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Earthquake Analysis of Reinforced Concrete Buildings with Plan and Mass Asymmetry

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Abstract: Earthquakes can have a significant and often destructive effect on built structures, depending on various factors such as the building's design, construction materials, location, and the intensity of the earthquake. A structure can be classified as irregular if it contains irregular distributions of mass, stiffness, and strength or due to irregular geometrical configurations.

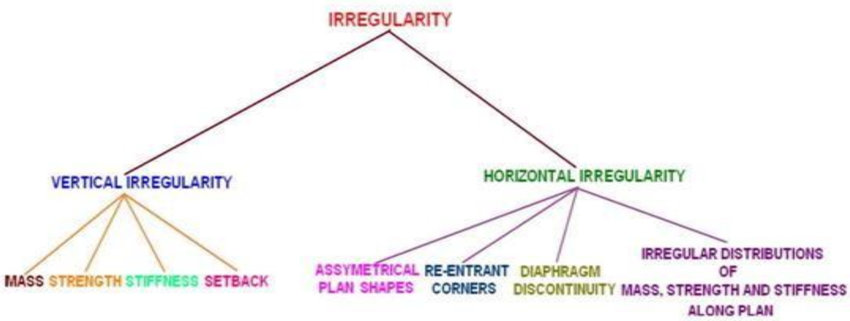
This research paper investigates the earthquake behaviour of plan and mass asymmetry reinforced concrete structures. The study is done for G+5 RC framed multi-storey building with fixed support conditions. Response spectrum analysis is performed using commercial software ETABS 2016 and IS code IS 1893:2002 (some clauses from IS 1893:2016). The storey displacement, storey drift, overturning moment, storey stiffness, natural time period, and various mode are obtained and compared to analyse the seismic behaviour of plan and mass asymmetry reinforced concrete structures. All the analyses have been carried out for various models of box, plus, C, I, L, T, and mass asymmetry with all models floor slabs as semi-rigid diaphragms and the results so obtained have been compared.

INTRODUCTION

Architects and designers should prioritize form, shape, and material of the structure, as well as functional and cost requirements, to prevent critical failures during earthquakes. Decisions made at the conceptual stage should be carefully considered due to their impact on the performance and cost of the structure. Simplicity, symmetry, ductility, and proper transfer of lateral loads to the ground are key factors in ensuring proper seismic behaviour. The overall form, regular configuration, flow of loads, and framing system are crucial in planning to avoid serious concerns. Structural engineers have more confidence in designing structures with uniform mass, stiffness, and strength. Building as a single unit enhances redundancy and integrity to better withstand earthquake forces.

Building Irregularities

- Irregularities in buildings, both vertical and plan, can lead to increased damage during earthquakes.
- Vertical irregularities result in sudden changes in strength, stiffness, geometry, and mass distribution, causing irregular forces.



- Plan irregularities involve asymmetrical shapes, cutouts, large openings, and abrupt changes, leading to torsion and stress concentration.
- Architectural preferences and population demands have led to an increase in irregular structures, requiring careful structural analysis and seismic design.
- Seismic codes address irregularities to reduce damage levels, but additional attention is needed for high-rise, asymmetric, and irregular buildings.

Reasons for Building Irregularities

- Irregularities can be caused by construction in hilly areas, modern trends in commercial complexes, and densely populated regions.
- Plan irregularities include symmetry issues, re-entrant corners, discontinuities, and nonparallel lateral load resisting systems.
- Vertical irregularities involve soft storeys, mass irregularity, vertical geometric irregularity, in-plane discontinuity, and weak storeys.
- Accidental irregularities can occur due to non-uniform construction practices and materials used.
- Buildings with irregular mass distribution can experience horizontal irregularity during earthquakes.
- Water tanks with large masses placed at corners of buildings can cause asymmetry in mass distribution and lead to twisting of the building.

Response of Structure to Earthquake Motion

Buildings respond to earthquake motion by resisting the distortions induced by the ground shaking. The response of a structure to earthquake motion is influenced by foundation properties, surrounding structures, and the characteristics of the motion. The building mass resists the ground shaking, causing the structure to undergo a complex series of oscillations.
Resonance can occur if the ground motion period is similar to the natural period of the structure. The stiffness, inertia forces, and damping characteristics of the structure affect its dynamic response. Consideration of soil structure interaction is necessary for accurate earthquake response analysis.

Dynamic Characteristics of Buildings

Buildings oscillate during earthquake shaking due to their dynamic characteristics. Natural period of a building is the time taken for one complete cycle of oscillation and depends on mass and stiffness. Buildings offer least resistance when shaken at their natural frequency.
Resonance rarely occurs in buildings due to the random and variable nature of ground motion frequencies.

Natural Period Tn of a building is the time taken by it to undergo one complete cycle of oscillation. It is an inherent property of a building controlled by its mass m and stiffness k. These three quantities are related by

$$T_n = 2\pi \sqrt{m/k}$$

Fundamental Natural Period of Building

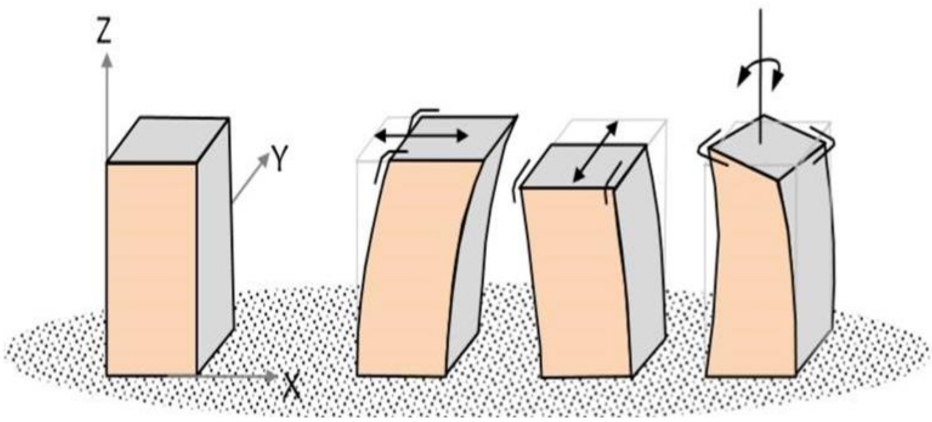
Buildings have multiple natural frequencies, with the fundamental mode having the smallest natural frequency and largest natural period. Regular buildings have three fundamental translational natural periods and one fundamental rotational natural period.

- Buildings have a finite number of natural modes of oscillation, which depend on the distribution of mass and stiffness.
- Natural periods of buildings reduce with increase in stiffness and increase with increase in mass.
- Taller buildings have larger fundamental translational natural periods.
- Buildings tend to oscillate in the directions in which they are most flexible and have larger translational natural periods.
- Natural periods of buildings depend on the spatial distribution of unreinforced masonry infill walls.

Mode Shape

Mode shape of oscillation is the deformed shape of the building when shaken at a natural period. A building has as many mode shapes as the number of natural periods. Fundamental mode shape is the deformed shape associated with the first natural period. Regular buildings have pure translational mode shapes, while irregular buildings have a mixture of pure mode shapes. The overall response of a building is the sum of the responses of its modes.

Fundamental Mode Shape of Oscillation



There are three basic modes of oscillation: pure translational along X direction, pure translational along Y direction, and pure rotation about Z axis. Irregular buildings have mode shapes that are a mixture of these pure mode shapes. Columns in buildings can be damaged under diagonal oscillations, which can be avoided by optimizing structural configuration. Design engineers need to tune the stiffness of the building to ensure fundamental modes are pure translational and torsional modes are outside a certain range. Axial stiffness of vertical elements should be high for reduced lateral deformation.

Damping

Damping is the mechanism of converting oscillatory energy to other forms. Structural damping is caused by factors like air resistance and micro cracking of concrete. Hysteretic damping arises from inelastic actions of reinforcement bars and concrete. Radiation damping occurs when the soil absorbs energy during earthquake shaking. Indian seismic codes recommend 5% damping for reinforced concrete buildings and 2% for steel structures.

Overturning Moment

Lateral forces lead to overturning moments in each level of a building. Overturning moments cause additional stresses in columns and walls, and upward or downward forces in the foundation. The calculation of overturning moments can be done by considering the building as a fixed end cantilever beam.

Seismic Design Requirements

Dead loads, live loads, and wind loads can be evaluated with accuracy, but earthquake forces are uncertain. Static lateral loading is used to determine the strength of the structure necessary to withstand dynamic loads induced by earthquakes. Uncertainties arise from factors like lack of empirical data, change in material properties during earthquakes, and soil structure interaction. Sufficient ductility is necessary for earthquake-resistant design. Design codes may need careful analysis for structures requiring high ductility.

Design Earthquake Loads

- Horizontal earthquake load: Design for full earthquake load in one horizontal direction at a time.
- Vertical earthquake load: Gravity loads factor of safety usually covers the induced vertical acceleration. Vertical force can be calculated considering vertical acceleration as two-thirds of the horizontal acceleration.

Scope of the present study

Analyses multi-storey RCC Frame structures with plan and mass irregularity ratios. Uses ETABS 2016 software for Response Spectrum Analysis. Compares various models and evaluates seismic performance for proposed building plan configurations.

LITERATURE REVIEW

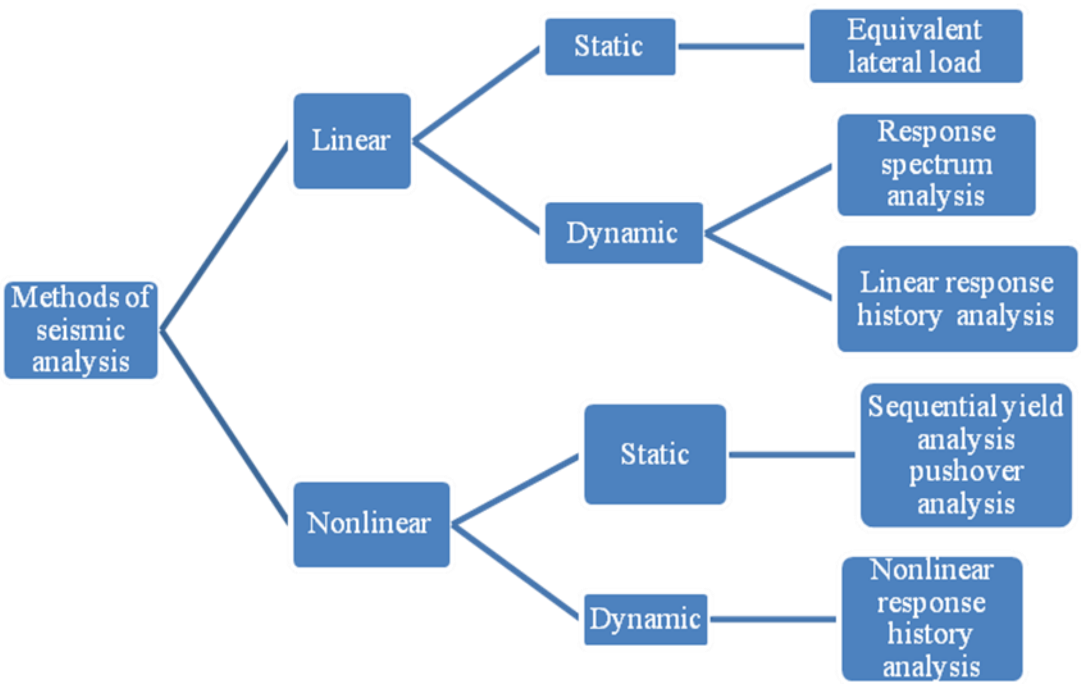
- **Balaji U & Selvarasan** [1] studied a residential building analysis for G+13 storied for earthquake loads using ETABS. Assuming that the material properties were linear, static and dynamic analysis was performed. These non-linear analyses were carried out by considering severe seismic zones and the behaviour was assessed by taking types II soil condition. Different response like displacement & base shear were calculated and it was observed that displacement increased with the building height.
- **Anirudh Gottala, shaik Yajdhani et al.** [2] studied static and dynamic analysis of G+9 multistoried building. Linear seismic analysis was done by static method (Seismic Coefficient Method) and dynamic method (Response Spectrum Method) using STAAD Pro as per the IS-1893-2002-Part-1. Parameters such as Bending moment, Axial force, Torsion, Displacement, Nodal displacement, beam and column end forces etc. were calculated.
- **Mahesh N. Patil, Yogesh N. Sonawane** [3] studied seismic analysis of 8 storey building. A 22.5mx22.5 m, 8 storey multi storey regular structure was considered for the study. Storey height was 3m. Modelling and analysis of the structure was done on 23 ETABS software. Analysis of the structure was done and then the results generated

by the software were compared with manual analysis of the structure using IS 1893:2002.

