerability of asymmetric structures various researches have been carried out on elastic and inelastic seismic behavior of asymmetric systems. A large number of studies exists which investigate torsional behavior and shear wall structures (Francisco Crisafulli et al. 2004; Ali Demir et al. 2010) and flat slab structures (Kavish Patwari et al. 2016; Gagankrishna R R et al. 2015).

Eccentricity between center of mass and center of rigidity in asymmetric building structures has resulted in lateral-torsional coupling which produces torsional vibration even under purely translational ground motion. During seismic movement of the structural systems, inertia force acts through the center of mass while the resistive force acts through the center of rigidity as shown in Fig -1. Torsional vibration of the structure in addition to the lateral vibration is caused due to non-concurrency of lines of action of the inertia force and the resistive force which produces a time varying twisting moment.

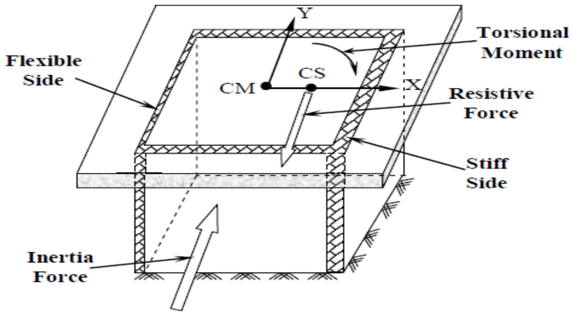

Fig -1: Torsional moment generation in asymmetrical structures under the action of seismic force

1.1 Torsional irregularity coefficient:

Torsional irregularity (TI) is one such horizontal irregularity which has to be taken care while designing a structure. A building is certified to be stable during its design process by inspecting the entire structure for both vertical and horizontal irregularities which is mentioned according to various international codes. When the earthquake forces occurred in X-direction then the total drift will be more in the opposite ends of the structure and in Y-direction also the total drift will be more in the opposite directions. Torsional irregularity depends on a number of factors which include positions of structural members, plan geometry, dimensions of members and number of story.

AS PER INDIAN STANDARDS IS-1893:2002 (PART 1)

- Building with $\Delta_{max}/\ \Delta_{avg} \geq 1.2$ are termed as torsional irregular coefficient as per IS 1893:2002.

  Where, $\Delta_{max}=\Delta_2$ is the maximum drift of the floor produced by the earthquake forces, and $\Delta_{avg}=(\Delta_1+\Delta_2)/2$ is the average of the drift of the extreme points of the structure.

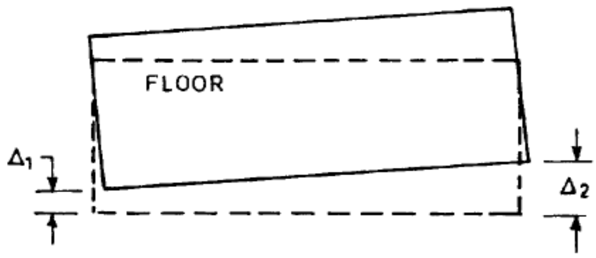

Fig - 2: Showing Δ_{max} and Δ_{min} in asymmetric building

1.2 Amplification factor :

As per the provisions of ASCE 7-10 in Clause 12.8.4.3 of the code, the accidental lateral load eccentricities of ±5 % are amplified by the factor known as torsional amplification factor (A_t).

$$A_t = \left(\frac{\Delta max}{1.2 * \Delta avg}\right)^2$$

The torsional amplification factor (A_t) shall not be less than 1 and is not required to exceed 3.0. These provisions may be expressed as follows:

a) If TI ≤ 1.2, then torsional irregularity does not exist, i.e., A_t = 1.

b) If 1.2< TI <2.083 then torsional irregularity exists and eccentricity amplification factor is computed as per above formula.

C) If TI >2.083 then, TI=2.083 and A_t=3.

