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P-Delta Analysis of Multi-Story Building Using ETABS Software

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ABSTRACT
Now a day's tall structures have gained popularity because of urbanization and population increase and land cost being higher day by day. A tall structure should be designed to resist the lateral load like Earthquake force within the permissible limits set by Standards. For tall structure it is necessary to consider nonlinearity, which is generally observed in geometry & materials. Our study is based on "P-Delta" analysis which incorporates geometric nonlinearity in the analysis. The study will be performed on structural software ETABS. 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 of multi storey building is studied and both, linear static analysis (without P- delta effect) and second order analysis (with P-delta effect) on multi storey building have been carried out. A building model with constant height (G+24) storeys with and without shear walls is prepared, and in each case linear static (first order) and P-delta (second order) analysis is carried out for gravity and earthquake loads. The maximum response in the building in terms of displacement, drift ratio, moment and shear forces has been found out and compared. The analysis of multistoried RC building have been done using ETABS 2016 structural analysis software.
Keywords: *Linear Elastic and Non-linear Elastic Analysis, P-Delta Effects, Geometric Non-linearity, Displacement, Drift, Base shear.*

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I. INTRODUCTION

The analysis of buildings is done by using linear elastic methods, which is the first order analysis. In a first order analysis displacements and internal force are evaluated in relation to the geometric unreformed structure. It does not consider buckling and material yielding. In case of first order elastic analysis, the deformations and internal forces are proportional to the applied loads. However, the deflection of the structure can have a second order effect (geometric non-linearity) on the behavior of the structure, which is not evaluated by the linear first order analysis. This type of geometric non-linearity can be analysed by performing through iterative processes which is only practicable by using computer programs. It is generally known as second order analysis. In this type of analysis, the deformations and internal forces are not proportional to the applied loads. P-Delta is a non-linear effect that occurs in every structure where elements are subject to axial load. Due to little knowledge of P-Delta and complexity of analysis, architectures and structural engineers are tempted to perform linear static analysis, which may eventually become the cause of a sudden collapse of the structure. In the case of short columns and medium rise structures, P-delta effect will be small and hence negligible. But in slender columns or high-rise structures, P-delta effect becomes more significant. In the design of high-rise buildings with vertical irregularity, it is very much important to examine whether the second order P-delta effects are significant.

1.1 Types of Nonlinear Static Analysis

1) Geometrical non-linearity
a. P-Delta effect
b. Buckling effect
c. Large Displacement effect
2) Material non-linearity (Effects of material properties)
a. Cracking in concrete
b. Crushing in concrete
c. Yielding in steel
d. Creep and Shrinkage

a. P-Delta Effect

P-Delta is a geometrical non-linearity and it give the additional shear forces and bending moment to the structure due the applied force P, whereas P is the load and delta is a lateral deformation. P-Delta is actually only one of many second-order effects

The effect of P-Delta is mainly dependent on the applied load and building characteristics. In addition to this it also depends upon the height, stiffness and asymmetry of the building. The building asymmetry may be unbalanced mass, stiffness, in plane, etc

The Initial P-Delta Analysis in ETAB-There are two ways to specify as follows.

1 .Non-Iterative based on mass

The load is computed automatically from the mass at each level as a story-by-story load upon the structure. This approach is approximate, but does not require an iterative solution. This method is identical to p-delta analysis in ETABS. This method essentially treats the building as a simplified stick model to consider the P-Delta effect. It is much faster than the iterative method. It does not capture local buckling as well as the iterative

$$\theta = \frac{P_x \Delta I}{VHC_d}$$

method. This method works best if you have a single rigid diaphragm at each floor level though it also works for other cases as well. The reason we provide this method is to allow you to consider P-Delta in cases where you have not specified gravity loads in your model. If you have specified gravity loads in your model, then in general, we recommend that you use the Iterative Based on Load Cases option.

