Article

P Delta Effects on Tall Concrete Buildings

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Abstract

P-delta effect is the secondary moment which is produced by wind or seismic effects. For tall reinforced concrete building the P-delta effects have a significant role on building stability, because in many cases it has been seen that the collapse of tall buildings is a function of slenderness and secondary order effects. One of the very important parts which has effects on these types of buildings is P-delta, which has significant effect on building stability and ductility during the design based on seismic or wind. In this research paper it will be seen that P-delta effect is an important phenomenon for structure stability, axial force, shear capacity, story drift, maximum displacement and moment. If the P-Delta effect does not include in analysis and design phase, if resulted, the structure based on its selfweight and secondary moment may damage in many parts of the building or even collapse of structure that it will occur during seismic or wind load. Due to complexity and low knowledge of P-Delta analysis, designers, engineers and architectures are prone to perform linear static analysis which may eventually become a cause of catastrophic collapse of the tall structure.

Keywords: *P-Delta, Concrete tall buildings, Structure stability, Catastrophic collapse, Story drift.*

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Introduction

According to the building codes the P-Δ or P-Delta effect is the sudden changes in ground shear, overturning moment, and/or the axial force distribution at the base of a tall structure or structural component when it is subjected to a lateral forces or critical lateral displacement. A distinction can be made between P-Delta effects on overall building and each structure member; it means that for overall building the P-Delta effect written as P-Δ and for each member written as P-δ [1]. The P-Delta effect is a destabilizing moment equal to the force of gravity multiplied by the horizontal displacement a structure undergoes when loaded laterally [2]. Sometimes it can be seen that, the P-Delta effect is maybe the same as buckling load of an elastic, small-scale solid column given the boundary conditions of a free end on top and a completely restrained end at the bottom, with the exception that there may exist an invariant vertical load at the top of the column. A rod planted firmly into the ground, given a constant cross-section, can only extend so far up before it buckles under its own weight; in this case the secondary effect or P-Delta will generates that is related to the building axial load, lateral displacement value and amount of lateral shear forces. On other hand analysis method of structure is also very important to take P-Delta effect in calculation, for example for static analysis method the P-Delta effect is omitted in many situations, but for non-linear static analysis P-Delta effect can be taken in calculation of many tall concrete buildings [3]. The other way to take in account P-delta analysis is nonlinear dynamic response history analysis [5-9]. Additionally, several standard and pre-standards are provided p-delta analysis process
[10-15].

1.1 Problem Statement

The development of technology and knowledge is quite advanced today, but little attention and fewer experiments have been carried out on P-delta calculations for building. Therefore, the P-delta effects will be calculated in the research paper by nonlinear and linear analysis method and the results will be compared with condition when no P-delta effects are included in analysis and design of tall reinforced concrete buildings during the seismic and wind.

1.2 Objectives

The aim of this study is to include the secondary effects of P-delta in analysis of a building and consider the results. As we know that buildings are analyzed for two purposes, one safety and the other is economy, so including the P-delta effects in analysis a building has somehow a major

effect on many aspects which are related to the safety. This study is focused on building behavior with and without P-delta effects and then compares the results very carefully, because whenever we include these effects to analysis of a building, they need to make a non-linear analysis and then compare the results with linear analysis conclusions, meanwhile the P-delta effects depend on building height and number of stories. The frame system is easy to build and found everywhere till structure of 12 story. To evaluate the P-delta effect it is required to perform the linear Static analysis simultaneously. To perform the analysis Etabs and Sap are used for all models of each case. Gradually increasing the height from story 4 to story 12, in 4 story intervals may draw a significant understanding in the trend of the P-delta effects. After comparing the performance of building with respect to axial, moment and displacement between two mentioned analyses above, essence of P-delta analysis over linear static analysis and variation of outcomes will be felt.

2 Literature Review

When seismic or wind load acts on, a High-Rise building might shake and vibrate the exterior lateral resistance systems of the building such as: columns and shear walls which are subject to fluctuating axial force both in compression and tension, shear forces and bending moments. The lowest part of the column is mostly conserving highest intensity of axial loads and shear. Story drift in lateral direction due to the lateral load and axial force causes the 2nd order loading effects known as "P-Delta effects" presented many ways of P-Delta analysis, while considering torsion, manual analysis, and analytical equation but did not line in the differences of P-Delta and linear static analysis and guide the height limitation of linear static analysis method.

The necessity of having a paper which represents P-delta effects on a building in simple words for easy understanding pushed to have this study. ACI (318-14) conducted an experimental study on P-Delta effect in RC high rise buildings [16]. P-Delta effect was examined through the tests on three one-fourth 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 subject to seismic force.

