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P-DELTA EFFECTS IN TALL R C BUILDINGS

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ABSTRACT

The P - delta effect becomes more important when columns are slender. A method of designing for p-delta effects in high rise buildings is presented. In this paper the effect of lateral load on the structural system is considered for the p delta effect. The drift ratio is found out for earthquake loading, considering with and without p-delta effect for different number of stories such as 10, 20, 30, 40, 50 stories.

The load–deflection curves and drift ratios have been obtained for different cases and the results so obtained have been compared to identify the drift ratios for different stories of the structure. The results of the analysis show that the p-delta effect is more in the upper stories for wind loading while it is more in lower stories for earthquake loading.

In this present study, the non-linear static analysis has been carried out using ETABS with identification of p-delta effects in multi- storey buildings based on its behavior. The load deflection curves and the results so obtained have been compared.

KEYWORDS : P-Delta, slender, high rise buildings, multi- storey buildings

INTRODUCTION

GENERAL

High rise design comes into play when a structure's slender nature makes it sensitive to lateral loads. In the design of multi-storey structures, allowance should be made for "p-delta" effects.

The p-delta effects are dependent on the applied load and material characteristics, in addition to parameters such as height and stiffness of a building. The degree of its asymmetry may also be of importance. P-delta effects become more significant when the columns are slender.

EARTHQUAKE

Earthquakes are one of nature's greatest hazards to life on this planet; throughout historic times, they have caused the destruction of countless cities and villages on nearly every continent. The hazards imposed by earthquake are unique in much respect, and requires unique engineering approach to mitigate. Every year, more than 300000 earthquakes occur on the earth. Many of these are of small intensity and do not cause any damage to our structures. Earthquakes of larger intensity in the vicinity of populated areas cause considerable damage and loss of life. It is estimated that on the average 15000 people have been killed each year throughout the world because of earthquakes (Ugur Ersoy, 1988).

The P-Delta effect is the second order overturning moments due to lateral movement of a storey mass to a deformed position. This second order behavior has been termed the P-Delta.

Due to the great height of these tall buildings, the lateral forces acting on the face of building lead to lateral deflection of the building. Control of this lateral deflection is an issue on which the structural engineers are concerned now-a-days. It is very important for the structure to have sufficient strength against vertical loads and adequate stiffness to resist lateral forces. There are several structural systems. Out of these shear wall frame system is one of the alternative systems used for reducing the lateral deflection.

As per the code India is divided into several seismic zones, i.e. Zone II, III, IV & V as shown in fig.1.1 Magnitude and seismic zone factor of each zone are given in table 1.1 and 1.2. The effect of earthquake on building as depicted in fig 1.2.

Zone	**Magnitude**
Zone V	Very High
	Risk Quakes of
	Magnitude ***8***
	and greater
Zone IV	High Risk
	Quakes up to
	Magnitude ***7.9***
Zone III	Moderate Risk
	Quakes up to
	Magnitude ***6.9***
Zone II	Seismic
	Disturbances
	up to
	Magnitude ***4.9***

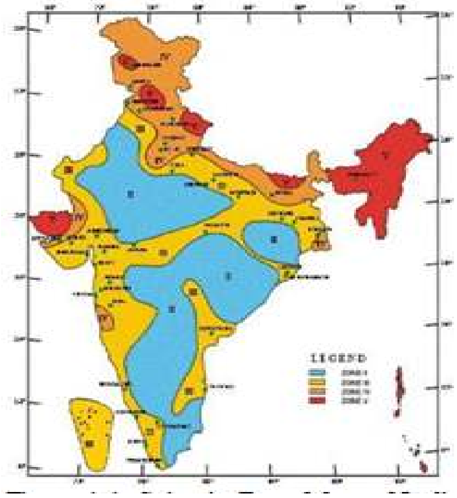


Table 1.2: Seismic Zone Factors, Z as per IS: 1893 (2002, Part 1)