2. OBJECTIVE OF THE WORK

The main objectives of the work are as follows:

1. To determine the effect and role of eccentrically placed shear wall on torsional and seismic response of the building.
2. To identify the influence of aspect ratio on building plan on seismic performance of the structure.
3. To evaluate seismic response parameters such as time period, base shear, and storey drifts.
4. To study the structural response of buildings for torsional irregularities coefficient as per IS 1893(Part-I):2002.
5. Torsional amplification factor is found for torsional irregular building as per provision of ASCE 7-10.

3. STRUCTURAL MODEL

Three different models are considered by varying plan aspect ratio and also by asymmetrical positioning of shear walls in plan. ETABS 2016 ver. 16.0.2 software is used for modeling and analysis is carried out by equivalent static method and time history analysis. Model contains panel size of 6 m X 6 m and 15 storeys with storey height of 2.8 m typical and 4.4 m at base, column dimension of 450 mm X 450 mm, slab 230 mm and shear wall dimension 300 mm is considered. All the models are RC frame structures with grade of concrete considered to be M25 and grade of steel is Fe500 grade.

Table -1: Data of 3D model

Sl. No	PROPERTY	DESCRIPTION
1	Structure	Flat-plate reinforced concrete building
2	Number of stories	15
3	Number of bays	4,4 (X,Y directions, Aspect ratio 1:1) 5,4 (X,Y directions, Aspect ratio 1:1.25) 6,4 (X,Y directions, Aspect ratio 1:1.50)
4	Dimension of panel	6m X 6m
5	Story height	2.8m & 4.4m @ base
6	Column section	0.45m X0.45m
7	Thickness of Shear Wall	300 mm
8	Thickness of Slab	230 mm
9	Column Support condition	Fixed at bottom

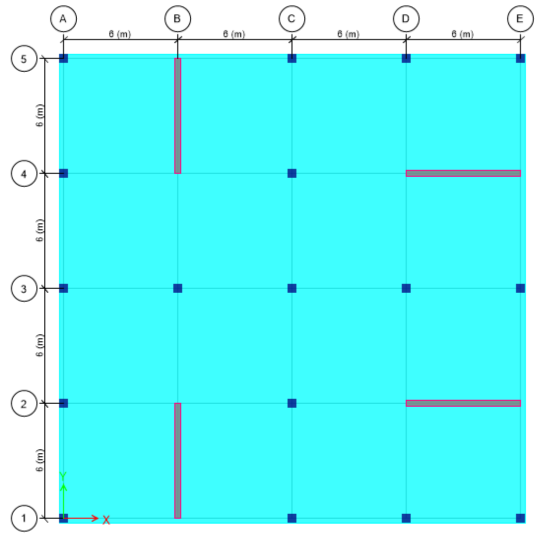

Fig – 3: Asymmetrically placed shear walls in square plan with aspect ratio 1:1.

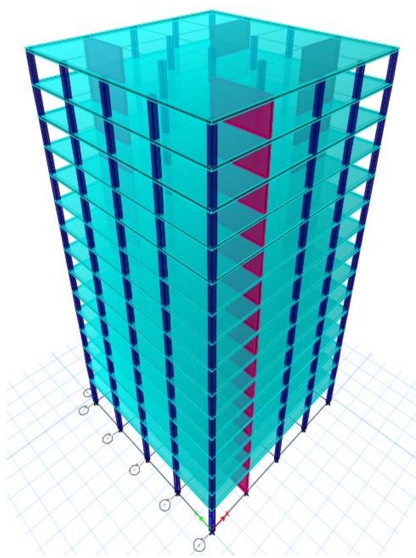

Fig – 4: 3D view of asymmetrically placed shear walls with aspect ratio 1:1.