2. Iterative based on load cases

The load is computed from a specified combination of static load cases. This is called the P-Delta load combination. ¾ P-Delta Load Combination: This area is active if you select the Iterative Based on Load Cases option in the Method area of the dialog box. Here you specify the single load combination to be used for the initial P-Delta analysis of the structure. As an example, suppose that the building code requires the following load combinations to be considered for design:

1) 1.4 DL
2) 1.2 DL+ 1.6 LL
3) 1.2 DL + 0.5 LL + 1.3 EQ
4) 1.2 DL + 0.5 LL - 1.3 EQ
5) 0.9 DL + 1.3 EQ
6) 0.9 DL - 1.3 EQ

For this case, the P-Delta effect due to the overall sway of the structure can usually be accounted for, conservatively, by specifying the P-Delta load combination to be 1.2 times dead load plus 0.5 times live load. This will accurately account for this effect in load combinations 3 and 4 above, and will conservatively account for this effect in load combinations 5 and 6. This P-Delta effect is not generally important in load combinations 1 and 2 since there is no lateral load.

1.2 Consideration of P-Delta Effect

As per ASCE/SEI 7-10 (Minimum Design Loads for Buildings and Other Structures) Clause no 12.8.7, P-delta effects on story shears and moments, the resulting member forces and moments, and the story drifts induced by these effects are not required to be considered where the stability coefficient (θ) as determined by the following equation is equal to or less than 0.10

1.3 Objective of the Project

The objective of this work is to find out the effect of P-delta analysis (Second-order effects) upon the responses of the structures such as displacement, bending moment, shear forces against the linear static analysis. Also, to study the effectiveness of shear wall in reducing the P-delta effect. Using ETABS software.

1. To perform linear static analysis (first order analysis) on multistory building
2. To study P-delta effect (second order effect) on multistory building
3. To find the effectiveness of shear wall in reducing P-delta effect
4. To study the parameters such as deflection, drift, overturning moments, shear forces for linear static analysis and P-delta effect and with and without shear wall.

II. METHODOLOGY

A G+24 storey building, each storey height of 3m is analysed using ETABS by considering p-delta effect and without p-delta effect also the models were analysed by providing shear wall with p-delta effect and without p-delta effect.

Modeling Steps in ETABS

1. Preparing grid for layout.
2. Assigning material properties.
3. Assigning member properties of beams, columns, slab and shear walls.
4. Preparing load cases like dead, live, earthquake.
5. Make load combinations and modal mass of the structure.
6. Run the analysis.
7. Note down the results.
8. Find out stability coefficient 'θ', if $\theta \leq .01$ do P-delta analysis.
9. Preparing P-Delta load case.
10. Run the analysis and comparing the results all models with the same procedure.

III. MODELING AND ANALYSIS

The analysis is carried out for G+24 storey commercial building, with constant storey height in finite element software ETABS V20 for dead, live, earthquake loads with model and concrete properties as specified below. For the analysis purpose two models are prepared with similar floor plan, one model with shear wall and other without shear wall. For each model linear static analysis and P-delta analysis is carried out. The responses of structure is carefully studied and compared.

Geometry of model	
Number of stories	G+24
Plan dimension	35m×34m
Storey height	3m
Location of structure	Guwahati
Section Properties	
Slab depth	150mm
Size of beams	300x600mm
Size of columns	750x750mm
Thickness of Shear wall	200mm
Thickness of brick wall	150mm
Material Properties	
Grade of steel	Fe550
Grade of concrete	M_{20},M_{30},M_{40}
Load and intensities	
Floor finish	1.5 kN/m2
Roof finish	1.5 kN/m2
Wall load	11.04 kN/m
Parapet wall load	6.9 kN/m
Live load on slab	4 kN/m2
Live load on roof-slab	1.5 kN/m2
Seismic Properties from IS 1893-2016	
Zone factor	0.36
Importance factor	1.5
Soil type	Medium soil

Damping	5%
Response reduction factor	5

SHARP EDGE AT THE CORNERS OF THE BUILDING

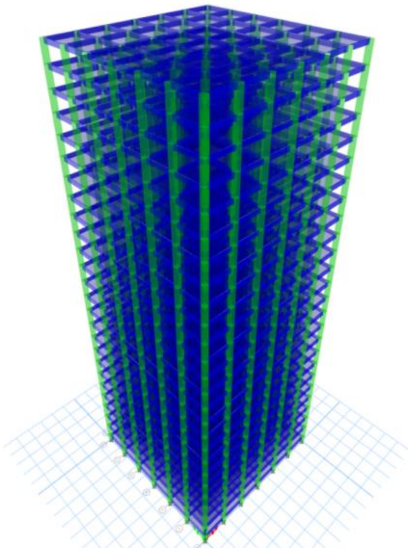

Fig 3.1: 3D view of model without shear wall (model1a)