Seismic Zone	II	III	IV	V
Seismic Intensity Z	0.10	0.16	0.24	0.36

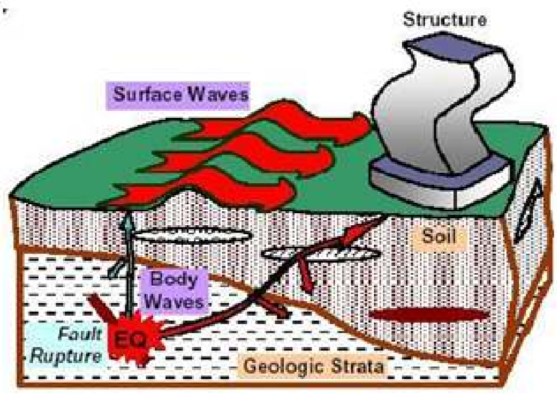


Figure 1.2-Earthquake and Buildings

Generally, the methods available to the design engineer to calculate seismic demands are either dynamic time history analyses or pushover analyses or p-delta analysis. Dynamic time history analysis requires as much as possible detailed mathematical models of multi-degree-of freedom systems, MDOF, i.e. structures, together with information on ground motion characteristics, rendering it quite impractical for everyday use, especially when overly complex structures need to be considered. Additionally the response derived from such an analysis is generally very sensitive to the characteristics of the ground motions as well as the material models used. A simpler option to assess the performance of structures is p-delta analysis or simplified nonlinear static analysis, even though this also requires as much as possible detailed mathematical models of MDOF systems. The method's applicability is increasing continuously in practice because of its relative simplicity. This method assumes that the response of a structure can be predicted by the first, or the first few modes of vibration, which remain constant throughout its response time. It involves the incremental application of loading that follows some predetermined pattern, until the failure modes of the structure can be identified, thus producing a force-displacement relationship or load - deflection curve, which gives a clear indication of the nonlinear response. The resulting displacement demands from the preceding analysis are then checked and the structural performance of the elements is assessed.

P-DELTA
DEFINITION

In structural engineering, the P-Delta effect refers to the abrupt changes in ground shear, overturning moment, the axial force distribution at the base of a sufficiently tall structure or structural component when it is subject to a critical lateral displacement.

GENERAL

Generally Structural designers are prone to use linear static analysis, which is also known as first order analysis, to compute design forces, moments and displacements resulting from loads acting on a structure. The first order analysis performed by assuming small deflection behavior where the resulting forces, moments and displacements take no account of the additional effect due to the deformation of the structure under vertical load prior to imposing lateral loads. P-Delta is a non-linear (2nd order) effect that occurs in every structure where elements are subject to axial loads. It is a genuine “effect” that is associated with the magnitude of the applied axial load (P) and a displacement (?). If a P-Delta affected member is subjected to lateral load, then it will be prone to deflect more which could be computed by P-Delta analysis not the linear static analysis. The magnitude of the P-delta effect is related to the magnitude of axial load, stiffness/slenderness of the structure as a whole and slenderness of individual elements. Here during analysis for easy visualization only slenderness of the whole structure is judged keeping other two factors constant. Again, excessive vertical loads buckle the compressive member and make them unsuitable as load bearer before coming lateral loads. When lateral loads appear it do not find the initial undeflected shape, but deflected shaped member left with vertical loads. The global slenderness ratio is the ratio of the height of the building and radius of gyration of the building. Again, it is possible to simply divide the height of the building by the width of the building for a quick estimation of the slenderness ratio what way is adopted for this study. If the building is too slender, it will be prone to deflect much, where the middle portion gives way, even at the top and bottom remain solid like each and every slender member. On the other hand, a very thick building which is opposite of slender, may be so heavy that it causes structural problems itself. The self-weight of thick building can be a significant issue in deflection of tall buildings.

In this context p delta analysis, which is an iterative procedure shall be looked upon as an alternative for the orthodox analysis procedures. Nonlinear static analysis has been developed over the past two decades, it is relatively simple and considers post elastic behavior, it has become the preferred analysis procedure for design and seismic performance evaluation purpose. However, the procedure involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of p delta analysis.

The lateral movement of a storey mass to a deformed position is generating second order overturning moments. This second order behavior has been termed the P-Delta.

High rise design comes into play when a structure’s slender nature makes it sensitive to lateral loads. In the design of multi-storey structures, allowance should be made for “p-delta” effects.

These are the additional overturning moments applied to the structure resulting from the seismic weights "p" load supported by the structure, acting through the lateral deflections.

P– delta effects are generally small in elastic structures, they frequently become the dominant factor in the behavior of inelastic structures.

The p-delta effects are dependent on the applied load and material characteristics, in addition to parameters such as height and stiffness of a building. The degree of its asymmetry may also be of importance. P-delta effects become more significant when the columns are slender. It is intended to study the interaction between the slenderness ratio and p-delta effect in tall reinforced concrete buildings. P-delta effects must be considered at the places where the wind speed is high.

