EFFECTS OF P-DELTA ON HIGH RISE BUILDINGS LOCATED IN SEISMIC ZONES

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Abstract – *P-Delta effect becomes more significant when columns are slender. A method of designing of P-Delta effects in high rise buildings 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 for both, earthquake and wind loading, considering with and without P-Delta effect for different number of stories such as G+10, G+20, G+30 and G+40 stories. The load deflection curves and drift ratios have been obtained for different cases and 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.*

In this present study, the Non-Linear static analysis has been carried out using ETABS 9.7 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.

Key Words: **P-Delta effect, displacements, inter storey drift and stiffness**

1. INTRODUCTION:

Design of high rise buildings are taken into account when the slender nature of structure makes it responsive to seismic loads. In the design of multi-storey structures, provision must be for P-Delta effects.

This P-Delta effect is dependent on the load applied and characteristics of materials, in addition to the parameters such as height and stiffness of the building. The amount of its irregularity may also be importance. When the columns are slender, P-Delta effects become more significant.

1.1 P-Delta:

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.

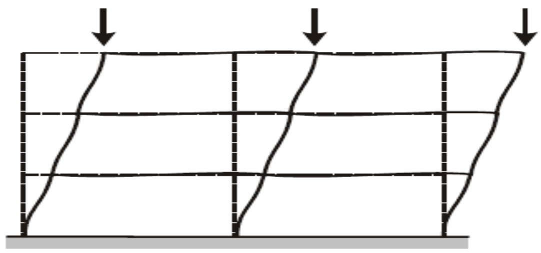

Fig 1.1: P-Delta effects

The amount of P-Delta effect is related to the:

- Slenderness/Stiffness of the structure as whole
- Slenderness of individual elements
- Amount of axial load

2. LITERATURE REVIEW:

T.J. Sullivan, et al., (2008), concluded that the design strength of high rise RC structures may be managed by P-Delta ratio limit of 0.3. A proposition was then made that for very long period systems, the peak displacements are limited by the peak displacement spectral displacement demands of the ground motion, irrespective of whether P-Delta effects are active or not. To examine the implication of P-Delta ratio further, a series of Single Degree of Freedom (SDOF) studies were carried out for systems designed with P-Delta ratios of upto 0.85. The results demonstrated that the P-Delta ratio has little influence on the behaviour of long period systems subject to real earthquake records and therefore it does not appear suitable to impose strict limits on the P-Delta ratio. Instead, it is recommended that the P-Delta effects be assessed for all high rise structure systems as part of an overall assessment of their response, using advanced non-linear time history analysis with real records and within a large displacement analysis system.

Yousuf Dinar, et al., (2013), concluded that analysing and designing of tall RC buildings need skilled observation and understanding. From the analysis it is found that the characteristics is flexible in nature, but it could be said that, under P-Delta analysis with increase in height of the storey and axial force, displacement will varies exponentially. Axial force alters in positive side quickly over the linear static analysis, if P-Delta is performed to find it. So, P-Delta and Linear Static both are required for RC structures and they have to use after proper understanding to avoid any terrible. By moment section to the linear static analysis, displacement and axial could be observed by P-Delta analysis.

Prashant Dhadve, et al., (2015), concluded that P-Delta effect becomes more essential as the number of stories increases. In case of 20 storey and 25 storey buildings and mostly in 25 storey building only in exterior columns and in adjacent beams in some load cases P-Delta effect is observed. If these load cases are leading load cases for design of members, then only P-Delta effect can be considerable. So it is required to check the analysis results by considering P-Delta effects and without considering P-Delta effects for the buildings. Upto 20 storey buildings there is no change in the results, so P-Delta analysis is considered for designing a minimum of 25 storey building considering seismic loads and buildings upto 20 stories can be designed by linear analysis or conventional primary analysis.

Nikun Mangukiya, et al., (2016), concluded that G+24 storey building is analysed with linear static analysis and with P-Delta analysis, from the comparison displacement is varying from 12% to 20% in the result. Similarly, for a load combination (EQ Y-) bending moment shows 5% to 20% variation, value of modal period, in the different mode shapes are also variable. It is advisable to account such effect in high rise structures.

Rajath R, et al., (2016), concluded that displacements with respect to earthquake load with P-Delta effects are maximum when compared with only earthquake load. From this it concludes that P-Delta effects have more effect than linear static effect in designing of a structure. Pounding action of two high rise structures with roof displacement can be minimised.

