STUDY OF P-DELTA EFFECTS AND AXIAL SHORTENING OF COLUMNS USING SEQUENTIAL ANALYSIS

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Abstract: *The basic principle of structural engineering is to maintain the stability and integrity of the structure for the designed life period of the structure. Softwares is helpful in modeling and analyzing the effects of different nature of forces, changes in their directions as well as in their magnitudes on the structure. There are two methods which are widely used to analyze the structures Conventional Lumped Analysis and Construction Sequential Analysis. Both the methods have their own benefits and shortcomings. The final values of bending moments, shear forces, torsion, deflections, etc. in different members are considerably much higher when the structure is sequentially analyzed. This paper focuses on the parameters which are often not approximated near their actual values during the conventional analysis, such as losses due to creep, shrinkage, axial shortening of column, lateral sway of columns due to P-Delta Effect and longitudinal rebar percentages variation in the columns. A Structure is analyzed by considering both sequential (step wise) and conventional (all at once) analysis using ETABS v. 18.1 (Extended Three-Dimensional Analysis of Building System) by following the IS 1893 code for Seismic Loads and IS 875 Part 3 code for Wind Loads. Further we have collected and scrutinized different research data to present a detailed study and draw a common conclusion based on which the importance of sequential analysis is projected.*

Keywords- *Lumped analysis, Sequential Analysis, P-Delta effect, ETABS v.18.1*

1. INTRODUCTION

It is a common saying among civil engineering students that one day we will see construction in the negative atmospheric pressure zone. Truly, the world is progressing at an exponential rate with the help of the developments in science and technology. Skyscrapers piercing the clouds are nowadays common in mega cities! Technological advancement has helped the Civil Engineering Industry tremendously. The effects of forces during natural phenomena such as floods, tsunamis, earthquakes, etc. can be studied with the help of the softwares. The accurate distribution and deflections of any member can be obtained by accumulating the results at each stage. Ignoring these effects would ultimately lead to incorrect analysis of the structure which creates problems in the building for a long term period and also especially at the top floors.

The basic problem of our research starts with the general practice of considering the linear material properties and analyzing the whole structure by applying all the static loads at once. But contrary to the software based model, the loads during construction of a structure gets accumulated as different phases of construction proceeds. This sequential addition of the load gives differences in the software based and in situ values of structural properties such as Shear Force, Bending Moment, Deflection, Response Time and Cross section and reinforcement values of the structural elements. If we consider small structures this difference is very small, but as the height of the structure increases the difference is quite significant. Also, this difference is considerably more in composite structures than RCC structures.

With introduction of loads on different structural elements at every single stage, the complexity of the analysis significantly increases, it takes a large amount of time to analyze these kinds of models and it is not economical either. Due to this, many companies avoid sequential analysis. But it is to be noted that once we apply load to any element, the intermolecular behavior and the resistance against the load, (*i.e. the elastic behavior*) of the element starts changing. With the increase of loads with respect to time, the material undergoes several different internal changes because of time dependent behavior of the building materials and hence the final values of structural properties are different with that of values calculated through linear material behavior.

In the following report, we have researched sequential analysis on a high rise structure and provided a thorough study of differences in the results using both linear and nonlinear methods of analysis. We have even gathered data from real life structures on which both analysis methods were experimented. It was found that the variation is significant which we can't neglect. Detailed study on losses, P- Delta Effect, experimenting different load combinations and variation in the properties of structural members using ETABS software is performed. We have carefully collated and processed data of different researches and tried to provide a summarized conclusion which in one line can be stated as "*Sequential Analysis is must while analyzing High Rise Structures*."