METHODOLOGY

In the present investigation a simple procedure of analysis has been done for tall buildings. The analysis is carried out using ETABS Commercially available finite element software.

The following ten types of models are considered for analysis under Earthquake loading

1. 10 storey RC building with p-delta
2. 10 storey RC building without p-delta
3. 20 storey RC building with p-delta
4. 20 storey RC building without p-delta
5. 30 storey RC building with p-delta
6. 30 storey RC building without p-delta
7. 40 storey RC building with p-delta
8. 40 storey RC building without p-delta
9. 50 storey RC building with p-delta
10. 50 storey RC building without p-delta

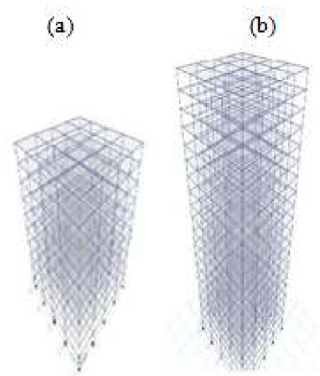
EFFECT OF EARTHQUAKE LOADING WITHOUT P-DELTA EFFECT

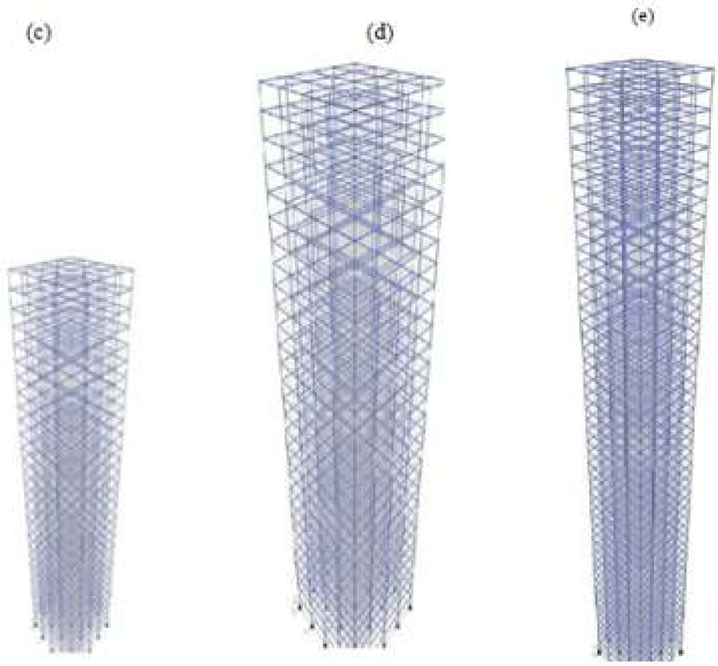
GENERAL

Flexibility of soil medium below foundation decreases the overall sti?ness of the building frames resulting in a subsequent increase in natural period of the system. It is well established that the seismic response may considerably alter due to the change in natural period of any building structure. This is the primary parameter which regulates the seismic response of the building.

Generally when the lateral earthquake effect comes into play at the high rise structure, it causes the deformation in the structure, which can lead to failure of the structure if not designed properly as per the IS code recommendations.

BUILDING MODELS





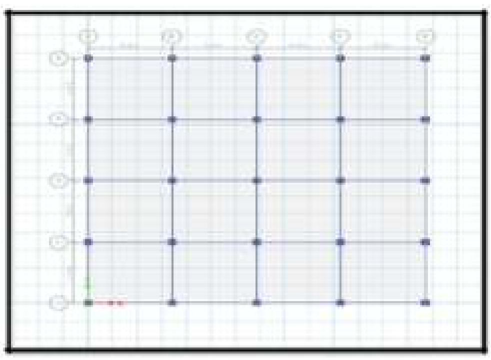
Building models

Five, 3-d building models have been considered for this study as shown in the figure.

1. 10 floors
2. 20 floors
3. 30 floors
4. 40 floors
5. 50 floors

PLAN

The buildings are square in plan of dimensions 24mx24m as shown in a figure.
The columns of square size have been used.