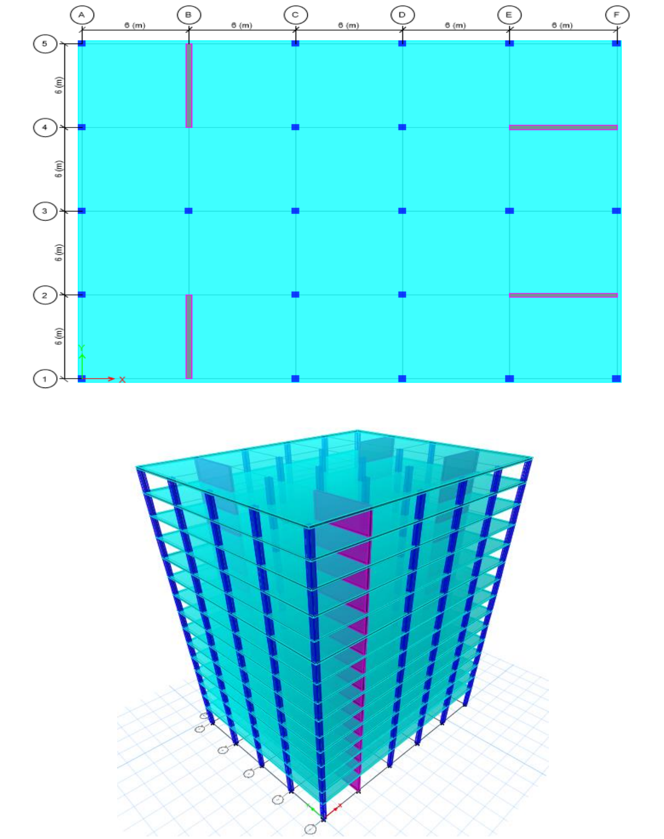

Fig – 5: Asymmetrically placed shear walls in rectangular plan and 3D view with aspect ratio 1:1.25

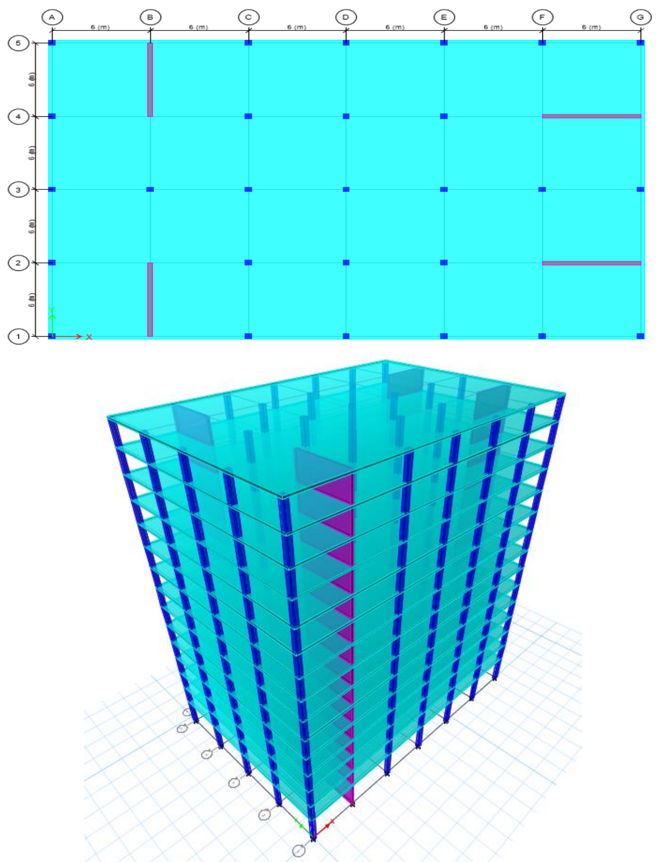

Fig – 6: Asymmetrically placed shear walls in rectangular plan and 3D view with aspect ratio 1:1.50

3.1 Load Calculation

Types of loads considered in analysis of structures are as follows:

i. **Dead load**
Self-weight of the structure is calculated by multiplying volume of the section with the density of material.

