INFLUENCE OF P-DELTA EFFECT ON REINFORCED CONCRETE BUILDINGS WITH VERTICAL IRREGULARITY - A REVIEW

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Abstract *– In modern multi-storied building construction, irregular type buildings (with irregularity in plan and elevation) are commonly increasing, mainly because of architectural aesthetics and functional requirements. Such types of construction will be highly fragile buildings in seismological sensitive areas. Inappropriate design of these irregular buildings leads to abrupt destruction of the structures; hence it requires special consideration in analysis and design. The additional action in the structure due to the structural deformation by virtue of the applied loads is termed as P-delta effect. 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.*

Key Words: P-Delta effect, Irregular buildings, slender column, High rise structure.

1 INTRODUCTION

In the recent years Earthquake is considered to be one of the most destructive or damaging natural calamity. These cause severe damages to lives and properties. Almost all deaths related earthquakes are caused by the collapse of structures. This is the major reason for increasing demand for earthquake-resistant buildings. During an earthquake tall buildings will have a tendency to shake more than short buildings. Moreover, buildings having irregular configuration are more susceptible to severe damages in an earthquake. Unlike regular building, behavior of irregular building is more complex and unpredictable during the course of an earthquake.

P-Delta effect, which is a second-order nonlinear effect occurring in every structure where elements are subject to axial load and more prominent in tall buildings. P-Delta effect holds an important role in the analysis of the structure. The P-Delta effect is mainly dependent on the applied loads and the building characteristics. It also depends upon the height, stiffness and asymmetry of the building. Building asymmetry leads to imbalances in distribution of mass, stiffness ,etc. Buildings constructed without considering the second order P-Delta effect and appropriate characteristic seismic resistance constitute the main source of risk during an earthquake.

Fig.1: Structural collapse due to effect of P-delta

2 THEORETICAL BACKGROUND

During an earthquake the failure of structure generally starts from the point of the structural weakness present in the building systems. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structural weakness generates further structural deterioration which leads to the structural collapse. The structures having these discontinuities are known as Irregular structures. These irregular structures constitute a large portion of the modern urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. For example structures with soft storey were the most remarkable structures which collapsed. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. The dynamic characteristics of buildings with vertically irregular configuration differ from the regular building. As per IS 1893:2002, building are to be considered as vertically irregular building where the horizontal direction of the lateral force resisting system in any story is more than 150 percent of that in its adjacent storey. When such buildings are constructed in high seismic regions the analysis and design becomes more complicated. Therefore structural engineer needs to have a thorough understanding of the seismic response of irregular structures.

2.1 P-Delta effect

P-Delta effect, also known as geometric nonlinearity, that occurs in every structure where elements are subject to axial load. P-Delta effect is actually only one of many second order effects. The magnitude of the P-Delta effect is related to the following points:

- Magnitude of axial load P
- Stiffness/slenderness of the structure as a whole
- Slenderness of individual element

If a P-Delta affected member is subjected to lateral, then it will prone to deflect more which could be computed by P-Delta analysis not the linear static analysis. Mainly there are two distinct types of P-Delta effects are P-Δ (sometimes referred to as "large P-Delta" or "P-Big delta"), and P-δ (sometimes referred to as "small P-delta" or "P-Small delta")

- P-Δ (P-Big delta or Large P-delta), the structure instability effect or frame instability effect, has a reference to the effects of the vertical loads acting on the laterally displaced structure. For example, wind or seismic forces (V) cause a horizontal displacement (Δ) of the structure, while the gravity loads (P) simultaneously act vertically on this displaced structure. The secondary moments are included into the structure equal to the total vertical load P times the structural displacement Δ.

- P-δ (P-small delta or small P-delta), the member instability effect, has reference to the effects of the axial load in an individual member subjected to the deflection (curvature) in between its end nodes. For example, column loads (P) due to gravity, wind or seismic forces act on a column that has a curvature induced by the connection conditions of supported beams. Moments are induced in the member proportional to the axial load P times the member deflection δ. Typically P-δ only becomes significant at large displacement values or in slender columns. Note that the axially loaded beams also experience these effects.

Since both the P-Δ effect and P-δ effect contribute to the deformation of the frame, it is important to consider their combined effect. These nonlinear effects cause the member to deform more and induce additional moments and stresses in the member. Also there are reductions of their strength and stiffness. These reduction in strength and stiffness results weakening or destabilizing effect on the structure. As the structure becomes more slender and less resistant deformation, the need to consider the P-Delta effect increases.

