Behavior of P-Delta Effect in High-Rise Buildings With and Without Shear Wall

PhaniKumar V, M.Deepthi, Saikiran K, R.B.N. Santhosh

Abstract: The high rise structures are proposed for residential and commercial purposes. They may easily effect by seismic as well as wind loads, so the buildings get deformed and collapsed easily. To avoid these problems we consider p-delta effect in designing. As the number of stories increases p-delta effect becomes very important. The P-Δ effect is relevant in structural engineering problems, especially in civil engineering, where we're dealing with large structures with proportionally decreasing small moments of inertia as they continue to be extended in absolute height. When designing structures, we may consider that they're immune to lateral deformation, and may therefore not account for their behaviour when sudden buckling or beam-column-like behaviour is introduced. In this study p-delta (P-Δ) effect on high-rise building studied for the analysis of G+29 RCC framed building and models were done by ETABS2016. Seismic and wind loads are applied to model as per IS-1893 (2002) and IS-875 (PART-III). The displacements, storey drifts, Bending Moments and Shear Forces are compared to the different models by considering with and without P-delta effect and by providing shearwalls at different locations.

Keywords: p-delta effect (P-Δ), displacement, shear wall, ETABS.

I. INTRODUCTION

National Building Code (NBC) defines all buildings which are 15 m or above in height are considered as high-rise buildings. But many development authorities define a high-rise building or a multi-storied building as a building of a height of 24 metres or above.

When a slender structure is exposed to lateral loads i.e. wind or seismic loads it experiences sway or lateral displacement. Whenever this lateral displacement is increased to peak then gravity loads start to act with an eccentricity. This is equal to the magnitude of elastic deflection causing an additional overturning moment. Due to which, a second order deflection is developed in the structure.

This second order effect caused in the structure is known as P-Delta effect. Where “P” is the gravity load and “Δ” is the displacement experienced through first order or elastic analysis for lateral forces. The P-Delta effect is shown in the Figure 1. Where the Δ is second order deflection caused due to P-delta effect.

Figure 1: P-Delta Effects on a Simple Cantilever Column The P-Δeffect is experienced in all structures when they were subjected to an axial load in combination with lateral displacement. The major effect is observed due to deflection of the structure as a whole and also termed as P-delta (P-Δ). However, this research is done on the P-delta effect observed through structural instability (P- Δ). Tall structures and buildings with more number of stories will undergoes large P-delta effect. They are to be designed with Proper recommended considerations. The importance of P-Delta non-linear analysis is continually increasing in high rise buildings are getting very popular and playing a key role.

II. OBJECTIVE OF WORK

✓ To perform linear static analysis of the tall structure by using ETABS2016 by providing shear-wall.
✓ And to study the P-Delta (non-linear) effect on tall structure by using ETABS and to study the effect of axial loading on the structure.
✓ To study the results of the structure, i.e. deflections and forces by considering with and without P-Delta effect by providing shear-wall.
✓ To compare the results with P-delta effect and without P-delta effect in structure.
III. ANALYSING OF BUILDING AND MODELLING IN ETABS

A G+29 storey building with plan of 35x40m each storey height of 3m was analysed in ETABS by considering p-delta effect and without p-delta effect and the models were analysed by providing shear wall at different locations in the plan of the building.

Modelled steps in ETABS:
1. Preparing grid for layout
2. Assigning member properties of beams, columns, and slab and wall panels.
3. Preparing load cases like Dead, live, earthquake and wind loads.
4. Make load combinations and modal mass of the structure.
5. Assigning P-delta loads and the structure
6. Run the analysis
7. Note down the results and comparing the models with the same procedure.

The materials used for the analysis are M-25 for slabs and M-30 grade reinforced concrete for beams and columns and Fe-500 grade steel for the entire structure.

A. Geometry of model:

The analysis is carried out for G+29 storey building with reinforced concrete properties as specified above.

The model details are given below:
- Number of stories = G+ 29
- no. of Bays in x-direction= 9
- no. of Bays in y-direction= 11
- Height of each storey= 3m
- Slab depth= 125mm
- Size of the transverse beams= 230x450mm
- Size of longitudinal beams= 230x600mm
- Size of the columns (ground to 15th floor)= 900x900mm.
- Size of the column (16 to 30 floor)= 600x600mm.
- zone= III
- Response reduction factor considered = 3
- Importance factor considered= 1.5

B. Load Proportions

i. Dead load (DL):
The dead load is considered as per IS code book i.e. IS 875-1987 part-I.
- Unit weight of concrete = 25KN/m³
- Floor finish =1KN/m³
- Roof finish = 1KN/m³

ii. Imposed load (LL):
Imposed load is also known as live load, it is considered as per IS code book i.e. IS 875-1987 part-II.
- Live load of slab = 4KN/m³
- Live load on roof = 3 KN/m³

iii. Earthquake load:
The earthquake load is considered as per IS code book i.e. IS-1893-2002 PART-I and the factors considered are
- Response reduction factor considered = 3.0
- Zone factor considered= 0.16
- Importance factor considered= 1.5
- Damping = 5%
- Soil condition = medium.

