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GEOMETRIC NON-LINEAR ANALYSIS OF HIGHRISE BUILDINGS UNDER SEISMIC LOADING

Ashish Chandra[*1], Saket Rusia[*1] and K. K. Pathak[2]
[*1]Department of Civil and Environmental Engineering, National Institute of Technical Teachers' Training and Research, Bhopal, India
[2]Department of Civil Engineering, Indian Institute of Technology, Varanasi (BHU)

ABSTRACT

P-delta effect is a secondary effect on structure, also known as 'Geometric nonlinearity effect'. With increase in number of stories, P-Delta effect becomes more important. If the variation within bending moments and displacements is more than 10%, P-delta effect should be considered in design. In this study, high rise building is studied and both, linear static analysis (without P-delta effect) and second order analysis (with P-delta effect) on high rise building having different number of stories have been carried out. Building models with different storey heights have been analyzed to investigate the maximum response in the building in terms of displacement, drift ratio, moment and shear forces. The analysis of multistoried RC building have been done using ETABS 2015 Ver. 15.2.0 structural analysis software.

Keywords:- *Second Order Analysis; Nonlinear Analysis; P-Δ Effect; ETABS; Seismic Analysis; High-Rise Building.*

I. INTRODUCTION

A tall building is the one in which the structural system is adopted to make it sufficiently economical and also to resist lateral forces due to earthquake or wind within the prescribed criteria for drift, strength, and comfort of the occupants. Tall buildings are the most structures that requires stability because it consists a lot of frame structures with different height and width. Structural designers are generally prone to use linear static analysis, which is known as first order analysis, to workout design forces, moments and displacements causing from loads acting on structure. First order analysis is done by keeping small deflection behavior in mind where the resulting moments, forces and displacements take no account of the extra effect due to deformation of structure under vertical loads anterior to imposing lateral loads. In the traditional first order analysis, the change in structure inculcated due to structure deformations are neglected. However, when a structure deforms, the loads applied may cause additional actions within structure that are called second order or p-delta effects.

P-Delta is a non-linear effect which occurs in all structures where elements are facing axial loads. It is associated with the magnitude of axial load 'P' applied and displacement 'Delta'. If a P-Delta stirred member is subjected to lateral load then it will have more deflection which can be computed by P-Delta analysis and not by the linear static analysis. Although, Development of knowledge and technology advancement is quite advanced today, yet there are a few practical experimental studies on the P-Delta effect on structure. The linear static analysis is most used structural analysis for reinforced concrete design and P-Delta effect is dropped which is very important to include in phases of analysis and design. Because of this, high rise structures may show potential exposure against lateral loads. The multi-storied buildings are analyzed usually using one step linear static analysis by assuming full loads to be applied on the structure, but there may be lot more differences in the outcomes received from the analysis against practical facets. Thus,to briefly understand and to get over this problem, a non-linear P-Delta analysis has been performed for the structure.

The objective of the current work is to find out in what manner the P-delta analysis act upon the variation of responses of the structure such as displacements, bending moments and shear forces against linear static analysis. To perform analysis, ETABS2015 software is used for all models of each case. It was decided that the best way to measure P-delta effects in tall buildings is by simulating all different cases by both P-delta and linear static analysis. Story height is changed to vary the slenderness.

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Charney (2015) illustrated the calculations for a nine-story office building drift and reviews on P-Delta effects. The analysis is carried out using the equivalent lateral force method and intervals have been chosen are 5,10,15,20 and 25, according to Yousuf Dinar *et.al.* Thus, In order to understand the trend of P-delta effects, the height of the building is gradually increased from story 5 to story 40 in 5 story intervals. Models have been analyzed for M25, M30, and M35 grade of concrete.

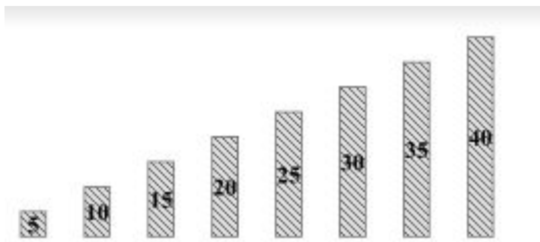

Figure 1: Model Cases - Storey Height Variation

After comparing the performance of RC structure with respect to displacement, drift ratio, shear and moment between two analyses mentioned above, necessity of P-delta analysis over linear static analysis will be understood clearly. In this way for a particular height of building six cases considering P-Delta effect and six cases for linear static analysis have been performed.Earthquake load is applied on model of structure as per IS-1893(2002) for Zone V in ETABS software. Load combinations for analysis are set as per IS-456(2000).