Objective of the work:

- Detailed study of P-Delta effect.
- To analyse G+10, G+20, G+30 and G+40 storey buildings with and without considering the P-Delta effects.
- Analysis procedure is carried out by using ETABS 9.7, for ascertaining the seismic ability of structures.
- To study the effects of axial loadings on high rise structures.
- To decide the minimum height of the structure for which it is required to include P-Delta effect in analysis.
- To calculate the percentage change in the values of deflections and forces by considering the P-Delta effect and without considering P-Delta effect of structures.
- To make a structure stiffer for bringing it within acceptable limit according to the code.

3. ANALYSIS OF BUILDING MODELS IN ETABS 9.7:

Buildings having same plan but with different number of stories are analyzed in ETABS 9.7 by considering P-Delta effect and without P-Delta effect and their results are compared, for

1. G+10 storey
2. G+20 storey
3. G+30 storey
4. G+40 storey

Plan of building:-

1. Residential building, RCC framed structure.
2. Storey height is 3.5m.
3. Length of building in X-direction = 42m.
4. Length of building in Y-direction = 24m.

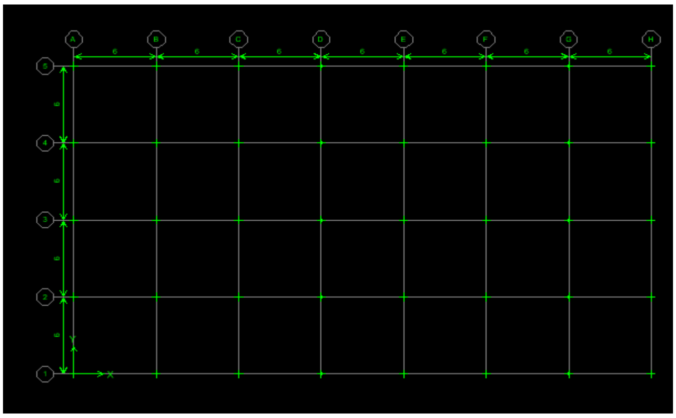

Fig 3.1: Typical key plan of building

3.1 Material properties:

The materials used for the construction is M-25 and M-30 grade reinforced concrete and Fe-500 grade steel. The stress-strain relationship is used as per IS 456:2000. The properties of materials used are as follows:
Characteristic strength of concrete for M-25, fck= 25 N/mm²
Characteristic strength of concrete for M-30, fck = 30 N/mm²
Young's modulus of concrete for M-25, Ec = 25000 N/mm²
Young's modulus of concrete for M-25, Ec = 25000 N/mm²
Characteristic strength of steel for Fe-500, fy = 500 N/mm²

3.2 Geometry of Model:

The analysis is carried out for G+10, G+20, G+30 and G+40 storey buildings with reinforced concrete properties as specified above. The concrete floors are modeled as rigid. The model details are given below:

- Number of stories = G+10, G+20, G+30, and G+40
- Bays along X-direction = 7 No.
- Bays along Y-direction = 4 No.
- Height of the each storey = 3.5 m
- Width of bay along X-direction = 6 m
- Width of bay along Y-direction = 6m
- Slab depth = 175 mm
- Size of the outer beam = 400mmX750mm
- Size of the inner beam = 400mmX600mm
- Size of the column = 600mmX600mm for G+10 storey
- Size of the column = 800mmX800mm for G+20 storey
- Size of the column = 900mmX900mm for G+30 storey
- Size of the column = 1000mmX1000mm for G+40 storey
- Zone = IV
- Response reduction factor = 5
- Importance factor = 1
- Soil condition = Hard soil

3.3 Description of the Model:

The RC frames are designed as per Bureau of Indian Standard codes, I.S.456:2000, "Plain and Reinforced Concrete-code of practice", I.S.1893-2002 (Part 1), "Criteria for earthquake resistant design of structures", the concrete of M-25 and M-30 grade are used for reinforcement.

The RC frames consist of beams, columns and slabs. Frames are analyzed using ETABS 9.7 software. Dead load, imposed load, earthquake load and load combinations are considered for analysis.

i. **Dead load (DL):**

The dead load is considered as per IS 875-1987 (Part I-Dead loads), "Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures".

- Unit weight of Reinforced Concrete = 25 kN/m^3
- Floor finish = 1 kN/m^3
- Roof finish = 1 kN/m^3

ii. **Imposed load (LL):**

Imposed load is also known as Live load. The imposed load is considered as per IS 875-1987 (Part II-Imposed loads), "Code of Practice for Design Loads (Other than Earthquake) for Buildings and Structures".