2. LITERATURE REVIEW

ManikRao[1], RajendrakumarS Harsoor[1], (2016), studied the effects of linear static analysis and P-Delta analysis on the displacement, shear stress and bending moments for four structures of 5, 10, 15 and 20 storeys. They found out that as the floor height increases, the change in displacement increases from 35% in the first floor to 43% in the fifth floor when P-Delta analysis is sequentially considered in comparison to when linear static analysis is used. Shear Forces shows an approximate increase of around 24% to 25% for each floor as compared to conventional analysis. The Bending Moment shows an increase of around 8% in the lower floors, with the rate decreasing up to 4% change in the top floors. As the height of the floors get increased, results increase linearly. But, as we increase the number of floors of the structure to 20, there is a gigantic difference in values corresponding to linear static analysis and sequential analysis. The variation in displacement values is as large as 65%. Similarly Shear Forces and Bending Moments show a very large variation from their conventional values. The results of this research conveyed that as the height of the structure is increased, the values of displacement, axial forces, shear forces and bending moments increase largely.

Nikunj Mangukiya[2], Arpit Ravani[2], Yash Miyani[2], Mehul Bhavsar[2] (2016), considered the geometric nonlinearity while studying the P-Delta effects on a 25 storey structure. The major topic of study of this paper was the second order effects such as the additional deflections, displacements, forces and moments getting added into the system due to phenomena such as P-Δ, P-δ and axial shortening of columns. It explains briefly the difference between the P-Δ and P-δ effects. It also considers the combined effect of P-Δ and P-δ on a 25 storey tower with 5 floors analyzed sequentially. The lateral displacement of the joint at the top most point differs by approximately 16% when P-Delta effects are and are not considered. It was also noted that as we moved up, the difference in Moments was reduced from 23% on the first floor to 6% on the 25th floor.

M.T.R Jayasinghe[3] and W.M.V.P.K Jayasena[3] (2004) considered the shortening of columns due to accumulation of axial loads when construction is carried on sequentially. The paper explains the significance of axial shortening, creep shortening, shrinkage shortening and elastic shortening of columns. They found out that the grade of concrete and cross sectional areas do not play any significant role in shortening of column as due to change in the said parameters, a subsequent change in rebar is seen. As the construction rate is increased from 7 days to 28 days per floor, the shortening of the column is reduced significantly. The variation is around 18% when days are increased from 7 to 28 for finishing a particular floor for lower floors. For higher floors, the variation is around 32% for the same change in rate of construction. It is evident that values of shortening are considerable as we increase the height of the structure. For a change in grade of concrete, very insignificant change is seen.

R. Pranay[4], I. Yamini Sreevalli[4], Er. Thota[4]. Suneel Kumar[4] in their paper presented the importance of sequential analysis while designing floating columns with transfer girder as supports for high rise buildings. The analysis included study of a 22 storey structure with floating columns and transfer girder. The final results were tabulated and a differential study of sequential and conventional lumped analysis was presented. It was observed that the transfer beams show an approximate increase of around 28% whereas the deflection of frames above these beams increases about 25%. Axial force, Shear Forces and Bending Moments show a change in the range of 27 to 31%. They concluded that since the change is very large, sequential analysis should be always considered while designing structures with transfer girders and floating columns.

M.U. Bhati[5], NL Shelke[5] (2020) studied the change in stability of framed structures with increase in time while taking in consideration of P-Delta effects. Both small and large displacements due to P-Delta are considered. They considered a G+21 storey structure and used the response spectrum analysis by considering the structure in seismic zone III. According to their analysis for transfer girder, its maximum torsion, shear force and deflection shows an increase of around 5.84%, 11.41% and 18.27% respectively. The maximum negative and positive bending moments show a subsequent change of 8.84% and 13.39% respectively. The results of the analysis argued that sequential analysis gives more realistic values of shear forces, deflections, torsion, maximum and minimum bending moments, hence sequential analysis should be considered over lumped analysis.