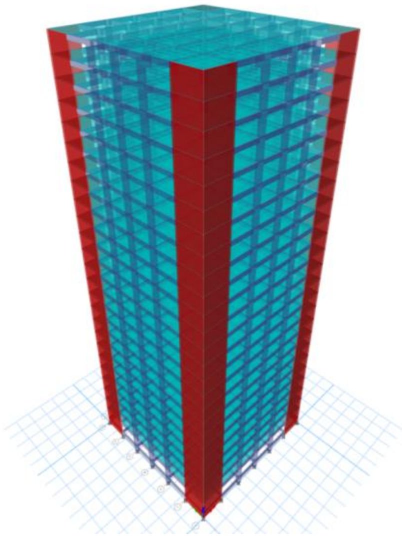

Fig 3.2: 3D view of model with shear wall (model1b)

CUT SHAPE AT THE CORNERS OF THE BUILDING

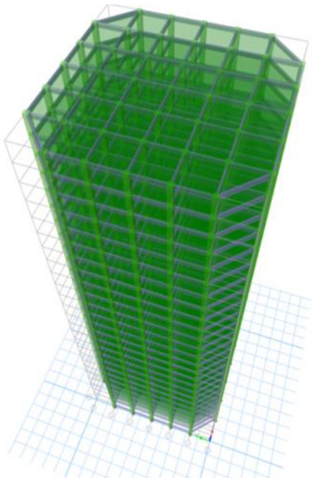

Fig 3.3: 3D view of model without shear wall (model 2a)

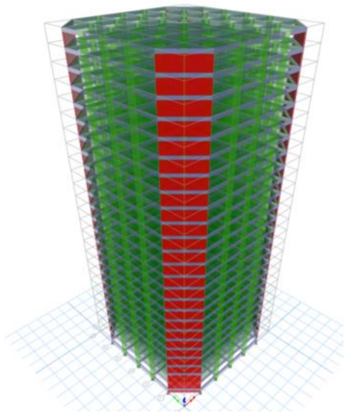

Fig 3.4: 3D view of model with shear wall
(model 2b)

RECESSED SHAPE AT THE CORNERS OF THE BUILDING

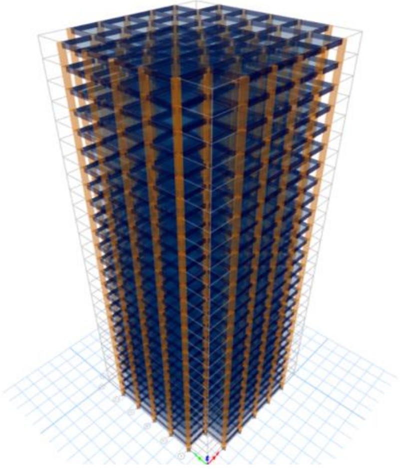

Fig 3.5: 3D view of model without shear wall
(model 3a)

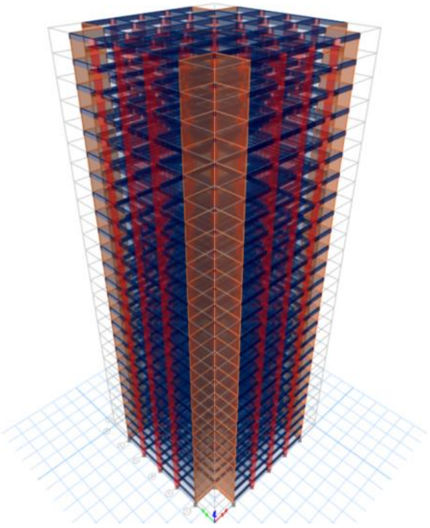

Fig 3.6: 3D view of model with shear wall
(model 3b)

IV. RESULTS AND DISCUSSION

Results are taken for linear static analysis and P-delta analysis also with and without shear wall models. The variation of displacement, drift, base shear and overturning moments are obtained from LSA and P-delta analysis and, are plotted in graphs. The results and discussions given are considered in detail with reference to required tables and figures.