ii. **Super dead load**
Floor finishes: 1 kN/m^2
Live load: 3 kN/m^2 (IS: 875 (Part II)-1987)

iii. **Earthquake forces**
Lateral load consists of earth quake load in X and Y directions as per the IS: 1893(Part III)-2002.

iv. **Percentage of Imposed load for seismic weight**
Percentage of imposed load considered is taken as per Table 8 of IS 1893 (Part I):2002. In addition to dead load, 25% of imposed load is considered for analysis if uniformly distributed load intensity is 3 kN/m^2 or less and 50% if imposed load is more than 3kN/m^2.

Table -2: Earthquake Load Parameters

Sl No.	PROPERTY	DESCRIPTION
1	Zone, zone factor Z	IV, 0.24
2	Importance factor, I	1
3	Soil type	Medium
4	Response reduction factor, R	5
5	Percentage of imposed load considered during seismic load calculation	50%
6	Damping ratio	0.05
7	Eccentric ratio	0.05
8	Number of modes	15
9	Method of Analysis	Equivalent static & Time history analysis

4. ANALYSIS

In this research work, static and dynamic analysis is carried out by Equivalent static and linear response time history analysis respectively.

Equivalent static analysis: It is a simplified approach to substitute the effect of dynamic loading of an expected earthquake by a static force distributed laterally on a structure for design purpose. Structural design over earthquake or wind forces must consider the dynamic nature of the forces, however, for regular structures and simple structures, analysis are done by equivalent linear static methods are common. Equivalent linear static method is permitted in codes for low- to medium-rise, regular buildings.

Dynamic Time History Analysis: Time-history analysis is carried out for linear or nonlinear evaluation of dynamic structural response under loading which may vary according to the specified time function. Dynamic equilibrium equations are solved using either modal or direct-integration methods. Initial conditions may be set by continuing the structural state from the end of the previous analysis. Present study is carried out on time history data of ELCENTRO (Fig. 7) earthquake. The following specifications are considered as per ELCENTRO earthquake:

Location: "Imperial Valley"
Date: 19th May 1940
Time: 4:39 am
Station: "El Centro Array #9"
Direction: Horizontal, 180°
Units of acceleration: g= 9.81 m/s^2 (acceleration due to gravity)
Number of time instants: 4,000
Sampling time: Δt= 0.01 s (f= 100 Hz)

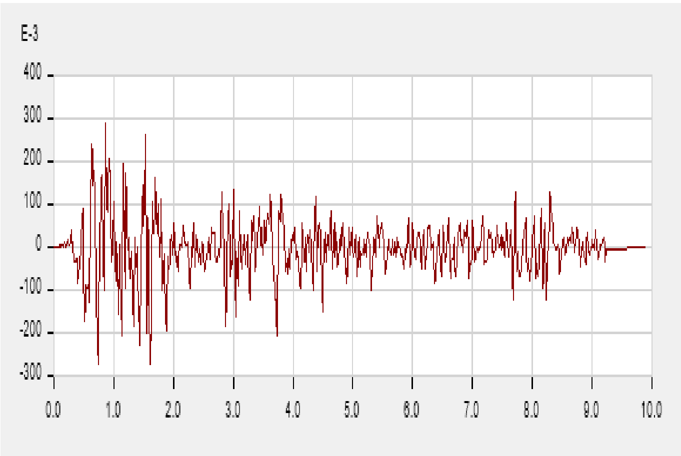

Fig - 7: Time History Input – El-Centro

5. RESULTS

5.1 Time period:

Results obtained from equivalent static analysis are plotted in Chart-1, and it is seen that fundamental period is more for plan with aspect ratio 1:1.50 model and it is less in case of aspect ratio 1:1 model. The fundamental period for 1:1.25 has the intermediate value. Same pattern of higher value of time period is observed in aspect ratio 1:1.50 model for all other modes. Due to increase in aspect ratio the distance between centre of mass and stiffness also increases, which implies that the structure with higher period of vibration have low resistance to seismic action.