- **Mohammed Rizwan Sultan, D. Gouse Peera** [4] studied behaviour of the structure in high seismic zone and also evaluated Storey overturning moment, Storey Drift, Displacement, Design lateral forces etc. For this purpose, a 15 storey high building of four totally different shapes like Rectangular, L-shape, H-shape, and C-shape were used for comparison.
- **Mohit Sharma, Savita Maru** [5] studied static and dynamic analysis with the help of STAAD-Pro software using the parameters for design as per the IS 1893:2002 part-1for the zones-2 and 3. G+30 storied regular building was analysed. Conclusions that were made are as follows:
    - For zone 2 and zone 3, the values of torsion at different points in the beam are negative and for Dynamic Analysis the values for Torsion are positive.
    - Moments and Displacement at different points in the beam was 10 to 15% and 17 to 28% higher for Dynamic Analysis than the values obtained for Static Analysis for moment and displacement at same point.
- **S. Mahesh, B. Panduranga Rao** [6] studied residential building of (G+11) regular and irregular configuration for earthquake and wind load using ETABS and STAAD PRO V8i. Assuming the material property to be linear, static and dynamic analysis was performed. This analysis was carried out by considering different seismic zones and for each zone; the behaviour was assessed by taking three different types of soils namely Hard, Medium and Soft.

METHODOLOGY

Methods of Seismic Analysis



Details of selected building models: For the selected study purposes, the Building location is assumed in a area which come under the seismic zone III and The assumed Building will be used for important services like call centre etc. and other building Details are given below:

TABLE: Building Parameters

BUILDING PARAMETERS	DETAILS
No. of storey	G+5
Grade of concrete	M30
Grade of steel	Fe415
Height of storey (each)	3 m
Base storey Height	3 m
Base Support	Fixed
Beam size in (mm)	250x400
Column size in (mm)	350x350
Slab thickness	150mm
Type of Diaphragm	Semi Rigid
Dead load (Except self wt.)	3 kN/m
Live load	5 kN/m
Width of Bay in X & Y Dir.	4 m

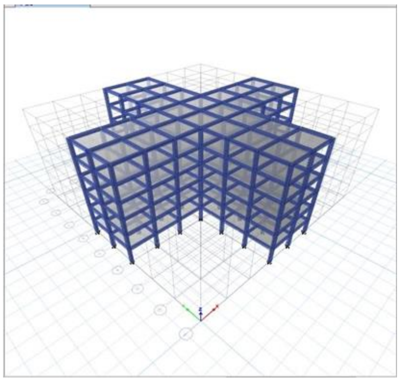
STOREY	MASS MODEL 1 (Dead load)	MASS MODEL 1 (Dead load)
Storey 6	13 kN/m	13 kN/m
Storey 5	3 kN/m	3 kN/m
Storey 4	3 kN/m	3 kN/m
Storey 3	3 kN/m	13 kN/m
Storey 2	3 kN/m	3 kN/m
Storey 1	3 kN/m	3 kN/m

Seismic Parameter	Details
Zone (Zone factor)	III (0.16)
Building Type	OMRF
Response Reduction factor	3
Importance factor	1.5
live load Reduction factor	0.5
Type of soil	Medium (Type 2)
Damping	5%
Code Use	IS1893:2002 or 1893:2016

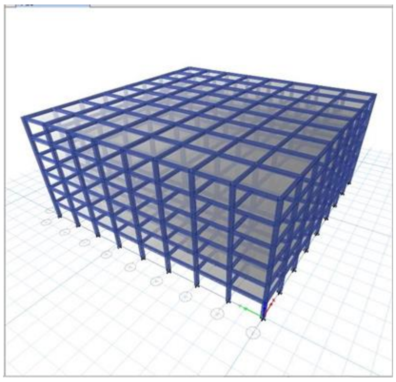
TABLE: Details of Seismic Parameters

Model properties:

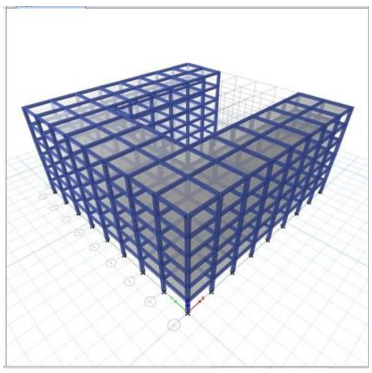
- **Regular structure:-** In this structure having regular structure like box. Effect of vertical, plan and mass irregularity is not considered in this model.
- **Mass Irregular Structure:-** The structure is modelled as same as that of regular structure except the loading due to increasing mass (swimming pool, heavy machines etc.) is provide in the sixth and third floor. We consider loading due to increasing mass is 10 kN/m2. The seismic weight of any storey is more than 200 percent of that of its adjacent storeys.
- **Plan Irregular Structure:-** The structure is not same as that of regular, is in form of L,C,T,+ and I Models



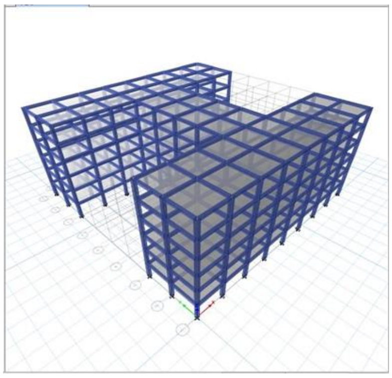
1. Plus Model



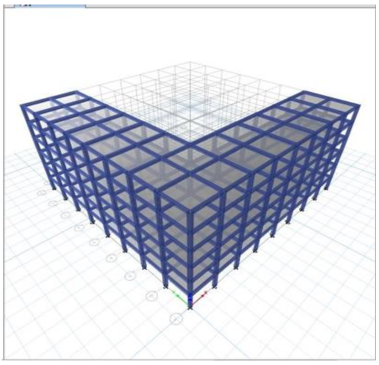
2. Box Model



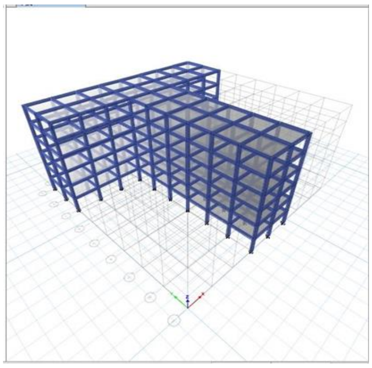
3. C- Model



4. H- Model



5. L- Model



6. T- Model

RESULTS:

1. BOX MODEL:

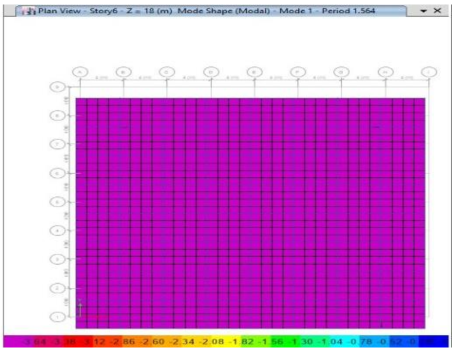


Figure: BOX MODE 1

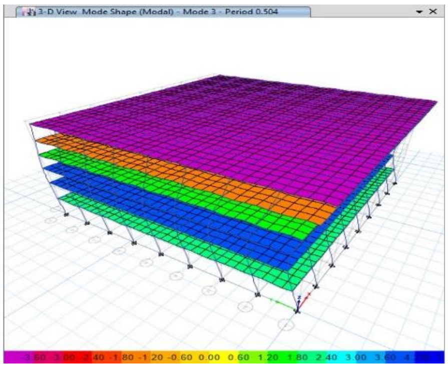


Figure: BOX MODE 2

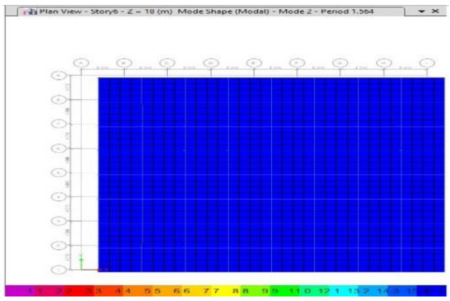


Figure: BOX MODE 3

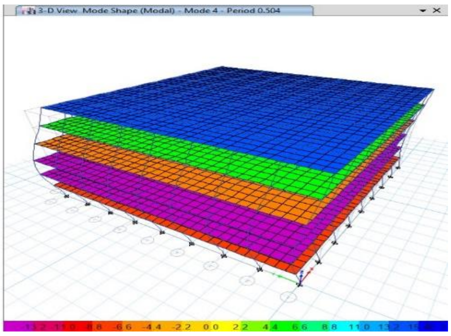


Figure: BOX MODE 4

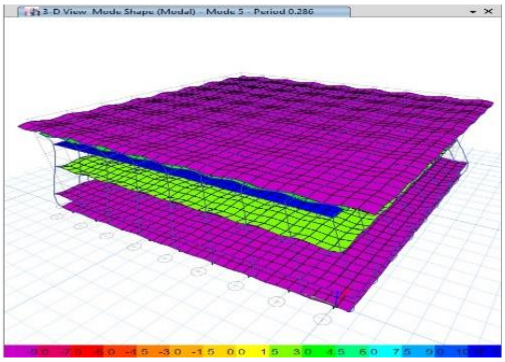


Figure: BOX MODE 5

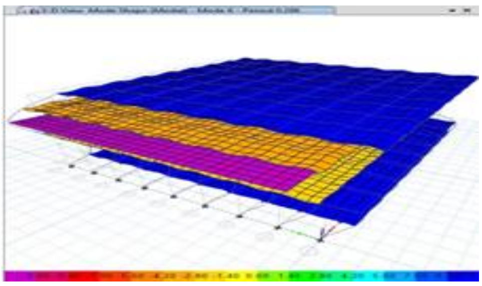


Figure: BOX MODE 6

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2. PLUS MODEL:

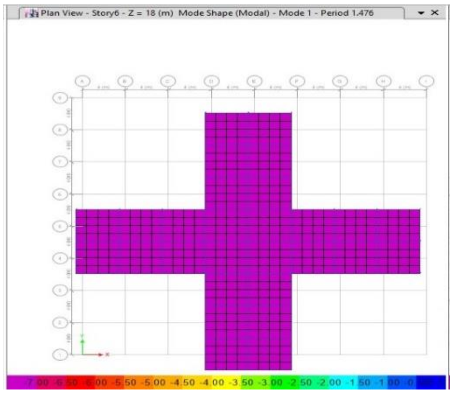


Figure: PLUS MODE 1

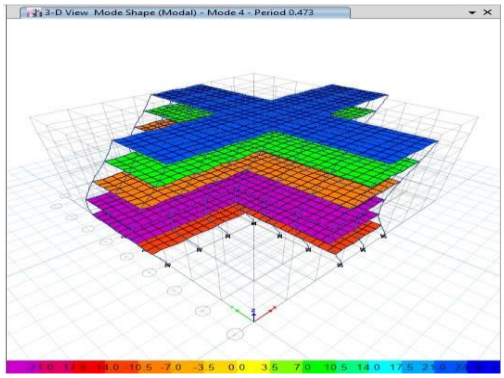
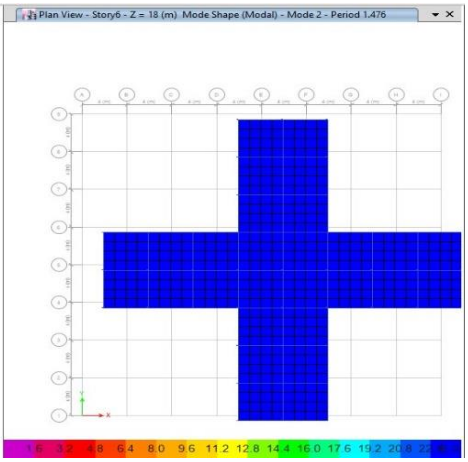


