Influence of Core Eccentricity on the P- Delta Sensitivity of Tall Reinforced Concrete Buildings

by Vaibhav Diamond

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Influence of Core Eccentricity on the P-Delta Sensitivity of Tall Reinforced Concrete Buildings

A dissertation submitted in
partial fulfilment of the Requirement for the Award of the Degree of

MASTER OF TECHNOLOGY

in

Structural Engineering

by

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(24/STE/03)

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Candidate's declaration

I, **Vaibhav Diamond, 24/STE/03** of MTech (Structural engineering), hereby declare that the project Dissertation titled "**INFLUENCE OF CORE ECCENTRICITY ON P-DELTA SENSITIVITY OF TALL REINFORCED CONCRETE BUILDINGS**" which is submitted by me to the **Department of civil engineering**, Delhi Technological University, Delhi in partial fulfilment of the requirements for the award of the degree of Master of Technology, is original and not copied from any source with proper citation. This word has not previously formed the basis for the award of the Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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I, hereby, certify that the project Dissertation titled "**INFLUENCE OF CORE ECCENTRICITY ON P-DELTA SENSITIVITY OF TALL REINFORCED CONCRETE BUILDINGS**" which is submitted by Vaibhav Diamond (24/STE/03), Department of Civil engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this word has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

Place: Delhi

Date: 29-05-2026

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Finally, I thank everyone who directly or indirectly contributed to the successful completion of this project and helped me throughout this academic journey.

Vaibhav Diamond

(24/STE/03)

ABSTRACT

In this thesis, we deal with the effects of P-delta on tall buildings which have core eccentricities and load irregularity in them. Seismic performance of buildings can also be greatly affected by this phenomenon.

A regular planed high-rise building is taken in this project and with help of shear walls eccentricity is introduced in the structure. To study the isolated effect of eccentricity and P-delta, all the other parameters such as size of members, grid spacing, loading and material properties were kept constant. Multiple models were created with P-delta effect on and off so as to get a better understanding of second order effects on high-rise buildings.

Building was created over 50m so as to meet the criteria of tall buildings according to IS CODE 16700: 2023. Grid spacing was kept at a constant of 8m with secondary beams provided to lessen the slab length. Material was kept M30 in all the members and models throughout the length and height of the building.

This study compares responses like Maximum storey displacement, Storey drift, Torsional moment about Z-axis, Overturning moment and time period of different models. The results indicate that as the eccentricity is increased in the structure and load irregularity increases, the torsional moment and displacement of top storey is considerably increased under P-delta effect.

Buildings with more centrally located cores show much more balanced response to the lateral forces such as Earthquake. We have used Response spectrum method to monitor the seismic performance of the building/ models.

This study ultimately shows the importance of core eccentricity and how the load should be equally distributed across the plan so as to decrease the second order effects such as P-delta and torsion.

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List of Symbols, Abbreviation

DL:	Dead load
LL:	Live load
kN:	Kilo-newton
kN-m:	Kilo-newton meter
mm/ m:	millimeter/ meter
ETABS:	Extender 3-D Analysis of building systems
M30:	Concrete grade
Fe550:	Steel grade
HYSD:	High yield strength deformed bars
M1, M2, M3:	Model variants
A.F:	Amplification factor
η_t:	Torsional irregularity factor
Δmax:	maximum displacement at one edge of diaphragm
Δavg:	average displacement of diaphragm edges
θ:	Inter-storey drift stability coefficient

CHAPTER 1
INTRODUCTION

1.1 General introduction

Due to urbanization of towns and rapid development of modern cities, horizontal expansion is limited and vertical construction is the way to go, not just for residential but also commercial and mixed-use projects. Reinforced buildings are widely being used to solve this problem because of their durability, strength and serviceability. However, as the height of any structure increased, its stability takes a toll and Earthquake/ Wind forces become critical to the structure. They are more sensitive to lateral loads than low-rise buildings.

1.2 Tall building behaviour under lateral loads

Structural response of tall buildings is greatly affected by load distribution, stiffness distribution and geometric configuration of the building itself. One of the primary and important factors to keep in mind is the structural core of the building.

The core generally consists of lift shafts and staircases enclosed by reinforced concrete walls which act as the primary lateral load resisting systems of tall buildings. When the core is evenly located about the plan, secondary effects like torsion and P-delta are negligible and do not play a great role in the stability of the building.

However, due to architectural constraints, sometimes core is not efficiently placed and can create an eccentricity in the plan of the building causing second order effects to take a greater role in the analysis and reduce the stability of buildings.

1.3 P-Delta effect in high-rise buildings

P-delta effect is a second order effect that becomes important in tall and slender buildings subjected to lateral loads such as Earthquake or Wind loads.
In structural analysis, "P" represents the axial gravity load acting on the building, while "Delta (Δ)" represents the lateral displacement of the building due to external load.
If the building goes under high lateral deflection, secondary order effects become important as the vertical loads no longer act along the original undeformed position of the structure.

$$M = P.\Delta$$

These secondary moments increase the overall internal forces and it is an iterative process.
Significance of P-delta effects greatly on things like building height, axial loading, slender ratio and Structural loading/ configuration. Buildings with irregular plans, soft stories or eccentric cores are highly affected by this secondary effects. It also increases the torsional response of the building and shows uneven displacement patterns. P-delta is used to come to a more realistic prediction of structural behaviour of the building.
With help of ETABS, we are able to efficiently perform second-order analysis of irregular high-rise buildings. This effect helps us evaluate the influence of geometric irregularities on structure and helps in identifying critical conditions related to drift, stability and overall safety of the building.
There it plays an important role in correctly predicting the behaviour of tall RCC buildings with irregular plan or loadings.

1.4 Core eccentricity in tall buildings

1.4.1 Symmetric and asymmetric core systems

Core eccentricity in tall buildings refers to when the structural core is positioned away from the geometrical centre of the building and it causes irregular stiffness distribution. Core generally consists of lift shafts, staircases and shear walls which are generally used to resist lateral forces such as Earthquake and Wind loads.

In modern construction practices, architectural and space constraints force us to design buildings with asymmetric core systems which cause torsion and elevate the second order effects in the building. This study is an attempt to get a better understanding of such structures.

1.4.2 Center of mass and Center of rigidity

Center of mass is the point where the total mass of the building is generally considered to be concentrated. Center of rigidity is the point through which lateral resisting elements act to resist horizontal forces.

In a symmetrical building, both of these points are close to each other. However, in asymmetric buildings, these points are far apart and this causes eccentricity in the building. Center of rigidity shifts towards the stiffer side of the structure. This separation between center of mass and rigidity produces torsional moments when lateral loads act on the building, causing the structure to rotate in addition to primary effects of forces.

1.5 Problem statement

In modern construction and rapid development of the cities, horizontal space is a constraint and we are often forced to expand vertically and have plans which are irregular or have asymmetric core in them which causes many secondary order effects as we have already discussed. P-delta becomes dominant if the height of the structure is high and more so if torsion is introduced in the building.

Center of mass and rigidity go further away from each other and cause an eccentricity in the building which develops torsional moment.

1.6 Need of the study

This present study focuses on evaluation of the behaviour of tall reinforced concrete buildings where we have kept the plan area and loading same throughout the different models but have introduced eccentricity in them via shear wall positioning and different core positioning.

This study aims to study parameters like maximum displacement of top storey, storey drifts, overturning moments and time period of the different models and how introducing eccentricity while keeping the same sizes effect these parameters.

1.7 Aim of the study

Aim of this study is to investigate the influence of core eccentricity on tall reinforced concrete buildings with emphasis on P-delta and Torsional effect.

1.8 Objectives of the study

1. To model and analyse a high rise RCC building with different core locations using ETABS.
2. To study the effect of eccentricity between center of mass and center of rigidity
3. To evaluate the influence of core eccentricity on storey displacement, storey drift, time period and overturing moment.
4. To examine how P-delta effect causes changes in these parameters throughout the different models.
5. To identify the configuration which gives the best and most stable results amongst all the models we have analysed.

1.9 Methodology

In this study, we have prepared three models on ETABS of a high rise building with consistent grid spacing, height and member sizes with a small distinction of their core placements. M1 has five cores which are equally placed throughout the structure. M2 has 2 cores which are concentrated on one side while M3 has one core on one side of the building causing it to be the most critical of all three models. We analyse these three models with P-delta ON and OFF, then we study the different parameters as mentioned before and identify the most critical case of all three configurations.

1.10 Organization of thesis

1. Chapter 1 – Introduction
2. Chapter 2 – Literature review
3. Chapter 3 – Methodology
4. Chapter 4 – Results and discussions
5. Chapter 5 – Conclusions and Insights.

CHAPTER 2
LITERATURE REVIEW

2.1 P-delta effects in tall structures.

P-delta effects is a secondary order effect which is caused when a large building undergoes lateral displacement due to lateral forces like earthquake or wind loads. Gravity load acting the columns and walls of the structure create additional moment due to the primary lateral displacement and these additional moments are what cause instability in tall, slender buildings.
Ignoring this effect can cause us underestimating the full effects that secondary order moments provide and can cause to unstable and unsafe analysis and design of a structure.

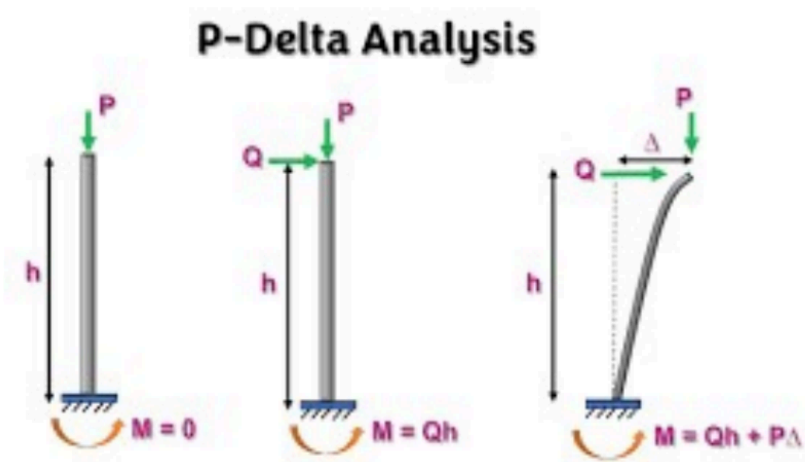


Fig. 2.1 Graphical representation of P-Delta effect

2.2 Core eccentricity in buildings.

Core of a building consists of lift shafts, staircases and shear walls which resist the lateral forces primarily. When placed efficiently, these cores provide great strength to the structure but if placed in such a way that it causes eccentricity in the structure then they can cause torsion and amplify secondary order effects like P-delta.

Due to modern architectural constraints, we are seeing more and more plans where the core is placed inefficiently due to space constraints, which causes instability and stiffness irregularity throughout the plan.

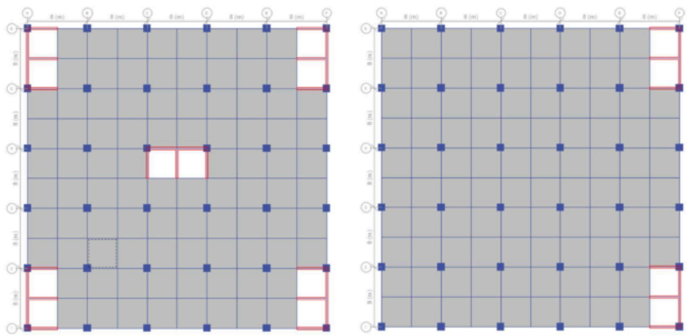


Fig. 2.2(a) Plan with eccentric core placements

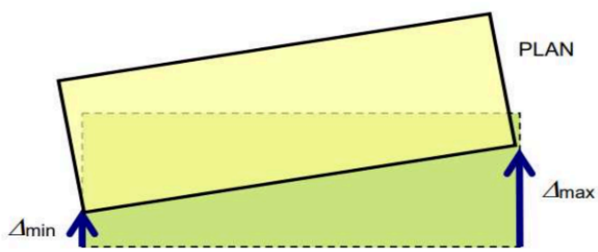


Fig. 2.2(b) Torsional irregularity in buildings

2.3 Response spectrum analysis

Response spectrum analysis is a linear dynamic seismic method where we study the peak response of a structure subjected to seismic excitation. It uses pre-defined spectrums representing the maximum expected response of the structure at different natural frequencies based on historic earthquake data and site details. This method captures the dynamic characteristics of a building by considering multiple modes of vibration and providing a realistic estimate of seismic demands without the computational cost of full time-history analysis. Response Spectrum Analysis combined with consideration of P–Delta effects form a practical approach widely used in seismic design codes such as IS 1893.

2.4 Distinction Between P–δ and P–Δ Effects

In the context of geometric nonlinearity in structural analysis, P-δ (small delta) and P-Δ (large delta) effects represent two different types of second-order effects:

- P–δ effects refer to local second-order moments caused by axial loads acting on the small lateral deflections on individual structural elements, such as beams and columns. These effects are primarily related to the member-level deformations.
- P–Δ effects represent the global second-order moments due to axial loads acting on the overall lateral displacement of the structure, essentially considering the displacement of the entire frame or building relative to the base.

This study focuses on P-Δ effects, which are significant in tall buildings and structures with core eccentricities. The P-δ effects have been excluded from this analysis to simplify the modelling process and because they are typically less critical compared to P-Δ effects in global stability assessments of multi-storey buildings.

2.5 Review of past research

The study of P-delta with seismic analysis has been an important and relevant topic of study for many years, particularly for tall buildings with irregular plan or loadings causing elevation of second order effects.

Nikunj Mangukiya et al. (2019) performed a P-delta study of a tall RCC building with G+24 storeys emphasising the importance of including second order effects and geometric non-linearity. This study shows that ignoring P-delta effects can lead underestimation of lateral displacements by 12–20% and bending moments by 5–20%, highlighting the importance of these effects in ensuring structural safety under seismic loads.

Likewise, **Lakshmi Subash (2017)** analysed the seismic response of tall RC buildings with different number of storeys in ETABS. The findings of the study showed that the P-Delta effects are more pronounced in buildings taller than 10 storeys and that the difference in displacement increases significantly with the height. The study concluded that the P-Delta induced storey drift may increase by up to 13.75% in comparison to linear static analysis in 30 storey buildings, but up to 7% in buildings with less than ten storeys. This highlights the importance of P-Delta effect on medium to high risers RC buildings to prevent unsafe design because of the underestimated lateral responses.

Samanta et al. (2020) studied the behaviour of the Intermediate Moment Resisting Frames (IMRF) under seismic loads, as an extension to RC frames under seismic loads. They found that the P-Delta effects have a significant effect on the initial lateral stiffness and base shear capacity of IMRFs. The omission of P-Delta in the code can result in overestimate of the base shear capacity, leading to misjudgement in seismic design and safety assessment. Furthermore, different kinds of displacement load patterns were shown to influence the nonlinear response of frames, indicating the importance of developing more sophisticated design procedures to incorporate P-Delta effects for providing accurate estimates of seismic response.

Wilson and Habibullah (1987) have been able to create an analytical method for including the P-Delta effects directly into the stiffness matrix of multistorey buildings. The study showed that second order effect has a significant effect on the lateral response, the storey displacement and dynamic characteristics of tall buildings. The authors found that ignoring P-Delta effect may result in non-conservative design of the structure in high-rise structures.