- Live load on slab = 4 kN/m^2
- Live load on roof = 1.5 kN/m^2

iii. **Earthquake load (EL):**

The earthquake load is considered as per the IS 1893-2002 (Part I). The factors considered are

- Zone factor = 0.24 (Zone IV)
- Importance factor = 1
- Response reduction factor = 1
- Soil condition = Hard soil
- Damping = 5 %

iv. **Load Combinations:**

The structural systems were subjected to 6 types of load combinations as per provisions of **IS 1893-2002 (Part I), Clause 6.3.1,** that deals with "Criteria for Earthquake Resistant Design of Structures", they are:

1) 1.2 (DL + LL + EQX)
2) 1.2 (DL + LL + EQY)
3) 1.5 (DL + EQX)
4) 1.5 (DL + EQY)
5) 0.9DL + 1.5EQX
6) 0.9DL + 1.5EQY

3.4 Parametric Studies:

3.4.1 Linear static analysis:

The linear static analysis is carried out for G+10, G+20, G+30 and G+40 storey building without considering the P-Delta effect in ETABS 9.7 program. From the analysis results, storey shear, displacements, axial force and bending moment at the base and at various structural members are obtained.

3.4.2 Non-Linear static or P-Delta analysis:

The non-linear static analysis is carried out for G+10, G+20, G+30 and G+40 storey building without considering the P-Delta effect in ETABS 9.7 program. From the analysis results, storey shear, displacements, axial force and bending moment at the base and at various structural members are obtained.

Different types of models are considered for the analysis as shown in the figures:

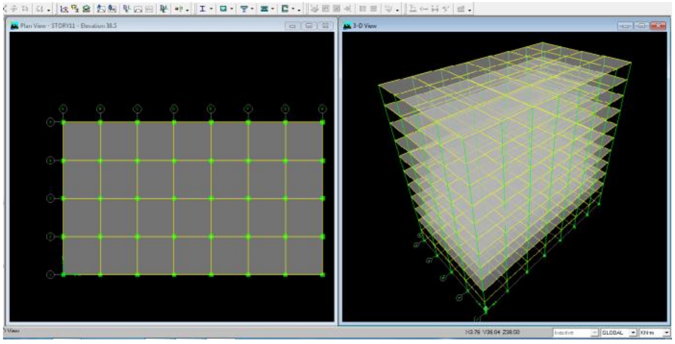

Fig 3.2: G+10 Storey building model without Shear wall

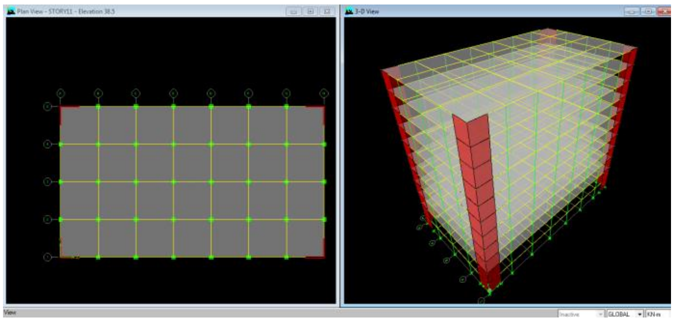

Fig 3.3: G+10 Storey building model with Shear wall

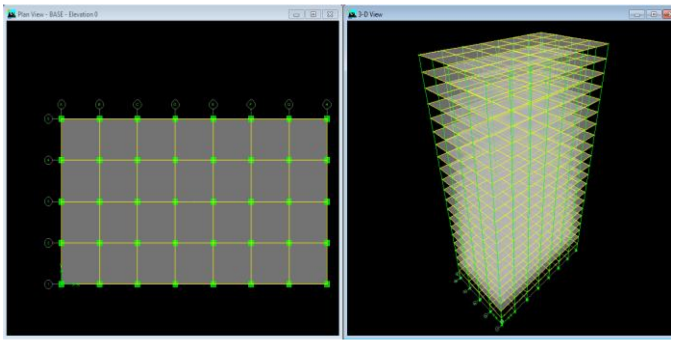

Fig 3.4: G+20 Storey building model without Shear wall

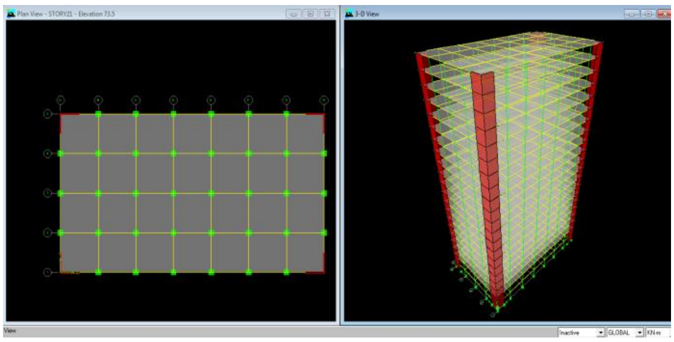

Fig 3.5: G+20 Storey building model with Shear wall

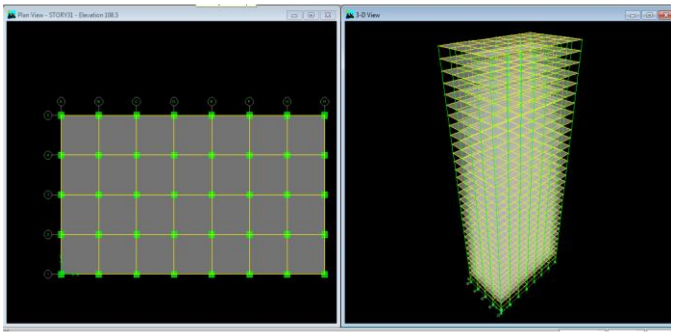

Fig 3.6: G+30 Storey building model without Shear wall

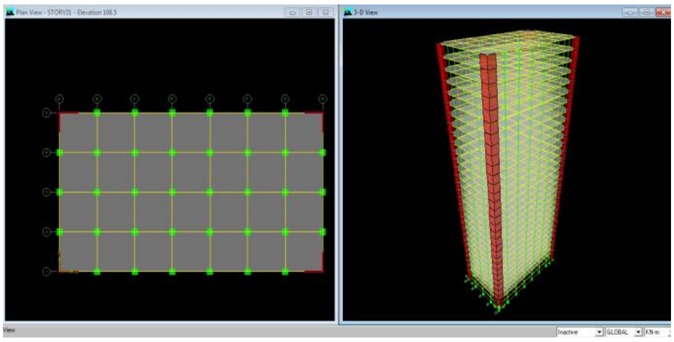

Fig 3.7: G+30 Storey building model with Shear wall

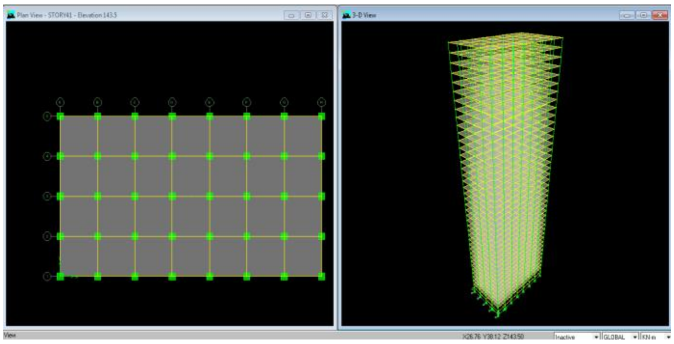

Fig 3.8: G+40 Storey building model without Shear wall

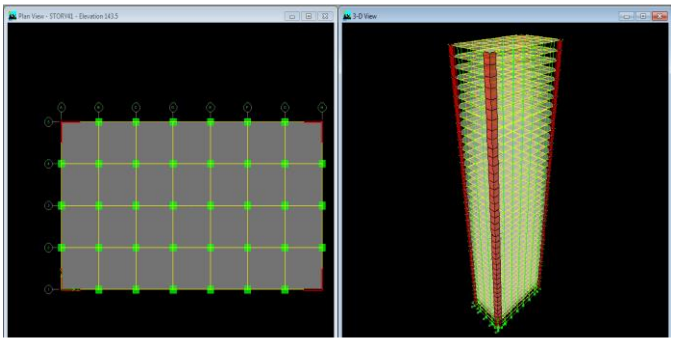

Fig 3.9: G+40 Storey building model with Shear wall

4. RESULTS AND DISCUSSIONS:

P-Delta analysis and Linear static analysis of 4 cases, in total 16 models exposes that P-Delta effects drastically influence the displacement of the structural elements and get higher value than the Linear static analysis. The difference particularly indentified when the slenderness ratio comparatively increases by increasing the storey. Variation is observed in several sections: Variation of displacement at top, variation of axial force in an exterior column, variation of storey displacement of P-Delta analysis and percentage variation against slenderness ratio to systematically examine the response characteristics to the structure due to P-Delta effects with respect to slenderness.