Figure: PLUS MODE 4



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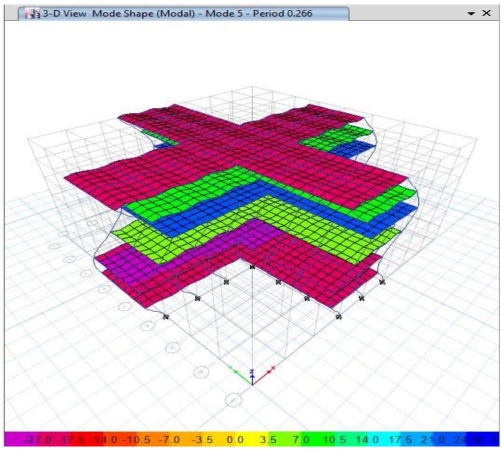

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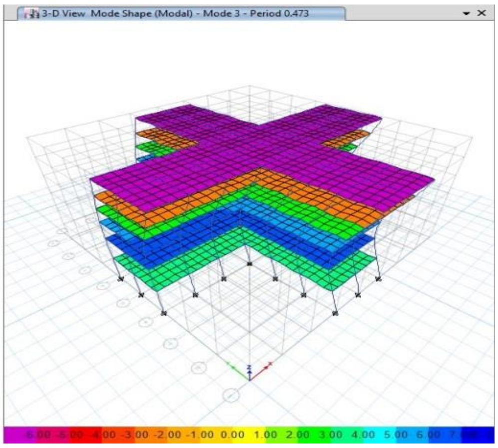

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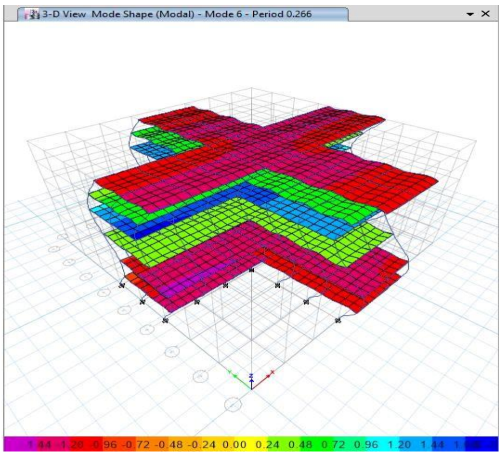
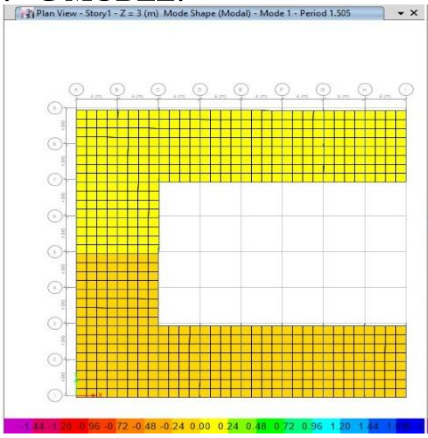


Figure: PLUS MODE 6

3. **C MODEL:**



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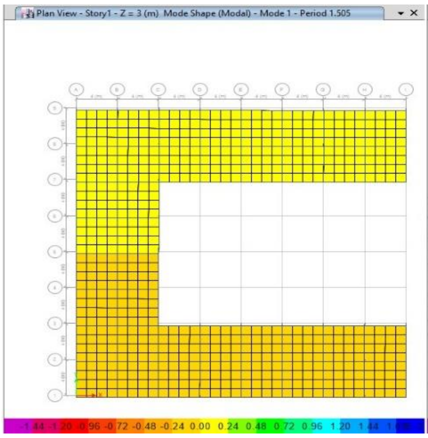

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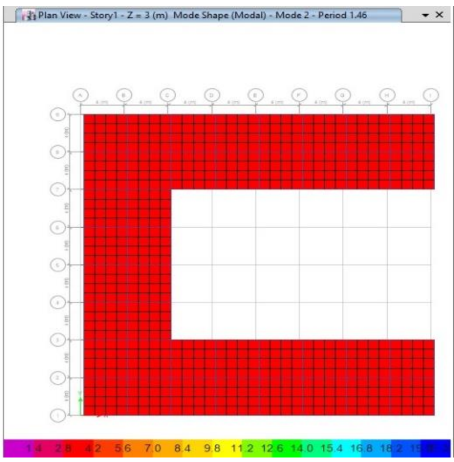

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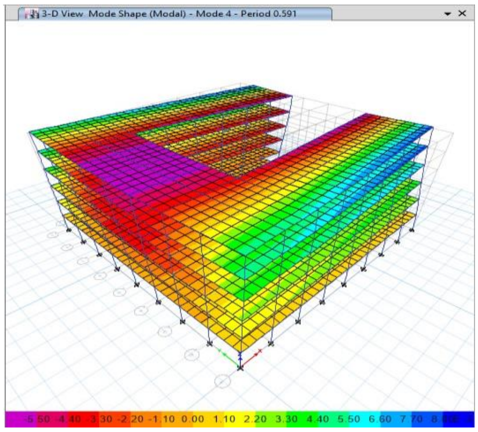

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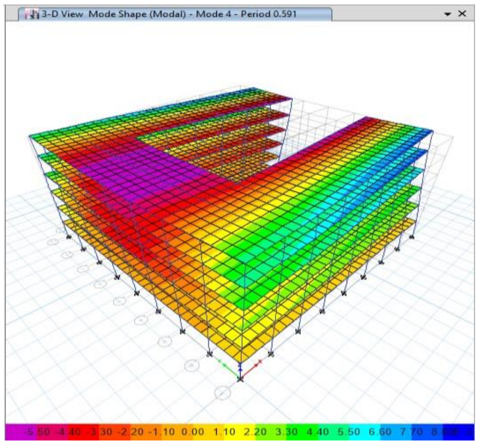

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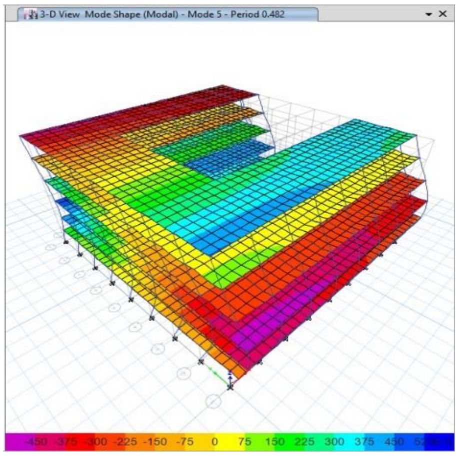

Figure: C MODE 6

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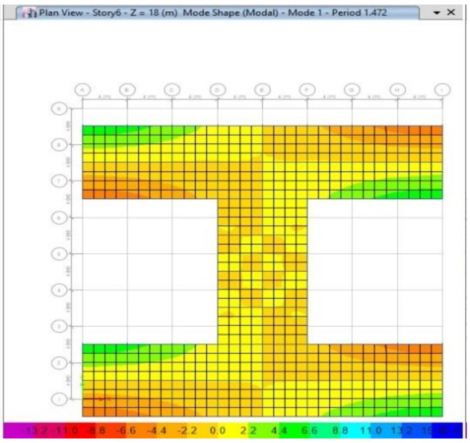
4. I MODEL:



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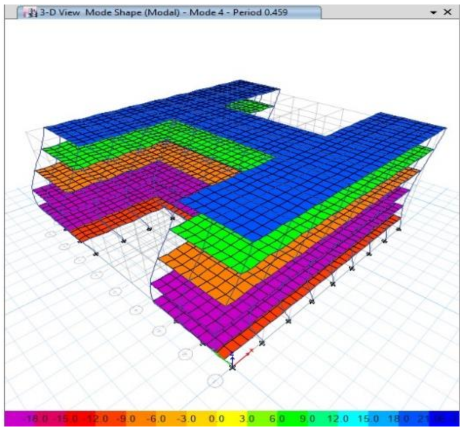

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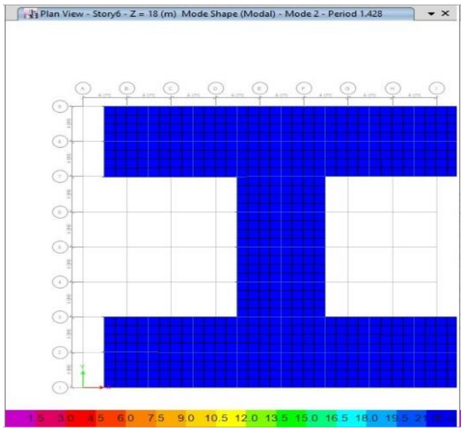

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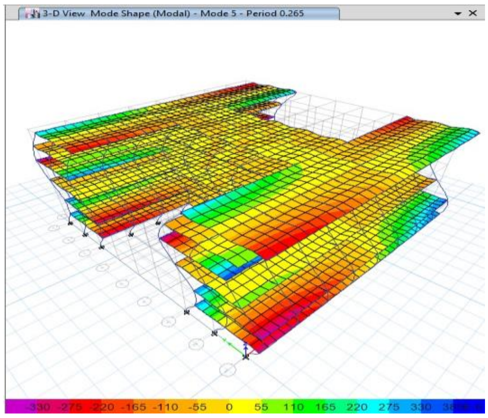

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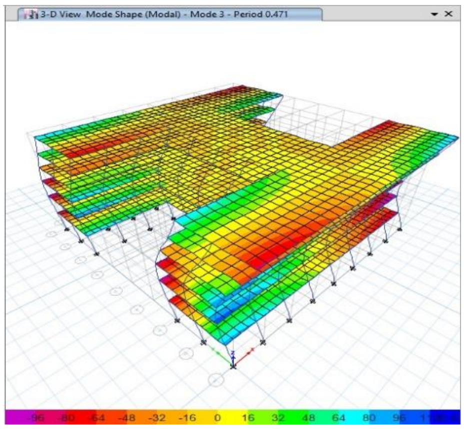

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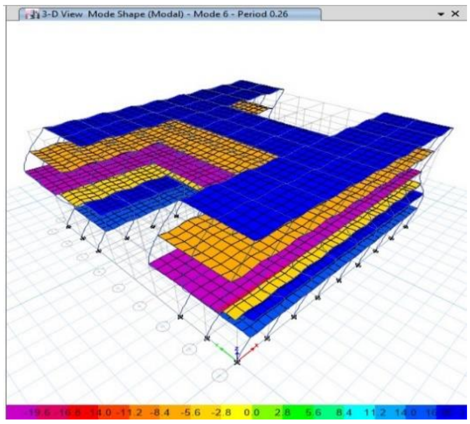

Figure: I MODE 6

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5. L MODEL:

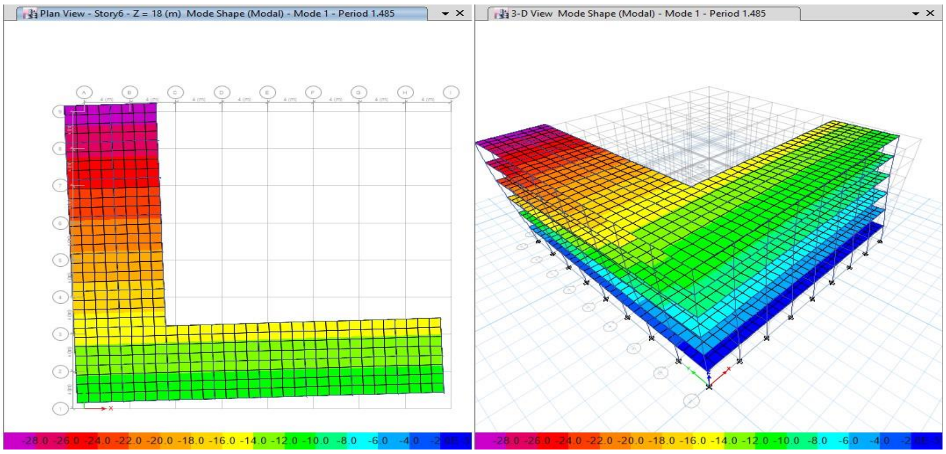
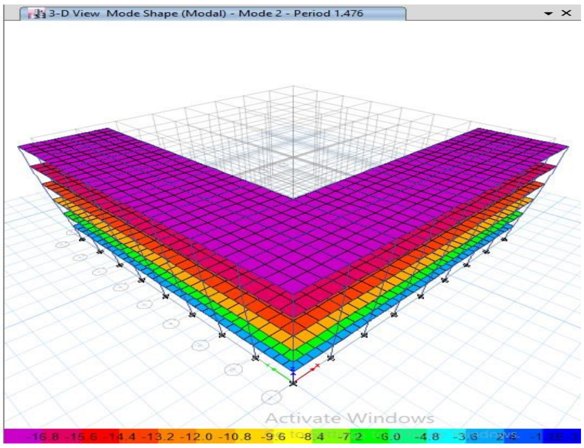