Typical floor plan of building models

MATERIAL PROPERTIES

The materials used for the construction is reinforced concrete with M-30 and M-40 grade concrete Fe-500 grade reinforcing steel. The Stress-Strain relationship used is as per I.S.456:2000. The

basic material properties used are as follows:
Modulus of elasticity of concrete for M-30, Ec = 27386.13 MPa
Modulus of elasticity of concrete for M-40, Ec = 31622.78 MPa
Density of concrete for M-30 = 30 kN/m3
Density of concrete for M-40 = 40 kN/m3
Density of steel = 78.5 kN/m3
Characteristic strength of concrete for M-30, fck = 30 MPa
Characteristic strength of concrete for M-40, fck = 40 MPa
Yield stress for steel, fy = 500 MPa

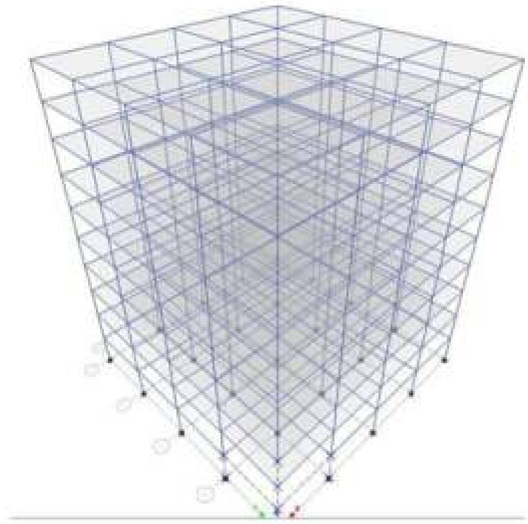
MODEL GEOMETRY

The structure analyzed is for 10, 20, 30, 40 & 50 storey building with reinforced concrete properties as specified above. The concrete floors are modeled as rigid. The details of the models are given below:

- Number of stories = 10, 20, 30, 40 & 50
- Number of bays along the X - direction = 5
- Number of bays along the Y – direction = 5
- Storey height = 3 meters
- Bay width along the X – direction = 6 meters
- Bay width along the Y – direction = 6 meters
- Depth of the slab = 150 mm
- Size of the beam in longitudinal and transverse direction = 600mm*300mm
- Size of the column = 500mm*500mm for 10 storey building
- Size of the column = 700mm*700mm for 20 storey building
- Size of the column = 800mm*800mm for ground 10 storey &700mm*700mm for the rest 20 storey.
- Size of the column = 1000mm*1000mm for ground 10 storey, 800mm*800mm for next 10 storey and 700*700mm for the rest 20 storey.
- Size of the column = 1100mm*1100mm for ground 10 storey, 1000*1000mm for next 10 storey, 800mm*800mm for next 10 storey and 700*700mm for the rest 20 storey.
- Zone = II
- Response reduction factor = 5
- Importance factor = 1
- Soil condition = Medium

EFFECT OF EARTHQUAKE LOADING WITHOUT P-DELTA EFFECT

Model - 1 STRUCTURAL LAYOUT



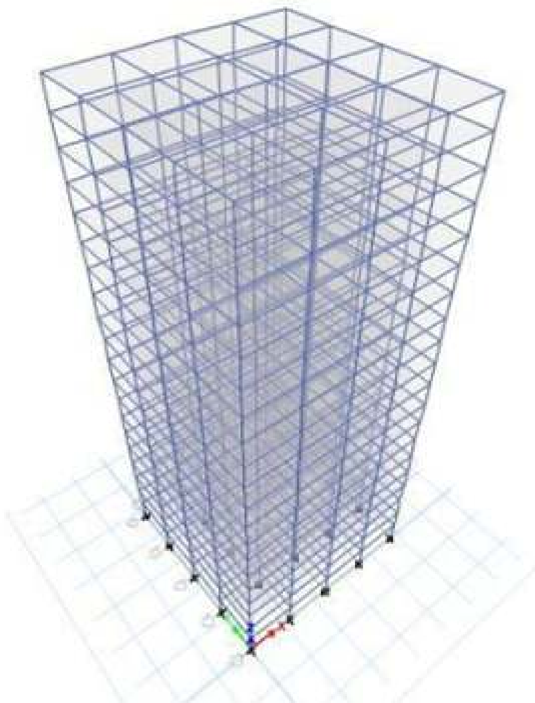
3-D view of 10 storey model

ANALYSIS OUTPUT

Displacements at different heights for 10 storey building model

Story level	Height (m)	Displacement (mm)
10	30	35.6
9	27	34.3
8	24	32.1
7	21	29
6	18	25.3
5	15	21.2
4	12	16.8
3	9	12.1
2	6	7.4
1	3	2.9