4.1 Displacement

The maximum values of displacements are tabulated by comparing X and Y directions.
The values of displacement of different models are obtained by subjecting the models to linear static analysis and P-delta analysis considering the case which shows max displacement.

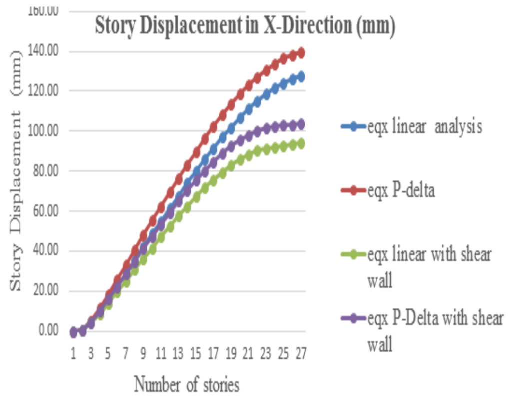

Fig 4.1: Displacement in X-direction at recessed shape

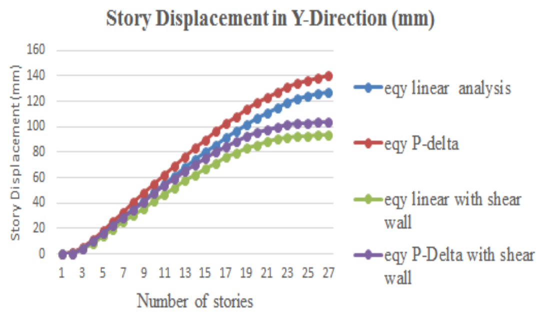

Fig 4.2: Displacement in Y-direction at recessed shape

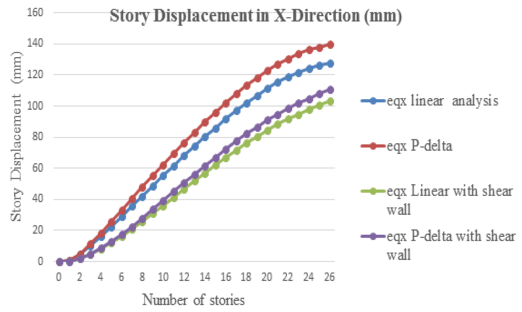

Fig 4.3: Displacement in X-direction at sharp edge

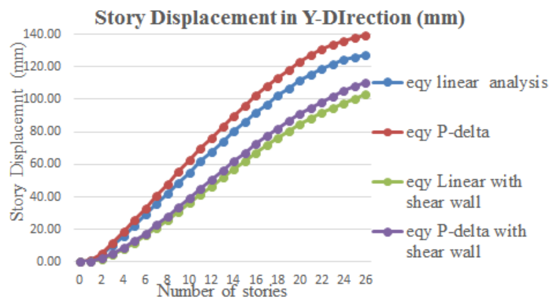

Fig 4.4: Displacement in Y-direction at sharp edge

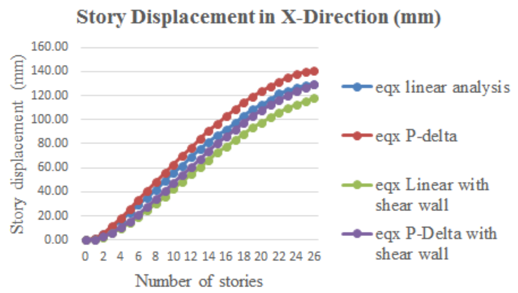

Fig 4.5: Displacement in X-direction at cut shape

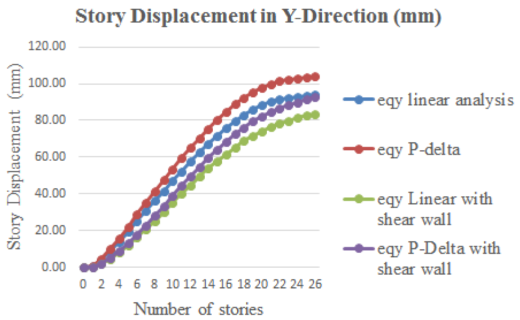

Fig 4.6: Displacement in Y-direction at cut shape

4.2 Storey Drift: Story drift is the lateral displacement of one level relative to the level above or below. Story drift results for the load case EQX and EQY are taken. Further the tabulated results are plotted in a graph and can be seen below figure.