Jadav and Desai (2020) studied the effect of P–Delta effects on the tall reinforced concrete buildings by implementing ETABS software. The effect of P-Delta effects on tall reinforced concrete building was investigated by Jadhav and Desai (2020) by implementing ETABS software. Various structural systems including moment resisting frames, shear wall system and tube system were studied under seismic loading. The study noted that the earlier mentioned P-Delta effects increase with the building height, flexibility and hence the displacement and drift value.

Bakalis, Makarios and Athanatopoulou (2021) analysed the inelastic dynamic eccentricity of asymmetric multistorey RC structures behaviour. A study of torsional response due to eccentricity of centre of mass and centre of stiffness was carried out. The study revealed that with an increase in eccentricity, the seismic demand and torsional rotation of buildings with asymmetric plan forms also increase.

The authors **Kumar, Madhuri and Olaiya (2025)** have studied the nonlinear seismic response of plan and vertically asymmetric reinforced concrete structures with directional earthquake loading. Structural eccentricity was introduced at different levels to investigate the torsional behaviour. The authors noted that the high eccentricity induced into tall buildings results in larger rotations of the floor, greater lateral displacement and greater torsional irregularity.

Sirsat and Pandit (2026) have studied seismic behavior of irregular high-rise RCC structure with and without shear wall with the consideration of P-Delta effect. Seismic loading was analysed on different irregular plan configurations. The study revealed that the irregularity affects the torsional response and the storey deformations in a negative way, while the shear walls have a positive effect on the lateral stiffness and excessive movement of the structure.

2.6 Research gap

While there are many studies dealing with the impact of P-Delta effects, the influence of seismic response and structural irregularities in tall R/C structures, few studies have addressed the impact of core eccentricity on amplifying P-Delta effects and torsional effects. In most of the previous studies, the irregularities in the general plan or the stiffness irregularities or the general behaviour of the P-Delta action on the maximum displacement and on storey drift are investigated. The direct connection among the position of the structural core and the torsional response due to the P-Delta effect has not been well explored.

In addition, few studies have been conducted with simple, regular plan configurations, with only the location of the cores changed and geometry, loading and structural properties kept the same. This is relevant to make it clear how the core eccentricity, independently, influences P-Delta sensitivity, torsional irregularity, storey drift and diaphragm rotation.

Hence, it is required to conduct a study of the effect of core eccentricities on seismic and second order behaviour of tall RC buildings. The main objective of the present study is to fill this gap by analysing regular tall building models with different core locations with the ETABS software while keeping all other parameters of the structural model constant, such as height, member sizes and grid spacing.

CHAPTER 3
METHODOLOGY

3.1 Introduction

The present study investigates the influence of core eccentricity on the seismic and P-delta behaviour of tall reinforced concrete buildings using ETABS software. A regular building having a constant grid spacing and same member sizes with different configurations is modelled and we introduce different core positions in the building to study the effect of said eccentricity and its effect of different parameters.

Three different models M1, M2, M3 are modelled with three different core locations and all three models are studied under the influence of P-delta effect ON and OFF.

After the analysis, we study the parameters to get a better understanding as to how differently the models are behaving.

The results obtained from ETABS output is then put carefully into graphs, tables and comparative discussions to identify the relationship between secondary order effects and core eccentricity that we have introduced in the models.

3.2 Description of the building

3.2.1 Building Geometry

Plan – 40m x 40m

Grid spacing – 5 grids spaced at 8m evenly

Number of storeys – G+13

Storey height – 4m

Total height – 52.5m

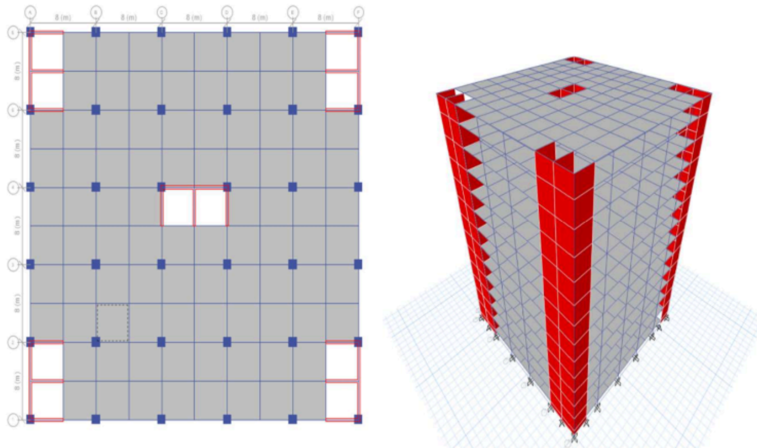
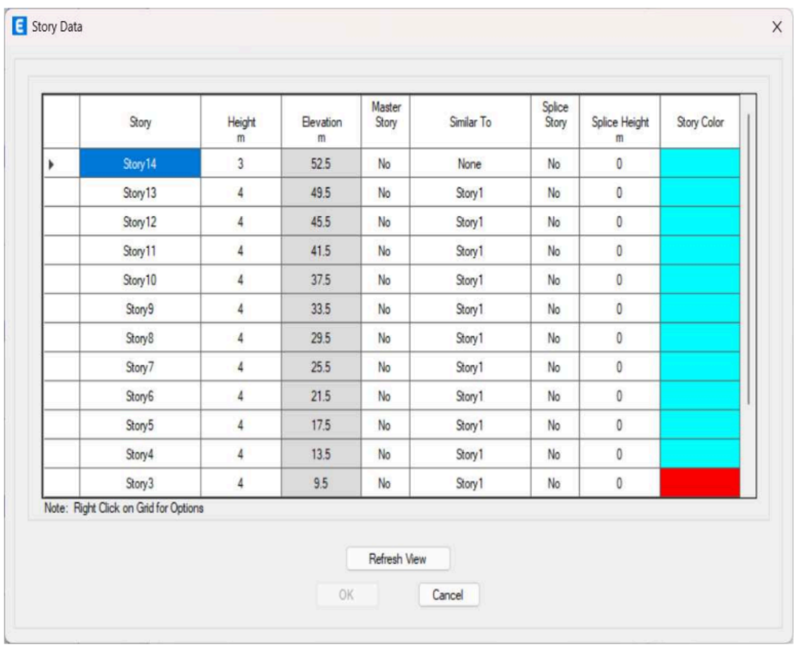


Fig. 3.2.1(a) Plan and 3-D view of Model M1 (reference model)



Story Data

	Story	Height m	Elevation m	Master Story	Similar To	Splice Story	Splice Height m	Story Color
▸	Story14	3	52.5	No	None	No	0	
	Story13	4	49.5	No	Story1	No	0	
	Story12	4	45.5	No	Story1	No	0	
	Story11	4	41.5	No	Story1	No	0	
	Story10	4	37.5	No	Story1	No	0	
	Story9	4	33.5	No	Story1	No	0	
	Story8	4	29.5	No	Story1	No	0	
	Story7	4	25.5	No	Story1	No	0	
	Story6	4	21.5	No	Story1	No	0	
	Story5	4	17.5	No	Story1	No	0	
	Story4	4	13.5	No	Story1	No	0	
	Story3	4	9.5	No	Story1	No	0	

Note: Right Click on Grid for Options

Refresh View

OK Cancel

Fig. 3.2.1(b) Storey heights defined in ETABS

3.2.2 Structural components

Primary beams – 350mm x 850mm

Secondary beams – 300mm x 600mm

Columns – 1000mm x 1000mm

Slabs – 150mm

Foundation – Fixed joint

Shear walls – 300mm

Bricks – Aerated Autoclaved Concrete (AAC)

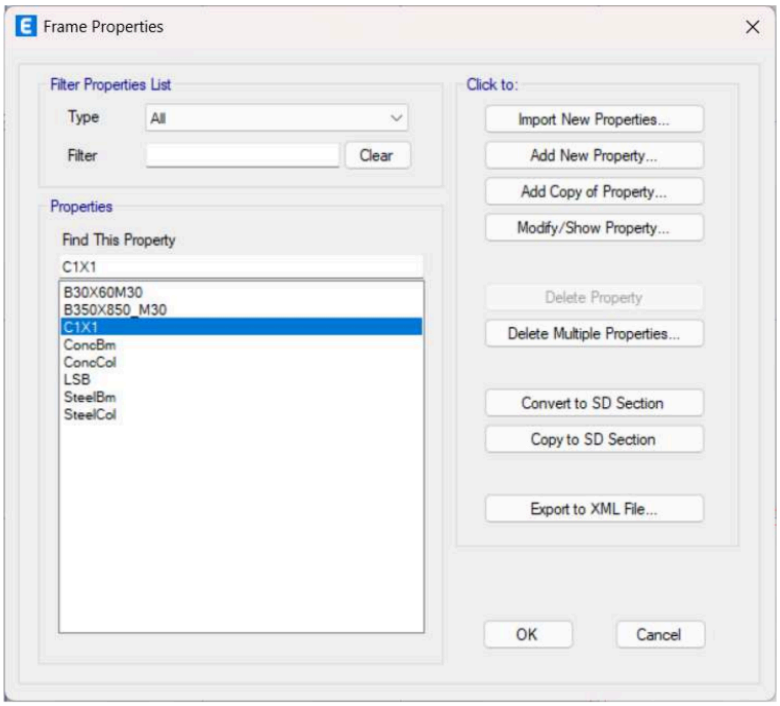


Fig. 3.2.2 Member sizes defined in all three models.

3.2.3 Material properties

Concrete mix – M30

Rebar properties – HYSD 550

Steel grade – FE250

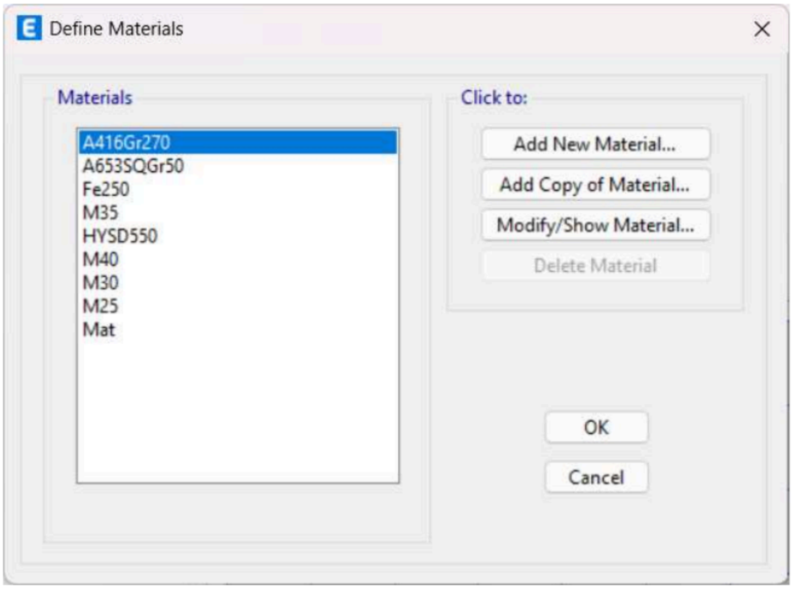


Fig. 3.2.3 Material properties defined in all three models

3.3 Loading details

3.3.1 Loads

Dead load consists of the load of all structural members and the self-weight of all the building and its components.

Floor finish – 1kN/ m^2

Live load – 4kN/ m^2

Wall loads on primary beams – 7kN/ m

Wall loads on secondary beams – 5.5 kN/m

3.3.2 Loads definition

3.3.2.1 Load pattern and Load cases

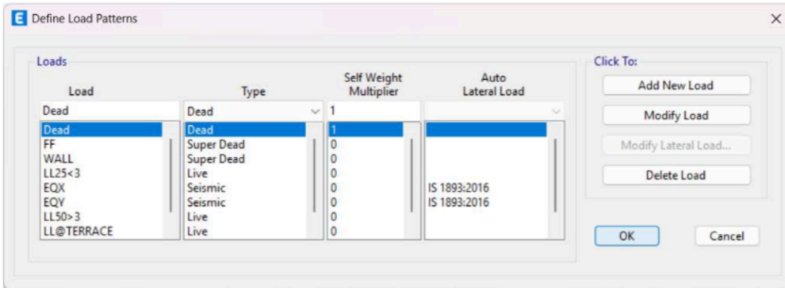


Fig. 3.3.2.1(a) Load Patterns defined in ETABS

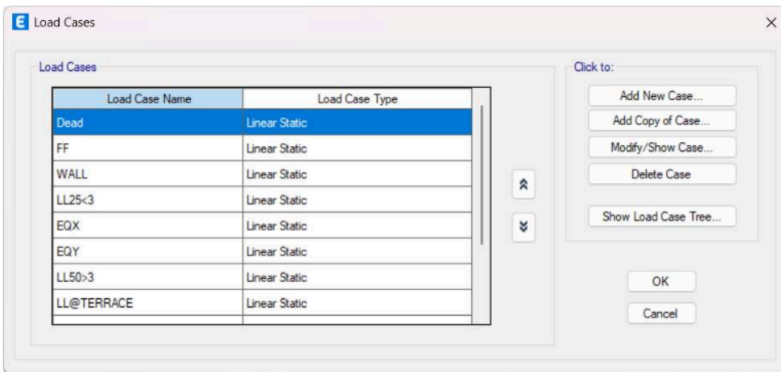


Fig. 3.3.2.1(b) Load cases defined in ETABS

Load Cases: The structure was subjected to gravity loads (dead and live loads) and seismic loads as per Indian code provisions

Load patterns: They are defined loads which we have used to load the building with in accordance to IS 875 Part 1 and Part 2.

Seismic loads are defined in accordance to IS 1893:2016

3.3.2.2 Load combinations

Appropriate load combinations were formulated to reflect the worst-case scenarios based on IS 1893 (Part 1):2016 and IS 456: 2016.

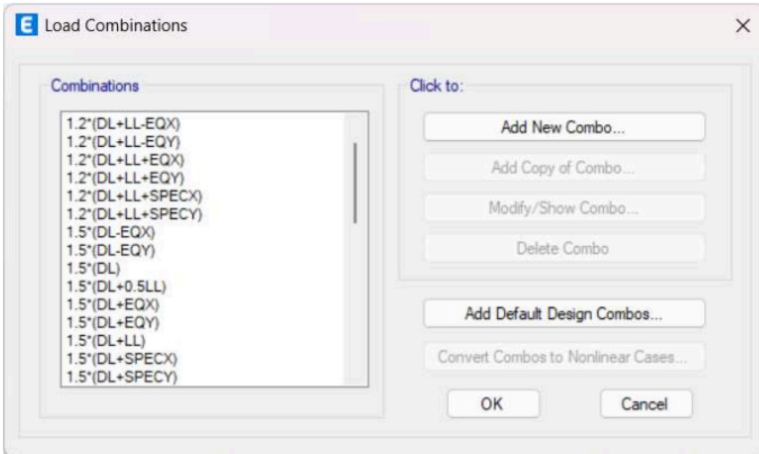


Fig. 3.3.2.2 Load combinations defined in ETABS

3.3.2.3 Mass source

The mass source for dynamic analysis was defined considering the slab and structural mass distribution.