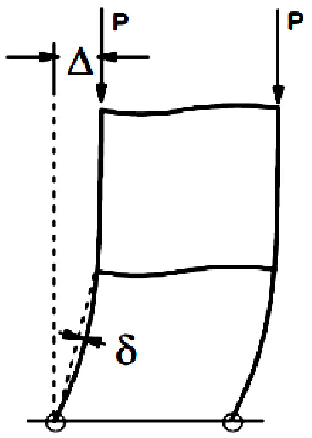

Fig. 2. P-Δ-δ effect

3 LITERATURE REVIEW

Ragina Gaiotti et al [1989] performed P-delta analysis of building structures. The P-Delta analysis method were reviewed and compared in terms of their efficiency and accuracy. The methods reviewed include the amplification factor method, the direct method, the iterative method, the negative property member method and second order computer program method. The results were identical to those given by the iterative method while the analysis took less than one-third of the time. It was found that P-Delta analysis is more suitable for high rise structures. They concluded that due to non-linear relationship between deflection and the gravity loads, it is necessary that loads corresponding to the failure state under consideration be used in P-Delta analysis.

Sharoz et al [1990] investigated the seismic behaviour of reinforced concrete frames with setbacks using response of two small-scale models. The displacement, acceleration and shear responses of setback frames during earthquake simulations are compared with that of seven frames with uniform profiles. It is found that setback frames are not observed to be more susceptible to higher mode effects than the frames with uniform profile. They concluded that the response of setback structure is no different than that of the regular structures and hence it does not require different design considerations.

Eggert V Valmundasson et al [1997] studied the seismic response of building frames with vertical structural irregularities. Two dimensional building frames with 5,10, and 20 stories having non-uniform mass, stiffness and strength distribution are analysed. The responses are found out by using time history analysis method, which was then compared with that predicted by equivalent lateral force method in UBC code. Considering mass and stiffness criteria in UBC there is a moderate increase in response quantities of irregular structures compared to regular structures. By considering the strength criteria there is large increase in response quantities in irregular structures than regular one.

M.A.A Mollik et al [1997] conducted an experimental study on P-Delta effect in RC high rise buildings. P-Delta effect was examined through the tests on three one-forth scale reinforced concrete frame structure model which represents the lower parts of high rise buildings subject to seismic force. From the results it is concluded that P-Delta effect is to be essentially included in analysis for the design of high rise buildings subjected to seismic force. His study revealed that P-Delta effect becomes an important factor to be taken into account if the storey drift of high rise building exceeds 1/85 rad during an expected earthquake excitation in seismic region. The test results also revealed need for a rigorous analysis in the design of high rise building rather than using the conventional equation for the member strength.

Akshay Gupta et al [2000] investigated the influence of P-Delta effect on flexible inelastic steel structures. Seismic performance of three building models of 3, 9, and 20 stories are designed for different seismic conditions. The computer program DRAIN-2D is used for modal analysis. The study revealed that the seismic response becomes very sensitive to building models if P-Delta effect is considered.

A. Aziminejad et al [2004] examined the interaction of torsion and P-Delta effects in tall buildings. The influence of asymmetry of building on the P-Delta effect in elastic ranges of behaviour is evaluated. Elastic static, elastic dynamic, inelastic static and inelastic dynamic behaviour of four different buildings with 7, 14, 20 and 30 storeys with and without P-Delta effect were investigated. Each building with 0%, 10%, 20% and 30% eccentricity levels were considered. It was found that the P-Delta-effect increases with increase in number of storeys and eccentricities of the buildings. The result indicated that the effect of P-Delta is quite sensitive to characteristics of ground motion such as the frequency content of earthquake. Conclusion is that the characteristics of lateral load resisting system have far more importance compared with the number of storeys in the building.

Ashraf Uddin et al [2013] studied P-Delta effect in reinforced concrete structures of rigid joint. 12 cases and 2 different analyses were performed to throw light into P-Delta effect in RC framed structures of rigid joints. He observed that, under P-Delta effect, displacement varies exponentially with increase in height or increment in stories. Axial force also varies with the height of the structure. It was concluded that both linear static and P-Delta analyses are necessary for tall RC structures.

Yousuf Dinar et al [2013] evaluated the deflection of high rise steel structures under the P-Delta effect. Linear static analysis was done to observe the severity of P-Delta phenomenon. The analysis was done by using STAAD Pro v8i software. They found that because of wide variation in displacement with increase in slenderness, P-Delta analysis is required for structures taller than 7 storeys.