Model - 2 STRUCTURAL LAYOUT



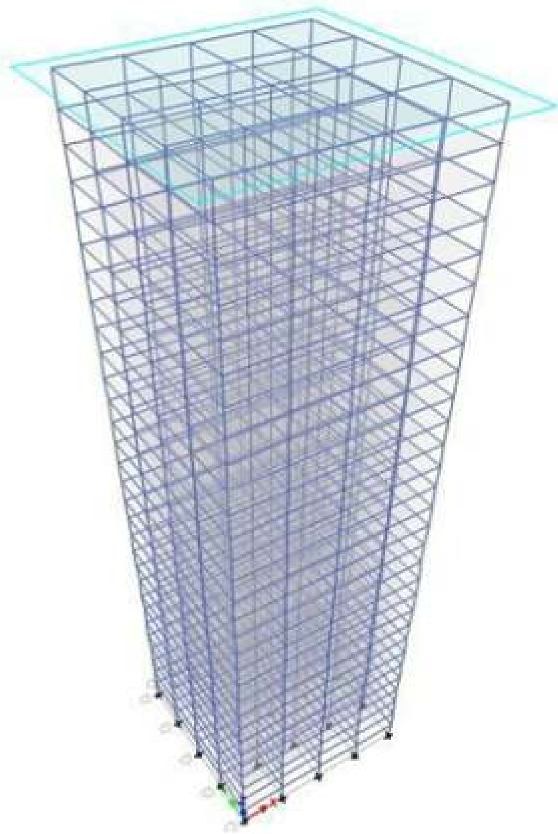
3-D view of 20 storey model

ANALYSIS OUTPUT

Displacements at different heights for 20 storey building model

Story level	Height (m)	Displacement (mm)
20	60	115.8
18	54	110.8
16	48	103.3
14	42	93.2
12	36	80.8
10	30	66.6
8	24	51.4
6	18	35.5
4	12	20
2	6	6.6

Model - 3 STRUCTURAL LAYOUT



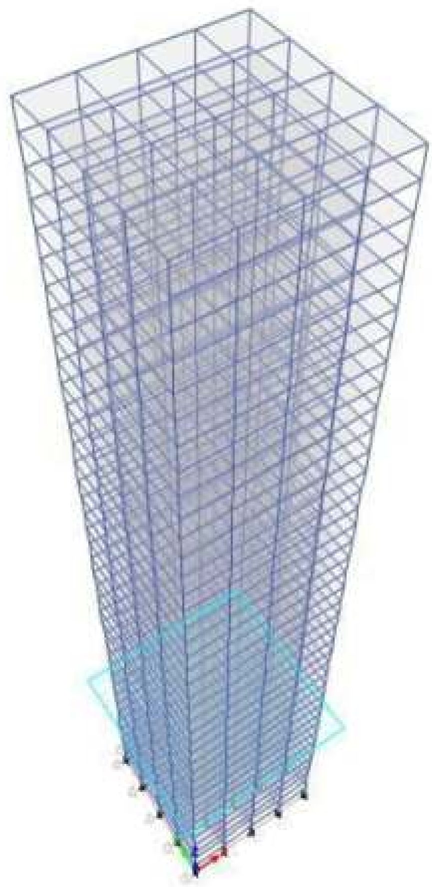
3-D view of 30 storey model

ANALYSIS OUTPUT

Displacements at different heights for 30 storey building model

Story level	Height (m)	Displacement (mm)
30	90	178.7
27	81	170.9
24	72	158.4
21	63	142
18	54	122.7
15	45	101.4
12	36	79
9	27	56.5
6	18	34.7
3	9	13.8