Figure: L MODE 1



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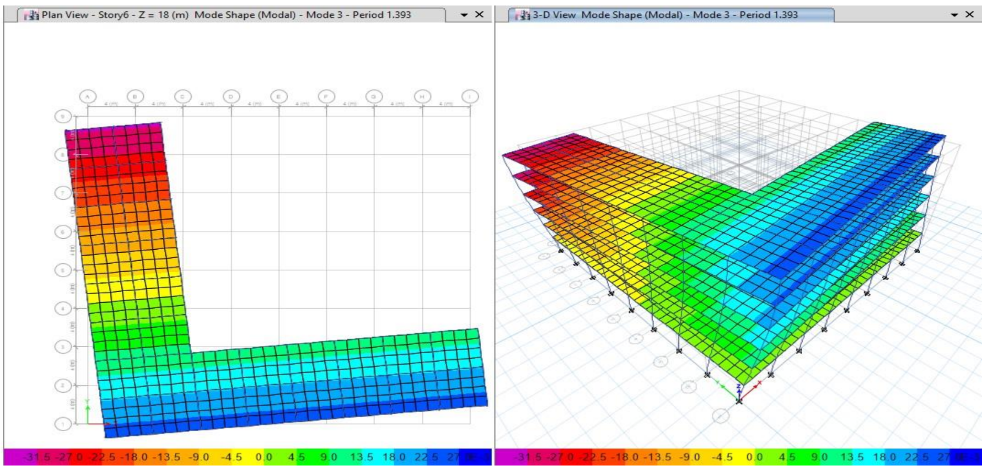

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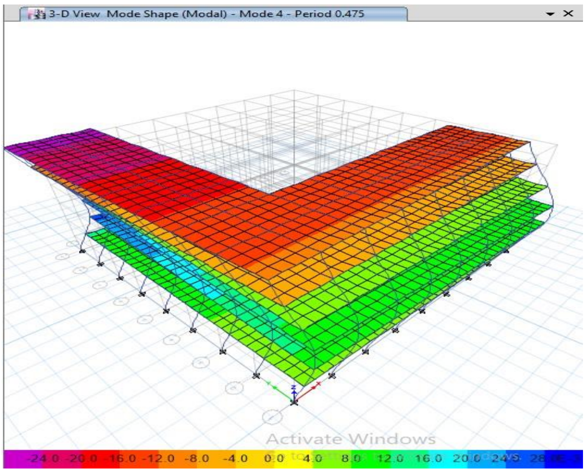

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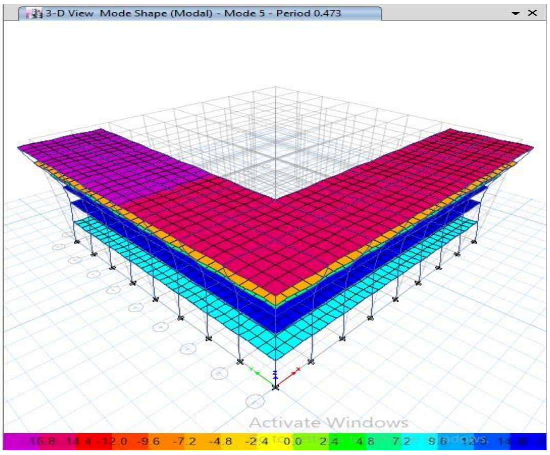

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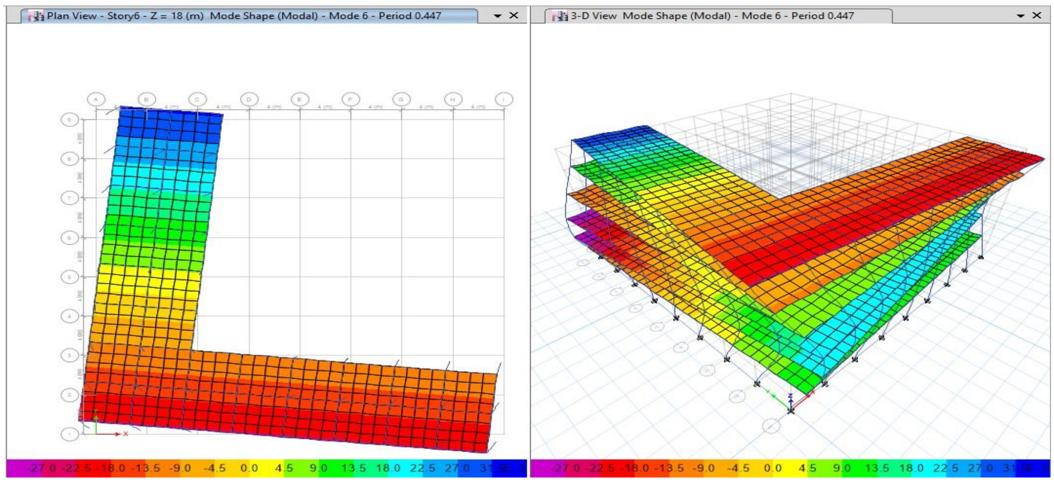

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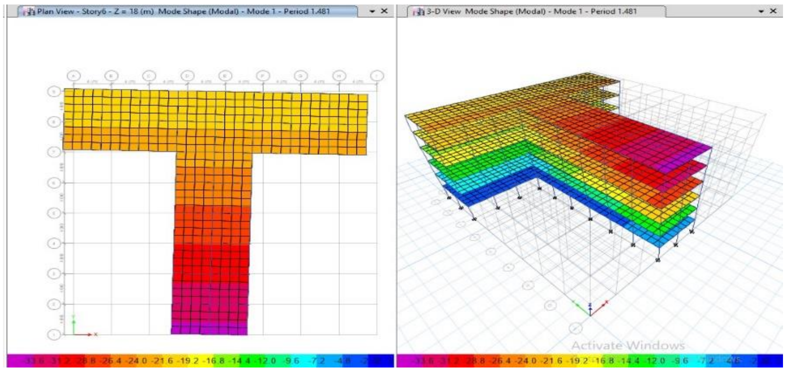
7. T MODEL:



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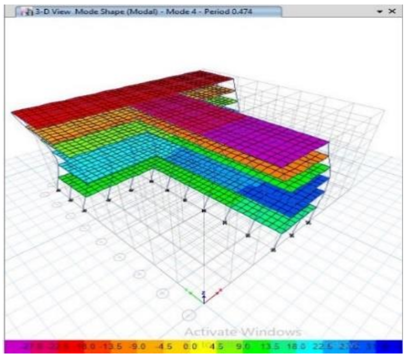

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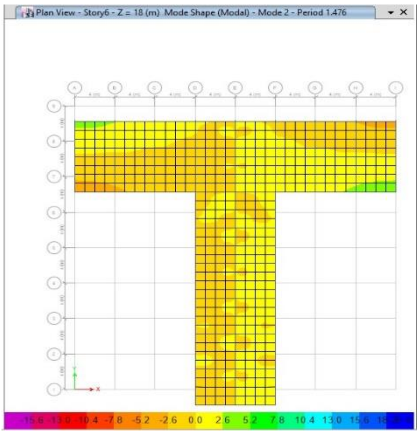

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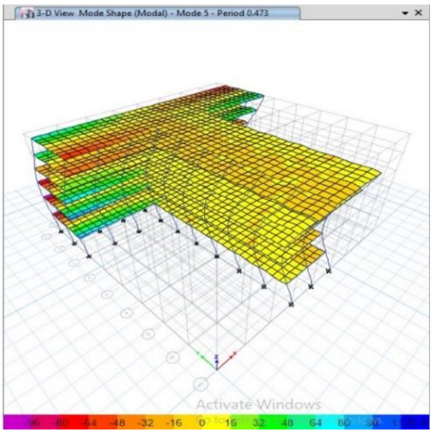

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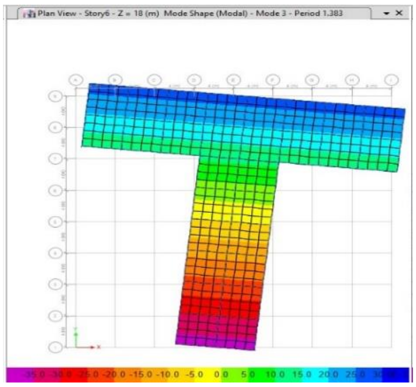

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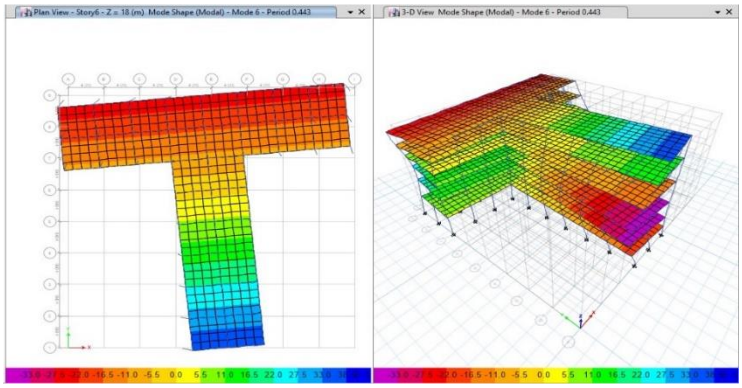

Figure: T MODE 6

COMPARISON CHARTS OF MODEL RESULTS:

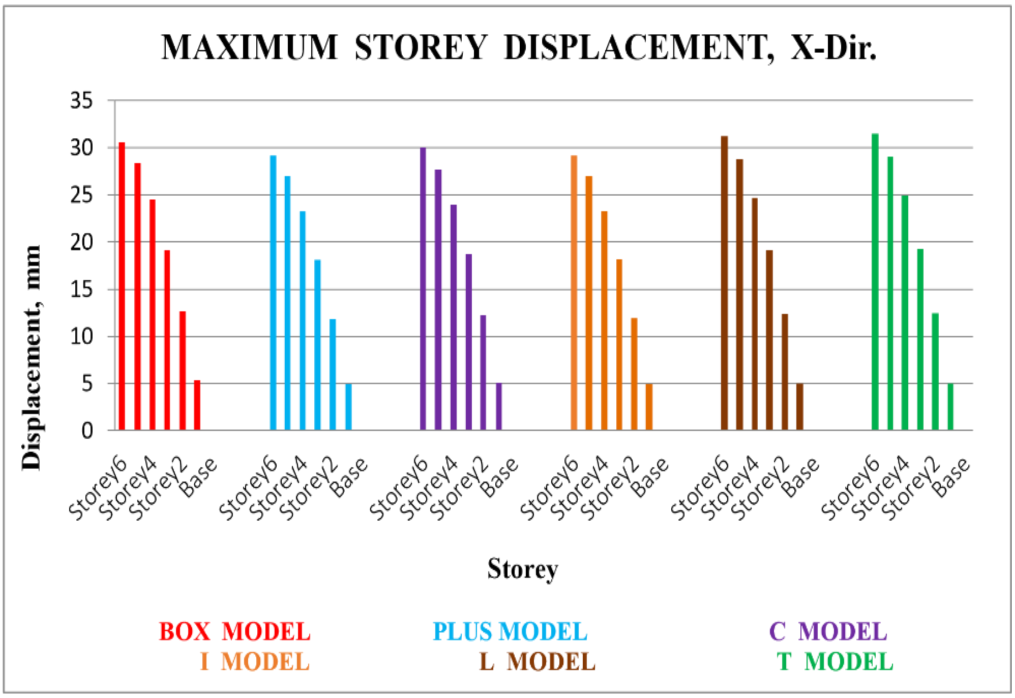

Chart 1: COMPARISON OF STOREY DRIFTS(X-Dir.) [FOR PLAN ASYMMETRY]