Spoorthy S K et al [2014] investigated the effect of soft story on tall buildings at various stories by using Pushover analysis. 5, 10, and 15 story reinforced concrete building models with both regular and irregular building plan were analysed. The study summarizes the performance based seismic analysis of tall buildings having soft story at various levels in building using Equivalent static and Pushover analysis method in ETABS 9.7.4 software. The story displacement, story drift, and story shear obtained from pushover analysis are about twice the story displacement, story drifts, and story shears of Equivalent static analysis. The parameter increases with increase in the number stories, mass and height of the building.

Deepak Soni et al [2014] experimented with the Dynamic behaviour of reinforced concrete framed buildings under non linear analysis. In this study, P-Delta analysis of 30 storied RC framed symmetric and asymmetric buildings in zone III and zone IV was performed using STAAD Pro V8i software. The building response quantities (storey drift, storey displacement and nodal displacement) under the P-Delta analysis on both symmetric and asymmetric buildings were evaluated. It was observed that response quantities were higher when P-Delta analysis was performed and also that the response quantities in respect of asymmetric structures higher than that of the symmetric structures.

Mallikarjuna B.N et al [2014] in this study describes seismic analysis for an 18 storey steel framed structure using in STAAD Pro V8i software. A comparison of P-Delta analysis with linear static analysis has been attempted. The influence of different bracing patterns like X, V, single diagonal, double X, K bracing etc. on the P-Delta effect has been investigated. It was found that the building response values on P-Delta analysis were twice as that on static analysis. The X bracing in continuous bracing pattern is proven to be more effective under both static and P-Delta analyses.

Sagar B Patil et al [2015] presented the behaviour of plan and vertical irregularity by seismic analysis. Reinforced concrete building of 10, 15 and 20 storey having 3m storey height is selected for the study. Time history analysis and response spectrum analysis method were carried out using 9.7.8 software. The maximum storey displacement was found in irregular structure. The study reveals that the shape of structure with irregularities in plan or vertical irregularities directly affects the whole structure in seismic action.

P V Dhanshetti et al [2015] investigated the action of P-Delta effect on multi-storey buildings. In this work, multi-storeyed reinforced concrete building models with different number of storeys were analyzed by using STAAD Pro V8i structural analysis software. The maximum response values in buildings in terms of storey drifts, column moments, beam moments, column shear and beam shear were investigated. It was observed that the P-Delta effect will be substantial when lateral forces exist on the structure and this increases with increase in number of storey. The P-Delta effect is not predominant on buildings up to seven storeys and it is very negligible when only gravity loading exists on the structure.

Manasa C. K et al [2016] examined the behaviour of reinforced concrete buildings under lateral loading. The focus of the study was to assess the P-Delta effect in tall RC buildings. Five building models with 10, 20, 30, 40 and 50 storey are analysed using non-linear static analysis method in ETABS 2015. The drift ratio is found out by considering P-Delta effect for all building models. The results demonstrated the effectiveness of P-Delta analysis in tall RC buildings. They concluded that the effect of P-Delta increases as the height of the building increases and it can be reduced up to certain extend by the construction of shear walls

Pushparaj J Dhawale et al [2016] conducted analysis of P-Delta effect on high rise buildings. Here linear static analysis (without P-Delta effect) and nonlinear static analysis (with P-Delta effect) were carried out on high rise RCC framed buildings with 20, 25 and 30 storeys. Buildings have been analysed using SAP2000-12 software in accordance with the provisions of IS-1893 (2002) for zone III and IS-456 (2000). Bending moments and storey displacements with and without P-Delta effect on all building models were compared. The results suggest that it is essential to consider the P-Delta effect for buildings 25 storeys and above. He found that P-Delta effect should be considered in the design of buildings having height 75m or more. He also concluded that first order analysis is sufficient for design of buildings up to 25 storey height, P-Delta effect need not be considered in such cases.

4 SUMMARY AND CONCLUSION

The literature review conducted as part of the study shows that there are numerous studies found on P-Delta effect. A brief review of several literatures presented shows that P-Delta effect is a major issue on high rise structures. It is also found that vertical irregular structures are more vulnerable to seismic loads, and which need much attention than regular structures. The following conclusions are drawn from the previous studies are:

- There is large increase in response quantities in irregular structures than regular one.
- The drift demands in the upper stories are much more sensitive to irregularities in the lower stories than the responses of lower stories are affected by irregularities in the upper stories.
- P-Delta effect is very negligible when only gravity loading exists on structure.
- As the number of storey increases P-Delta effect becomes more important.
- Generally P-Delta effect is negligible up to 7 storey buildings.
- Effect of P-Delta is quite sensitive to characteristics of ground motion such as the frequency content of earthquake.
- Llinear static and P-Delta both are necessary for RC structures.
- Due to wide displacement variation with increase in slenderness P-Delta analysis is required for the structures higher than 7 storeys.

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