Adam A.S has presented a different way of P-Delta analysis while considering torsion, manual analysis, and analytical equation but does not line in the differences of P-Delta and linear Static analysis and guide the height limitation of Linear Static analysis method by presentation of Rigid joint RC structure [17]. The necessity of having a paper which represents

PDelta effects of RC rigid frame structures in simple words for easy understanding pushed to have this study. Christophe Adam and Luis F. Ibarra (2014) addresses the assessment of destabilizing effects of gravity, usually referred to as P-Delta effects, in highly inelastic structures when subjected to seismic excitations. P-Delta effect is incorporated via an auxiliary backbone curve, which is rotated by a uniform stability coefficient [18]. The procedure is evaluated for several multistory generic frame structures. The results were approximately the same for those given by the iterative method, while the analysis took less than one-third of the time. It was resulted the P-Delta analysis is more reasonable for tall structures. They found 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. Based on the AISC, the P-delta effects on buildings have many important effects on story shears and moments, the resulting member forces and moments, and the story drifts [19]. Induced by these effects are not required to be considered where the stability coefficient is equal or less than 0.1, actually the stability index explained the need of P-Delta to be observed in design of building. ACI (318-17) is recommended that the analysis process must be included the P-Delta effects, these effects are considered differently for braced frames and sway frames [20]. For the braced frames the effect of PDelta is limited to individual member's stability and for sway frames components lateral drift effects. P-delta analysis performed by Regina Galotti et al in (2017) addresses the P Delta analysis, of building structures and several methods were reviewed, amplification factor method, direct method, iterative method, negative property member method and second order computer program method [21]. The other important aspect must be observed for P-delta analysis is columns location of a frame, it means that the columns must be located in center of each frame axis intersection [2223]. For latter case, an accidental torsion of 7% will be occurred [24].

It resulted that to prevent concrete buildings from collapse, the observation of P-Delta effect seems to be very important and play a significant role in structure stability, because when seismic or wind loads are applied to a concrete building, the amount of displacement becomes larger than ever and due to building self-weight the secondary moment is created and it is very dangerous if the designer not in analysis of building.

3 Methodology

There are two primary ways to include P-delta effects in analysis:

- Create a static nonlinear analysis case for each load combination which is the most accurate.
- Create an initial P-Delta analysis case for the gravity loads.

When the loads acting on a structure and the resulting interior forces and deflection are small enough, the load-deflection relationship for the building is linear and for bigger interior forces and deflection the building behavior may not be linear and said to be non-linear. If the building behavior is non-linear, it is essential to include P-delta effects in calculations.

The result of the P-delta actions found from analyses can be assessed in terms of two different factors, as outlined below:

- The primary or first factor is magnification factor, which is the ratio of the yield strength a structure requires for a given ductility demand calculated:

$M1 = \alpha M$

Where M is moment and α is the amplification factor.

- The P-delta effects or action will be taken in account, when the stability index (θi) is greater than 10% and can be ignored and for stability index (θi) less than 10%. [25].

$$\theta i = P\Delta i/Vh$$ Where:

P is axial load

Δ is building horizontal displacement

V is building base shear

H is building height

The value of stability index must be greater than minimum stability index as follow:

$$\theta max = 1.25/R < 0.25$$

R is the magnification factor

To observe the P-Delta effects in calculation and design we can follow the following steps:

- Include the P-delta effects with the other properties in analysis
- Calculate the internal forces of structure members
- Calculate the increased stories displacements (Δwi)

4 Data Analysis and Results

It should be known that, when the building stories are increased, the P -delta effects increase as well, in such a case I have analyzed a 12 and 4 story RC buildings, and then compared the results with and without P-delta effects.

The analysis of P-delta is performed in three stages:

- Linear analysis of the building without P-delta effects
- Linear analysis of the building with P-delta effects

- Nonlinear analysis of the building with P-delta effects

Among the three mentioned stages, the nonlinear analysis of the building with P-delta effects is more accurate than linear analysis of the building with P-delta effects and the following steps have been done for it:

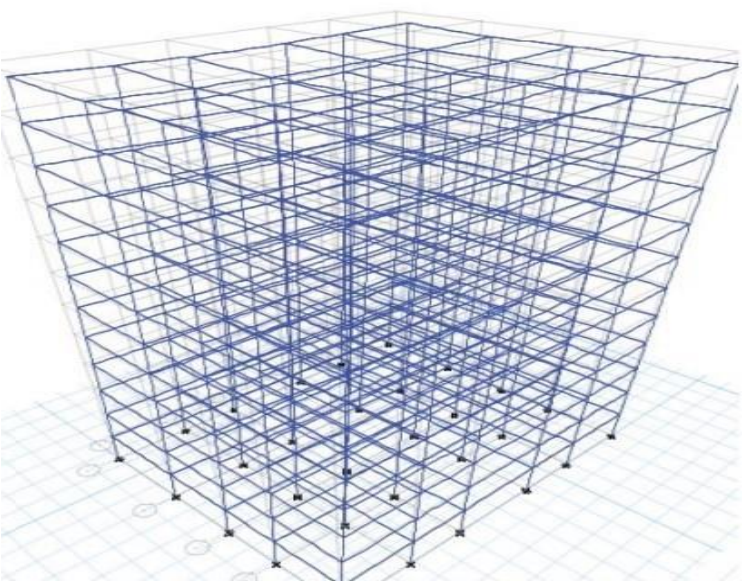
- Modeling and draw the members
- Define material properties
- Define crack moment of inertia for members
- Define the gravity and lateral loads
- Loads combinations for gravity and lateral loads
- Click on P-delta option and make load combination for P-delta effects
- From load case define the nonlinear properties of materials
- Analysis the model and check the results

For example, the P-delta load combination and deflection for 4 and 12 story buildings are done in below table and chart:

Table.1: Load Combinations for P-delta Analysis

P-delta Load Combination	Code
1.2Dead load + 1.6Live load	American Concrete Institute for concrete projects
1.05Dead load + 1.275 Live load + 1.403Earthquake	American Concrete Institute for concrete projects
1.05Dead load + 1.275 Live load - 1.403Earthquake	American concrete Institute for concrete projects
1Dead load + 1.2Live load + 1.2 Earthquake	International Concrete Standards

Figure 1: 12 Story Deflected form due to Effect of P-Delta



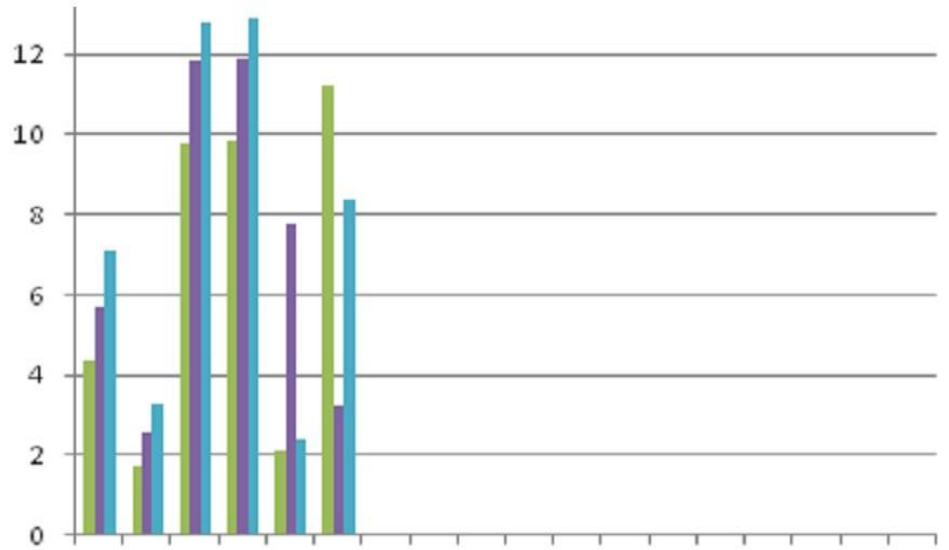


Chart.1, Increases in deflection due to p-delta for 4 and 12 story buildings

5 Results and Discussion

After the loading, load combination, load cases and analysis of the 4 and 12 stories, the following results are found: **For 4 Story Building**

- Change in bending moment at base is 2-6%
- Change in deflection is 1-11%
- Change in bending moment of beams are less than 10%
- Change in bending moment of columns are less than 20%

Some member is in some load cases, but it is found that their initial values are very small (not more than 30KN-m) so we can say that practically not necessary to consider P-delta effects.

Hence for 4 story building, it is not necessary to consider P-delta effects, so building can be designed by first order analysis.