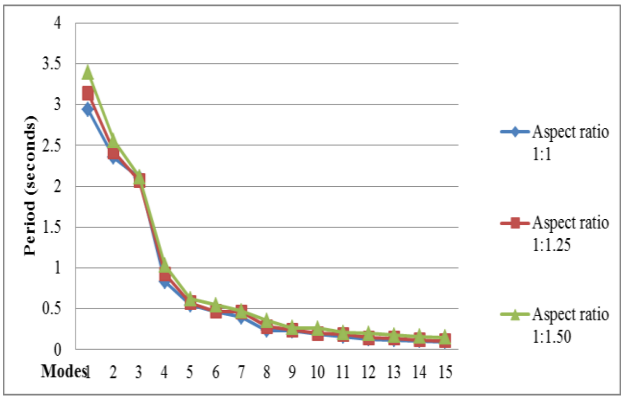

Chart -1: Mode numbers versus natural period of vibration for different aspect ratio

5.2 Torsional Irregularity Co- efficient:

Findings from equivalent static analysis is presented in Table -3 and Chart -2, it is inferred that as aspect ratio increases the torsional irregularity also increases. All three cases of aspect ratio indicate that considered models are torsional irregular since TI coefficient value exceeds 1.2. Higher value is seen in with plan aspect ratio 1:1.50. Lower TI value is observed in model with aspect ratio 1:1. Table -3 indicates that maximum torsional irregularity is seen in lower storey i.e., Storey1. Also it is perceived from analysis that greater value of TI is found in Y direction since the placement of shear wall along Y-axis is asymmetrical.

Table -3: Variation in Maximum to average drift ratio for models with varying aspect ratio.

Aspect Ratio	Storey no.	Max Drift (mm)	Average Drift (mm)	TI= Max Drift / Avg.Drift
1:1	1	0.000682	0.00053	1.285
1:1.25	1	0.002078	0.001014	2.049
1:1.50	1	0.002626	0.001306	2.098

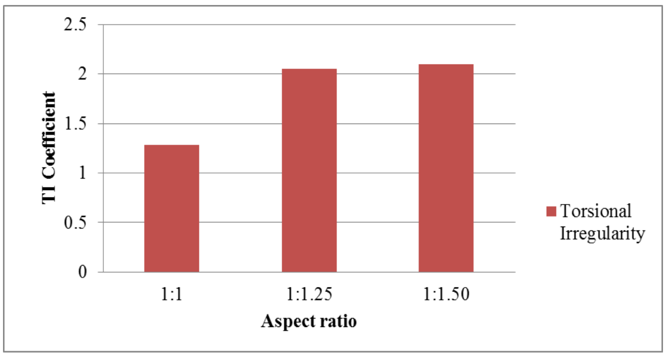

Chart -2: Torsional Irregularity (TI) Coefficient for varying aspect ratio.

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5.3 Torsional Amplification Factor:

Outcomes from equivalent static analysis is shown in Table -4 and Chart -3, it seen that in model for aspect ratio 1:1.50, TI > 2.083 then, therefore A_t=3.00 and it is highest when compared to other two models. Torsional amplification factor value is least for aspect ratio 1:1 model and increases as aspect ratio increases. Torsional irregularity coefficient in the range, 1.2< TI <2.083 for models with aspect ratio 1:1 and 1:.25, hence the value of A_t is calculated as per the formula. It is seen as eccentricity distance increases amplification of accidental torsion also increases.

Table -4: Torsional amplification factor, A_t for model with varying aspect ratio.