II. MODELLING & MATERIAL SPECIFICATIONS

ETABS is an elaborated and exceptional purposeanalysis and design software program developed particularly for tall building system.In total, 96 cases have been analyzed in this study for following desired outcomes, Top storey displacement, Maximum Bending moment, story drift and Base shear.

Figure 2: Model Cases

For modeling, Density of brick wall is considered ϒ brick = 20kN/m3 and grade of steel is fy = 415N/mm2.

Table 1: Material Specifications

Concrete Properties	Unit	Grade of Concrete		
		M25	M30	M35
Modulus of elasticity (E)	MPa	25000	27386.13	29580.4

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Shear modulus (G)	MPa	10416.67	11410.89	12325.17
Poisson's ratio (μ)	------	0.2	0.2	0.2
Coefficient of thermal Expansion (α)	/ºC	0.0000055	0.000055	0.000055

Dimension in X direction is 20m and in Y direction dimension is15m.

Story Height is taken 3.5m. Plan view of the section can be seen in Figure 3. Beams, columns, slabs and wall thickness are shown in Table 2 as sectional dimensions.

Table 2: Sectional Dimensions

Members	Member Size (mm)
Beams	350 x 450
	300 x 400
Columns	450 x 600
	300 x 450
Slabs	200 (Thickness)
Wall	100

III. LOADING & COMBINATION

Load acting on the structure are Dead load (DL), Live load and Earthquake load (EL). Structural models have not been analyzed for wind load, since earthquake loads exceed the wind loads. Loading combination of self-weight, dead load, live load and seismic load was taken into consideration according to IS-code 875(Part 5).

$$[1.2\ (DL + LL \pm EL)]$$

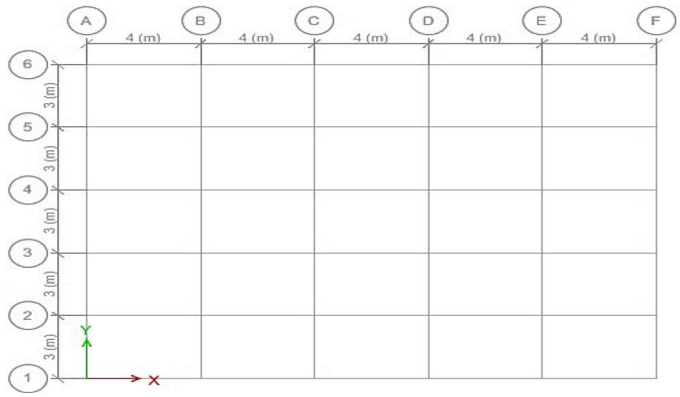

Figure 3: Plan View

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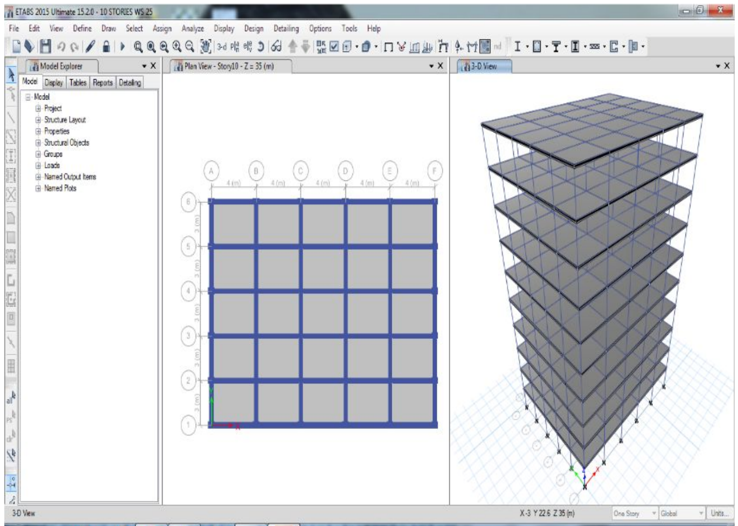

Figure 4: RC Structure

Self-weight comprises of the weight of beams, columns and slab of the building. Calculations of loads are as follows,

Wall load = (unit weight of brick masonry X wall thickness X wall height)= 20 kN/m^3 X 0.1m X 3.5m= 7 kN/m (acting on the beam)

Floor Finish: 1 kN/m^2, Liveload: 4 kN/m^2 (IS 875 (Part 2) acting on beams.Seismic load is considered along two directions, EQ length and EQ width as per [IS 1893(Part-1):2002. Table 1, 2 & 3]. Seismic zone: V with zone factor Z=0.36, Soil type: II i.e. medium soil, damping equals to 5 %and importance factor equal to 1 have been considered while analysis. is the design lateral force at floor i is calculated using following formula,

, where

is the seismic weight of the floor i, is the height of floor imeasured from base, Depth of foundation below ground was taken equal to 2.5 m. The infill walls in upper floors may contain large openings in high rise structures, although the solid walls are considered in load calculations. Therefore, fundamental time period is obtained by using the following formula.