For 12 Story Building

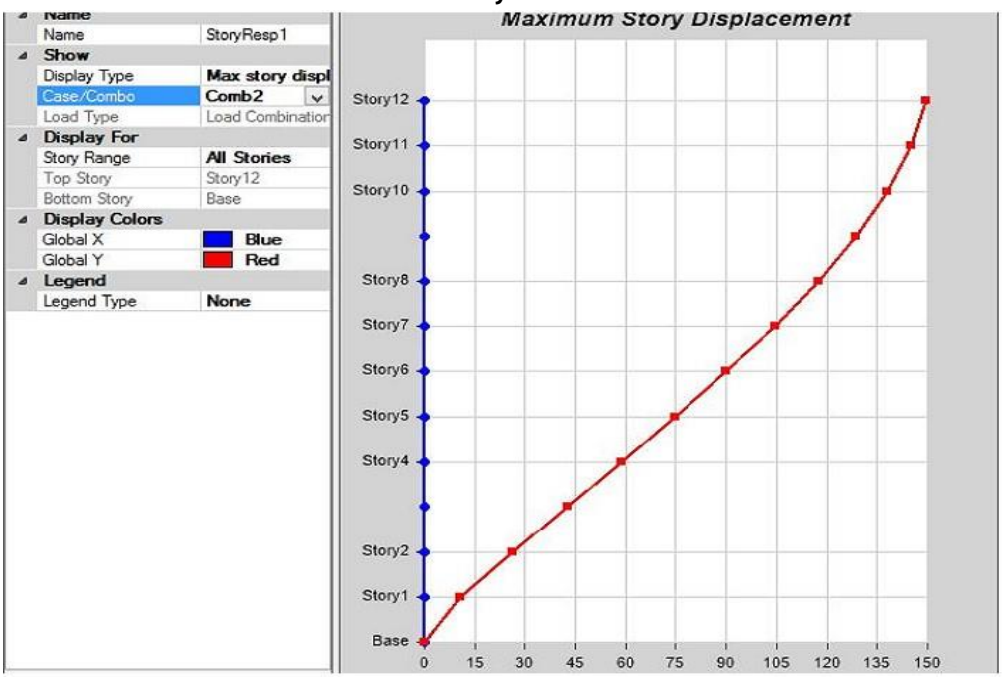
- Change in bending moment at base is 2-4%
- Change in the deflection is 2-14%
- Change in bending moment of beams is up to 155
- Change in bending moment of columns is 8-30%. It is more observed

At the exterior columns and nearby beams and also it is more observed at intermediate stories, so P-delta effect is observed in some load cases for 12 story building and it is necessary to consider P-delta effects while analyzing and design a 12 story building.

Table 2: Base Reaction for Combo-3 With and Without P-delta

Load Case/Com	Fx tonf	Fy tonf	Fz tonf	MX tonf-m	MY tonf-m	MZ tonfm	X m	Y m	Z m
Non Linear	-190	0	5523	36455	63550	1342	0	0	0
Non Linear	-190	0	5523	36455	63550	1342	0	0	0
Load Case/Com	Fx tonf	Fy tonf	Fz tonf	MX tonf-m	MY tonf-m	MZ tonfm	X m	Y m	Z m
Non Linear/P delta Max	-190	0	5523	37257	65774	1342	0	0	0
Non Linear/P delta Min	-190	0	5523	37257	65774	1342	0	0	0

Figure 2: Maximum Displacement without P-Delta Effects for Static Analysis



The maximum or target displacement at top of 12 story building is 160mm for linear analysis of the building without P-delta effects, on other hand it can be seen that the maximum or target displacement at top of the 12 story building for non-linear analysis is 360mm, so by compering these results show that the accuracy of the analysis by taking P-delta effects in account is more than without it.

6 Conclusion

This unit presents the main conclusion of P-delta analysis and its importance for buildings analysis, design and construction. During the last century we were witnesses that many buildings which were constructed near fault line or seismic zones, had catastrophic failure or members collapse due to lack of modern engineering knowledge and usage of software. In fact, engineers then had to use limited analysis method such as approximate method and some other linear methods to analyze the vertical building.

After the 1997, many codes and engineering software were revised and updated and it was really a new revolution for engineers to use the non-linear method for analysis of the building and besides the newest safety concepts for buildings safety during an earthquake, P-delta effects are also used for high rise buildings. Based on second order analysis the following conclusions can be drawn:

- As the number of stories increase, P-delta effect becomes more important.
- We can say that, at least it is necessary to check the results of analysis with and without considering P-delta effect for a building.
- For high rise buildings which are located in seismic zone, it is very important to observe the P-delta effect, because due to the seismic forces the secondary moment and buckling will be created at top stories of the building.
- Calculation of P-delta effect will be increased in the base shear of building and by increasing the base shear the building will be designed safely.
- P-delta effect calculation is important because while the earthquake occurs, the structure behavior becomes very important and run out to its first order behavior and go to directly to second order, therefore it needs to analysis the structure by one of the nonlinear analysis method such as pushover or any other to observe the P-delta effect.
- We can see that for four story building the analysis results with and without P-delta effect were very close to each other and it was not necessary to observe or take in account the P-delta effect, but for twelve story building many properties such as moments, shear forces, displacements and story drifts have been changed and it can be concluded that P-delta effect is a disturbance effect for tall building and it is necessary to include in calculations to rescue the tall building from sudden collapse.

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