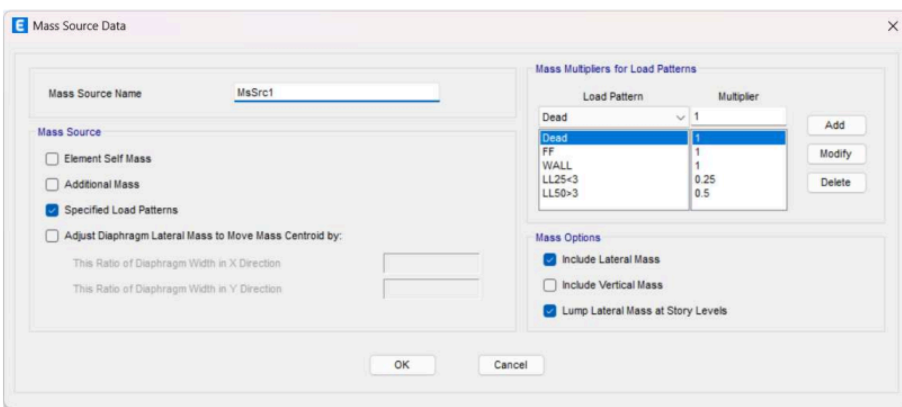


Fig. 3.3.2.3 Mass source defined in ETABS

3.4 Response Spectrum Analysis

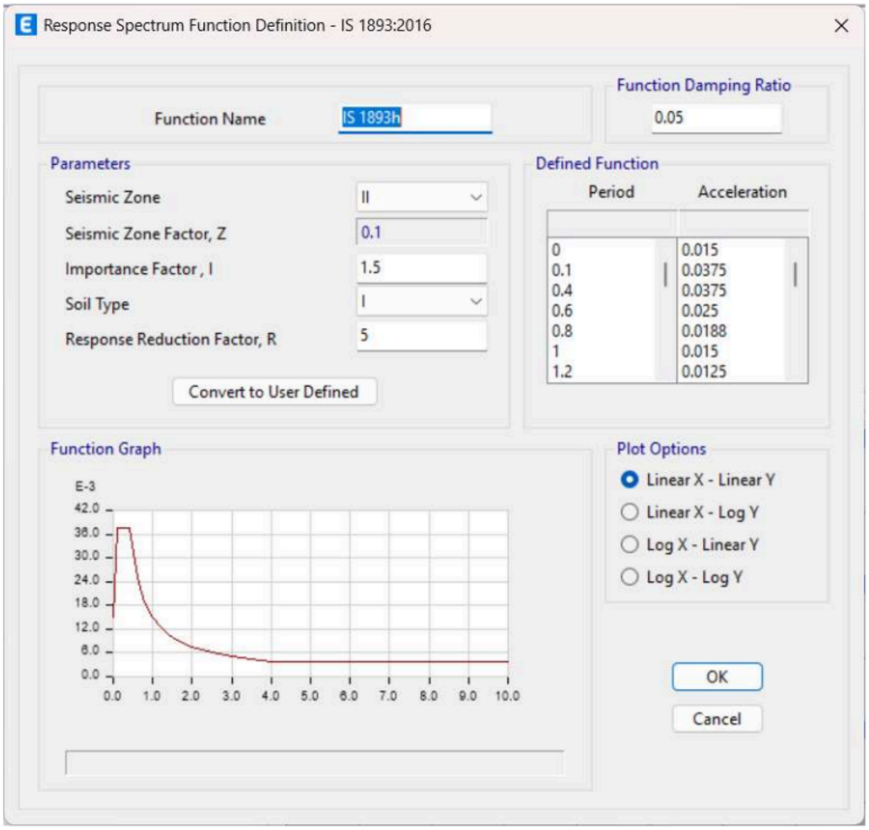


Fig. 3.4 Response spectrum parameters defined

Response spectrum is defined to capture the maximum expected structural response such as displacement, acceleration and forces at different vibration frequencies during an earthquake. It simplifies dynamic seismic analysis by providing peak values without performing full time-history simulations, enabling efficient and accurate design of earthquake-resistant structure. This method uses less computational power than Time-History method, which is advantageous to our project.

3.5 Description of Three models

3.5.1 M1

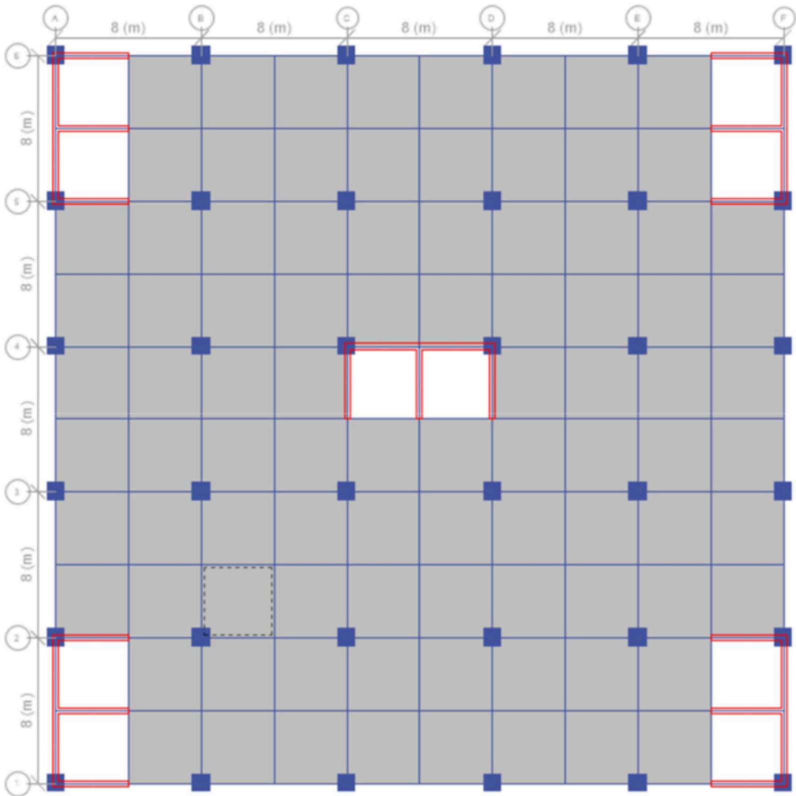


Fig. 3.5.1 Plan view of Model M1

Model M1 has 5 cores located at equidistant spots in such a way that there is not much eccentricity introduced in the structure. Cores consist of shear walls for lift shafts and staircases. This type of arrangement keeps the center of mass and center of rigidity relatively close to each other.

3.5.2 M2

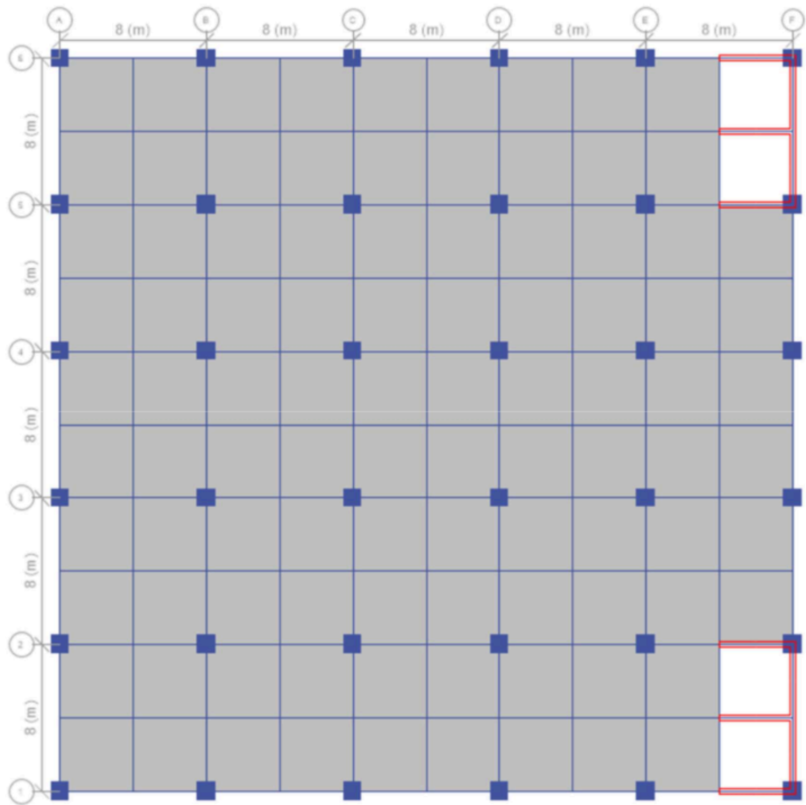


Fig. 3.5.2 Plan view of Model M2

Model M2 has two cores located on one side of the building. This type of arrangement creates an unsymmetrical arrangement and causes stiffness irregularity in the plan which gives us a higher eccentricity than M1 to give us a better idea as to how core locations affect our parameters. This arrangement makes the building more susceptible to torsional moments.

3.5.3 M3

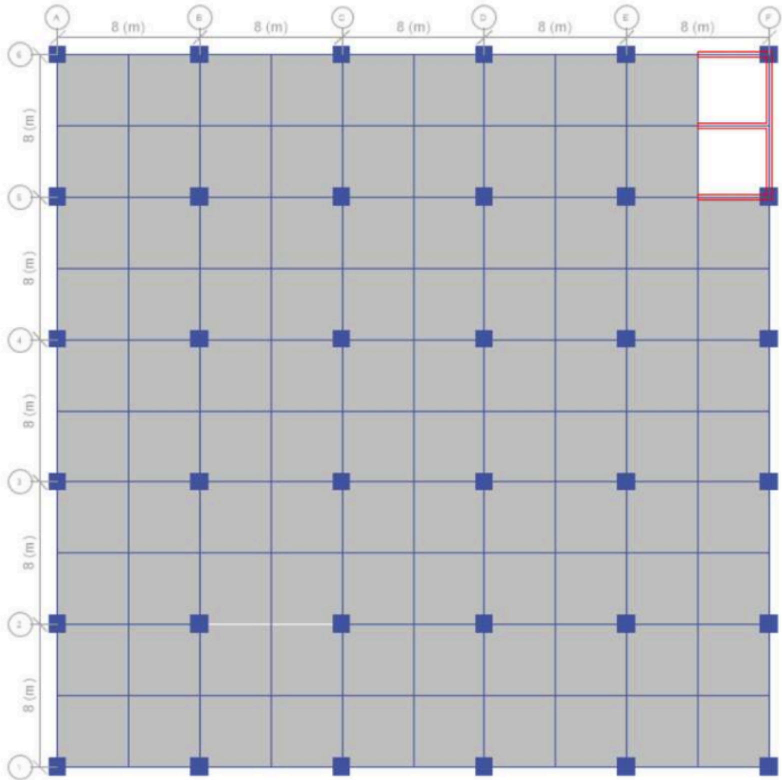


Fig. 3.5.3 Plan view of Model M3

Model M3 has one core concentrated at one end of the building, many architectural constraints can cause us to have such arrangements. This type of configuration can elevate the secondary order effects even higher than M2 and cause the building to be highly unstable. This configuration causes the most separation between center of mass and center of rigidity, causing the higher eccentricity.

3.6 P-delta settings

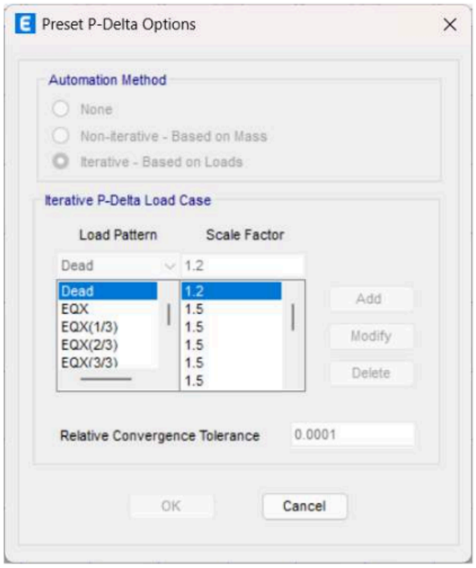


Fig. 3.6 P-delta settings and parameters opted in ETABS

P-delta setting was used in this modelling in accordance to the provisions mentioned in IS 16700: 2023, which is the IS Code for tall buildings. We used the iterative P-delta method based on gravity loads. This helps in getting a better understanding and analysis of the structure.

3.7 Parameters considered for comparison

Seismic behaviour of the buildings was studied and some important parameters were selected to compare the relationship between core eccentricity and second order effects.

The parameters considered are:

- Torsional moment
- Storey drift
- Max displacement
- Overturning moment

3.8 Validation of model consistency and pre-analysis checks

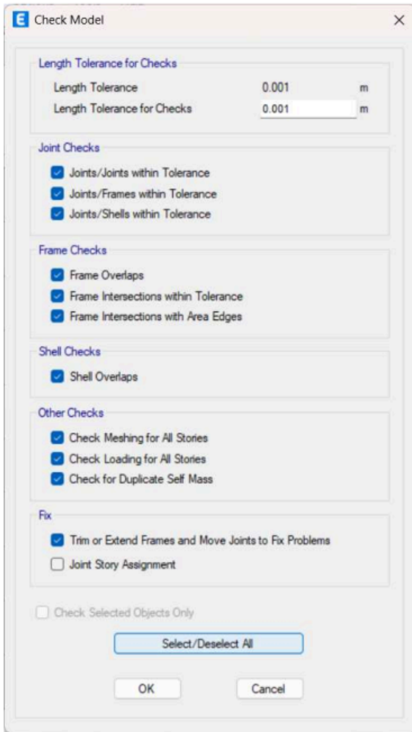


Fig. 3.8 Check Model dialogue box

The ETABS model is subjected to various pre-analysis checks so as to confirm that joints and diaphragms are properly connected to one another. To ensure that load path is uninterrupted. The model is also checked for irregularities in stiffness and orphan nodes. It is also checked for unintentional moment or member releases at places where it is not required. These checks ensure that any modelling error does not creep in and don't affect the structural analysis of the model.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter represents the results and findings of the research we've done in this project. We study the graphs, tables and other technical data that we've obtained from the ETABS software such as Maximum displacement, Storey drift variation, Torsional moment and overturning moment of the building.

In this chapter, we'll objectively come to a conclusion as to which configuration is better amongst the three models we've designed. We'll state which configuration, with the help ETABS output, is best structurally and how architects and designers should keep important influences like eccentricities in mind while planning a building, especially high-rise, as tall buildings are susceptible to secondary order effects such as P-delta due to increased axial loading and lateral displacements.

We've considered many load cases in the analysis of these models but we'll focus on couple of cases specifically as they give us the most critical data regarding most of the parameters. The load combinations we've taken into consideration are combinations we've taken into account due to Response Spectrum analysis in accordance to provisions in IS 1893: 2016.

Two critical combinations we've considered are:

- 1.5*(DL+SPECX)
- 1.5*(DL+SPECY)

While these combinations provide highest values for torsion and top storey displacement, these are NOT the only combinations we've considered. These are two of many combinations we've used for analysis.