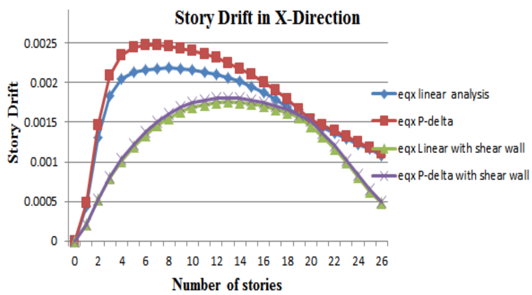

Fig 4.7: Story drift in X-direction at sharp edge

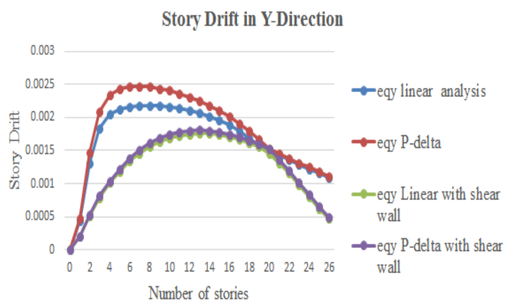

Fig 4.8: Story drift in Y-direction at sharp edge

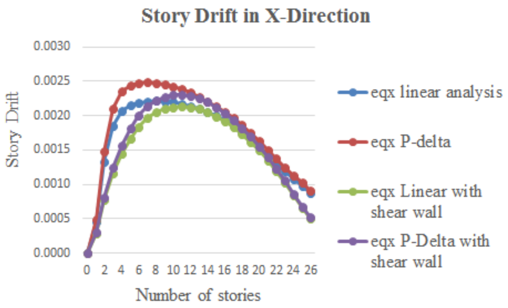

Fig 4.9: Story drift in X-direction at cut shape

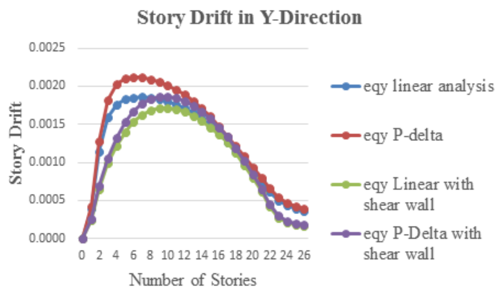

Fig 4.10: Story drift in Y-direction at cut shape

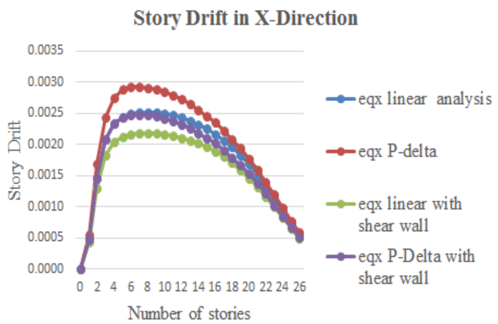

Fig 4.11: Story drift in X-direction at recessed shape

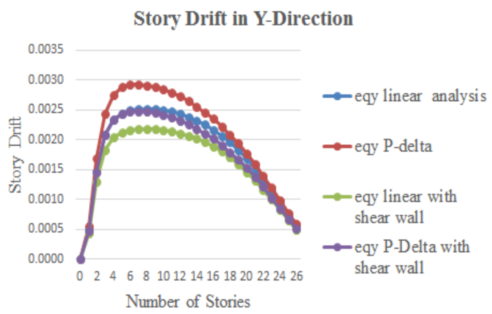

Fig 4.12: Story drift in Y-direction at recessed shape

4.3 Base Shear: Base shear is a measure of the maximum expected lateral force that will happen due to the seismic ground motion at the base of the structure.