S. D. Ajane[6], H. P. Rathi[6], S. A. Junghare[6] (2020) presented the effect of Creep and Shrinkage on a 4 storey structure considering sequential analysis. Creep and Shrinkage contribute majorly in the shortening of columns, which can give rise to the introduction of eccentric loading patterns. This can also lead to uneven shortening and further development of overturning moments due to uneven shortening of adjacent columns. The paper also studies the effects of change in percentage of longitudinal reinforcements. They concluded that there is no difference in change of axial force in sequential and conventional analysis, but column shortening introduces extra end moments on columns. In sequential analysis, the time dependent creep and shrinkage effects are around 2-3 times more than that of conventional analysis. Initially, the percentage rebar didn't show any effect when only dead loads were considered, but as creep and shrinkage effects are taken into consideration, the percentage rebar needs to be increased.

Drisya S Kumar[7], Margaret Abraham[7] (2019) studied the second order effect or the secondary effect caused due to the geometric nonlinearity of the structural elements. A fundamental relation between the kinematic and equilibrium conditions is studied. For a deformed structure, considering the P-Delta effects is necessary to increase the accuracy of the analysis. They found that the most affected parameter in P-Delta analysis is the base shear overturning moment, which increases significantly in sequential analysis as compared to conventional analysis. The P-Delta effects need to be considered when there is a variation of about 10%. They also concluded that in general trends, the values of lateral sway, deflections, shear forces, bending moments, etc. increases in sequential analysis. But this trend is unpredictable for irregular buildings.

Phani Kumar.V[8], M.Deepthi[8], Saikiran K[8], R.B.N. Santhosh[8] (2019) considered the effects of wind and seismic loads on stability of high rise commercial and residential towers considering the P-Delta effects. They performed an analysis on a G+29 structure and compared different parameters such as displacements, story drifts, bending moments and shear forces by providing shear walls at some places considering the P-Delta effects. Another similar model is analyzed without considering the P-Delta effects. They reported that the lateral displacement and story drifts are more when P-Delta analysis is considered in comparison to conventional analysis. The efficiency of the structure is enhanced when the Shear wall is placed in the center of the frame as opposed to when the shear wall is placed at the corners of the frame. The least effective model was the one without shear wall. The bending moments in the shear wall increases by 18% when P-Delta effects are taken into consideration. The paper also found out that even if there is an increase in eccentricity, not all the members show an increase in Mass Moment of Inertia.

3. METHODOLOGY

The Mathematical Models we develop on softwares such as ETABS generally analyze a structure by adding loads once the model is finished rendering. But in actuality as we know the loads get added in a structured pattern. Due to this many different parameters change when we compare the theoretical values to the in situ values of displacement, shear force, bending moments, response time, etc.

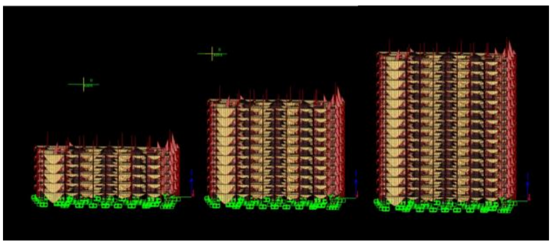

Figure 1

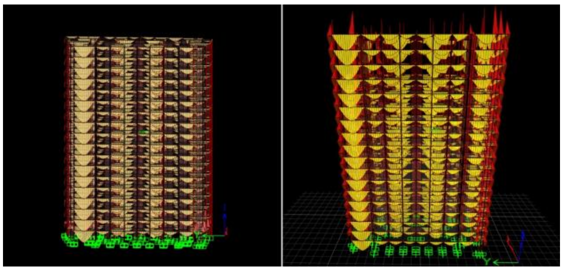

Figure 2

Figure 1 shows the construction of a 16 storey structure considering sequential analysis.

Figure 2 shows a side by side Shear force distribution comparison of a final structure obtained by sequential analysis and conventional analysis.

Further many other factors which we generally do not consider are the P-Delta effect, axial shortening of columns, etc. Let us understand these factors:

P-Δ: For an ideal structure, we assume the load transfer mechanism as Slab-Beam-Column-Foundation-Soil Strata. But this is when we neglect the effect of horizontal forces. There are many horizontal forces to be considered such as wind and seismic loads which act laterally on a structure. Due to this the structure undergoes horizontal displacement. This displacement gives rise to eccentricity to the gravitational forces, which cause an increase in the overturning moment. This effect needs to be considered for high rise structures.