4.2 Results of Model M1

4.2.1 Torsional moment

With P-delta iterative effect-

TABLE: Base Reactions				
Output Case	Case Type	MX	MY	MZ
		kN-m	kN-m	kN-m
Dead	LinStatic	5088517.533	-5069969	-0.6143
FF	LinStatic	449929.1712	-450876.3003	-0.0821
WALL	LinStatic	556172.7063	-540165.9113	-0.0254
LL25<3	LinStatic	0	0	0
EQX	LinStatic	0.0159	-42493.3031	73950.8422
EQX	LinStatic	0.0159	-42493.3031	73950.8422
EQX	LinStatic	0.0159	-42493.3031	73950.8422
EQY	LinStatic	31944.5275	0.0079	-55390.0194
EQY	LinStatic	31944.5275	0.0079	-55390.0194
EQY	LinStatic	31944.5275	0.0079	-55390.0194
LL50>3	LinStatic	1551660.817	-1555186	-0.3088
LL@TERRACE	LinStatic	0	0	0
EARTHPRESSURE	LinStatic	0	0	0
SPEC-Y	LinRespSpec	571731.4914	710.499	349042.4421
SPEC-X	LinRespSpec	921.4372	676871.4862	394394.4165
1.5*(DL+SPECX)	Combination	9143311.272	-8076210	591590.542
1.5*(DL+SPECX)	Combination	9140546.961	-10106824	-591592.7073
1.5*(DL+SPECY)	Combination	9999526.354	-9090451	523562.5804
1.5*(DL+SPECY)	Combination	8284331.879	-9092582	-523564.7457

Table. 4.2.1 (a) Base reaction table M1 with P-delta

Without P-delta iterative effect-

TABLE: Base Reactions				
Output Case	Case Type	MX	MY	MZ
		kN-m	kN-m	kN-m
Dead	LinStatic	4765382.397	-4746698	0
FF	LinStatic	449952	-450880	0
WALL	LinStatic	556192	-540176	0
LL25<3	LinStatic	0	0	0
EQX	LinStatic	0	-40234.894	70493.0036
EQX	LinStatic	0	-40234.894	70493.0036
EQX	LinStatic	0	-40234.894	70493.0036
EQY	LinStatic	30285.6956	0	-52787.957
EQY	LinStatic	30285.6956	0	-52787.957
EQY	LinStatic	30285.6956	0	-52787.957
LL50>3	LinStatic	1551744	-1555200	0
LL@TERRACE	LinStatic	0	0	0
EARTHPRESSURE	LinStatic	0	0	0
SPEC-X	LinRespSpec	748.7823	575855.7298	350252.7302
SPEC-Y	LinRespSpec	498883.2275	577.3596	316114.4736
1.5*(DL+SPECX)	Combination	8658412.77	-7742847	525379.0953
1.5*(DL+SPECX)	Combination	8656166.423	-9470414	-525379.0953
1.5*(DL+SPECY)	Combination	9405614.437	-8605765	474171.7104
1.5*(DL+SPECY)	Combination	7908964.755	-8607497	-474171.7104

Table. 4.2.1(b) Base reaction table M1 without P-delta

Difference in Torsional moment (MZ) considering 1.5 (DL+SPECX)

%change = $\frac{(With\ P-delta-Without\ P-del\quad)}{(With\ P-del\quad)}$

%change = $\frac{(591{,}590-525{,}379)}{(591{,}590)}$

%change = **11.192%** change in torsion between the two configurations.

-Difference in Torsional moment (MZ) considering 1.5 (DL+SPECY)

%change = $\frac{(With\ P-delta-Withou\quad P-delta)}{(With\ P-del\quad)}$

%change = $\frac{(523{,}56\qquad {,}171)}{(523{,}562)}$

%change = **9.434%** change in torsion between the two configurations.

This result clearly shows how P-delta, even without much core eccentricity, increases secondary order effects like Torsion by substantial amount of **11.192%** and **9.434%** in principal directions of X and Y respectively. As even a symmetric building undergoes lateral sway due to seismic excitation, gravity loads start to produce torsion in the building, which we know as the P-delta effect.

This result shows how P-delta can affect tall high-rise buildings, and significantly influence the torsional moment in the building. We'll see ahead how much this effect increases in buildings with asymmetrical cores.

4.2.2 Maximum displacement (X-displacement)

With P-delta iterative effect-

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.050859	-0.050958	0.002667	-0.006254
Story13	49.5	Top	0.048208	-0.048298	0.002477	-0.005762
Story12	45.5	Top	0.044462	-0.04454	0.002267	-0.005166
Story11	41.5	Top	0.040498	-0.040566	0.002118	-0.004586
Story10	37.5	Top	0.036305	-0.036361	0.00197	-0.004041
Story9	33.5	Top	0.031902	-0.031948	0.001805	-0.003498

Table. 4.2.2(a) Maximum X-displacement M1 with P-delta

Without P-delta iterative effect-

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.045478	-0.045592	0.00243	-0.005795
Story13	49.5	Top	0.043257	-0.043361	0.002251	-0.005341
Story12	45.5	Top	0.040142	-0.040233	0.002063	-0.004802
Story11	41.5	Top	0.036804	-0.036882	0.001943	-0.004279
Story10	37.5	Top	0.033209	-0.033275	0.001838	-0.003798
Story9	33.5	Top	0.029379	-0.029432	0.001701	-0.003305

Table. 4.2.2(b) Maximum X-displacement M1 without P-delta

-Difference in X-displacement considering 1.5 (DL+SPECX)

$$\%\text{change} = \frac{(With\ P-delta-Without\ P-delta)}{(With\ P-del\quad)}$$

$$\%\text{change} = \frac{(50.958-4\ \ .592)}{(50.958)}$$

%change = **10.530%** change in X-displacement between the two configurations.

4.2.2 Maximum displacement (Y-displacement)

With P-delta iterative effect-

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.000445	-0.000669	0.031977	-0.035547
Story13	49.5	Top	0.000236	-0.000434	0.029967	-0.033324
Story12	45.5	Top	0.000246	-0.000298	0.027443	-0.030329
Story11	41.5	Top	0.000281	-0.000253	0.024745	-0.027181
Story10	37.5	Top	0.000281	-0.000238	0.021931	-0.023973
Story9	33.5	Top	0.000271	-0.000226	0.019058	-0.020735

Table. 4.2.2(c) Maximum Y- displacement M1 with P-delta

Without P-delta iterative effect-

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.000458	-0.000662	0.029898	-0.033259
Story13	49.5	Top	0.000224	-0.000414	0.028094	-0.031255
Story12	45.5	Top	0.000214	-0.000281	0.025895	-0.028625
Story11	41.5	Top	0.000257	-0.00024	0.02351	-0.025821
Story10	37.5	Top	0.00026	-0.000227	0.020981	-0.022921
Story9	33.5	Top	0.000253	-0.000214	0.018361	-0.019958

Table. 4.2.2(d) Maximum Y- displacement M1 without P-delta

-Difference in Y-displacement considering 1.5 (DL+SPECY)

$$\%\text{change} = \frac{(With\ P-delta-Without\ P-delta)}{(With\ P-del\quad)}$$

$$\%\text{change} = \frac{(35.547-33.259)}{(35.547)}$$

%change = **6.436%** change in Y-displacement between the two configurations.

Torsional irregularity ratio

$$\eta_t = \frac{\Delta \max}{\Delta avg}$$

where,

- Δmax = maximum displacement at one edge of diaphragm
- Δavg = average displacement of diaphragm edges

Left edge displacement at storey 14 = 50.859

Right edge displacement at storey 14 = 50.958

Δmax = 50.958

$\Delta avg = \frac{(50.859+ \quad .958)}{2}$ = 50.9085

$\eta_t = \frac{50.958}{50.9085}$ = 1.01

Table 4 Definitions of Irregular Buildings — Plan Irregularities (Fig. 3)

(*Clause* 7.1)

Sl No.	Irregularity Type and Description
(1)	(2)
i)	*Torsion Irregularity* To be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. Torsional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure

Table. 4.2.2(e) Definitions of irregular buildings

η_t < 1.2 states the building is pretty symmetric.

4.2.3 Storey drift (X-direction)

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.000967	0.000167
Story13	49.5	Top	0.001002	0.00016
Story12	45.5	Top	0.001067	0.000156
Story11	41.5	Top	0.001124	0.000152
Story10	37.5	Top	0.001169	0.000149
Story9	33.5	Top	0.001196	0.000145
Story8	29.5	Top	0.001204	0.00014
Story7	25.5	Top	0.001194	0.000133
Story6	21.5	Top	0.00116	0.000124

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.000809	0.000154
Story13	49.5	Top	0.000836	0.000146
Story12	45.5	Top	0.0009	0.000141
Story11	41.5	Top	0.000963	0.000138
Story10	37.5	Top	0.001017	0.000136
Story9	33.5	Top	0.001054	0.000133
Story8	29.5	Top	0.001075	0.000129
Story7	25.5	Top	0.001079	0.000124
Story6	21.5	Top	0.001061	0.000116

Table. 4.2.3(a) Maximum X- direction storey drift M1 with and without P-delta

-Difference in X-direction considering 1.5 (DL+SPECX)

$$\%\text{change} = \frac{(With\ P-delta - Without\ P-delta)}{(With\ P-delta)}$$

$$\%\text{change} = \frac{(0.001204-0.001079)}{(0.001204)}$$

%change = **10.382%** change in X-direction drift between the two configurations.

4.2.3 Storey drift (Y-direction)

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.000106	0.000801
Story13	49.5	Top	0.000046	0.000803
Story12	45.5	Top	0.000022	0.000822
Story11	41.5	Top	0.000014	0.000841
Story10	37.5	Top	0.000013	0.000848
Story9	33.5	Top	0.000012	0.00084
Story8	29.5	Top	0.000013	0.000818
Story7	25.5	Top	0.000013	0.000784
Story6	21.5	Top	0.000014	0.000738

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.000115	0.000716
Story13	49.5	Top	0.000046	0.000717
Story12	45.5	Top	0.00002	0.000735
Story11	41.5	Top	0.000013	0.000762
Story10	37.5	Top	0.000012	0.000777
Story9	33.5	Top	0.000011	0.000779
Story8	29.5	Top	0.000012	0.000767
Story7	25.5	Top	0.000012	0.000743
Story6	21.5	Top	0.000013	0.000707

Table. 4.2.3(b) Maximum X- direction storey drift M1 with and without P-delta

Difference in Y-direction considering 1.5 (DL+SPECY)

$$\%\text{change} = \frac{(With\ P{-}delta{-}Without\ P{-}del\quad)}{(With\ P{-}del\quad)}$$

$$\%\text{change} = \frac{(0.000848-0.000777)}{(0.000848)}$$

%change = **8.372%** change in Y-direction drift between the two configurations.

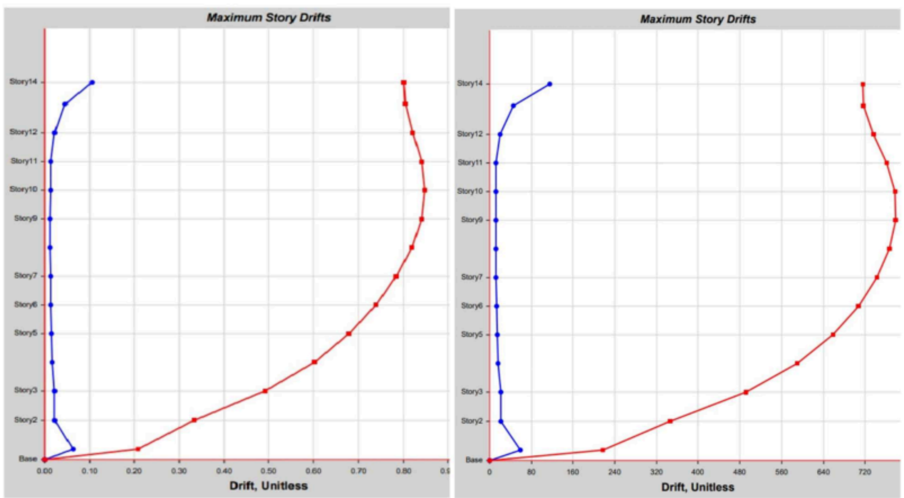


Fig. 4.2.3 Storey drift graphical comparison

These graphs clearly show that maximum storey drift occurs at the middle storeys and there is a concentration of lateral deformation pattern and stiffness distribution along the height of the building.

In tall buildings subjected to seismic activity, lower storeys are held in place with high stiffness because of the foundation and the higher storeys experience lesser shear force, so the relative displacement is maximum at the intermediate storeys. Presence of secondary order effects and torsion increase this in the building as we'll observe in further results.

P-delta amplification Coefficient

$$\mathbf{A.F} = \frac{\boldsymbol{DRIFT\ WITH\ P{-}DELTA}}{\boldsymbol{DRIFT\ WITHOUT\ P{-}DELTA}}$$

- X-Direction:

A.F = $\frac{\mathbf{0.001204}}{\mathbf{0.001075}} = \mathbf{1.12}$

This shows there is an **12%** of amplification due to P-delta in X-direction.

- Y-Direction:

A.F = $\frac{\mathbf{0.000848}}{\mathbf{0.000777}} = \mathbf{1.091}$

This shows there is an **9.1%** of amplification due to P-delta in Y-direction.

Alternatively,

$$\mathbf{A.F} = \frac{\mathbf{1}}{\mathbf{1-\theta}}$$

θ – Inter-storey drift stability coefficient

Putting these values of A.F in above equation,

- **X-direction,**

$\frac{\mathbf{1}}{\mathbf{1-\theta}} = 1.12$

θ = 0.12 for X-direction

- **Y-direction,**

$\frac{\mathbf{1}}{\mathbf{1-\theta}} = 1.091$

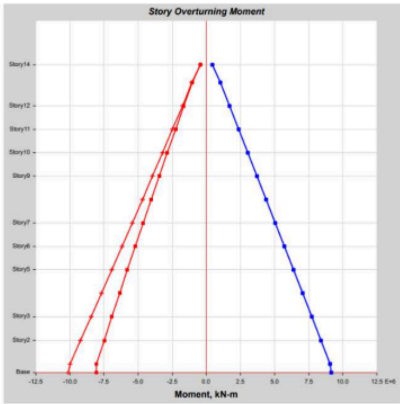
θ = 0.091 for Y-direction

Clause 7.3.10 of IS 1893:2016 states that Inter-storey stability index should be less than equal to 0.2.