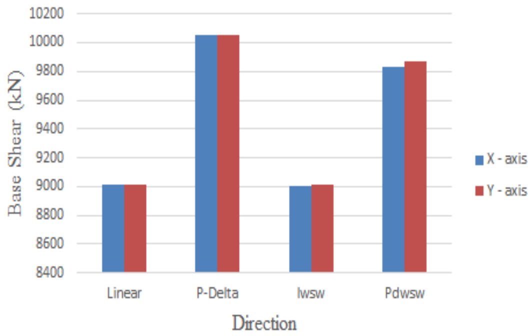

Fig 4.13: Base Shear in both directions for sharp edge at the corners of the building

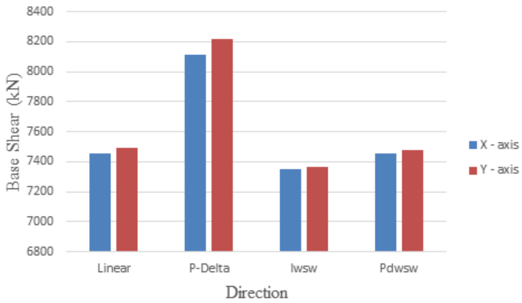

Fig 4.14: Base Shear in both directions for Recessed Shape at the corners of the building

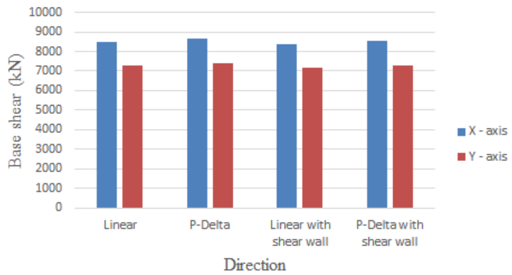

Fig 4.15: Base Shear in both directions for cut shape at the corners of the building

4.4 Overturning Moment: The overturning moment at any horizontal plane is the moment on the structure asa whole resulting from the dynamic earthquake forces above the plane.

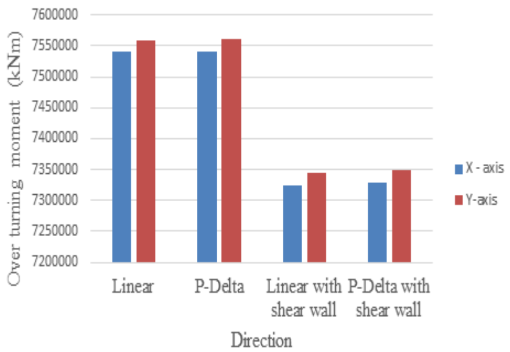

Fig 4.16: Over turning moment in both directions for sharp edge at the corners of the building

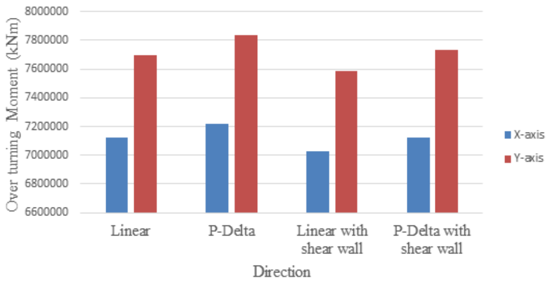

Fig 4.17: Over turning moment in both directions for cut shape at the corners of the building

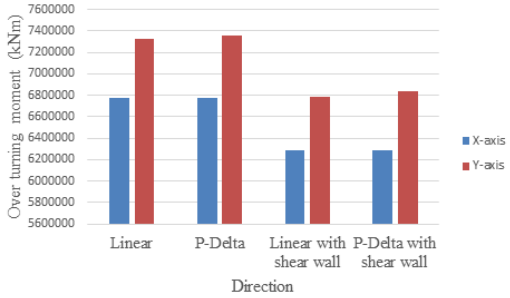

Fig 4.18: Over turning moment in both directions for recessed shape at the corners of the building

V. Discussion

Linear static analysis and P-delta analysis without shear wall for sharp edge model

- Change in the displacement about X-axis is 9.5%-13.1%
- Change in the displacement about Y-axis is 9.5%-13.1%
- Change in the drift about X-axis is 2.1%-13%
- Change in the drift about Y-axis is 2.1%-13%
- Change in base shear about X-axis is 1.08%
- Change in base shear about Y-axis is 1.08%
- Change in overturning moment about X-axis is0.08%
- Change in overturning moment about Y-axis is 0.08%