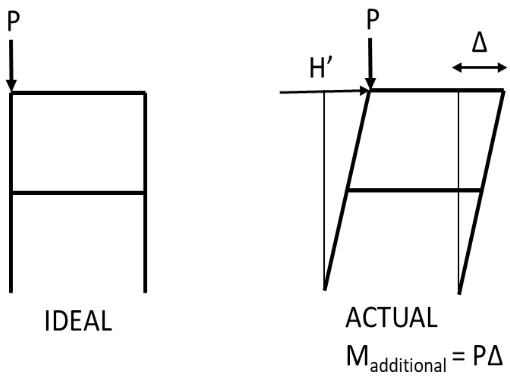

Figure 3

P- δ: As time passes, different members are subjected to continuous deflection with respect to time. These deflections give rise to additional moments for axially loaded members. These members can be axially loaded beams as well as columns. Since the deflection due to long term loading is comparatively less, the moments are less than that of the P-Δ case.

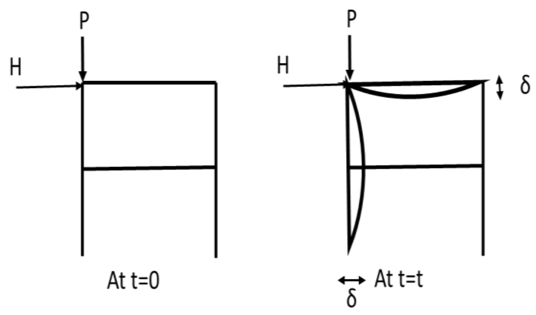

Figure 4

Combined Effect: As we can see that both systems contribute together after a significant amount of time has passed, the effect is cumulative and gives rise to a considerable amount of deflection resulting in increase of moment ultimately. As time passes, the effect keeps on increasing due to continuous lateral sway of the structure. The strength of the structure is reduced and the structure starts losing its stability. The P-Δ/δ effects can be reduced by introducing heavy members in the structure. It can also be reduced by increasing the stiffness of frames.

Lateral Sway: Generally the P-Delta effect is responsible for the lateral sway of the structure. According to the National Building Code, any structure above 15m is said to be a high rise structure. When we consider the wind effects on such slender structures in sequential analysis, the sway values are reported to be greater than what we obtain through conventional analysis. When we consider seismic loads, the lateral sway effectively increases in higher structural members. Its effect is comparatively less in the lower members.

Axial Shortening of Columns: According to Hooke's law, whenever a member is subjected to axial forces equal and opposite in direction, elongation or compression is seen in the member. As the loads on a column get accumulated with increase in number of floors above the member, elastic shortening is seen in columns as well as shear walls. As time passes, the effect of creep and shrinkage will also come under consideration. It was observed that axial shortening of vertical members is insignificant but horizontal members such as beams and slabs show larger values of deflection.

i. Creep of Concrete

ii. Shrinkage

iii. Elastic Stresses above Column

Creep and Shrinkage Losses: As stated earlier many building materials are time dependent i.e. properties change with the progress of time. Creep loss is the deformation of the structure under a sustained loading, which gets piled up and after a period of time the structure starts showing deformation and failures because the particular element could not sustain the loading above causing cracks and fails. Similarly concrete is a time dependent material as the time proceeds, it starts losing moisture the reduction in the volume of concrete due to evaporation and without impact the impact of external applied loads is called shrinkage loss

The effects of Creep and Shrinkage are much more visible during the first 5 years of construction, then the later period losses are not studied because it is saturated and the losses are diminished. Both Creep and Shrinkage contribute to axial shortening of columns, which is very dangerous especially at the top floors where the instability is much more felt. Apart from time dependence the losses are also dependent on age of concrete, longitudinal rebar in the elements, humidity and environment around.