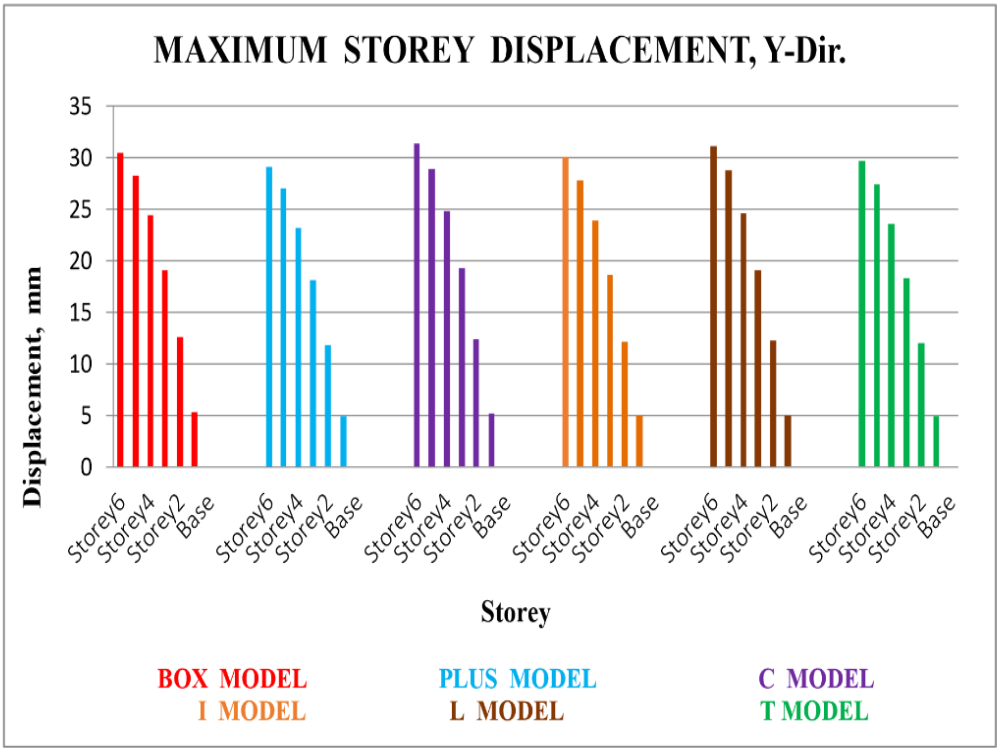

Chart 2: COMPARISON OF STOREY DRIFTS(Y-Dir.) [FOR PLAN ASYMMETRY]

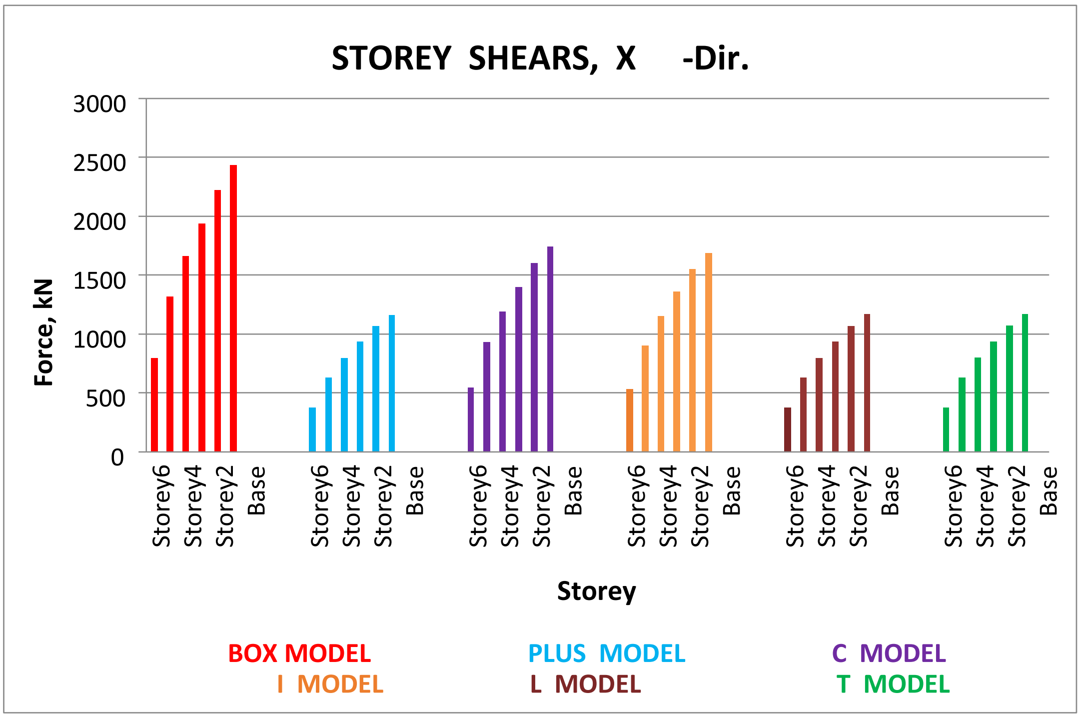

Chart 3: COMPARISON OF STOREY SHEARS(X-Dir.) [FOR PLAN ASYMMETRY]

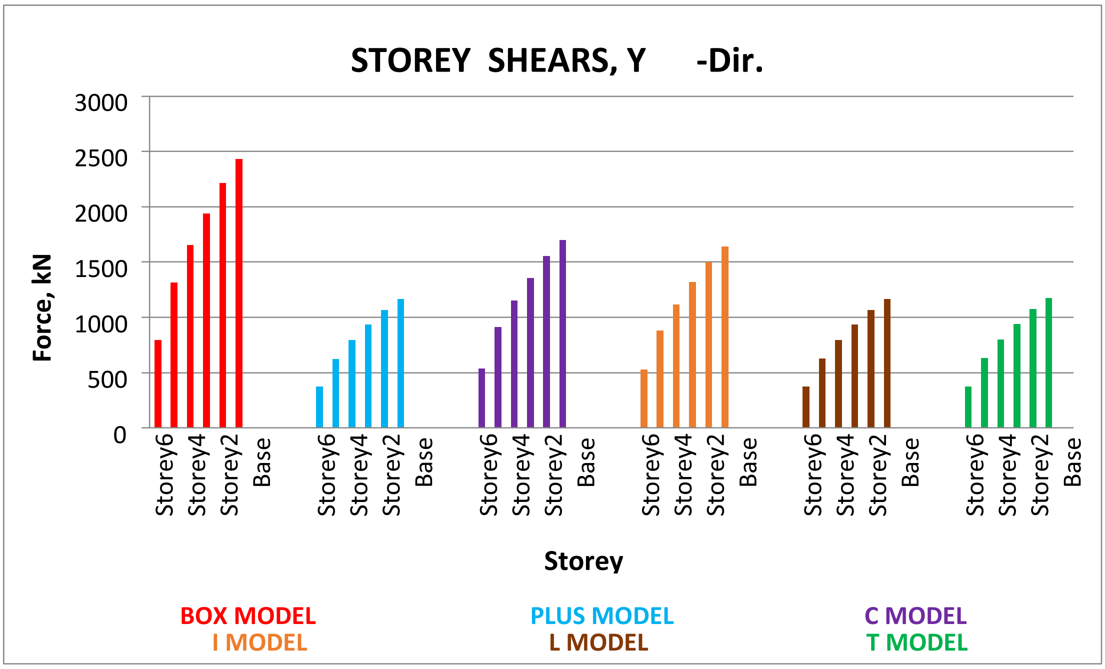

Chart 4: COMPARISON OF STOREY SHEARS(Y-Dir.) [FOR PLAN ASYMMETRY]

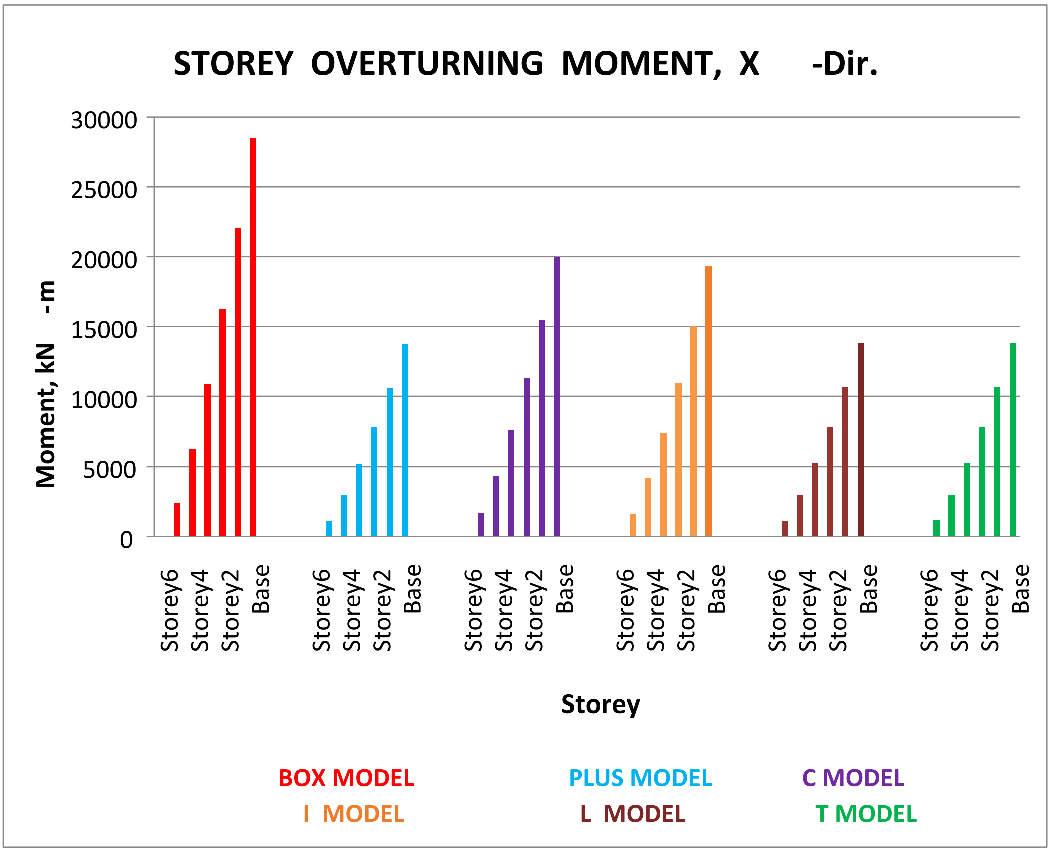

Chart 5: COMPARISON OF STOREY OVERTURNING MOMENT(X-Dir.) [FOR PLAN ASYMMETRY]