Model – 4 STRUCTURAL LAYOUT



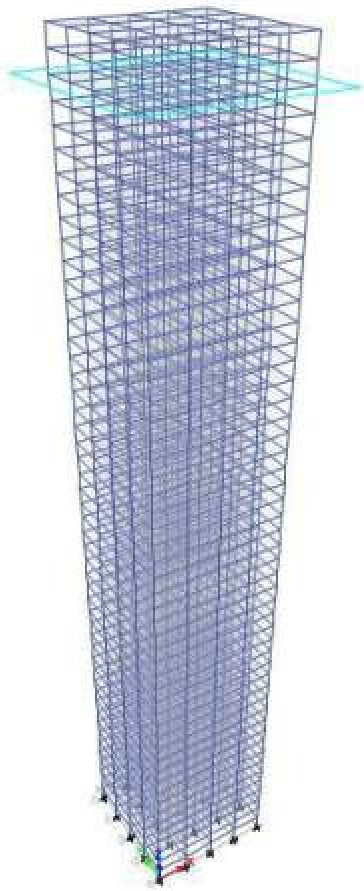
3-D view of 40 storey model

ANALYSIS OUTPUT

Displacements at different heights for 40 storey building model

Story level	Height (m)	Displacement (mm)
40	120	251.5
36	108	239.1
32	96	220
28	84	195.6
24	72	167.3
20	60	136.5
16	48	105.8
12	36	74.7
8	24	44.9
4	12	17.2

Model – 5 STRUCTURAL LAYOUT



3-D view of 50 storey model

ANALYSIS OUTPUT

Displacements at different heights for 50 storey building model

Story level	Height (m)	Displacement (mm)
50	150	337.8
45	135	319.5
40	120	292.4
35	105	258.4
30	90	219.8
25	75	179.7
20	60	138.4
15	45	98.5
10	30	59.2
5	15	22.8

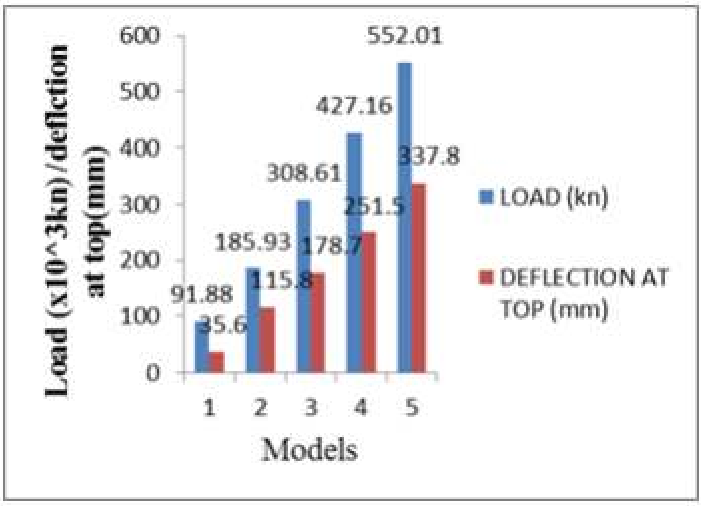
LATERAL DISPLACEMENT

RESULTS FOR EARTHQUAKE LOADING WITHOUT P- EFFECT

SL NO	No. Of Stories	Height (M)	Load (KN)	Base Shear (KN)	Deflection At Top (mm)	Story Drift at Top
1	10	30	91885.554	1985.86	35.6	0.000373
2	20	60	185931.26	3847.86	115.8	0.000634
3	30	90	308615.1	5786.61	178.7	0.000597
4	40	120	427162.7	8101.25	251.5	0.000703
5	50	150	552010.16	12151.875	337.8	0.000844

Load, Base shear, Deflection at top & Story drift at top

RELATIONSHIP BETWEEN LOAD, DEFLECTION AND NO. OF STORIES



Load, Deflection & No. of stories

The relationship between load, deflection and no. of stories is shown under earthquake loading without considering p-delta effects from the analysis.

EFFECT OF EARTHQUAKE LOADING WITH P-DELTA EFFECT

In the seismic design of a multi-storey structures allowance should be made for “p-delta” effects. These are additional overturning moments applied to the structure resulting from the seismic weights (p), supported by the structure, acting through the lateral deflections (?), which directly results from the horizontal seismic inertia forces. They are second order effects which increase the displacements, the member actions and lengthen the effective fundamental period of the structure.