Linear static analysis and P-delta analysis with shear wall for sharp edge model

- Change in the displacement about X-axis is 4.7%-8.1%
- Change in the displacement about Y-axis is 4.7%-8.1%

- Change in the drift about X-axis is 1.5%-4.36%
- Change in the drift about Y-axis is 1.5%-4.36%
- Change in base shear about X-axis is 0.88%
- Change in base shear about Y-axis is 0.91%
- Change in overturning moment about X-axis is 0.06%
- Change in overturning moment about Y-axis is 0.05%

Linear static analysis and P-delta analysis without shear wall for cut shape model

- Change in the displacement about X-axis is 7.8%-14.7%
- Change in the displacement about Y-axis is 10.1%-13.3%
- Change in the drift about X-axis is 4.2%-12.6%
- Change in the drift about Y-axis is 6.2%-14.0%
- Change in base shear about X-axis is 1.53%
- Change in base shear about Y-axis is 1.51%
- Change in overturning moment about X-axis is 1.36%
- Change in overturning moment about Y-axis is 1.8%

Linear static analysis and P-delta analysis with shear wall model

- Change in the displacement about X-axis is 6.8%-10.1%

- Change in the displacement about Y-axis is 2.8%-10.11%
- Change in the drift about X-axis is 3.04%-8.3%
- Change in the drift about Y-axis is 4.9%-8.9%
- Change in base shear about X-axis is 0.16%
- Change in base shear about Y-axis is 0.14%
- Change in overturning moment about X-axis is 0.13%
- Change in overturning moment about Y-axis is 0.15%

Linear static analysis and P-delta analysis without shear wall for recessed shape model

- Change in the displacement about X-axis is 9.2%-13.2%
- Change in the displacement about Y-axis is 9.2%-13.2%
- Change in the drift about X-axis is 3.8%-16.5%
- Change in the drift about Y-axis is 3.8%-16.5%
- Change in base shear about X-axis is 0.84%
- Change in base shear about Y-axis is 0.92%
- Change in overturning moment about X-axis is 0.09%
- Change in overturning moment about Y-axis is 0.05%

Linear static analysis and P-delta analysis with shear wall for recessed shape model

- Change in the displacement about X-axis is 9%-13%
- Change in the displacement about Y-axis is 9%-13%
- Change in the drift about X-axis is 2.9%-14.03%
- Change in the drift about Y-axis is 2.9%-14.03%
- Change in base shear about X-axis is 0.13%
- Change in base shear about Y-axis is 0.14%
- Change in overturning moment about X-axis is 0.02%
- Change in overturning moment about Y-axis is 0.06%

VI. CONCLUSIONS

1. From the above it can be seen linear static analysis considers only first order loading effect that is not realistic for tall slender structures, but P-delta analysis is suitable for getting iterative action as it consider second order loading effect after performing the first order effects.
2. The displacement values of conventional building model (without P- Delta) are less when compared with building model with P-Delta. About sharp edge 9-13.1%, cut shape 7.8-14.7%, recessed shape 9.2-13.2% increases in displacement values can be seen. Though story displacement values are within permissible limit.
3. Story drift is found maximum in near about middle story's in the structure.
4. By comparison, shear walls are highly efficient in resisting lateral loads, hencedisplacement, hence P-delta effects about sharp edge 37.10%, cut shape 19.65%, recessed shape 15.2% reduction in displacement, 86.80% sharp edge, 34.85% cut shape and recessed shape 17.32% reduction in drift. And no significant amount of variation base shear and overturning moments due to shear walls.
5. In above 3 model case recessed shape is better because of Base shear and Overturning moment are 8111.32kN and 6776640kNm, but in cut shape 8643.41kN and 7218634kNm, sharp edge 10048.87kN and 7541517kNm
6. It is necessary to check the results of analysis with and without considering P-delta effect for a multistoried building.
7. P-delta effect shows up only in high rise buildings.
8. In case of minor modifications of structures like sharp edge at the corners of the building and recessed shape at the corners of the building concluded that, due to action of earthquake loads , recessed shape at the corners of building structure is capable of reducing seismic effect with observations of story displacement, story drift and base shear values.
9. In case of minor modifications of structures like sharp edge at the corners of the building and recessed shape at the corners of the building, recessed shape at the corners of building structure is suitable only for seismic zone V.

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