4.2.4 Overturning moment (X-direction)

4.2.4.1 Overturning moment due to 1.5 (DL+SPECX)

With P-delta iterative effect



Tabulated Plot Coordinates

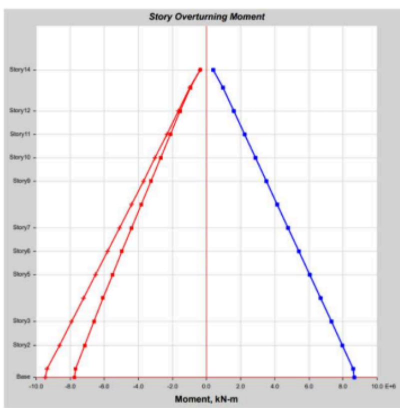
Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	421942.1689	421942.0715	-422435.4326	-422456.4868
Story13	49.5	Top	1040708.2862	1040670.4789	-1023744	-1052084
Story12	45.5	Top	1709614.0639	1709473.7609	-1648863	-1756872
Story11	41.5	Top	2378534.6257	2378252.3966	-2259222	-2476419
Story10	37.5	Top	3047464.4137	3047013.1777	-2859842	-3205707
Story9	33.5	Top	3716399.8488	3715760.4084	-3453897	-3941559
Story8	29.5	Top	4385339.6884	4384496.5108	-4043269	-4682093
Story7	25.5	Top	5054284.2518	5053222.932	-4628792	-5426478
Story6	21.5	Top	5723234.4612	5721940.9148	-5210465	-6174715
Story5	17.5	Top	6392189.6149	6390650.0835	-5787745	-6927339
Story4	13.5	Top	7061141.7959	7059342.6818	-6359879	-7685068
Story3	9.5	Top	7730107.3439	7728035.7811	-6926397	-8448422
Story2	5.5	Top	8399087.9529	8396731.6164	-7487354	-9217344
Story1	1.5	Top	9068083.92	9065432.1857	-8043584	-9990997
Base	0	Top	9143311.2723	9140546.9607	-8076210	-10106824

Fig 4.2.4.1(a) Overturning moment (X) with P-delta

Table 4.2.4.1(a) Overturning moment (X) with P-delta

Without P-delta iterative effect



Tabulated Plot Coordinates

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	387300.6969	387300.6969	-387804.5906	-387804.5906
Story13	49.5	Top	971428.6002	971393.3691	-955417.2631	-981849.3972
Story12	45.5	Top	1605700.2936	1605572.6451	-1548953	-1648942
Story11	41.5	Top	2239987.4855	2239736.4226	-2129809	-2328714
Story10	37.5	Top	2874283.8176	2873891.0598	-2703124	-3016028
Story9	33.5	Top	3508585.7241	3508040.1227	-3272060	-3707719
Story8	29.5	Top	4142892.2198	4142184.5962	-3838383	-4402025
Story7	25.5	Top	4777203.6759	4776324.1095	-4402676	-5098360
Story6	21.5	Top	5411520.5996	5410458.1552	-4964571	-5797093
Story5	17.5	Top	6045843.1415	6044586.5825	-5523058	-6499234
Story4	13.5	Top	6680171.3713	6678709.3221	-6076907	-7206014
Story3	9.5	Top	7314505.6699	7312825.9929	-6625173	-7918376
Story2	5.5	Top	7948846.4437	7946936.1884	-7167559	-8636619
Story1	1.5	Top	8583193.2637	8581040.3378	-7704644	-9360162
Base	0	Top	8658412.7695	8656166.4227	-7742847	-9470414

4.2.4.1(b) Overturning moment (X) without P-delta

Table 4.2.4.1(b) Overturning moment (X) without P-delta

Difference in X-direction considering 1.5 (DL+SPECX)

$$\%\text{change} = \frac{(9140546.9607 - 8656166.4227)}{(9140546.9607)}$$

%change = **5.230%** change in X-direction drift between the two configurations.

4.2.4 Overturning moment (Y-direction)

4.2.4.2 Overturning moment due to 1.5 (DL+SPECY)

With P-delta iterative effect

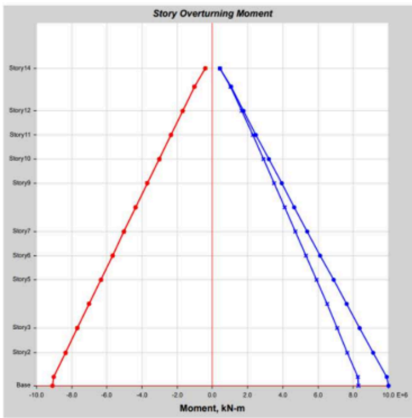


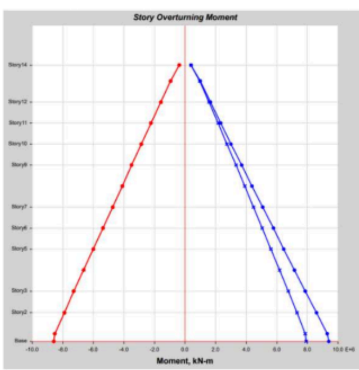
Fig 4.2.4.2(a) Overturning moment (Y) with P-delta

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	421946.5167	421937.7238	-422445.7608	-422446.1586
Story13	49.5	Top	1052222.885	1029155.8801	-1037899	-1037928
Story12	45.5	Top	1753871.5367	1665216.2881	-1702812	-1702923
Story11	41.5	Top	2468293.1583	2288493.8639	-2367709	-2367932
Story10	37.5	Top	3191370.2508	2903107.3406	-3032597	-3032952
Story9	33.5	Top	3920216.263	3511943.9942	-3697477	-3697978
Story8	29.5	Top	4653066.106	4116770.0932	-4362352	-4363010
Story7	25.5	Top	5389134.2126	4718372.9712	-5027222	-5028048
Story6	21.5	Top	6128418.8277	5316756.5484	-5692089	-5693091
Story5	17.5	Top	6871422.9284	5911416.7701	-6356947	-6358137
Story4	13.5	Top	7618783.2406	6501701.2372	-7021778	-7023169
Story3	9.5	Top	8370967.8869	7087175.2381	-7686609	-7688210
Story2	5.5	Top	9127946.5475	7667873.0218	-8351440	-8353258
Story1	1.5	Top	9889034.1745	8244481.9312	-9016268	-9018313
Base	0	Top	9999526.3536	8284331.8793	-9090451	-9092582

Table 4.2.4.2(a) Overturning moment (Y) with P-delta

Without P-delta iterative effect



4.2.4.2(b) Overturning moment (Y) without P-delta

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	387300.6969	387300.6969	-387804.5906	-387804.5906
Story13	49.5	Top	982148.4018	960673.5676	-968619.5963	-968647.064
Story12	45.5	Top	1646676.6098	1564596.3289	-1598896	-1598999
Story11	41.5	Top	2322441.8041	2157282.1039	-2229161	-2229362
Story10	37.5	Top	3005325.3705	2742849.5069	-2859420	-2859731
Story9	33.5	Top	3692475.3299	3324150.5168	-3489674	-3490105
Story8	29.5	Top	4382222.8681	3902853.9479	-4119926	-4120482
Story7	25.5	Top	5073967.392	4479560.3934	-4750174	-4750862
Story6	21.5	Top	5767983.9351	5053994.8196	-5380419	-5381246
Story5	17.5	Top	6465114.0543	5625315.6698	-6010659	-6011633
Story4	13.5	Top	7166347.4086	6192533.2848	-6640896	-6642025
Story3	9.5	Top	7872426.6474	6754905.0153	-7271127	-7272422
Story2	5.5	Top	8583519.9676	7312262.6645	-7901352	-7902825
Story1	1.5	Top	9299066.422	7865167.1795	-8531573	-8533233
Base	0	Top	9405614.4374	7908964.7549	-8605765	-8607497

Table 4.2.4.2(b) Overturning moment (Y) without P-delta

Difference in Y-direction considering 1.5 (DL+SPECY)

%change = $\frac{(With\ P-delta-Without\ P-del\quad)}{(With\ P-delta)}$

%change = $\frac{(9092582-860\qquad)}{(9092582)}$

%change =**5.345%** change in Y-direction drift between the two configurations.

The overturning moment is not greatly affected in this Model M1 because factors effecting overturning moment are mainly the seismic weight and lateral displacement of the building, while displacement does change due P-delta and second order effects like torsion, the overall weight and base shear remains the same of the building.

Core eccentricity does separate the center of mass and rigidity but it does not greatly influence the global parameter such as overturning moment.

4.3 Results of Model M2

4.3.1 Torsional moment

With the P-delta iterative effect

TABLE: Base Reactions				
Output Case	Case Type	MX	MY	MZ
		kN-m	kN-m	kN-m
Dead	LinStatic	4698391.287	-4933091	2.2382
FF	LinStatic	495357.3405	-463525.2551	0.4034
WALL	LinStatic	599869.6695	-541466.5678	0.3841
LL25<3	LinStatic	0	0	0
EQX	LinStatic	-0.0981	-41386.3039	71429.741
EQX	LinStatic	-0.0981	-41386.3039	71429.741
EQX	LinStatic	-0.0981	-41386.3039	71429.741
EQY	LinStatic	31204.1254	-1.319	-54769.2951
EQY	LinStatic	31204.1254	-1.319	-54769.2951
EQY	LinStatic	31204.1254	-1.319	-54769.2951
LL50>3	LinStatic	1658870.613	-1596234	1.1107
LL@TERRACE	LinStatic	0	0	0
EARTHPRESSURE	LinStatic	0	0	0
SPEC-Y	LinRespSpec	319370.0108	305.3425	266812.1508
SPEC-X	LinRespSpec	393.8679	524478.1303	329970.2225
1.5*(DL+SPECX)	Combination	8691018.247	-8120407	494959.8722
1.5*(DL+SPECX)	Combination	8689836.643	-9693842	-494950.7952
1.5*(DL+SPECY)	Combination	9169482.461	-8906666	400222.7647
1.5*(DL+SPECY)	Combination	8211372.429	-8907582	-400213.6877

Table. 4.3.1 (a) Base reaction table M2 with P-delta

Without the P-delta iterative effect

TABLE: Base Reactions				
Output Case	Case Type	MX	MY	MZ
		kN-m	kN-m	kN-m
Dead	LinStatic	4375107.677	-4610658	0.00000246
FF	LinStatic	495360	-463680	0
WALL	LinStatic	599872	-541632	0
LL25<3	LinStatic	0	0	0
EQX	LinStatic	0	-38892.8275	67973.2372
EQX	LinStatic	0	-38892.8275	67973.2372
EQX	LinStatic	0	-38892.8275	67973.2372
EQY	LinStatic	29275.4925	0	-52175.597
EQY	LinStatic	29275.4925	0	-52175.597
EQY	LinStatic	29275.4925	0	-52175.597
LL50>3	LinStatic	1658880	-1596672	0.000001348
LL@TERRACE	LinStatic	0	0	0
EARTHPRESSURE	LinStatic	0	0	0
SPEC-X	LinRespSpec	370.6724	427166.7689	281897.5072
SPEC-Y	LinRespSpec	262242.5262	290.0575	246995.52
1.5*(DL+SPECX)	Combination	8206065.524	-7783205	402846.2609
1.5*(DL+SPECX)	Combination	8204953.507	-9064705	-402846.2609
1.5*(DL+SPECY)	Combination	8598873.305	-8423520	340493.28
1.5*(DL+SPECY)	Combination	7812145.726	-8424390	-340493.28

Table. 4.3.1 (b) Base reaction table M2 without P-delta

-Difference in Torsional moment (MZ) considering 1.5 (DL+SPECX)

%change = $\frac{(With\ P-delta-With\quad P-delta)}{(With\ P-del\quad)}$

%change = $\frac{(494959.8722-40284\quad .2609)}{(494959.8722)}$

%change = **18.619%** change in torsion between the two configurations.

-Difference in Torsional moment (MZ) considering 1.5 (DL+SPECY)

%change = $\frac{(With\ P-delta-Without\ P-delta)}{(With\ P-delta)}$

%change = $\frac{(400222.7647-340493.28)}{(400222.7647)}$

%change = **14.923%** change in torsion between the two configurations.

This result shows that with a little eccentricity introduced in the system of models, percent change in torsion can increase substantially from **11.192%** and **9.434%** to **18.619%** and **14.92%** in principal directions of X and Y. We'll further see as to how a little eccentricity can affect other parameters as well.

Asymmetric core introduces separation between center of mass and center of rigidity, which causes an eccentricity to develop in the building and torsional moments as well as second order effects are amplified.

4.3.2 Maximum displacement (X-displacement)

With P-delta iterative effect-

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.04896	-0.073177	0.000259	-0.000257
Story13	49.5	Top	0.047558	-0.069795	0.000166	-0.000161
Story12	45.5	Top	0.045345	-0.064895	0.000095	-0.00012
Story11	41.5	Top	0.042618	-0.059456	0.000093	-0.000096
Story10	37.5	Top	0.039423	-0.053709	0.000094	-0.000084
Story9	33.5	Top	0.035781	-0.047653	0.000121	-0.000099
Story8	29.5	Top	0.031711	-0.041313	0.000145	-0.000123

Table. 4.3.2(a) Maximum X- displacement M2 with P-delta

Without P-delta iterative effect-

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.042024	-0.064073	0.000272	-0.000264
Story13	49.5	Top	0.041061	-0.061296	0.000166	-0.000158
Story12	45.5	Top	0.039436	-0.057221	0.000088	-0.00011
Story11	41.5	Top	0.037322	-0.052636	0.000085	-0.000087
Story10	37.5	Top	0.034756	-0.047748	0.000097	-0.000079
Story9	33.5	Top	0.031759	-0.042558	0.000126	-0.000105
Story8	29.5	Top	0.028355	-0.03709	0.00015	-0.000129

Table. 4.3.2(b) Maximum X- displacement M2 without P-delta

Difference in X-displacement considering 1.5 (DL+SPECX)

%change = $\frac{(With\ P-delta-Withou\ \ P-delta)}{(With\ P-del\ \ \ )}$

%change = $\frac{(73.177-64.073)}{(73.177)}$

%change = **12.455%** change in X-displacement between the two configurations

4.3.2 Maximum displacement (Y-displacement)

With P-delta iterative effect-

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.018352	-0.042415	0.064204	-0.064201
Story13	49.5	Top	0.018266	-0.040463	0.062756	-0.062754
Story12	45.5	Top	0.018158	-0.037707	0.059987	-0.059985
Story11	41.5	Top	0.017768	-0.034608	0.056422	-0.05642
Story10	37.5	Top	0.017048	-0.031336	0.052248	-0.052247
Story9	33.5	Top	0.016021	-0.027897	0.047534	-0.047533
Story8	29.5	Top	0.014692	-0.024298	0.042311	-0.04231

Table. 4.3.2(c) Maximum Y- displacement M2 with P-delta

Without P-delta iterative effect-

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.014625	-0.036479	0.055139	-0.055138
Story13	49.5	Top	0.014637	-0.03483	0.054059	-0.054058
Story12	45.5	Top	0.014733	-0.032514	0.051876	-0.051875
Story11	41.5	Top	0.014586	-0.0299	0.048989	-0.048989
Story10	37.5	Top	0.014148	-0.027144	0.045565	-0.045565
Story9	33.5	Top	0.013442	-0.024245	0.041661	-0.041661
Story8	29.5	Top	0.012467	-0.021208	0.037307	-0.037308

Table. 4.3.2(d) Maximum Y- displacement M2 without P-delta

Difference in Y-displacement considering 1.5 (DL+SPECY)

%change = $\frac{(With\ P-delta-Withou\ \ P-delta)}{(Wit\ \ \ P-del\ \ \ )}$

%change = $\frac{(64.204-55.138)}{(64.204)}$

%change = **14.110%** change in Y-displacement between the two configurations

Torsional irregularity ratio

$$\eta_t = \frac{\Delta m}{\Delta av}$$

where,

- Δmax = maximum displacement at one edge of diaphragm
- Δavg = average displacement of diaphragm edges

Left edge displacement at storey 14 = 48.96

Right edge displacement at storey 14 = 73.177

Δmax = 73.177

$\Delta avg = \frac{(48.96+7\ .177)}{2}$ = 61.0685

$\eta_t = \frac{73.177}{61.0685}$ = **1.19**

Table 4 Definitions of Irregular Buildings — Plan Irregularities (Fig. 3)

(*Clause* 7.1)

Sl No.	Irregularity Type and Description
(1)	(2)
i)	*Torsion Irregularity* To be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. Torsional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure

Table. 4.3.2(e) Definitions of Torsional irregularity

η_t < 1.2 states the building is pretty symmetric and stable.