Model – 1

ANALYSIS OUTPUT

Displacements at different heights for 10 storey building model

Story level	Height(m)	Displacement(mm)
10	30	36.6
9	27	35.3
8	24	33
7	21	30
6	18	26.2
5	15	22
4	12	17.4
3	9	12.6
2	6	7.7
1	3	3

Model – 2

ANALYSIS OUTPUT

Displacements at different heights for 20 storey building model

Story level	**Height(m)**	**Displacement(mm)**
20	60	132.6
18	54	127.4
16	48	119.4
14	42	108.4
12	36	94.6
10	30	78.6
8	24	60.9
6	18	42.2
4	12	23.6
2	6	7.7

Model – 3

ANALYSIS OUTPUT

Displacements at different heights for 30 storey building model

Story level	Height (m)	Displacement (mm)
30	90	189.5
27	81	181.4
24	72	168.5
21	63	151.5
18	54	131.3
15	45	108.9
12	36	85.1
9	27	60.9
6	18	37.4
3	9	14.8

Model – 4

ANALYSIS OUTPUT

Displacements at different heights for 40 storey building model

Story level	Height (m)	Displacement (mm)
40	120	272.6
36	108	259.6
32	96	239.6
28	84	213.8
24	72	183.6
20	60	150.4
16	48	117
12	36	82.8
8	24	49.7
4	12	18.9

Model – 5

ANALYSIS OUTPUT

Displacements at different heights for 50 storey building model

Story level	Height(m)	Displacement(mm)
50	150	375.6
45	135	355.9
40	120	326.9
35	105	290.3
30	90	248.2
25	75	204.1
20	60	157.9
15	45	112.8
10	30	67.8
5	15	25.8

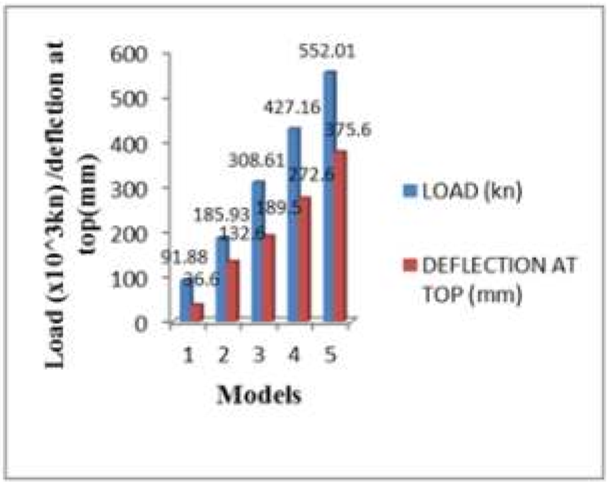
LATERAL DISPLACEMENT

RESULTS FOR EARTHQUAKE LOADING WITH P-EFFECT

Sl No	No. of Stories	Height (m)	Load (KN)	Base Shear (KN)	Deflection at top (mm)	Story Drift at Top
1	10	30	91885.554	1985.86	36.6	0.000377
2	20	60	185931.26	3847.86	132.6	0.00067
3	30	90	308615.1	5786.61	189.5	0.000619
4	40	120	427162.7	8101.25	272.6	0.000743
5	50	150	552010.16	12151.875	375.6	0.000912

Load, Base shear, Deflection at top & Story drift at top

RELATIONSHIP BETWEEN LOAD, DEFLECTION AND NO. OF STORIES



Load, Deflection & No. of stories

The relationship between load, deflection and no. of stories is shown under earthquake loading considering with p-delta effects from the analysis.

CONCLUSIONS AND RECOMMENDATIONS

In the present study, the non-linear response of tall RC buildings using ETABS under the lateral loading has been carried out with the intention to study the relative importance of p-delta effects on tall RC buildings, story drift ratios and to identify the load deflection curves and the results so obtained have been compared.

SUMMARY AND RESULTS OF STORY DRIFT UNDER EARTHQUAKE LOADING

Sl no	No of stories	Height (m)	Story drift at top without p-?	Story drift at top with p-?
1	10	30	0.000373	0.000377
2	20	60	0.000634	0.00067
3	3	90	0.000597	0.000619
4	40	120	0.000703	0.000743
5	50	150	0.000844	0.000912

Comparison of drift ratios

CONCLUSIONS

The p-delta analysis is a simple way to investigate the nonlinear behavior of the buildings. The drift ratio is found out for earthquake loading, considering with and without p-delta effect for different number of stories such as 10, 20, 30, 40 & 50 in ETABS software. The selection of building configuration is basically done as per IS:456 and the loading details are taken as per IS: 875 provisions.

Loading has significant effect on the building.

• Drift ratio is very small in lower stories and reaches a maximum at the top stories.
• The effect of p-delta increases as the height of the building increases.
• Behavior of p- effect can be easily known for the slender members.

P-delta effect can be reduced up to certain extend by the construction of shear walls and also by adopting light weight construction at the upper level of the building.

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