C. linear static analysis and non-linear static analysis (p-delta):
The linear static & non-linear is carried out for G+29 storey building with P-delta(Δ) and without considering P-delta(Δ) effect and providing shear wall in ETABS.

From the analysis results, story drifts, displacements, BM and SF are obtained and these are compared.

IV. MODELS CONSIDER FOR ANALYSIS

A. Model 1A

G+29 building model, considering p-delta effect.

Figure – 2 shows the plan and 3d model.
B. Model2A

G+29 building model with p-delta effect and shearwall provided at the centre of the walls in the direction of X&Y axis. Figure – 3 shows the plan and 3d model, location of shear walls at centre of the bays.

C. Model3A

G+29 building model with p-delta effect and shearwall provided in all four corners of the structure. Figure – 4 shows the plan and 3d model, location of shear walls at corners of the structure.

D. Model 1B

Consideration no p-delta effect in this model. Figure – 5 shows the plan and 3d model.
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Figure 5a: Model 1B_Plan

Figure 5b: Model 1B_3D Model

E. Model 2B

In this model: the structure without p-delta effect and shear wall provided along X&Y axis at the centre. Figure – 6 shows the plan and 3d model, location of shear walls at centre of the bays.

Figure 6a: Model 2B_Plan

Figure 6b: Model 2B_3D Model

F. Model 3B

In this model, the structure with no p-delta effect and shear wall provided in all corners. Figure – 7 shows the plan and 3d model, location of shear walls, at corners of the structure.

Figure 7a: Model3B_Plan

Figure 7b: Model 3B_3D Model

V. RESULTS
### A. Maximum displacements and storey drifts

#### Table no.1

| Storey no. | Max.displacements(mm) | Max.displacements(mm) |
|------------|-----------------------|-----------------------|
|            | P-delta (P-Δ)1A       | Without p-delta (P-Δ) 1B | P-delta (P-Δ) 1A | Without p-delta (P-Δ) 1B |
| 5          | 9.459                 | 5.552                 | 971x10^6        | 594x10^6        |
| 7          | 16.214                | 9.181                 | 1170x10^6       | 719x10^6        |
| 9          | 23.884                | 13.533                | 1310x10^6       | 803x10^6        |
| 11         | 32.158                | 18.230                | 1390x10^6       | 856x10^6        |
| 13         | 40.791                | 23.130                | 1450x10^6       | 886x10^6        |
| 15         | 49.556                | 28.109                | 1470x10^6       | 892x10^6        |
| 17         | 58.537                | 33.191                | 1489x10^6       | 907x10^6        |
| 19         | 67.305                | 38.164                | 1490x10^6       | 883x10^6        |
| 21         | 75.690                | 42.918                | 1370x10^6       | 835x10^6        |
| 23         | 83.523                | 47.356                | 1280x10^6       | 776x10^6        |
| 25         | 90.695                | 51.410                | 1166x10^6       | 703x10^6        |
| 27         | 97.167                | 55.056                | 1050x10^6       | 628x10^6        |
| 30         | 105.581               | 59.841                | 929x10^6        | 532x10^6        |

#### Table no.2

| Storey no. | Max.displacements(mm) | Max.displacements(mm) |
|------------|-----------------------|-----------------------|
|            | P-Δ with SW @ center 2A | Without P-Δ & with SW @ center 2B | P-Δ with SW @ center 2A | Without P-Δ & with SW @ center 2B |
| 5          | 4.602                 | 5.674                 | 463x10^6        | 448x10^6        |
| 7          | 7.865                 | 8.475                 | 570x10^6        | 497x10^6        |
| 9          | 11.683                | 11.521                | 657x10^6        | 536x10^6        |
| 11         | 15.931                | 14.754                | 724x10^6        | 567x10^6        |
| 13         | 20.503                | 18.124                | 773x10^6        | 589x10^6        |
| 15         | 25.269                | 21.573                | 805x10^6        | 594x10^6        |
| 17         | 30.296                | 25.121                | 841x10^6        | 616x10^6        |
| 19         | 35.407                | 28.684                | 855x10^6        | 617x10^6        |
| 21         | 40.52                 | 32.208                | 851x10^6        | 608x10^6        |
| 23         | 45.544                | 35.646                | 833x10^6        | 591x10^6        |
| 25         | 50.413                | 38.936                | 803x10^6        | 569x10^6        |
| 27         | 55.083                | 42.136                | 770x10^6        | 544x10^6        |
| 30         | 61.615                | 46.623                | 729x10^6        | 504x10^6        |

### B. Lateral Displacements:

![Figure 8a: Max. Displacement of storeys with and without P-Delta.](image-url)
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C. Storey Drifts:

Figure 8b: Max. displacement of storeys with and without P-Delta considering shear wall at center

Figure 8c: Max. Displacements of storeys with and without P-Delta considering shear wall at corner.

D. Time periods

The natural time period is found for building with p-delta effect, without p-delta & with and without p-delta and shear wall provided at center, and with and without p-delta shear wall (sw) provided at corner.