4.3.3 Storey drift (X-direction)

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.001101	0.000075
Story13	49.5	Top	0.001147	0.000026
Story12	45.5	Top	0.001289	0.000017
Story11	41.5	Top	0.001367	0.000012
Story10	37.5	Top	0.001431	0.00001
Story9	33.5	Top	0.001479	0.000009
Story8	29.5	Top	0.001511	0.000009
Story7	25.5	Top	0.00153	0.000008
Story6	21.5	Top	0.00153	0.000008
Story5	17.5	Top	0.001493	0.000008
Story4	13.5	Top	0.001389	0.000009

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.001332	0.000069
Story13	49.5	Top	0.001382	0.000023
Story12	45.5	Top	0.001534	0.000016
Story11	41.5	Top	0.001611	0.000012
Story10	37.5	Top	0.001672	0.000011
Story9	33.5	Top	0.001716	0.00001
Story8	29.5	Top	0.001741	0.00001
Story7	25.5	Top	0.00175	0.000009
Story6	21.5	Top	0.001733	0.000009
Story5	17.5	Top	0.001669	0.000009
Story4	13.5	Top	0.001525	0.00001

Table. 4.3.3(a) Maximum X- direction storey drift M2 with and without P-delta

-Difference in X-direction considering 1.5 (DL+SPECX)

%change = $\frac{(With\ P-delta-Without\ P-del\ \ )}{(With\ P-del\ \ )}$

%change = $\frac{(0.001733-0.00153)}{(0.001733)}$

%change = **11.712%** change in X-direction drift between the two configurations.

4.3.3 Storey drift (Y-direction)

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.000654	0.000517
Story13	49.5	Top	0.000678	0.000697
Story12	45.5	Top	0.000754	0.000917
Story11	41.5	Top	0.00079	0.001063
Story10	37.5	Top	0.000815	0.001169
Story9	33.5	Top	0.000832	0.00125
Story8	29.5	Top	0.000843	0.001321
Story7	25.5	Top	0.000854	0.001385
Story6	21.5	Top	0.000858	0.00144
Story5	17.5	Top	0.000847	0.001476
Story4	13.5	Top	0.000802	0.001472

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.000774	0.000635
Story13	49.5	Top	0.000804	0.000885
Story12	45.5	Top	0.00089	0.001128
Story11	41.5	Top	0.000933	0.001286
Story10	37.5	Top	0.000962	0.001399
Story9	33.5	Top	0.000983	0.00149
Story8	29.5	Top	0.000996	0.001568
Story7	25.5	Top	0.001005	0.001635
Story6	21.5	Top	0.001003	0.001684
Story5	17.5	Top	0.000979	0.001701
Story4	13.5	Top	0.000911	0.001662

Table. 4.3.3(b) Maximum Y- direction storey drift M2 with and without P-delta

Difference in Y-direction considering 1.5 (DL+SPECY)

$$\%change = \frac{(With\ P{-}delta{-}Without\ P{-}del\quad)}{(With\ P{-}delta)}$$

$$\%change = \frac{(0.001701-\ .001476)}{(0.001701}$$

%change = **13.222%** change in X-direction drift between the two configurations.

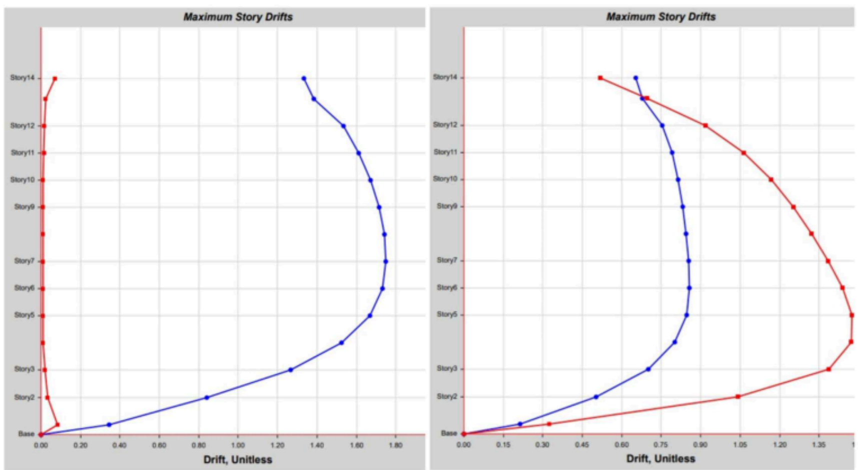


Fig. 4.3.3 Storey drift graphical comparison

Here, we see an important observation that storey drift is maximum at lower storeys compared to M1 where we saw intermediate storeys with maximum storey drift. This is attributed to concentration of lateral deformation in lower storeys due to combined factor of high seismic shear forces and irregular stiffness created by cores placed at the side of the building plan. Since lower storeys resist more gravity load of higher levels, irregular stiffness introduced by eccentric cores increase torsional demand, as we have seen, and storey drift increases at lower levels.

P-delta amplification Coefficient

$$\mathbf{A.F} = \frac{DRIFT\ WITH\ P-DELTA}{DRIFT\ WITHOUT\ P-DELTA}$$

- X-Direction:

A.F = $\frac{\mathbf{0.001173}}{\mathbf{0.001530}} = \mathbf{1.14}$

This shows there is an **14%** of amplification due to P-delta in X-direction.

- Y-Direction:

A.F = $\frac{\mathbf{0.001701}}{\mathbf{0.001476}} = \mathbf{1.15}$

This shows there is an **15%** of amplification due to P-delta in Y-direction.

Alternatively,

$$\mathbf{A.F} = \frac{1}{1-\theta}$$

θ – Inter-storey drift stability coefficient

Putting these values of A.F in above equation,

- **X-direction,**

$\frac{1}{1-\theta} = 1.14$

θ = 0.14 for X-direction

- **Y-direction,**

$\frac{1}{1-\theta} = 1.15$

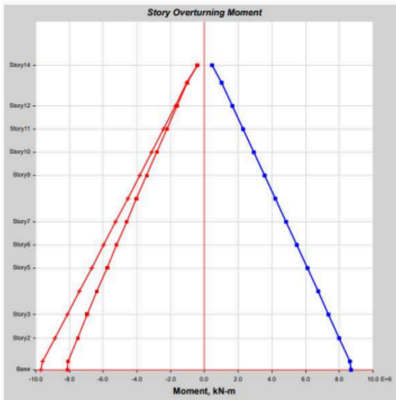
θ = 0.15 for Y-direction

Clause 7.3.10 of IS 1893:2016 states that Inter-storey stability index should be less than equal to 0.2.

4.3.4 Overturning moment (X-direction)

4.3.4.1 Overturning moment due to 1.5 (DL+SPECX)

With P-delta iterative effect



4.3.4.1(a) Overturning moment (X)

with P-delta

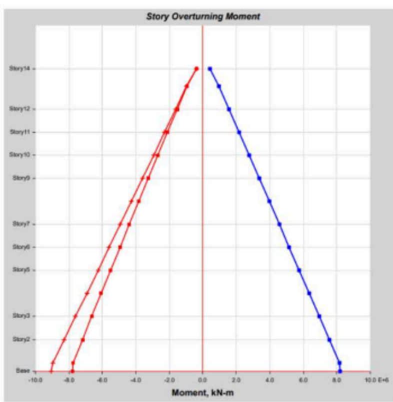
Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	437562.5111	437562.1061	-428474.7126	-428477.5921
Story13	49.5	Top	1035036.1428	1035019.2964	-1022407	-1046880
Story12	45.5	Top	1668514.7782	1668450.1845	-1639001	-1731431
Story11	41.5	Top	2302001.6813	2301872.9592	-2243770	-2427737
Story10	37.5	Top	2935494.0267	2935290.6039	-2841329	-3131196
Story9	33.5	Top	3568990.4524	3568704.5877	-3434567	-3838926
Story8	29.5	Top	4202489.8722	4202115.9607	-4025360	-4549061
Story7	25.5	Top	4835991.2946	4835525.0646	-4614576	-5260745
Story6	21.5	Top	5469493.7977	5468930.5388	-5202162	-5974042
Story5	17.5	Top	6102996.103	6102328.7593	-5787378	-6689701
Story4	13.5	Top	6736491.5717	6735710.9793	-6369043	-7408886
Story3	9.5	Top	7369993.3537	7369096.4415	-6946146	-8132693
Story2	5.5	Top	8003500.294	8002485.9956	-7518212	-8861621
Story1	1.5	Top	8637011.12	8635876.7263	-8085689	-9595237
Base	0	Top	8691018.2466	8689836.643	-8120407	-9693842

Table 4.3.4.1(a) Overturning moment (X)

with P-delta

Without P-delta iterative effect



4.3.4.1(b) Overturning moment (X)

without P-delta

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	402921.4015	402921.4015	-393851.315	-393851.315
Story13	49.5	Top	965755.2714	965738.551	-954227.6918	-976562.7955
Story12	45.5	Top	1564593.1653	1564530.4155	-1539795	-1622977
Story11	41.5	Top	2163438.5326	2163314.8067	-2115913	-2278841
Story10	37.5	Top	2762288.4505	2762094.6471	-2687007	-2939729
Story9	33.5	Top	3361141.6249	3360871.231	-3255635	-3603082
Story8	29.5	Top	3959997.2583	3959645.3561	-3823321	-4267378
Story7	25.5	Top	4558854.9783	4558417.3944	-4390608	-4932072
Story6	21.5	Top	5157714.9219	5157187.2091	-4957205	-5597457
Story5	17.5	Top	5756577.4331	5755954.4564	-5522196	-6264448
Story4	13.5	Top	6355442.8931	6354718.7547	-6084245	-6934380
Story3	9.5	Top	6954311.6142	6953479.792	-6642109	-7608498
Story2	5.5	Top	7553183.6265	7552237.538	-7195025	-8287563
Story1	1.5	Top	8152058.4541	8150992.4688	-7743052	-8971517
Base	0	Top	8206065.5243	8204953.507	-7783205	-9064705

Table 4.3.4.1(b) Overturning moment (X)

without P-delta

Difference in X-direction considering 1.5 (DL+SPECX)

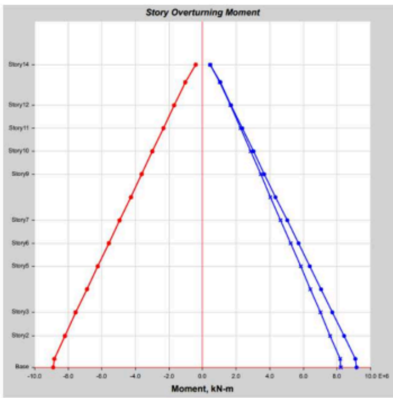
$$\%\text{change} = \frac{(8691018.2466 - 8204953.507)}{(8691018.2466)}$$

%change = **5.6%** change in X-direction drift between the two configurations.

4.3.4 Overturning moment (Y-direction)

4.3.4.1 Overturning moment due to 1.5 (DL+SPECY)

With P-delta iterative effect



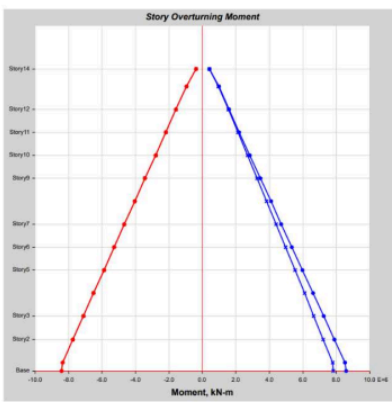
Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	437564.2093	437560.408	-428476.088	-428476.2166
Story13	49.5	Top	1041688.6048	1028366.8344	-1034636	-1034651
Story12	45.5	Top	1693607.263	1643357.6997	-1685189	-1685242
Story11	41.5	Top	2352227.4439	2251647.1966	-2335701	-2335805
Story10	37.5	Top	3015818.6828	2854965.9478	-2986180	-2986344
Story9	33.5	Top	3683338.8193	3454356.2208	-3636631	-3636862
Story8	29.5	Top	4353730.3936	4050875.4392	-4287060	-4287361
Story7	25.5	Top	5025922.6879	4645593.6713	-4937474	-4937847
Story6	21.5	Top	5699285.0095	5239139.3269	-5587879	-5588326
Story5	17.5	Top	6373839.2275	5831485.6348	-6238277	-6238801
Story4	13.5	Top	7050129.7553	6422072.7957	-6888661	-6889268
Story3	9.5	Top	7728910.9538	7010178.8414	-7539072	-7539767
Story2	5.5	Top	8410762.2508	7595224.0389	-8189523	-8190309
Story1	1.5	Top	9095678.4608	8177209.3855	-8840023	-8840902
Base	0	Top	9169482.4611	8211372.4285	-8906666	-8907582

4.3.4.1(c) Overturning moment (Y) with P-delta

Table 4.3.4.1(c) Overturning moment (Y) with P-delta

Without P-delta iterative effect



Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	402921.4015	402921.4015	-393851.315	-393851.315
Story13	49.5	Top	971957.1302	959536.6923	-965387.9534	-965402.534
Story12	45.5	Top	1587552.1344	1541571.4464	-1581360	-1581412
Story11	41.5	Top	2208473.6402	2118279.6991	-2197327	-2197427
Story10	37.5	Top	2832765.7296	2691617.368	-2813290	-2813445
Story9	33.5	Top	3459397.474	3262615.3819	-3429250	-3429467
Story8	29.5	Top	4087714.4945	3831928.1199	-4045208	-4045490
Story7	25.5	Top	4717219.673	4400052.6997	-4661165	-4661515
Story6	21.5	Top	5347724.5802	4967177.5509	-5277121	-5277541
Story5	17.5	Top	5979415.8703	5533116.0191	-5893075	-5893568
Story4	13.5	Top	6612788.4445	6097373.2034	-6509027	-6509598
Story3	9.5	Top	7248444.9566	6659346.4496	-7124976	-7125630
Story2	5.5	Top	7886897.6663	7218523.4983	-7740923	-7741665
Story1	1.5	Top	8528289.8048	7774761.1181	-8356868	-8357702
Base	0	Top	8598873.3049	7812145.7264	-8423520	-8424390

4.3.4.1(d) Overturning moment (Y) without P-delta

Table 4.3.4.1(d) Overturning moment (Y) without P-delta

Difference in Y-direction considering 1.5 (DL+SPECY)

$$\%change = \frac{(With\ P{-}delta - With \quad P{-}delta)}{(With\ P{-}delta)}$$

$$\%change = \frac{(8907582 - 842 \quad)}{8907582)}$$

%change = **5.43%** change in Y-direction drift between the two configurations.

As we have noted earlier, a global parameter like overturning moment is not greatly affected by secondary order effects or even torsion itself. Seismic weight of the building and base shear remain the same under both conditions and eccentricity developed is not enough to increase the lateral displacement so much that overturning moment gets affected.

We see similar value of %change in overturning moment in both principal directions in both models M1 and M2, as even with some eccentricity, the overall affects and forces are not enough to create much difference in overturning moment.