Storey displacements for both P-Delta analysis and Linear static analysis found maintaining the same trend of increasing with increasing the storey whereas the displacement outcomes of P-Delta analysis is found to be greater than that of corresponding displacement of Linear static analysis. This characteristic is found in every storey case and represents the presence of P-Delta effects during performing P-Delta analysis.

4.1 Natural time period:

The natural time period is found for building without and with P-Delta and without and with Shear wall as shown below

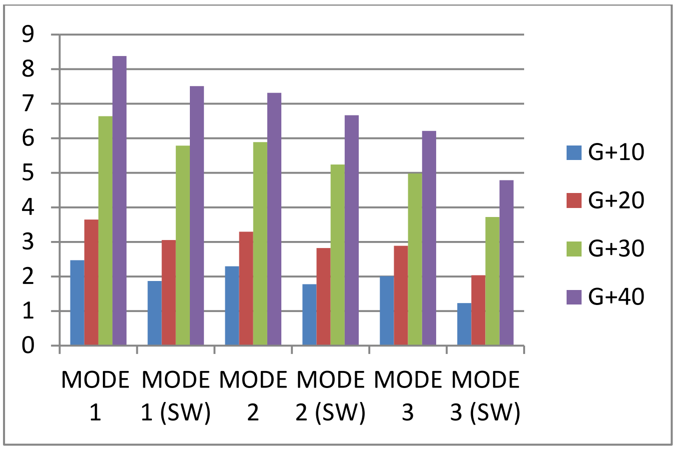

Chart 1: Variation of natural time period of building without P-Delta

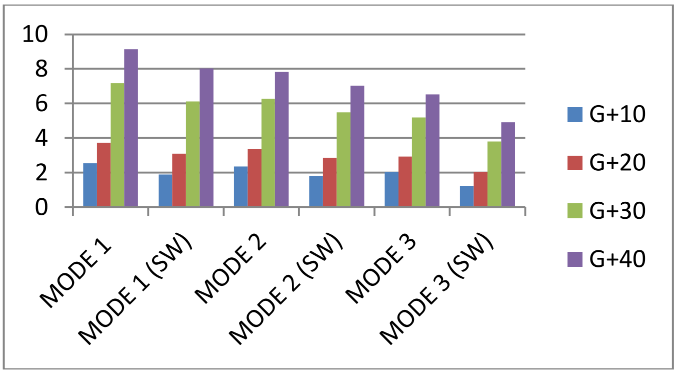

Chart 2: Variation of natural time period of building with P-Delta

4.2 Base Shear:

The base shear is found for building without and with P-Delta and without and with Shear wall as shown below

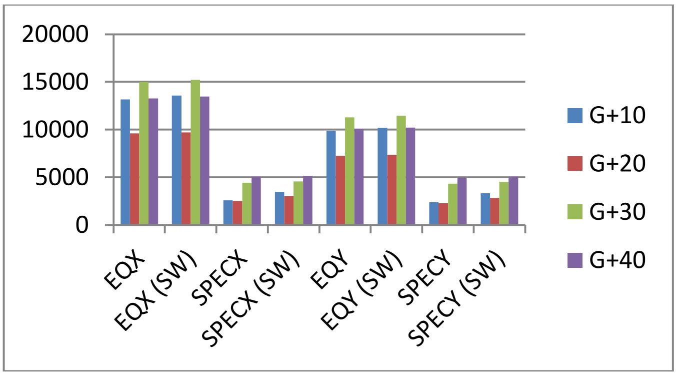

Chart 3: Variation of base shear of building without P-Delta

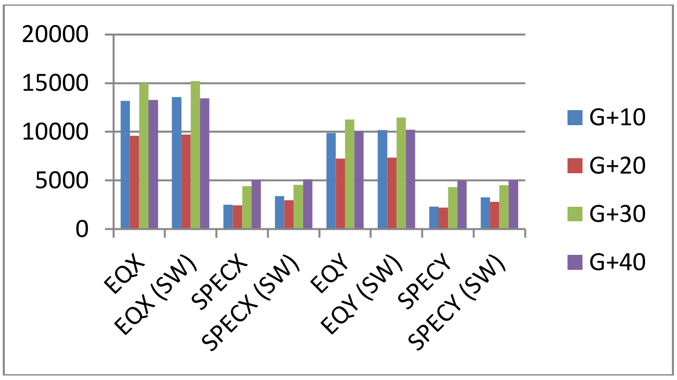

Chart 4: Variation of base shear of building with P-Delta

4.3 Lateral Displacement:

According to IS-456:2000 (Cl.no 20.5 p.no.33), maximum limit for lateral displacement is H/500, where H is building height.