= (0.09×)/√ [IS 1893 (Part 1):2002, Clause 7.6.1]

Where, Ta is the empirical time period of building, h is the height of building from the base and d is the base dimension.

S_a/g = 1.36/0.97 = 1.402 [IS: 1893 (Part 1): 2002, Figure 2]

Ductile detailing is assumed for the structure as it is mandatory in Zones III, IV and V. Hence, Response Reduction Factor, R, is taken equal to 5.0., where, W is the seismic weight of the structure and is design horizontal seismic coefficient.

IV. RESULTS & DISCUSSION

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The bottom of the section lies in XY- plane, various outcomes have been studied for each of the lateral X and lateral Y directional force due to earth quake.

TOP STOREY DISPLACEMENT –

For the Seismic loading in X direction, the maximum top storey displacement is found in X direction only, and vice – versa. The value of maximum storey displacement increases when type of analysis changes from linear to P-Delta.

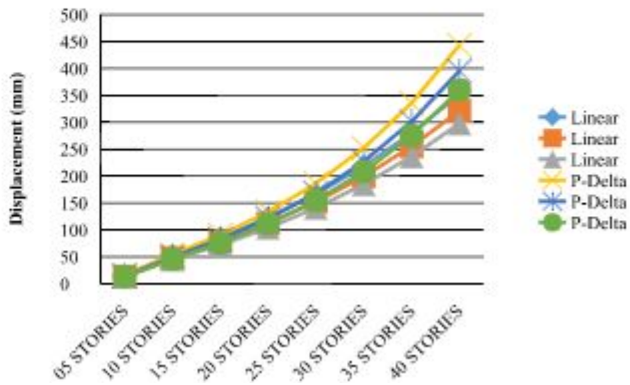

Figure 5: Maximum Top Story Displacement

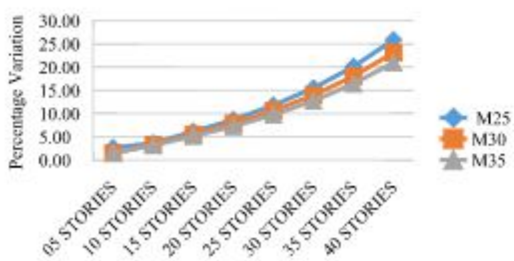

Figure 6: Percentage Variation in Maximum Top Story Displacement

The percentage variation of maximum storey displacement increases with the storey height. For a particular height of structure, the percentage variation of maximum storey displacement decreases with increase in the grade of concrete used. The rate of change in variation of maximum storey displacement increases with increase in storey height.

STOREY DRIFT RATIO –

The storey drift ratio is only calculated in X direction only, and vice – versa, for the Seismic loading in X direction, the value of storey drift ratio increases when type of analysis changes from linear to P-Delta. The variation is following an upward trend with increasing storey. For a particular height of structure, the percentage variation of storey drift decreases with increase in the grade of concrete used.

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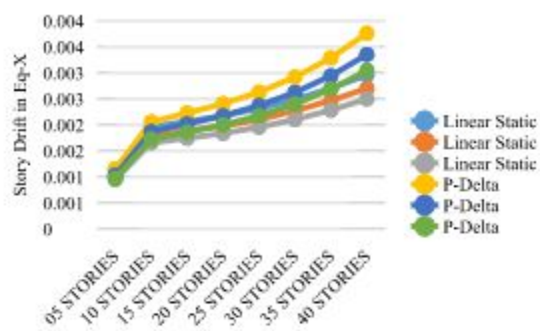

Figure 7: Maximum Story Drift ratio

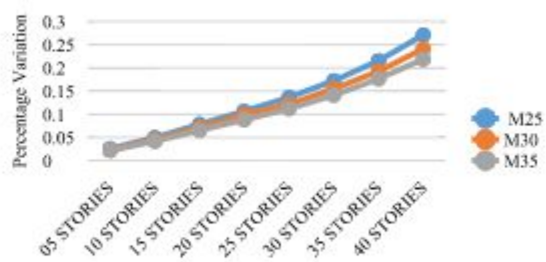

Figure 8: Percentage Variation in Maximum Story Drift ratio

The rate of change in variation of storey drift ratio increases with increase in storey height. Storey drift ratio effect changed at faster rate for buildings with lower number of stories, up to 10th storey. Storey drift ratio is found maximum in near about middle storey of the building.