4.4 Results of Model M3

4.4.1 Torsional moment

With P-delta iterative effect

TABLE: Base Reactions				
Output Case	Case Type	MX	MY	MZ
		kN-m	kN-m	kN-m
Dead	LinStatic	4664531.028	-4678582	-1.3992
FF	LinStatic	498831.2499	-497031.8253	-0.3835
WALL	LinStatic	595264.6055	-534651.3142	-0.2369
LL25<3	LinStatic	0	0	0
EQX	LinStatic	-100.6498	-40876.0948	71185.0957
EQX	LinStatic	-100.6498	-40876.0948	71185.0957
EQX	LinStatic	-100.6498	-40876.0948	71185.0957
EQY	LinStatic	30744.625	75.9763	-53157.5934
EQY	LinStatic	30744.625	75.9763	-53157.5934
EQY	LinStatic	30744.625	75.9763	-53157.5934
LL50>3	LinStatic	1665640.271	-1662075	-0.4643
LL@TERRACE	LinStatic	0	0	0
EARTHPRESSURE	LinStatic	0	0	0
SPEC-X	LinRespSpec	231035.108	377412.7005	210923.4114
SPEC-Y	LinRespSpec	257941.5606	180609.0182	243990.838
1.5*(DL+SPECX)	Combination	8984492.988	-7999278	316382.0876
1.5*(DL+SPECX)	Combination	8291387.664	-9131516	-316388.1467
1.5*(DL+SPECY)	Combination	9024852.667	-8294484	365983.2274
1.5*(DL+SPECY)	Combination	8251027.985	-8836311	-365989.2865

Table. 4.4.1 (a) Base reaction table M3 with P-delta

Without P-delta iterative effect

TABLE: Base Reactions				
Output Case	Case Type	MX	MY	MZ
		kN-m	kN-m	kN-m
Dead	LinStatic	3784380.667	-3800224	0.000001022
FF	LinStatic	498880	-497120	0
WALL	LinStatic	595296	-534768	0
LL25<3	LinStatic	0	0	0
EQX	LinStatic	0.000001123	-34810.1273	61846.6122
EQX	LinStatic	0.000001123	-34810.1273	61846.6122
EQX	LinStatic	0.000001123	-34810.1273	61846.6122
EQY	LinStatic	26202.3536	-9.169E-07	-46141.932
EQY	LinStatic	26202.3536	-9.169E-07	-46141.932
EQY	LinStatic	26202.3536	-9.169E-07	-46141.932
LL50>3	LinStatic	1665792	-1662336	5.479E-07
LL@TERRACE	LinStatic	0	0	0
EARTHPRESSURE	LinStatic	0	0	0
SPEC-X	LinRespSpec	152153.4575	230154.4933	136621.351
SPEC-Y	LinRespSpec	156088.8271	119305.4287	194560.6565
1.5*(DL+SPECX)	Combination	7546065.186	-6902936	204932.0266
1.5*(DL+SPECX)	Combination	7089604.814	-7593400	-204932.0266
1.5*(DL+SPECY)	Combination	7551968.241	-7069210	291840.9847
1.5*(DL+SPECY)	Combination	7083701.759	-7427126	-291840.9847

Table. 4.4.1 (b) Base reaction table M3 with P-delta

Difference in Torsional moment (MZ) considering 1.5 (DL+SPECX)

%change = $\frac{(Wit \quad P-delta-Withou \quad P-delta)}{(With \; P-delta)}$

%change = $\frac{(316{,}382-204{,}932)}{(316{,}382)}$

%change = **35.223%** change in torsion between the two configurations.

-Difference in Torsional moment (MZ) considering 1.5 (DL+SPECY)

%change = $\frac{(With \; P-delta-Without \; P-del \quad)}{(With \; P-del \quad)}$

%change = $\frac{(365{,}983-291840)}{(365{,}983)}$

%change = **20.252%** change in torsion between the two configurations.

Here we can clearly see the eccentric behaviour of the building with only one core at the corner of plan. We see such architectural and space constrains all over the place and such behaviour of buildings is unsuited and dangerous to its stability.

Our earlier models had substantia; %change in their torsional moments but here we see about 3**5.223%** and **20.252%** increase in the moments in X and Y principal directions respectively which is not suitable for design or analysis.

4.4.2 Maximum displacement (X-displacement)

With P-delta iterative effect

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.062921	-0.083616	0.062676	-0.079304
Story13	49.5	Top	0.062094	-0.081538	0.06193	-0.07755
Story12	45.5	Top	0.060201	-0.077351	0.060176	-0.073904
Story11	41.5	Top	0.057526	-0.072288	0.057644	-0.069459
Story10	37.5	Top	0.054105	-0.066587	0.05436	-0.064367
Story9	33.5	Top	0.049995	-0.060329	0.050371	-0.058671

Table. 4.4.2(a) Maximum X- displacement M3 with P-delta

Without P-delta iterative effect

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.05119	-0.062008	0.04142	-0.049795
Story13	49.5	Top	0.050361	-0.060575	0.040848	-0.048757
Story12	45.5	Top	0.048741	-0.057841	0.039703	-0.046728
Story11	41.5	Top	0.046472	-0.054347	0.038031	-0.044099
Story10	37.5	Top	0.043616	-0.050296	0.035866	-0.041016
Story9	33.5	Top	0.040223	-0.045769	0.033248	-0.037537

Table. 4.4.2(b) Maximum X- displacement M3 without P-delta

Difference in X-displacement considering 1.5 (DL+SPECX)

%change = $\frac{(With\ P-delta-Wit\quad P-del\ )}{(With\ P-del\ )}$

%change = $\frac{(83.616-62.008)}{(83.616)}$

%change = **25.844%** change in X-displacement between the two configurations

4.4.2 Maximum displacement (Y-displacement)

With P-delta iterative effect

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.030242	-0.041072	0.043773	-0.052148
Story13	49.5	Top	0.029866	-0.040074	0.04319	-0.051099
Story12	45.5	Top	0.029135	-0.038235	0.042008	-0.049032
Story11	41.5	Top	0.028037	-0.035911	0.040259	-0.046327
Story10	37.5	Top	0.026577	-0.033255	0.037975	-0.043126
Story9	33.5	Top	0.024775	-0.030318	0.035197	-0.039486

Table. 4.4.2(c) Maximum Y- displacement M3 with P-delta

Without P-delta iterative effect

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		m	m	m	m
Story14	52.5	Top	0.044853	-0.065561	0.057295	-0.073931
Story13	49.5	Top	0.044528	-0.063972	0.0568	-0.072417
Story12	45.5	Top	0.04363	-0.060782	0.055498	-0.069225
Story11	41.5	Top	0.042155	-0.056916	0.053413	-0.065227
Story10	37.5	Top	0.04007	-0.052553	0.050562	-0.060568
Story9	33.5	Top	0.037433	-0.047768	0.047028	-0.055328

Table. 4.4.2(d) Maximum Y- displacement M3 without P-delta

Difference in X-displacement considering 1.5 (DL+SPECY)

$$\%\text{change} = \frac{(With\ P{-}delta{-}Witho\quad P{-}del\quad)}{(With\ P{-}delta)}$$

$$\%\text{change} = \frac{(73.931\qquad .148)}{(73.931)}$$

%change = **29.463%** change in X-displacement between the two configurations

Torsional irregularity ratio

$$\eta_t = \frac{\Delta max}{\Delta avg}$$

where,

- Δmax = maximum displacement at one edge of diaphragm
- Δavg = average displacement of diaphragm edges

Left edge displacement at storey 14 = 51.19

Right edge displacement at storey 14 = 83.616

$\Delta max = 83.616$

$\Delta avg = \frac{(83.616+51.19)}{2} = 67.403$

$\eta_t = \frac{83.616}{67.403} = \mathbf{1.24}$

Table 4 Definitions of Irregular Buildings — Plan Irregularities (Fig. 3)

(*Clause* 7.1)

Sl No.	Irregularity Type and Description
(1)	(2)
i)	*Torsion Irregularity* To be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. Torsional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure

Table. 4.4.2(e) Definitions of Irregular buildings

η_t > 1.2 states the building is asymmetric and it exhibits Torsional Irregularity.

4.4.3 Storey drift (X-direction)

Tabulated Plot Coordinates

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.00086	0.000463
Story13	49.5	Top	0.000893	0.000662
Story12	45.5	Top	0.001052	0.000848
Story11	41.5	Top	0.001198	0.000966
Story10	37.5	Top	0.001302	0.001051
Story9	33.5	Top	0.001384	0.001115
Story8	29.5	Top	0.001451	0.00117
Story7	25.5	Top	0.001509	0.001221
Story6	21.5	Top	0.001557	0.001271
Story5	17.5	Top	0.001592	0.001316
Story4	13.5	Top	0.001597	0.001342
Story3	9.5	Top	0.001521	0.0013

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.001497	0.000806
Story13	49.5	Top	0.001561	0.001216
Story12	45.5	Top	0.001684	0.001445
Story11	41.5	Top	0.001757	0.001579
Story10	37.5	Top	0.001828	0.001689
Story9	33.5	Top	0.001883	0.001792
Story8	29.5	Top	0.001965	0.001879
Story7	25.5	Top	0.002034	0.001947
Story6	21.5	Top	0.002076	0.002002
Story5	17.5	Top	0.002086	0.002042
Story4	13.5	Top	0.002063	0.002052
Story3	9.5	Top	0.001974	0.001979

Table. 4.4.3(a) Maximum X- direction storey drift M3 with and without P-delta

-Difference in X-direction considering 1.5 (DL+SPECX)

$$\%\text{change} = \frac{(With\ P{-}delta - Withou\ \ P{-}delta)}{(With\ P{-}del\ \ )}$$

$$\%\text{change} = \frac{(0.002086 - 0.001597)}{(0.002086)}$$

%change = **23.441%** change in X-direction drift between the two configurations.

4.4.3 Storey drift (Y-direction)

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.000655	0.000587
Story13	49.5	Top	0.000675	0.000647
Story12	45.5	Top	0.000753	0.000845
Story11	41.5	Top	0.000839	0.000977
Story10	37.5	Top	0.000888	0.001072
Story9	33.5	Top	0.000922	0.001147
Story8	29.5	Top	0.000954	0.001214
Story7	25.5	Top	0.000988	0.001277
Story6	21.5	Top	0.001024	0.001335
Story5	17.5	Top	0.001055	0.001384
Story4	13.5	Top	0.001071	0.001408
Story3	9.5	Top	0.001033	0.001358

Story Response Values

Story	Elevation	Location	X-Dir	Y-Dir
	m			
Story14	52.5	Top	0.001126	0.000863
Story13	49.5	Top	0.001176	0.000987
Story12	45.5	Top	0.001235	0.001232
Story11	41.5	Top	0.001342	0.00141
Story10	37.5	Top	0.00143	0.001543
Story9	33.5	Top	0.001493	0.001644
Story8	29.5	Top	0.00154	0.00173
Story7	25.5	Top	0.001579	0.00181
Story6	21.5	Top	0.001618	0.001879
Story5	17.5	Top	0.00165	0.001929
Story4	13.5	Top	0.001664	0.001952
Story3	9.5	Top	0.001617	0.001904

Table. 4.4.3(b) Maximum Y- direction storey drift M3 with and without P-delta

Difference in Y-direction considering 1.5 (DL+SPECY)

$$\%change = \frac{(With\ P-delta-Wit \qquad P-del\ \ )}{(With\ P-delta)}$$

$$\%change = \frac{0.001952-0.001408\ )}{(0.001952)}$$

%change = **27.866%** change in Y-direction drift between the two configurations.

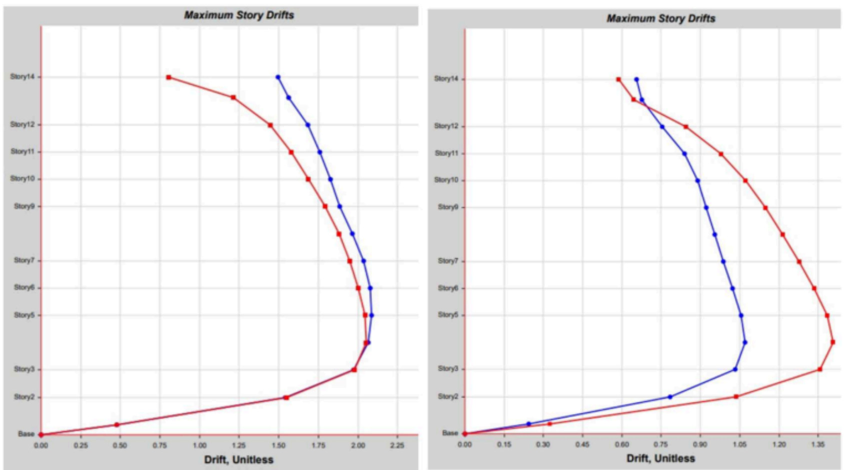


fig. 4.4.3 Storey drift graphical comparison

Here we yet again see, even lower storeys where the storey drift is maximum, this is attributed to the single core placed at the end of the plan. This much eccentricity in the building causes high torsion and accumulation of seismic shear forces at the lower storey levels. Such an arrangement produces a highly irregular stiffness distribution and significant separation between center of mass and center of rigidity. This shift of maximum drift towards the lower levels shows the critical nature of this configuration and lower levels require even higher structural demand than it would've in previous models M1 and M2.

P-delta amplification Coefficient

$$\textbf{A.F} = \frac{DRIFT\ WITH\ P-DELTA}{DRIFT\ WITHOUT\ P-DELTA}$$

- X-Direction:

A.F = $\frac{\mathbf{0.002086}}{\mathbf{0.001592}} = \mathbf{1.31}$

This shows there is an **31%** of amplification due to P-delta in X-direction.

- Y-Direction:

A.F = $\frac{\mathbf{0.001952}}{\mathbf{0.001408}} = \mathbf{1.38}$

This shows there is an **38%** of amplification due to P-delta in Y-direction.

Alternatively,

$$\textbf{A.F} = \frac{1}{1-\theta}$$

θ – Inter-storey drift stability coefficient

Putting these values of A.F in above equation,

- **X-direction,**

$\frac{1}{1-\theta} = 1.31$

θ = 0.31 for X-direction

- **Y-direction,**

$\frac{1}{1-\theta} = 1.38$

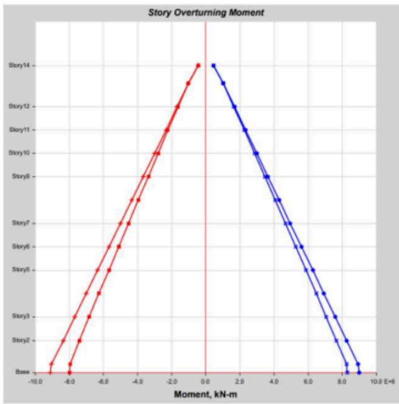
θ = 0.38 for Y-direction

Clause 7.3.10 of IS 1893:2016 states that Inter-storey stability index should be less than equal to 0.2. This value shows how unstable the model is.