Aspect Ratio	Storey no.	$TI=\frac{Max\ Drift}{Avg.Drift}$	Torsional Amplification Factor, A_t
1:1	1	1.285	1.15
1:1.25	1	2.049	2.92
1:1.50	1	2.098	3.00

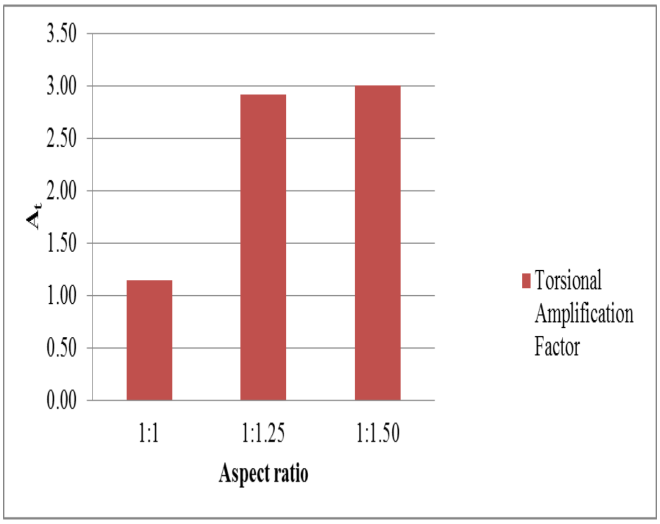

Chart -3: Torsional Amplification factor, A_t for varying aspect ratio

5.4 Base Shear

Results obtained from equivalent static analysis are mentioned in Table -5 and Chart-4, it is observed that, the decrease in base shear was nearly 26.2%, and 15.7% in model with aspect ratio 1:1 and 1:1.25 compared to model with aspect ratio 1:1.50. This indicates that as aspect ratio increases the base shear also increases and thus it is inferred that as shear walls are placed nearer, results in base shear value increases.

Table -5: Maximum base shear values for three models with varying aspect ratio.

Aspect Ratio	Base Shear (kN)
1:1	3610.30
1:1.25	4125.08
1:1.50	4892.62

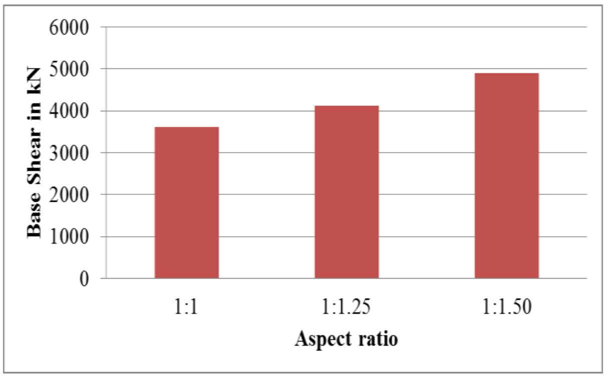

Chart -4: Maximum base shear values for varying aspect ratio.

5.5 Peak Acceleration

Results obtained from time history analysis is represented in Table-6, and Chart - 5, 6 and 7. Maximum peak acceleration is seen for model with aspect 1:1.25 in Y direction, and least value is observed in case of model with aspect ratio 1:1.50 along Y direction.