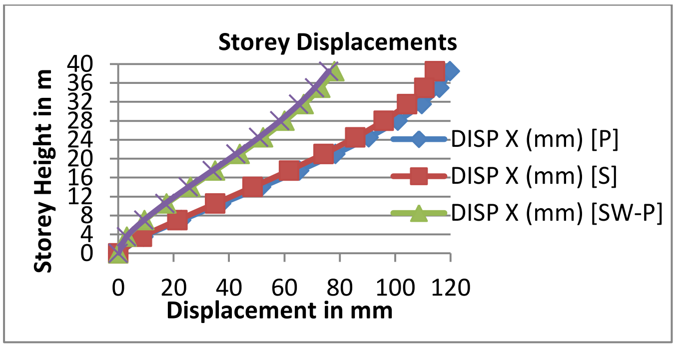

Chart 5: Variation of displacements for G+10 storey building model

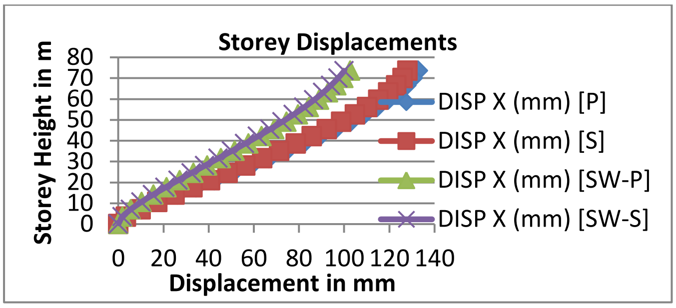

Chart 6: Variation of displacements for G+20 storey building model

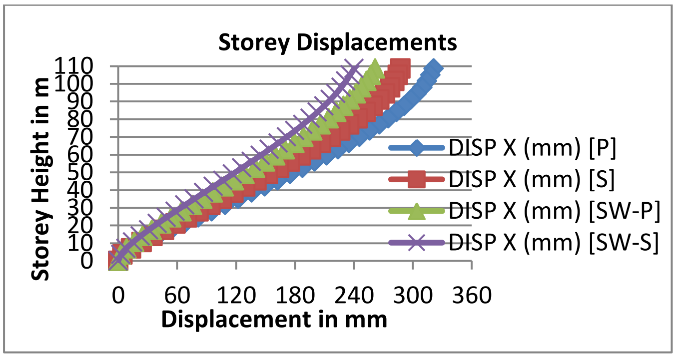

Chart 7: Variation of displacements for G+30 storey building model

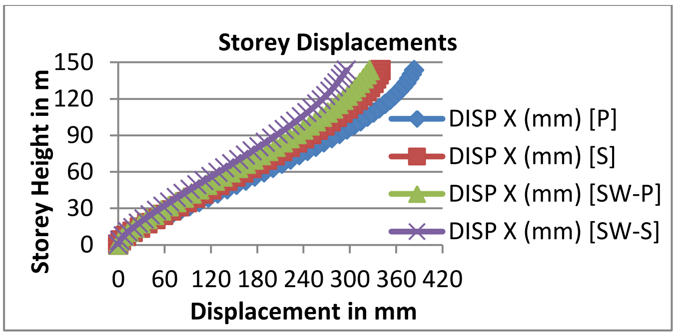

Chart 8: Variation of displacements for G+40 storey building model

4.4 Inter storey drift:

According to IS-1893:2002 (Part I) Cl.no. 7.11.1 P.no.27, maximum limit for storey drift with partial load factor 1.0 is 0.004 times of storey height.