BENDING MOMENT –

For the Seismic loading in X direction, the maximum bending is found about Y axis, and vice – versa. Being an important parameter torsional moment is calculated about Z axis because models are in X-Y plane. The value of maximum bending moment increased when type of analysis changes from linear to P-Delta. The value of maximum torsional moment decreasedfor the same. The percentage variation of maximum bending moment increases with the storey height.

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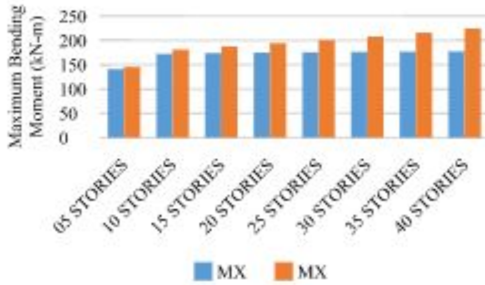

Figure 9: Maximum Bending Moment

For a particular height of structure, the percentage variation of maximum bending moment do not get affected by the change in grade of concrete and for the same, the percentage variation of maximum torsional moment do not get affected by the change in grade of concrete. Percentage variation in maximum torsional moment have not shown any type of proportionality with change in height. The relation cannot be predicted clearly.

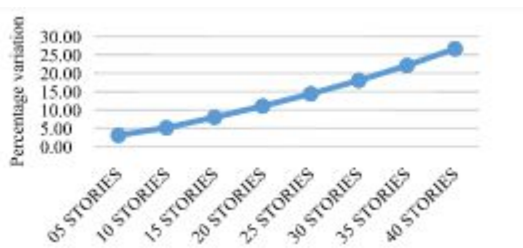

Figure 10: Percentage Variation in Max B.M

BASE SHEAR –

For the Seismic loading in X direction, the maximum base shear is found in X direction, and vice – versa. Maximum base shearincreased when type of analysis changes from linear to P-Delta.

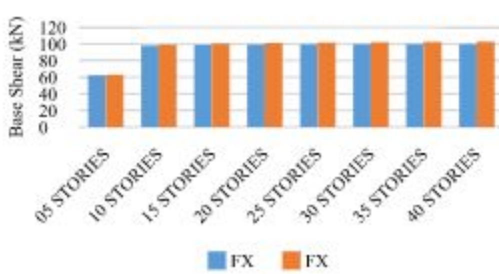

Figure 11: Base Shear in X-direction

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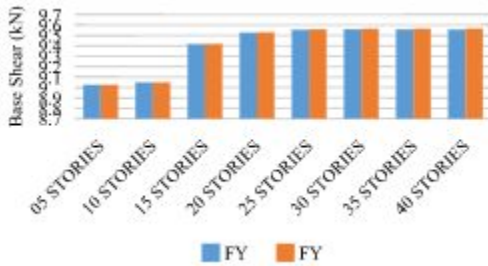

Figure 12: Base Shear in Y-direction

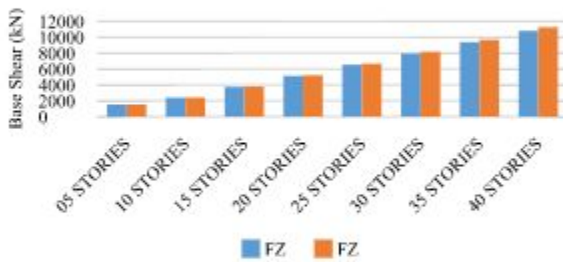

Figure 13: Base Shear in Z-direction

The value of maximum base shear has increased with increase in height of the structure. The value of design lateral load has found almost same when storey height is increased further by 10 storey. Its percentage variation do not get affected by the change in grade of concrete for a particular height.

V. CONCLUSIONS

This study represented that linear static analysis considers only first order loading effects that is not realistic for tall slender structures, but P-delta analysis is suitable to get the iterative action as it consider second order loading effects after performing the first order effects.

- The value of maximum storey displacement, maximum bending moment, storey drift ratio have increased when type of analysis changes from linear to P-Delta.
- Storey drift ratio is found maximum in near about middle storey in the high-rise buildings.
- Axial reaction is found to be near about same in both type of analysis of models for a particular height of the structure.
- The percentage variation of maximum base shear, storey drift ratio and top storey displacement have found high for higher structures.
- From the study what is inferred is that P-delta is essential for storey higher than 15 storey because percentage variation for various outcomes follows upward trending path.
- Percentage variation in maximum torsional moment has not found to follow a predictable path.

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That is how, this research has canvased the effects of various provisions of the Indian standards on the seismic performance of RC buildings in linear static and P-delta analysis.

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