Table -6: Peak acceleration values

Aspect Ratio	Peak Acceleration (m/s^2)
	Y Dir.
1:1	4.30
1:1.25	8.865
1:1.50	3.80

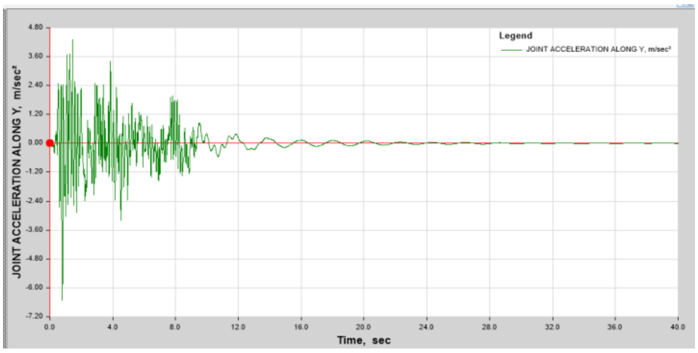

Chart -5: Acceleration v/s Time along Y- direction for aspect ratio 1:1

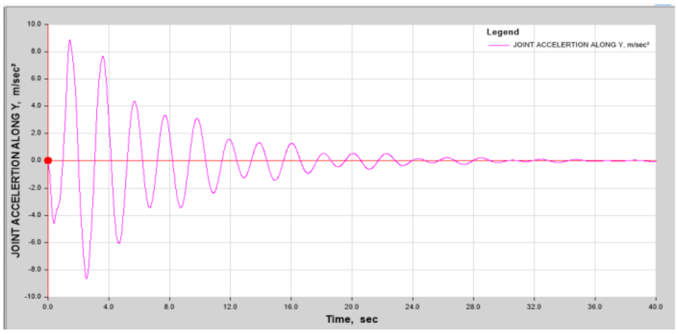

Chart -6: Acceleration v/s Time along Y- direction for aspect ratio 1:1.25

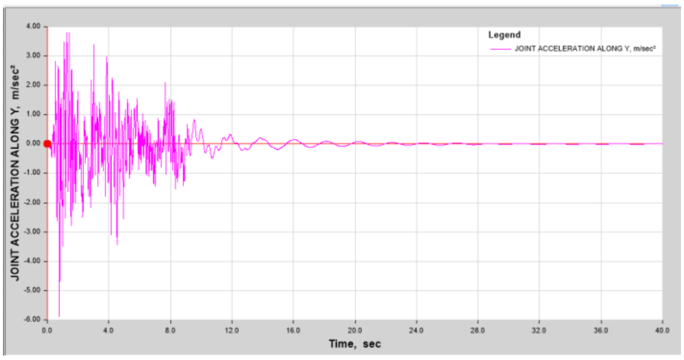

Chart -7: Acceleration v/s Time along Y- direction for aspect ratio 1:1.50

6.6 Peak Displacement

Outcomes from time history analysis are shown in Table -7, Chart -8, 9, 10, it is seen that higher value of peak displacement is seen for aspect ratio 1:1.50. Least value is observed in case of model with aspect ratio 1:1. Peak value of displacement occurred as aspect ratio increases.