4.4.4 Overturning moment (X-direction)

4.4.4.1 Overturning moment due to 1.5 (DL+SPECX)

With P-delta iterative effect



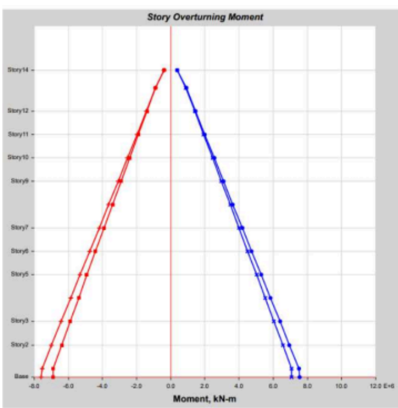
4.4.4.1(a) Overturning moment (X) with P-delta

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	437623.0024	437618.7335	-436637.2177	-436642.5937
Story13	49.5	Top	1037842.7192	1026183.9817	-1016961	-1032856
Story12	45.5	Top	1683019.3964	1639948.7913	-1618430	-1679315
Story11	41.5	Top	2332663.8349	2249223.534	-2211073	-2334558
Story10	37.5	Top	2984820.3882	2855968.1019	-2797811	-2995670
Story9	33.5	Top	3638861.637	3460813.734	-3380870	-3660434
Story8	29.5	Top	4294378.2436	4064172.8923	-3961631	-4327473
Story7	25.5	Top	4950965.5363	4666452.8442	-4540745	-4996142
Story6	21.5	Top	5608381.3052	5267897.3124	-5118327	-5666332
Story5	17.5	Top	6266698.8908	5868432.8944	-5694056	-6338366
Story4	13.5	Top	6926318.1172	6467648.0815	-6267346	-7012813
Story3	9.5	Top	7587857.6942	7064965.5478	-6837655	-7690280
Story2	5.5	Top	8251746.6859	7659959.8914	-7404666	-8371095
Story1	1.5	Top	8917813.2374	8252805.6447	-7968644	-9055003
Base	0	Top	8984492.9875	8291387.6636	-7999278	-9131516

Table 4.4.4.1(a) Overturning moment (X) with P-delta

Without P-delta iterative effect



4.4.4.1(b) Overturning moment (X) without P-delta

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	387575.0196	387575.0196	-386766.7158	-386766.7158
Story13	49.5	Top	901258.0742	891733.7441	-884028.3113	-895445.1757
Story12	45.5	Top	1446187.3323	1411207.512	-1395195	-1438040
Story11	41.5	Top	1993977.6527	1927820.2175	-1901158	-1985837
Story10	37.5	Top	2541969.5893	2444231.3068	-2404274	-2536483
Story9	33.5	Top	3089424.2496	2961179.6724	-2906002	-3088516
Story8	29.5	Top	3636930.3122	3478076.6358	-3407069	-3641209
Story7	25.5	Top	4185223.7478	3994186.2262	-3907604	-4194435
Story6	21.5	Top	4734604.0831	4509208.9168	-4407360	-4748440
Story5	17.5	Top	5285099.3229	5023116.7029	-4906014	-5303547
Story4	13.5	Top	5836878.8647	5535740.1871	-5403214	-5860108
Story3	9.5	Top	6390185.9401	6046836.1376	-5898519	-6418564
Story2	5.5	Top	6945157.4673	6556267.6363	-6391386	-6979458
Story1	1.5	Top	7501696.4749	7064131.6547	-6881484	-7543121
Base	0	Top	7546065.186	7089604.8136	-6902936	-7593400

Table 4.4.4.1(b) Overturning moment (X) without P-delta

Difference in X-direction considering 1.5 (DL+SPECX)

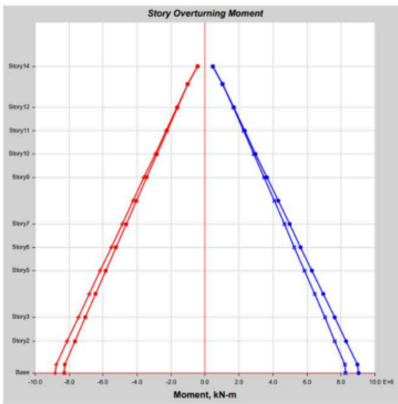
$$\%change = \frac{(8984492.9875-754606\ \ .186)}{(8984492.9875)}$$

%change = **16.010%** change in X-direction drift between the two configurations.

4.4.4 Overturning moment (X-direction)

4.4.4.1 Overturning moment due to 1.5 (DL+SPECX)

With P-delta iterative effect



4.4.4.1(c) Overturning moment (Y)

with P-delta

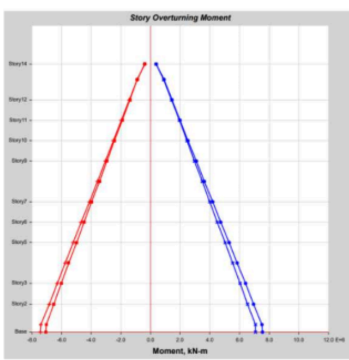
Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	437623.1604	437618.5755	-436638.1965	-436641.6149
Story13	49.5	Top	1036658.6251	1027368.0759	-1020332	-1029485
Story12	45.5	Top	1679408.5503	1643559.6373	-1631995	-1665750
Story11	41.5	Top	2327959.0859	2253928.283	-2239973	-2305657
Story10	37.5	Top	2981328.1441	2859460.3459	-2845693	-2947789
Story9	33.5	Top	3638422.5581	3461252.8128	-3449808	-3591496
Story8	29.5	Top	4298130.2538	4060420.882	-4052852	-4236252
Story7	25.5	Top	4959516.0379	4657902.3427	-4655272	-4881615
Story6	21.5	Top	5621977.786	5254300.8315	-5257307	-5527351
Story5	17.5	Top	6285373.3383	5849758.4469	-5858859	-6173563
Story4	13.5	Top	6949974.193	6443992.0057	-6459496	-6820663
Story3	9.5	Top	7616367.728	7036455.514	-7058683	-7469252
Story2	5.5	Top	8285085.1513	7626621.426	-7656060	-8119702
Story1	1.5	Top	8956211.2621	8214407.62	-8251766	-8771882
Base	0	Top	9024852.6665	8251027.9845	-8294484	-8836311

Table 4.4.4.1(c) Overturning moment (Y)

with P-delta

Without P-delta iterative effect



4.4.4.1(d) Overturning moment (Y)

without P-delta

Story Response Values

Story	Elevation	Location	X-Dir Max	X-Dir Min	Y-Dir Max	Y-Dir Min
	m		kN-m	kN-m	kN-m	kN-m
Story14	52.5	Top	387575.0196	387575.0196	-386766.7158	-386766.7158
Story13	49.5	Top	900032.3395	892959.4789	-885872.3554	-893601.1316
Story12	45.5	Top	1442035.1175	1415359.7268	-1402678	-1430556
Story11	41.5	Top	1987560.8081	1934237.0621	-1917388	-1969608
Story10	37.5	Top	2535318.2892	2450882.607	-2431698	-2509058
Story9	33.5	Top	3084355.8366	2966248.0855	-2946027	-3048490
Story8	29.5	Top	3634213.9706	3480792.9774	-3460253	-3588025
Story7	25.5	Top	4184698.681	3994711.2929	-3974171	-4127868
Story6	21.5	Top	4735742.0359	4508070.9639	-4487642	-4668158
Story5	17.5	Top	5287358.8633	5020857.1625	-5000498	-5209063
Story4	13.5	Top	5839756.8193	5532862.2324	-5512422	-5750900
Story3	9.5	Top	6393399.2176	6043622.8601	-6023124	-6293959
Story2	5.5	Top	6948929.1094	6552495.9941	-6532496	-6838347
Story1	1.5	Top	7506850.9303	7058977.1992	-7040632	-7383973
Base	0	Top	7551968.2405	7083701.7591	-7069210	-7427126

Table 4.4.4.1(d) Overturning moment (Y)

without P-delta

Difference in Y-direction considering 1.5 (DL+SPECY)

$$\%change = \frac{(With\ P{-}delta - With\ \ \ \ P{-}delta)}{(With\ P{-}delta)}$$

$$\%change = \frac{(9024852.6665 - 7551968.2405)}{(9024852.6665)}$$

%change = **16.323%** change in Y-direction drift between the two configurations.

This result shows how even a global parameter like overturning moment gets affected when such a high degree of eccentricity is introduced in the model.

M3 with just one core at the corner of the plan is high asymmetric and creates a big separation in center of mass and center of rigidity. It creates a high irregular stiffness distribution, which causes high torsion and lateral displacement which in turns affects overturning moment.

This increase from **5%** to **16.232%** from previous models M1 and M2 to M3 goes to show how eccentricity can affect overturning moment.

This happens because gravity loads interact with high lateral displacement which occur due to high seismic excitation.

4.5 Overall Comparative Discussion (X-direction)

	M1	M2	M3
Core eccentricity extent	5 cores places equidistant	2 cores placed at one side of the plan	1 core placed at the corner of plan.
Increase in torsional moment due to P-delta	11.192%	18.619%	35.223%
Increase in maximum displacement due to P-delta	10.530%	12.455%	25.844%
Increase in storey drift due to P-delta	10.382%	11.712%	23.441%
Increase in overturing moment due to P-delta	5.230%	5.6%	16.010%
P-delta amplification coefficient (A.F.)	1.12	1.14	1.31
Inter-storey drift stability coefficient (θ)	0.12	0.14	0.31

Table. 4.5 (a) Table for a comparative study of parameters in X-direction

As we can see, M3 has values which are not within the criteria of IS Code and general structural analysis, this proves how core eccentricity can amplify the second order effects in a high-rise building

4.5 Overall Comparative Discussion (Y-direction)

	M1	M2	M3
Core eccentricity extent	5 cores places equidistant	2 cores placed at one side of the plan	1 core placed at the corner of plan.
Increase in torsional moment due to P-delta	9.434%	14.923%	20.252%
Increase in maximum displacement due to P-delta	6.436%	14.110%	29.463%
Increase in storey drift due to P-delta	8.372%	13.222%	27.866%
Increase in overturing moment due to P-delta	5.345%	5.43%	16.323%
P-delta amplification coefficient (A.F.)	1.091	1.15	1.38
Inter-storey drift stability coefficient (θ)	0.091	0.15	0.38

Table. 4.5 (b) Table for a comparative study of parameters in Y-direction

As we can see, M3 has values which are not within the criteria of IS Code and general structural analysis, this proves how core eccentricity can amplify the second order effects in a high-rise building

4.6 Torsional irregularity ratio (η_t)

	M1	M2	M3
η_t	1.01	1.19	1.24

Table. 4.6 Torsional irregularity table for all models

- **η_t < 1.2 states the building is pretty symmetric and stable.**
- **η_t > 1.2 states the building is asymmetric and it exhibits Torsional Irregularity**

4.7 Flowchart representing correlation between core eccentricity and Structural response parameters

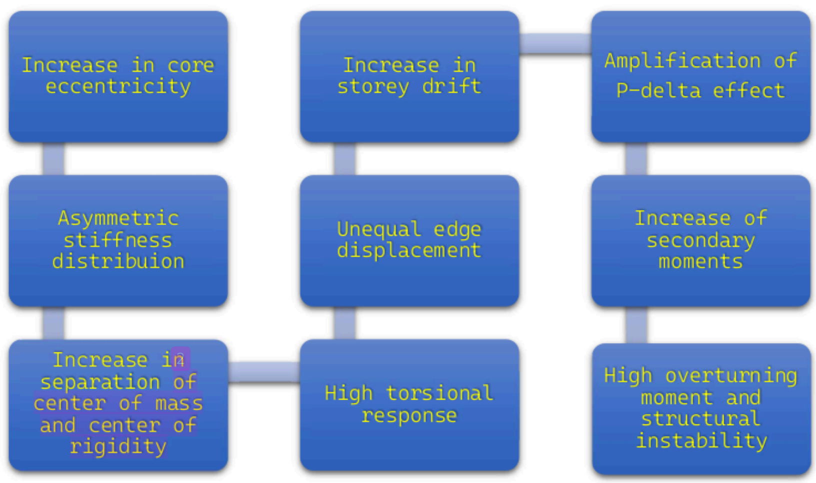


Fig. 4.7 Research methodology flowchart

This flowchart tries to portray as to what we've learned in this study.
Models M1, M2 and M3 had increasingly more core eccentricity introduced in them and as result we saw how M3 was highly unstable and required high structural demand.
Increase in eccentricity causes asymmetric stiffness distribution which in turn gives birth to higher torsion, higher secondary order effects and amplify P-delta, which is highly relevant in high-rise buildings.

4.8 Engineering implications of the study

The findings of this study highlight the practical and real-world importance of proper core positioning. Not just core placement but equal distribution of loading and stiffness regularity is also as important as core placement.
However, in practicality, architectural and space constraints exist which cause designers to put core, lift shafts, staircases and shear walls in such places where they can produced eccentricity. As we've noticed in Model M3, buildings with core placed at one corner or unevenly in the plan can cause great amplifications in global parameters like Overturning moment, Maximum displacement and storey drift. This study also shows us that lower storeys in eccentric configurations are subjected to greater drift concentration and instability effects. This is engineeringly important as lower storeys resist the most gravity load cumulatively as well as seismic shear forces. Excessive drift concentration in these levels may lead to damage in columns, shear walls, beam-column joints and other lateral force resisting elements like the frame itself. Therefore, it is important for us designers to keep adequate stiffness and loading balance throughout the plan.
This study further solidifies the need of P-delta analysis in tall buildings, as we have clearly seen even in Models M1 and M2, where eccentricity is controlled, P-delta can cause high %change in parameters like maximum displacement, torsion and storey drifts. Neglecting these effects in tall buildings can underestimate the torsional requirement and lateral stability needed in members to resist the forces like earthquake and wind.
Such heightened parameters can increase the economic cost of the project substantially, which is not ideal for anyone. Models like M3 can demand huge columns, beams, higher concrete mix, bigger hefty foundations. Hence. A balanced core with stiffness regularity is what the aim should be going forward and something designers and architects should keep in mind in the preliminary stages of planning.

CHAPTER 5
CONCLUSIONS

5.1 Introduction

This chapter represents the overall conclusions of this study, derived from the analytical interpretations of raw data we extracted from ETABS. The study focussed on tall high-rise buildings with P-delta effects and core eccentricity. We noted and studied important structural parameters like Torsional moment, Maximum displacement, Storey drift and overturning moments. Three structural models were modelled in ETABS with same plan and grid spacing but with different core placements and eccentricities.

5.2 Summary of Work

In this present study, we modelled a building with constant grid spacing and constant storey height. Later we made three different configurations where we introduced eccentricity via different core placements in the plan. M1 has 5 cores equally placed, M2 has 2 cores placed at one side while M3 has 1 core placed at the corner of the building.

Seismic analysis was carried out and P-delta effect was considered in accordance to relevant IS Codes to study the behaviour of the structure. Response of all different models were considered and studied via 4 major parameters namely Torsional moment, Storey drift, Maximum displacement and overturning moment. Graphs, tables and flowchart were then drawn and studied to get a deep understanding of these effects.

Study primarily aimed to understand how increasing eccentricities in the plan can affect torsion and other secondary order moments and forces.

5.3 Major findings

- Increase in eccentricity resulted in significant amplification of torsional moment and lateral deformation
- Model M1 with the most equally distributed cores showed the most stable structural behaviour and relatively lower drift and torsion.
- Model M2 showed moderate increase in torsion and displacement but was with torsional regularity as its coefficient didn’t go over 1.2.

- Model M3 showed the most instability because of its single core in the corner, it showed torsional irregularity and high overturning moments.
- Storey drift concentration increased towards lower storeys as we went from M1 to M3.
- Lower storey drift concentration leaves lower level vulnerable to seismic loading.
- Inclusion of P-delta increased torsional response even in same configurations with same core placement.
- Overturning moment leaped in Model M3, showing how high eccentricity can cause changes in global parameters too.
- Separation of center of mass and center of rigidity causes rotational effects and uneven distribution of seismic forces.
- Balanced stiffness and symmetric core placement significantly reduces the parameters and increases seismic and structural performance of the buildings.

5.4 Limitations of the study

- Study was limited to rectangular plan building with equal grid spacing.
- Only core eccentricity was varied throughout the models while other parameters were kept constant.
- Soil- Structure interaction was not taken into consideration.
- Study was focussed on seismic loading conditions.

5.5 Concluding remarks

Based on the findings of the study it can be concluded that core eccentricity plays a big role in structural stability of the building, especially in tall reinforced buildings which are susceptible to earthquakes and wind loading.

High eccentric configuration like Model M3 is super unstable and structurally weak due to concentration of multiple factors like torsion, storey drift concentration, high over turning moment. The building becomes very economically and engineeringly unjustified to be designed.

The study emphasises the importance of a balanced core and even distribution of stiffness and loading throughout the plan.

CHAPTER 6

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