Figure 9a: Max. storey drift of storeys with and without P-Delta

Figure 9b: Max. storey drift of storeys with and without P-Delta considering shear wall at center

Figure 9c: Max. Storey drift of storeys with and without P-Delta considering shear wall at corner.

E. Base shear:

Base shear is found for all 6 models and compared in below figure 11.
This table shows the maximum bending moments of the structure in all the models:

| Storey no | p-delta (P-A) | Without p-delta | With P-Δ&S corner | Without P-Δ&S corner | Without P-delta SW at corner | Without P-delta SW at corner |
|-----------|---------------|-----------------|-------------------|----------------------|-----------------------------|-----------------------------|
| 5         | 63.91         | 36.32           | 32.89             | 28.06                | -47.57                      | 35.08                       |
| 7         | 77.28         | 43.92           | 40.75             | 32.16                | -56.49                      | 43.38                       |
| 9         | 86.54         | 49.26           | 47.06             | 36.00                | -63.52                      | 49.57                       |
| 11        | 92.46         | 52.77           | 53.65             | 38.55                | -68.70                      | 53.93                       |
| 13        | 96.18         | 54.74           | 56.80             | 39.34                | -72.17                      | 56.71                       |
| 15        | 96.56         | 54.74           | 59.05             | 39.74                | -73.01                      | 57.14                       |
| 17        | 99.33         | 56.21           | 63.97             | 43.31                | -76.46                      | 59.31                       |
| 19        | 96.49         | 54.74           | 65.56             | 43.65                | -75.78                      | 58.41                       |
| 21        | -91.18        | -51.81          | 65.79             | -43.38               | -73.49                      | 56.25                       |
| 23        | -84.74        | -48.18          | -65.02            | -42.49               | -70.04                      | 53.17                       |
| 25        | -77.66        | -43.96          | -63.53            | -41.31               | -66.06                      | 49.64                       |
| 27        | -71.87        | -39.98          | -61.66            | -37.69               | -62.51                      | 46.25                       |
| 30        | -60.92        | -34.28          | -54.44            | -35.83               | -55.34                      | -39.95                      |

**G. Maximum shear forces (kN)**
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Table: The maximum shear force value of all models

| Storey | p-delta | Without p-delta | p-delta SW@center | Without p-delta SW@center | p-delta SW@corner | Withou t p-delta SW @ corner |
|--------|---------|----------------|------------------|--------------------------|------------------|-----------------------------|
| 5      | 30.97   | 17.66          | 16.00            | 13.65                    | 23.14            | 18.80                       |
| 7      | 37.72   | 21.38          | 19.84            | 15.66                    | 27.52            | 23.21                       |
| 9      | 42.32   | 23.99          | 22.92            | 17.54                    | 30.96            | 26.48                       |
| 11     | 45.35   | 25.71          | 26.14            | 18.79                    | 33.50            | 28.78                       |
| 13     | 47.07   | 26.68          | 27.68            | 19.34                    | 35.20            | 30.24                       |
| 15     | 47.09   | 26.65          | 28.76            | 19.37                    | 35.61            | 30.42                       |
| 17     | 45.13   | 25.53          | 29.04            | 19.67                    | 34.72            | 26.12                       |
| 19     | 43.86   | 24.80          | 29.77            | 19.84                    | 34.40            | 28.65                       |
| 21     | 41.42   | 23.54          | 29.90            | 19.71                    | 33.34            | 27.56                       |
| 23     | 38.46   | 21.87          | 29.54            | 19.30                    | 31.76            | 26.02                       |
| 25     | 35.20   | 19.93          | 28.84            | 18.74                    | 29.93            | 24.27                       |
| 27     | 32.25   | 18.09          | 27.98            | 17.09                    | 28.26            | 22.59                       |
| 30     | 27.16   | 15.33          | 24.47            | 16.14                    | 24.73            | 19.00                       |

VI. DISCUSSION

P-delta analysis and linear static analysis by providing shear wall in 6 models, the result of analysis of these models shows the effect of p-delta will be considerable when lateral loads on building. P-delta is negligible when the gravity loads on buildings. In all models the differences are observed very clearly. Storey displacement for both p-delta and without p-delta found the same trend of increasing.

VII. CONCLUSIONS

1. The displacements of conventional building models (without p-delta) is less when compare to building with p-delta.
2. The storey drifts in building models with p-delta effect are more when comparing with models analysed using equivalent static analysis method (without p-delta effect).
3. Shearwall placed at centre of frame shows more effectiveness when comparing with shear wall placed at corner and without shear wall of the structure.
4. Bending moment (BM) in column at fifth floor found 75% increases after the investigation of p-delta analysis.
5. The results show the bending moment (BM) in shearwall 18% increases after p-delta effect.
6. The results of analysis were checked with P-Δ effect and without p-delta effect (P-Δ) in the building models.
7. In elastic or inelastic dynamic analyses, increase in eccentricity causes change in the of p-delta effect. The change is very important in elastic analysis and is somewhat less important in inelastic analysis. However, the variation does not have a constant increasing or decreasing trend. One of the facts that the increase in eccentricity the mass moment of inertia is not increased in all cases.

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