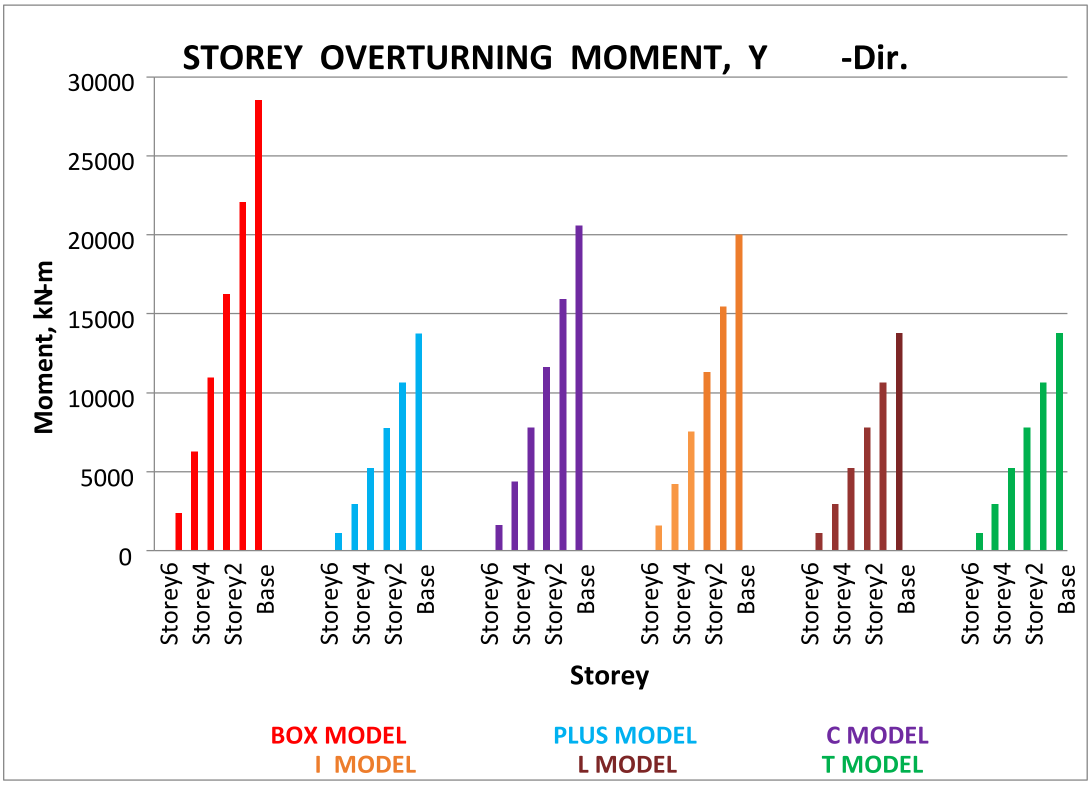

Chart 6: COMPARISON OF STOREY OVERTURNING MOMENT(Y-Dir.) [FOR PLAN ASYMMETRY]

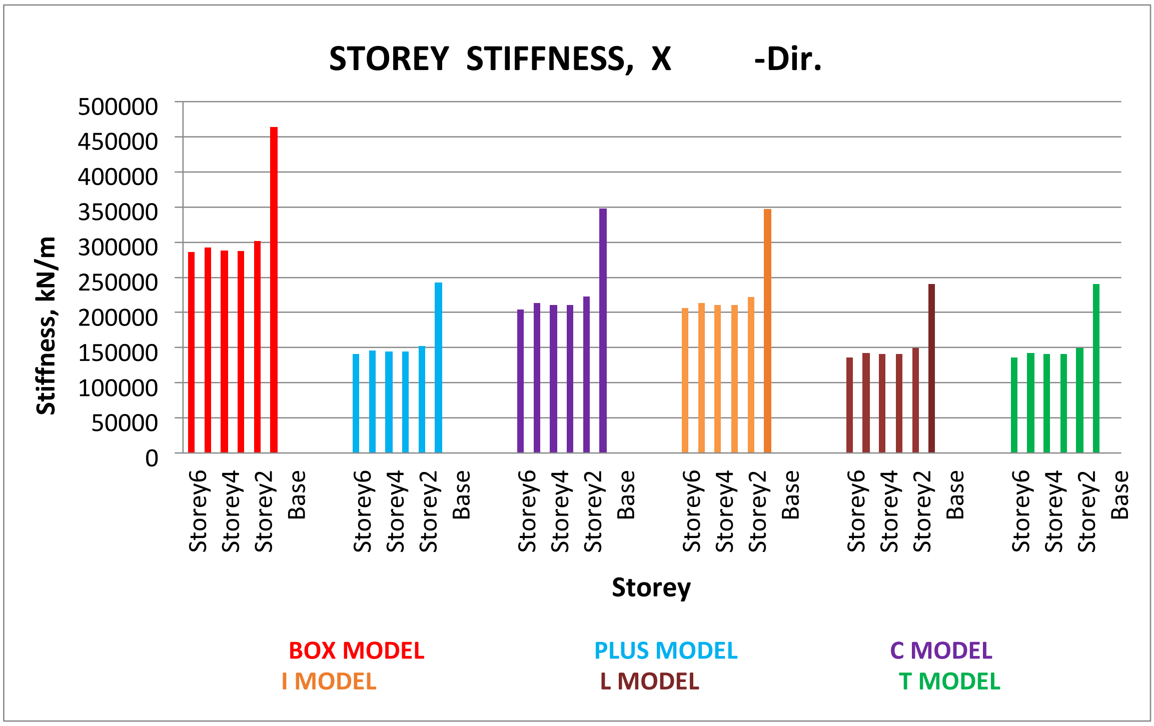

Chart 7: COMPARISON OF STOREY STIFFNESS(X-Dir.) [FOR PLAN ASYMMETRY]

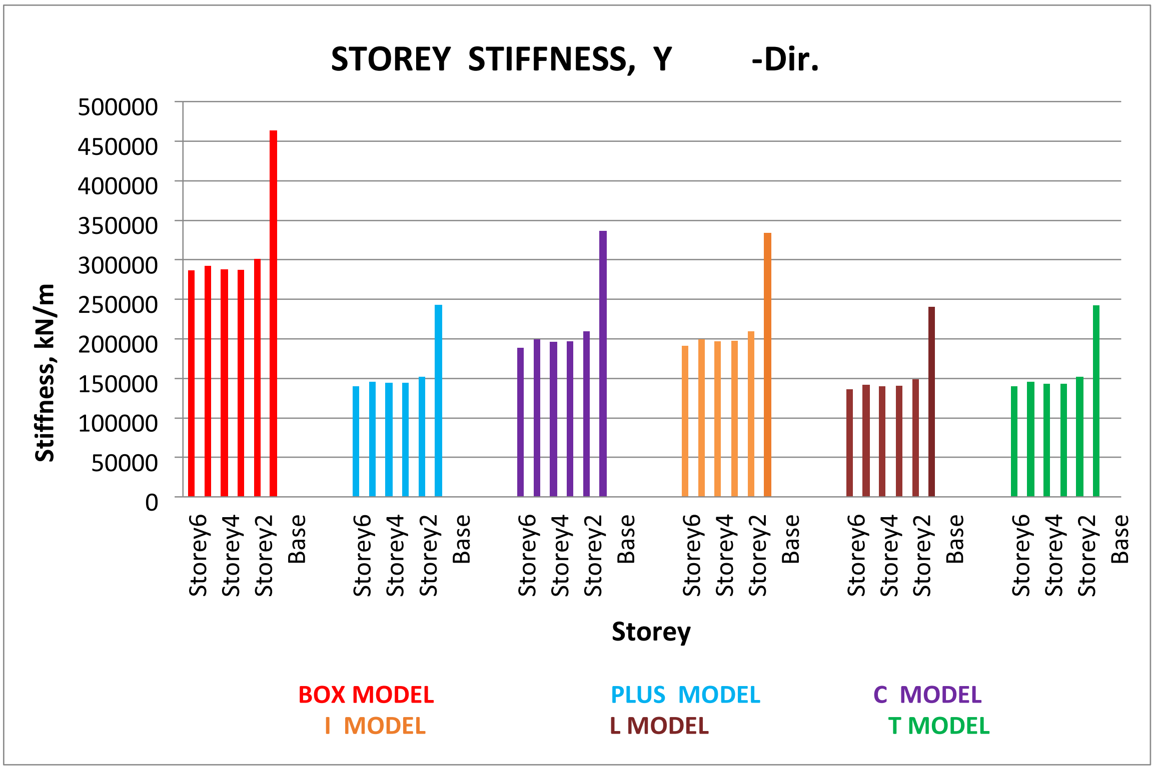

Chart 8: COMPARISON OF STOREY STIFFNESS(Y-Dir.) [FOR PLAN ASYMMETRY]

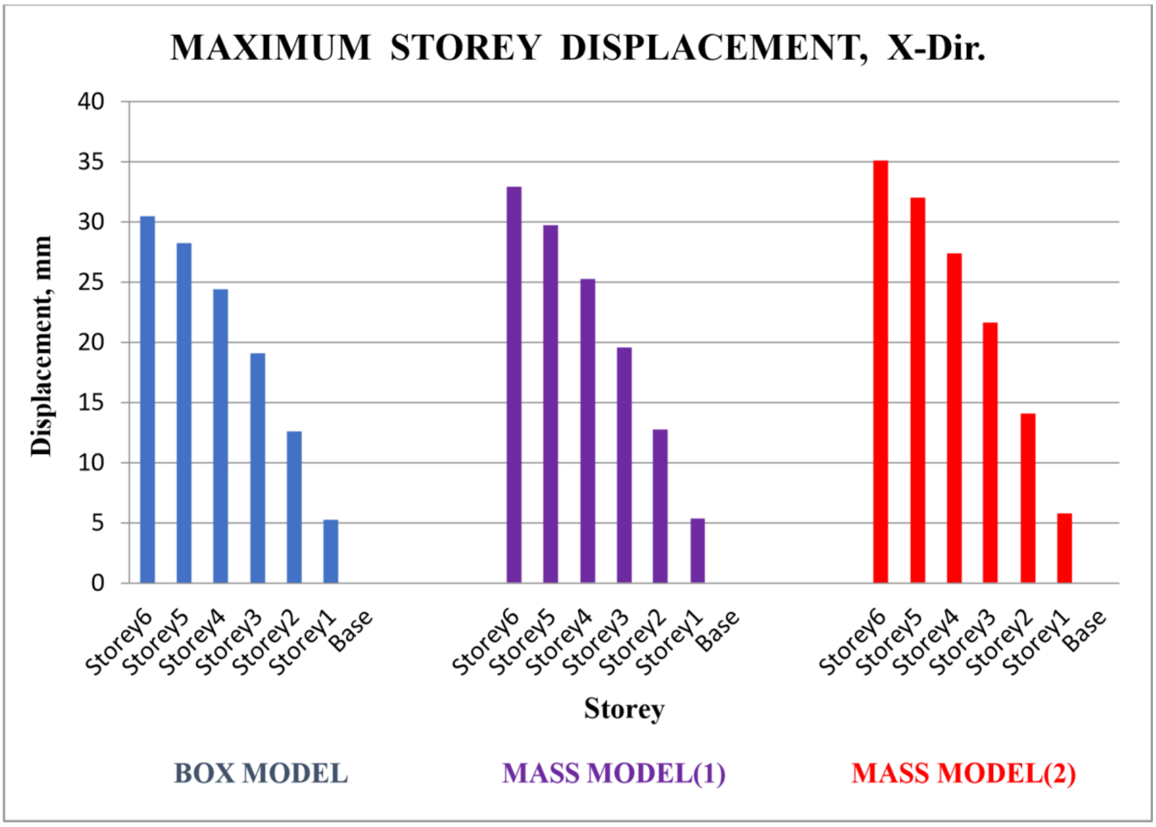

Chart 9: COMPARISON OF STOREY DISPLACEMENT(X-Dir.) [FOR MASS ASYMMETRY]