Table -7: Peak displacement values

Aspect Ratio	Peak displacement (mm)
1:1	89.44
1:1.25	90.22
1:1.50	93.44

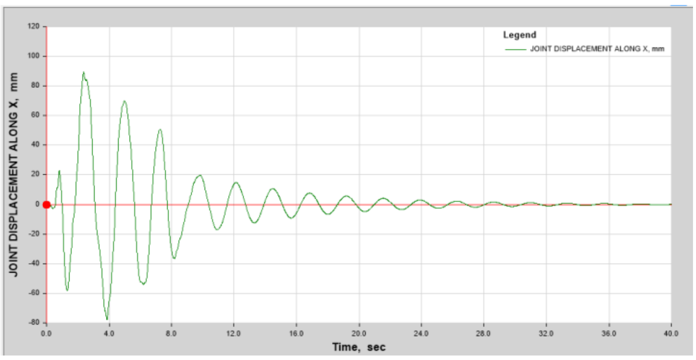

Chart -8: Displacement v/s Time for model with aspect ratio 1:1

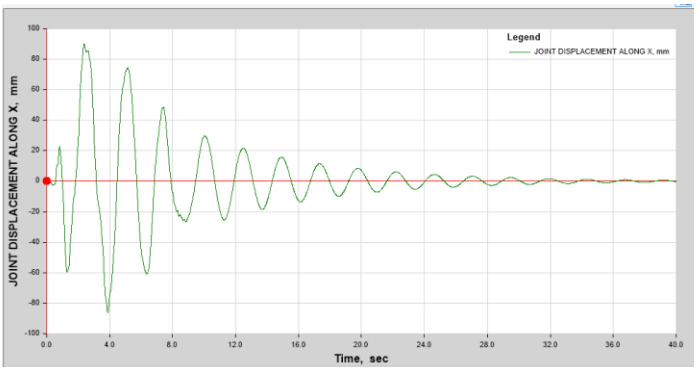

Chart -9: Displacement v/s Time for model with aspect ratio 1:1.25

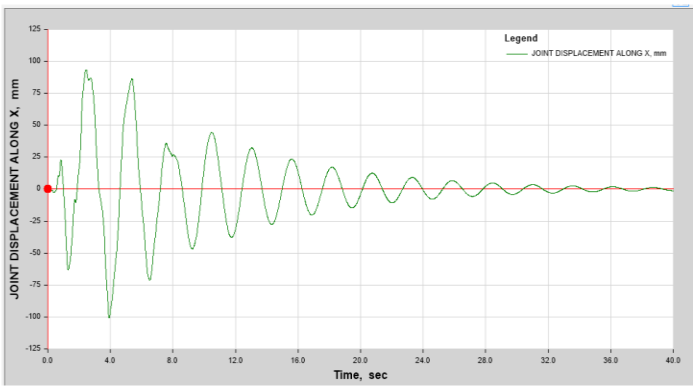

Chart -10: Displacement v/s Time for model with aspect ratio 1:1.50

6. CONCLUSIONS

From the analysis following conclusions are condensed:

- Due to increase in aspect ratio the distance between centre of mass and stiffness also increases, thus torsional irregularity coefficients reaches maximum value as aspect ratio increases.
- It is found that fundamental period of building is increased when the shear walls are placed relatively far from the geometric centroid of the plan.
- Torsional irregularity coefficients are found to increase as the story numbers decrease, i.e., maximum torsional irregularity coefficients occur for single story structures.
- Peak value of acceleration was found at shorter intervals, and it is also noted that peak value of acceleration and displacement occurred as aspect ratio increases.

7. SCOPE FOR FUTURE WORK

- There is a scope for analysing the building models with bi-directional eccentricity subjected to ground motion.
- Soil-structure interaction can be carried out for both mass and stiffness eccentric buildings.
- Analysis can be done for non- linear static push over analysis.

8. REFERENCES

[1] Kavish Patwari, L G Kalurkar, "Comparative study of flat slab building with and without shear wall to earthquake performance", International Journal of Scientific Development and Research (IJSDR), volume-1, 2016, pp. 284 – 291, issue-6, ISSN: 2455-2631.

[2] Gagankrishna R R, Nethravathi S M, "Push over of framed structure with flat plate and flat slab for different structural systems", International Journal of Innovative Research and Creative Technology, Volume 2, 2015, ISSN: 2454-5988.

[3] Francisco Crisafulli, Agustín Reboredo, Gonzalo Torrisi, "Consideration of torsional effects in the displacement control of ductile buildings", 13th World Conference on Earthquake Engineering (WCEE), Vancouver, B.C, Canada, August 1-6, 2004, pp. 1111.

[4] Ali Demir, Duygu Donmez Demir, Recep Tugrul Erdem , Muhiddin Bagc, "Torsional irregularity effects of local site classes in multiple storey structures" , IJRRAS, 2010, pp. 258 – 262.

[5] IS 1893(part-I):2002- "Criteria for Earthquake Resistant Design of Structures Part1 General Provision and Buildings" (Fifth Revision).

[6] IS: 456-2000- "Indian Standard Plain and Reinforcement Concrete Code of Practice, Bureau of Indian Standards", New Delhi (Fourth Revision).

[7] IS 875(part 1): 1987, "Indian Standard Code of practice for design loads (other than earthquake for building and structures): Dead loads, Bureau of Indian Standards", New Delhi.

[8] IS 875(part 2): 1987, "Indian Standard Code of practice for design loads (other than earthquake for building and structures): Imposed loads, Bureau of Indian Standards", New Delhi.