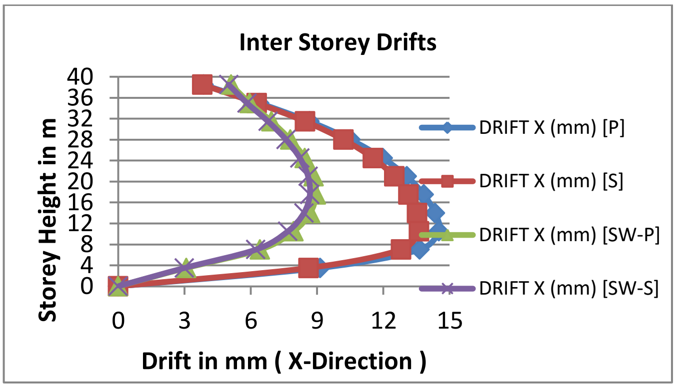

Chart 9: Variation of inter storey drift for G+10 storey building model

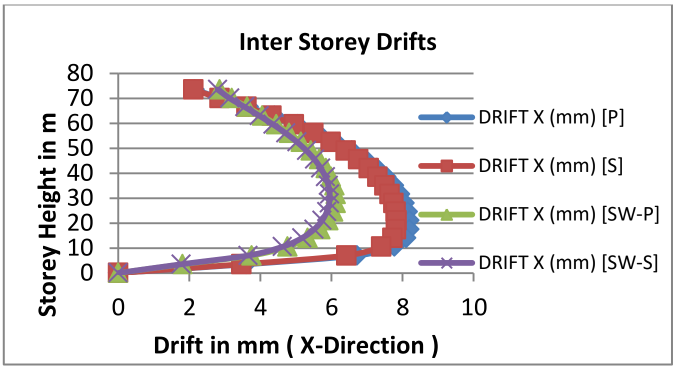

Chart 10: Variation of inter storey drift for G+20 storey building model

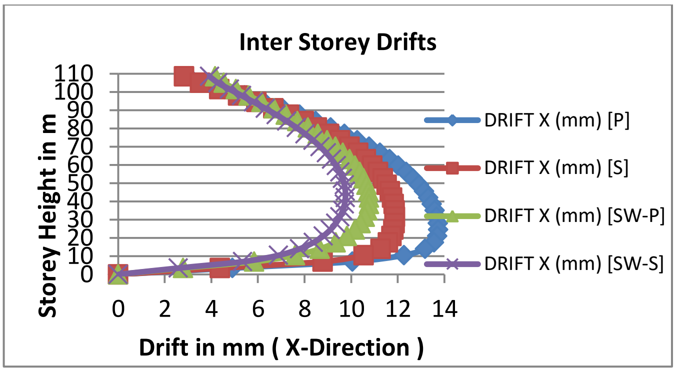

Chart 11: Variation of inter storey drift for G+30 storey building model

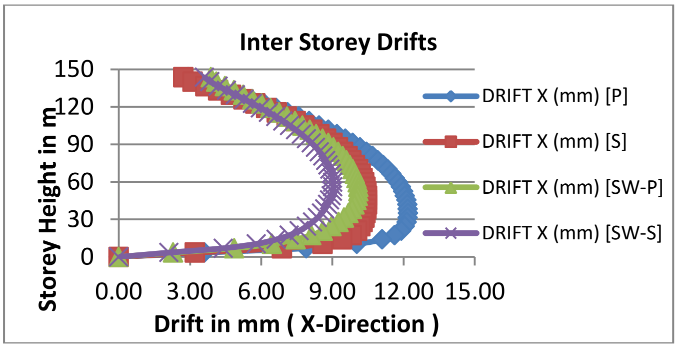

Chart 12: Variation of inter storey drift for G+40 storey building model

4.5 Stiffness:

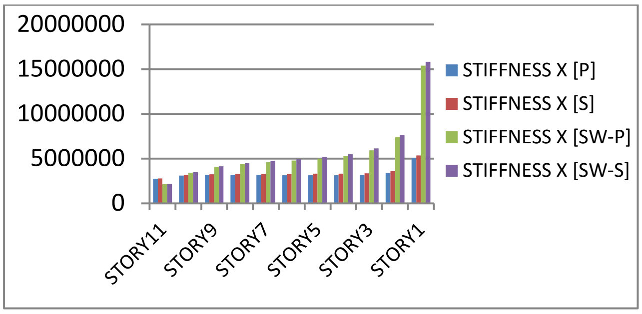

Chart 13: Variation of stiffness for G+10 storey building model

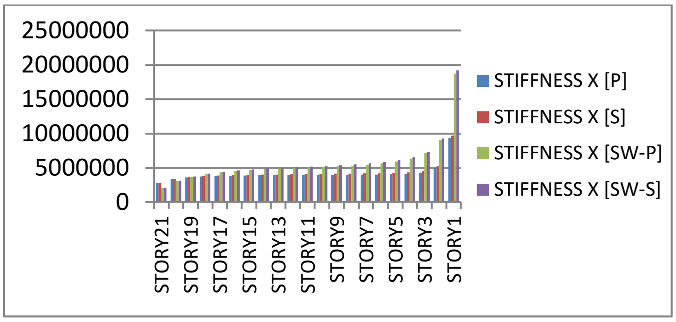

Chart 14: Variation of stiffness for G+20 storey building model

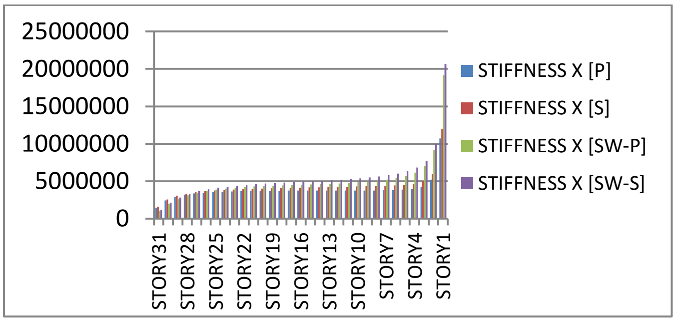

Chart 15: Variation of stiffness for G+30 storey building model

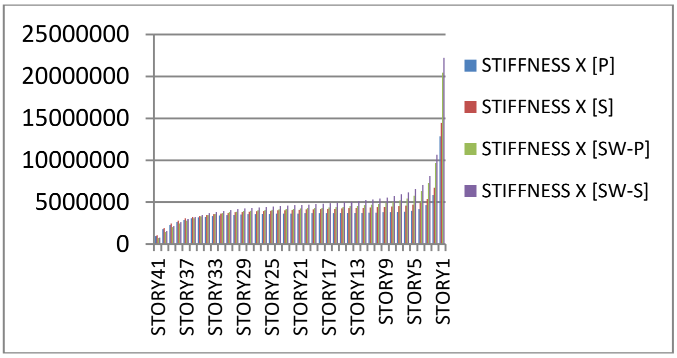

Chart 16: Variation of stiffness for G+40 storey building model

5. CONCLUSIONS:

1. The structural systems with shear wall observe more lateral forces when compared to conventional systems.
2. For G+10 storey Beam-Column structure, the top storey displacement with P Delta effect is P Delta analysis has more value of displacement varying from 4% to 5% when compared to structure without P-Delta analysis.
3. For G+20 storey Beam-Column structure, the top storey displacement with P Delta effect is P Delta analysis has more value of displacement varying from 3% to 5% when compared to structure without P-Delta analysis.
4. For G+30 storey Beam-Column structure, the top storey displacement with P Delta effect is P Delta analysis has more value of displacement varying from 10% to 12% in Lateral EQX Direction and 12 to 14% in Lateral Y-Direction when compared to structure without P-Delta analysis.
5. For G+40 storey Beam-Column structure, the top storey displacement with P Delta effect is P Delta analysis has more value of displacement varying from 10% to 12% in Lateral EQX Direction and 14 to 16% in Lateral Y-Direction when compared to structure without P-Delta analysis.