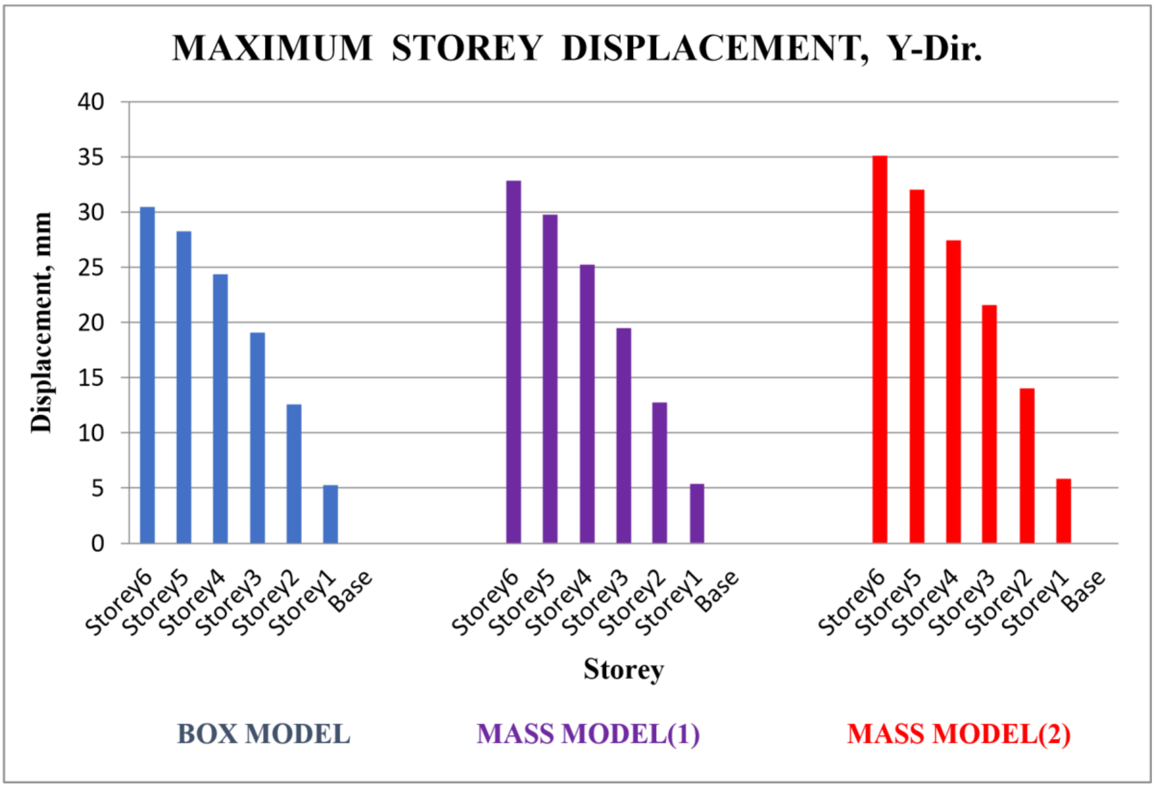

Chart 10: COMPARISON OF STOREY DISPLACEMENT(Y-Dir.) [FOR MASS ASYMMETRY]

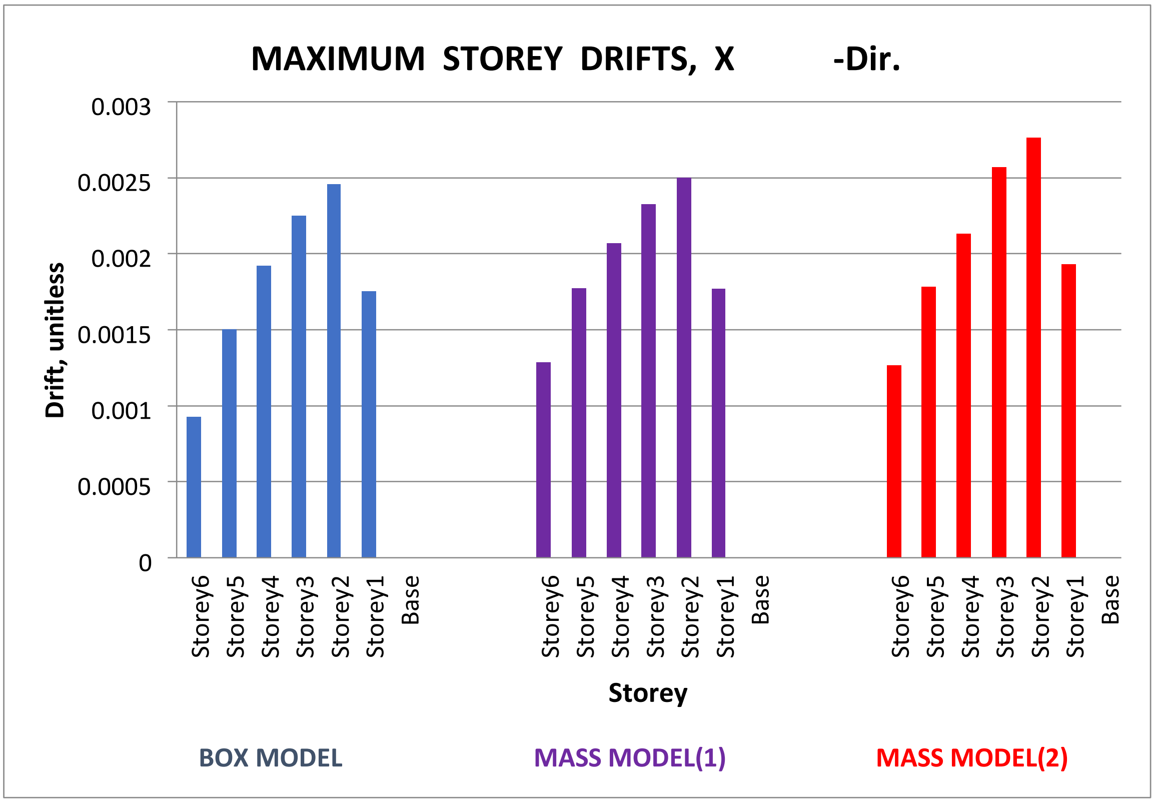

Chart 11: COMPARISON OF STOREY DRIFT(X-Dir.) [FOR MASS ASYMMETRY]

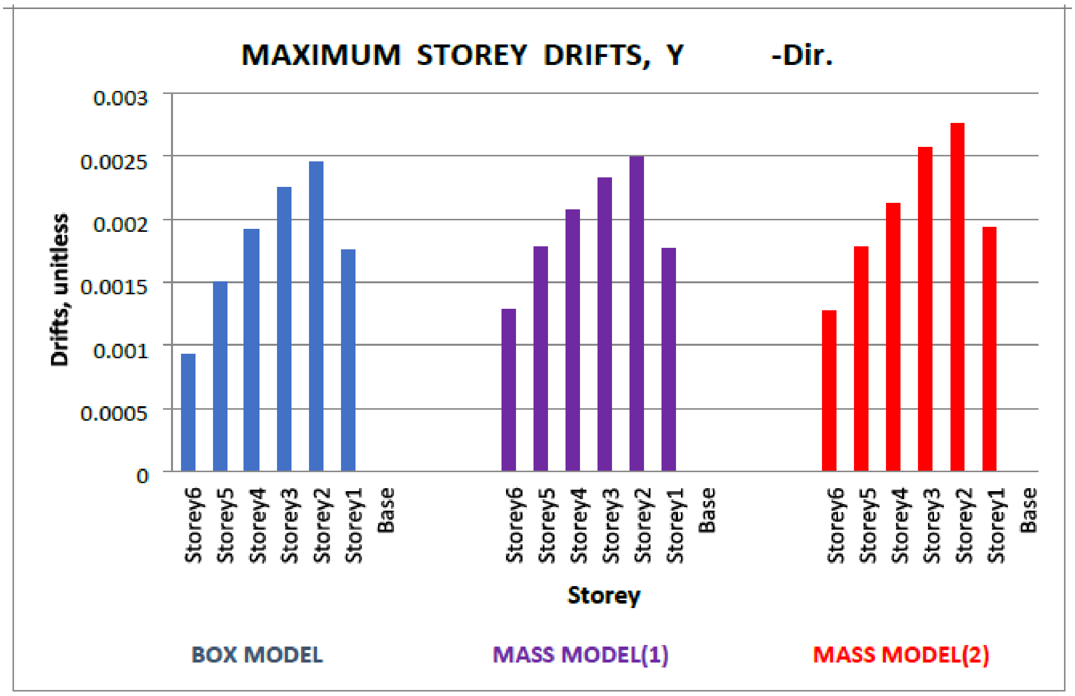

Chart 12: COMPARISON OF STOREY DRIFT(Y-Dir.) [FOR MASS ASYMMETRY]

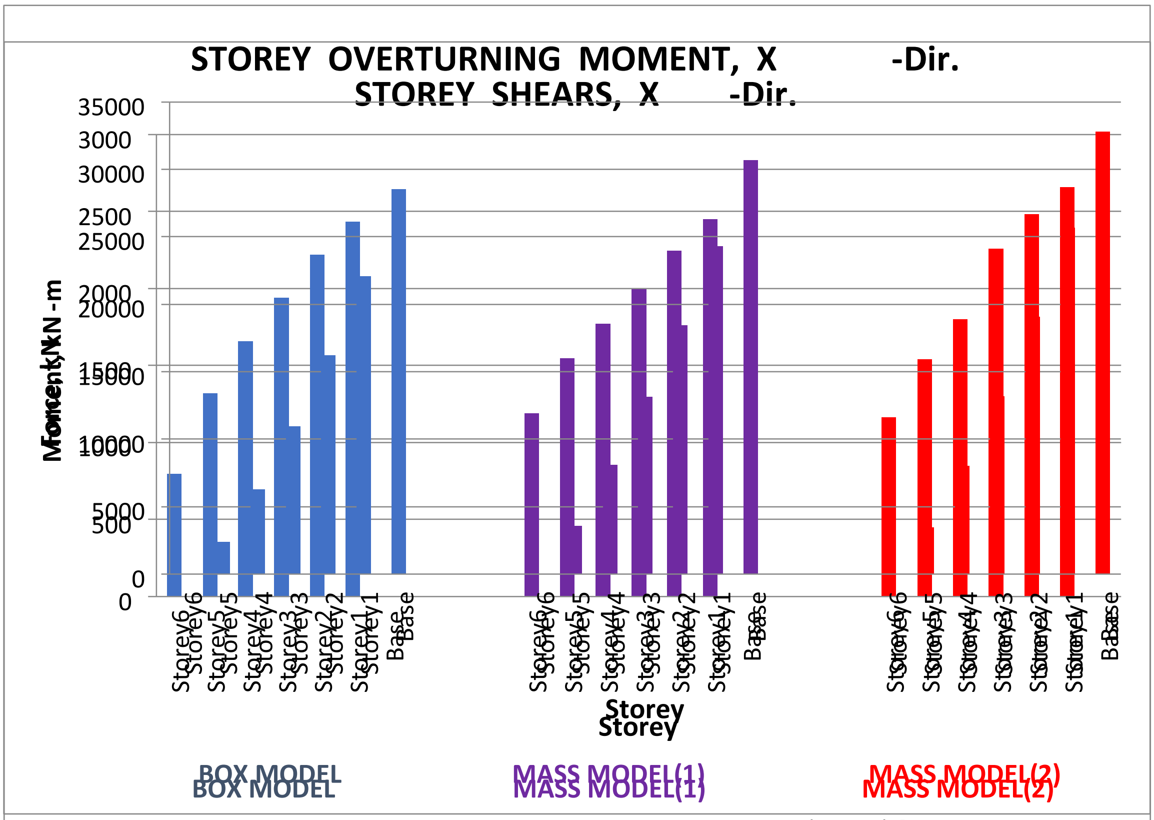

Chart 15: COMPARISON OF STOREY OVERTURNING MOMENT (X-Dir.) [FOR MASS ASYMMETRY]

Chart 13: COMPARISON OF STOREY SHEARS(X-Dir.) [FOR MASS ASYMMETRY]