Creep and Shrinkage losses are considered during the construction sequential analysis when the loads are applied sequentially on the frames, which is neglected in the lumped analysis, which causes a considerable amount of variation in the values of bending moments.

Creep: Creep generally varies with the dimension of the member and the percentage of reinforcement in a particular cross section. It also depends on the loading history. As the percentage of reinforcement increases, the creep deformation will decrease as more stresses will be transferred from concrete to reinforcement.

Shrinkage: Shrinkage generally depends on the moisture content of the near environment and the surface area of the concrete member available for evaporation. Concrete has pores which allow water to eject out from the void and get evaporated, causing a slight decrease in the dimensions of the member. Hence, if the Volume to Surface ratio is less, the evaporation is more resulting in larger deflection of the member. Similar to creep, it was found that as the reinforcement increases, the deflection due to shrinkage also decreases.

Elastic Shortening: It is the sudden shortening in a member due to introduction of either dead or live load on a member. If it is perfectly axially loaded, then only direct stresses act. But if loaded eccentrically, bending stresses also contribute. The deflection generally depends on the material properties and the dimensions of the member.

We expect the effect of shortening due to the above mentioned reasons is negligible, but in the worst cases it can cause malfunctioning of elevators, cracking of partitions, damage to the pipeline system. Often for a floor system, the members are casted uniformly. But if the members are not similar in dimensions, percentage reinforcement or material property, uneven shortening depending on the position of dead or live load may occur, resulting in slight tilting of the horizontal member which in turn can cause changes in Bending Moments and Shear Forces acting on it.

Longitudinal Rebar Percentage in Column: The axial shortening of columns leads to variation in the column size, properties and bending moment at the ends. The reinforcements in columns are calculated by applying various load combinations. When we consider the creep and shrinkage which is also one of the reasons for column shortening, the design reinforcement varies in both conventional and sequential analysis.

There is a considerable difference in the percentage of steel which cannot be neglected. There is more change in the steel percentage found in the columns at lower storeys where variation is in the range of 80 percent as compared to the upper storeys where it lies between range 40 to 50 percent. The axial shortening is caused due to overstressing of columns which were found safe in the conventional lumped analysis.

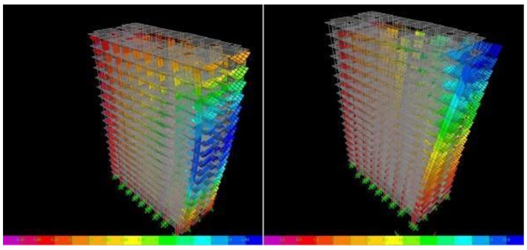

Figure 5

Figure 5 shows the final displacement difference between the same structure analyzed using sequential and conventional analysis.

4. CONCLUSIONS

i. One of the solutions to overcome the P-Delta effect was to provide heavier sections but this will cause an increase in the dead weight of the structure along with increased financial expenses.

ii. As the height of the structure increases, the shortening of supports cannot be neglected. The change in values of Bending Moments and Shear force decreases as we move higher in a structure whereas the sway displacement increases from bottom to top.

iii. There is relatively less shortening for a particular member if the rate of construction is decreased. On an average, the deflection for lower floors decreases. around 21% if the rate of construction of each floor is decreased from 7 days to 28 days. This difference is significantly higher i.e. around 35% for higher members for the same rate of change of construction. The rate of construction is one of the major factors that affects the column shortening. The site engineer can adjust the sequence of construction of vertical members so as to efficiently minimize the column shortening.

iv. It can also be seen that grade of concrete and change of cross sectional areas do not contribute significantly as change in the above properties automatically changes the reinforcement percentage of the member.

v. As the height of the structure increases, the shortening difference between two adjacent members increases. It is highest between members around mid level and top of structure. In order to counter it, extra reinforcement can be provided.

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