6. For G+10 storey Shear wall structure, the top storey displacement with P Delta effect is P Delta analysis has more value of displacement varying from 2% to 3% when compared to structure without P-Delta analysis.
7. For G+20 storey Shear wall structure, the top storey displacement with P Delta effect is P Delta analysis has more value of displacement varying from 2.5% to 3.5% when compared to structure without P-Delta analysis.
8. For G+30 storey Shear wall structure, the top storey displacement with P Delta effect is P Delta analysis has more value of displacement varying from 8% to 9% in Lateral EQX Direction and 10 to 11% in Lateral Y-Direction when compared to structure without P-Delta analysis.

9. For G+40 storey Shear wall structure, the top storey displacement with P Delta effect is P Delta analysis has more value of displacement varying from 10% to 12% in Lateral EQX Direction and 11 to 12% in Lateral Y-Direction when compared to structure without P-Delta analysis.
10. The P-Delta effect increases as the height of the structure increases.
11. The effect of P-Delta can be reduced upto certain extent by providing the shear walls. Thus Structure with dual configuration (columns with shear wall) performs better than conventional beam-column system.
12. With P-Delta analysis for flexible system, the inter storey drift exceeded its permissible limit in Flexible structure (Beam-Column System)
13. As the number of Storey increased, mass of the structure increases and hence the structure with P-Delta analysis attracted larger inter-storey drifts when compared to structure without P-Delta analysis.
14. Structure with dual configuration (Column-Shear wall) is less vulnerable to seismic forces as compared to structure with beam-column system.
15. Stiffer structures results in lesser inter-storey drift.

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