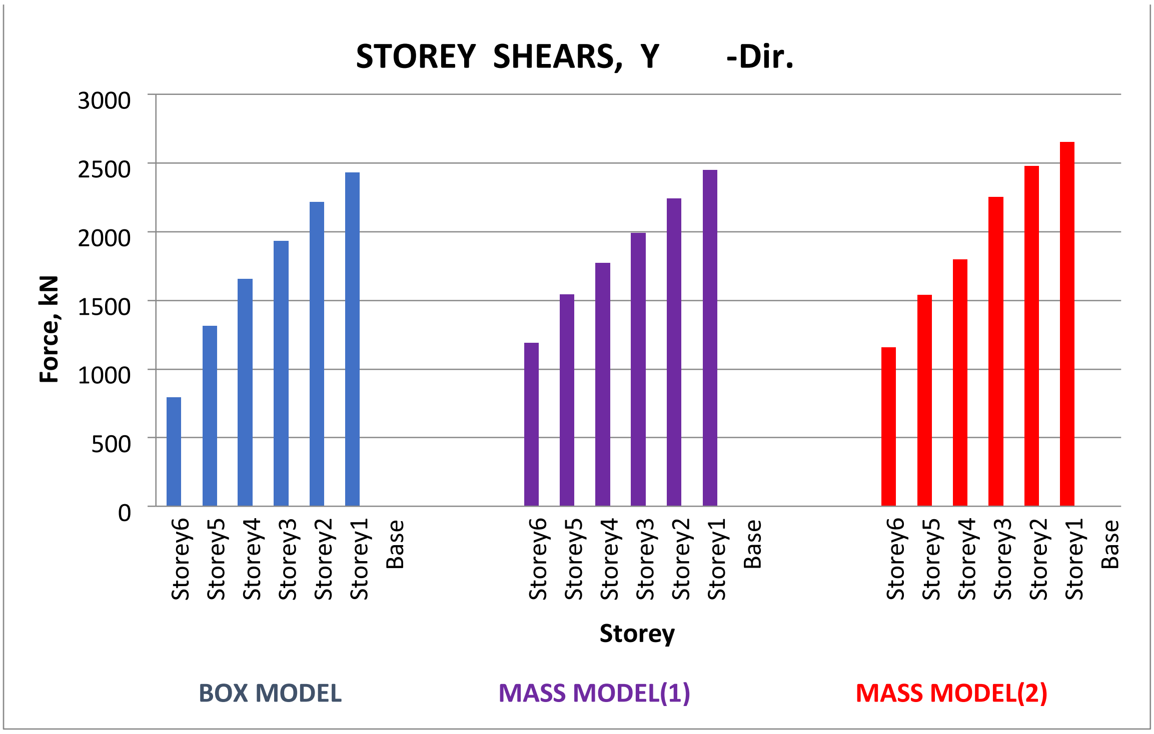

Chart 14: COMPARISON OF STOREY SHEARS(Y-Dir.) [FOR MASS ASYMMETRY]

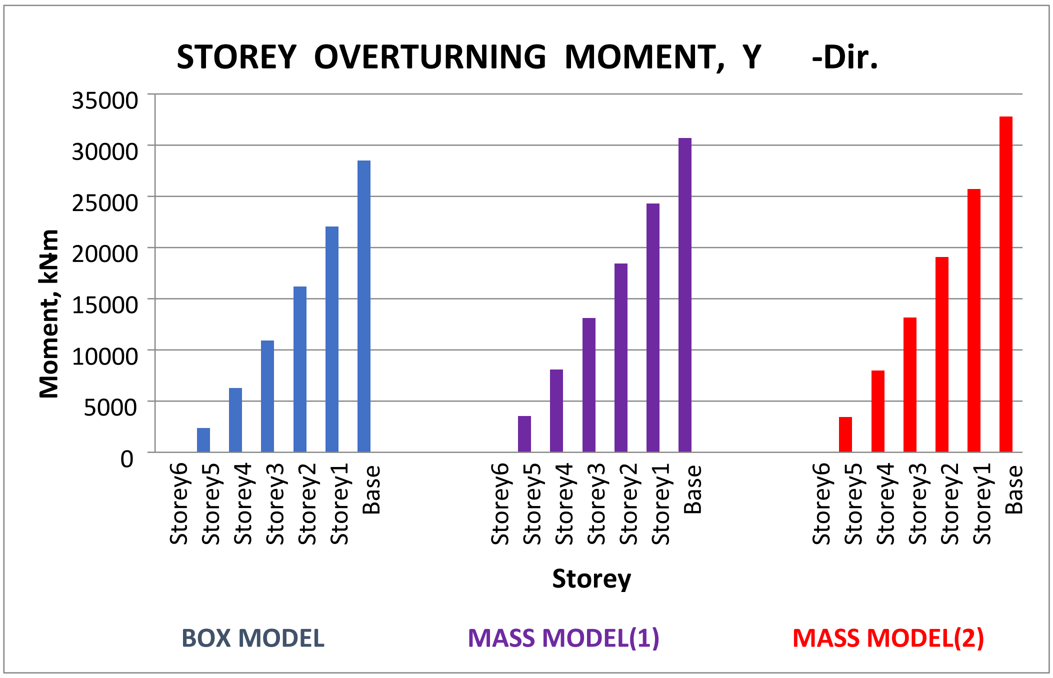

Chart 16: COMPARISON OF STOREY OVERTURNING MOMENT (Y-Dir.) [FOR MASS ASYMMETRY]

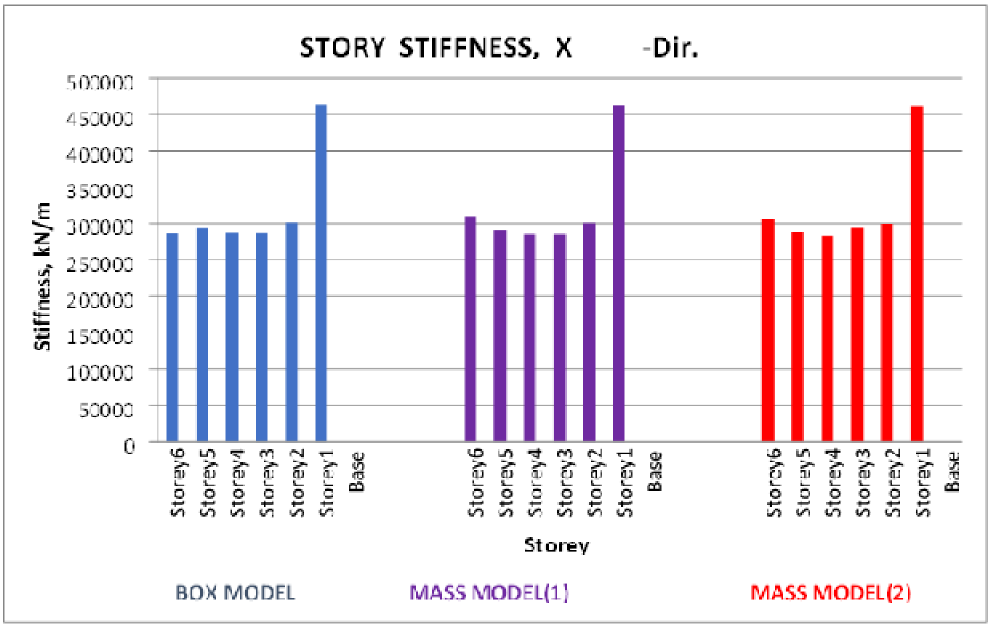

Chart 17: COMPARISON OF STOREY STIFFNESS (X-Dir.) [FOR MASS ASYMMETRY]

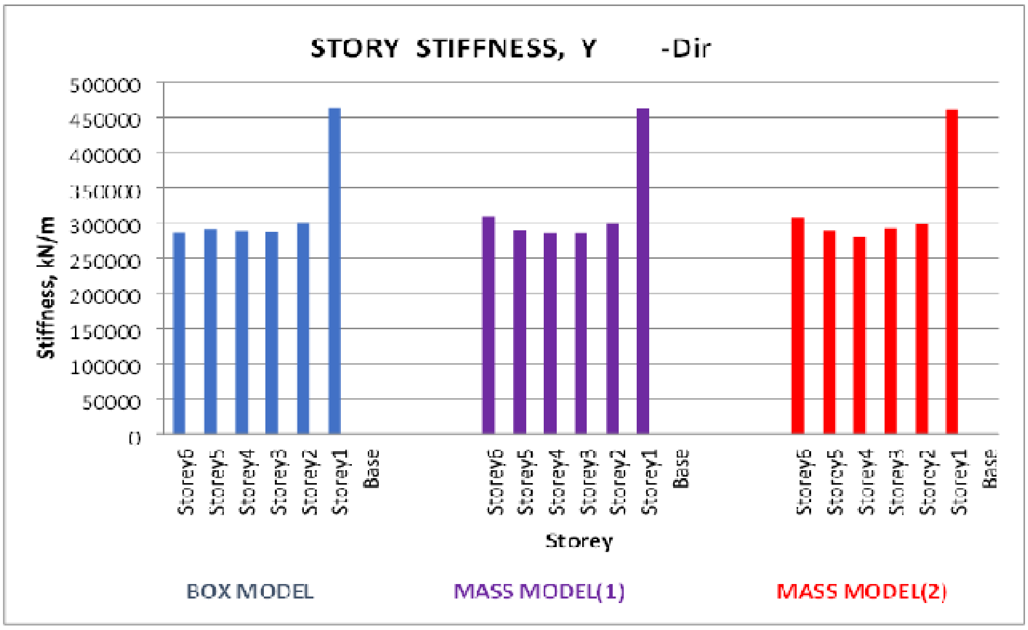

Chart 18: COMPARISON OF STOREY STIFFNESS (Y-Dir.) [FOR MASS ASYMMETRY]

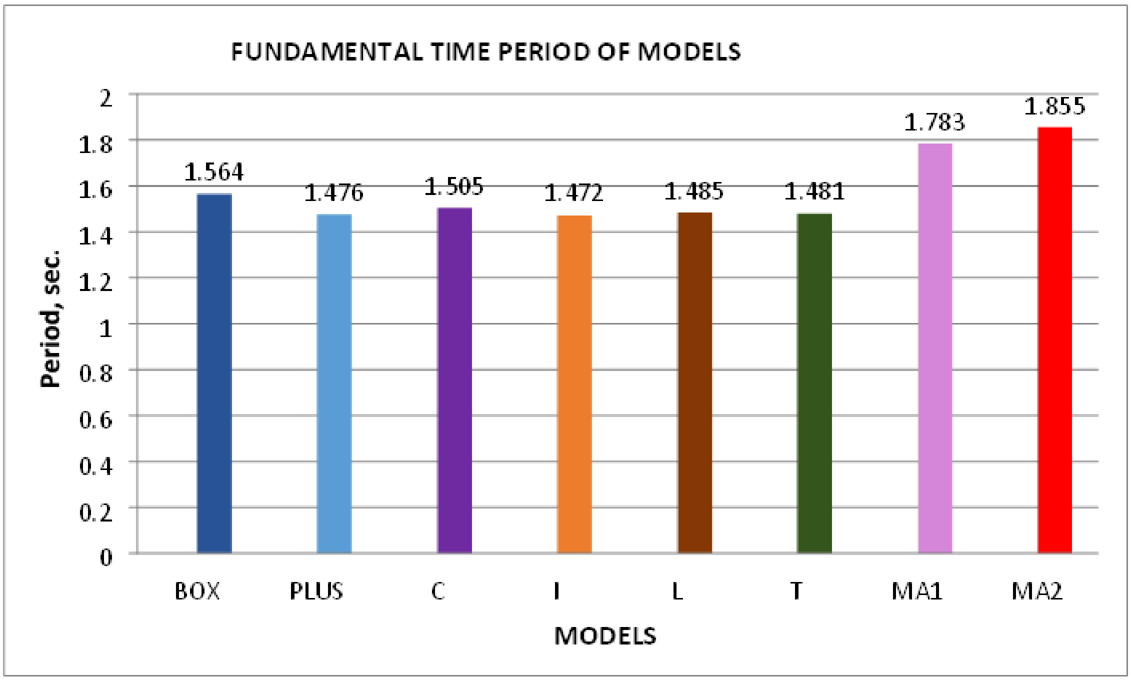

Chart 19: FUNDAMENTAL TIME PERIOD OF MODELS

CONCLUSIONS

Plan Asymmetry

- No significant differentiation on the basis of displacement and drift for models with low projection and symmetry in plan (plus and I).
- Box model has the highest overturning moment, storey shear, and stiffness.

- Models with higher projections (C, L, and T) generate torsion modes, with T model generating a mixed mode in the first mode.

Mass Asymmetry

- Increasing mass in MA1 and MA2 models increases displacement, drift, shear, and overturning moment, but decreases stiffness.
- Plus and I models do not generate torsion modes due to symmetry and low projection.
- C, L, and T models generate torsion modes in the third mode, but T model generates a mixed mode in the first mode.
- Low mass asymmetry does not generate torsion modes and does not adversely affect building behaviour.
- High mass asymmetry generates torsion modes and is not recommended.

Fundamental natural time period

- Increases with increasing mass in MA1 and MA2 models due to decreasing stiffness.
- Decreases in plus, C, I, L, and T models as compared to the box model.

Overall Conclusions

- Low mass asymmetry does not adversely affect the seismic behaviour of reinforced concrete structures.
- High mass asymmetry can significantly impact the seismic behaviour of reinforced concrete structures and should be avoided.
- Buildings with low projections and symmetry are less susceptible to seismic damage.

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