Staged Construction, Creep and Shrinkage Effects in Tall Buildings

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Summary:

There have been considerable developments in computer-aided analysis and design of engineering structures which allowed engineers to solve complex problems with the help of computer software. In conventional structural analysis practice, the structure is assumed to be constructed in one step (which will be referred as "all-in-one analysis" in this study), therefore construction stages and time dependent effects are neglected. In high rise reinforced concrete buildings, analysis results obtained utilizing staged construction, creep and shrinkage effects may be significantly different than all-in-one analysis results. In this study, a 25 story high rise building has been analyzed using the advantages of Construction Stages Manager (CSM) module of SOFISTIK software, which gives users the opportunity to simulate construction stages as well as the long term effects. Three different types of analyses as conventional all-in-one analysis, staged construction analyses with and without creep and shrinkage effects were conducted and results were compared. It was concluded that staged construction, creep and shrinkage influence should be carefully evaluated and included in the structural analysis and design of tall buildings.

1 INTRODUCTION

Traditional engineering practice uses the results taken from 2D or 3D analysis which use the finished construction properties disregarding time effects. Analysis models are formed through the completed structure (all-in-one). Structural and member responses are taken from all-in-one analysis for design. This analysis could give sufficient results for ordinary structures whereas additional care should be given for more complex structures such as irregular structures in plan and height, tall buildings, hybrid structures etc.

As the construction of building progresses, vertical members are subjected to load increments and deflect with each load increment. During the construction and service life of the structure, it also experiences creep and shrinkage deformations which would result in redistribution of the forces in indeterminate structures. The total shortening of a vertical member is composed of instantaneous deformations, and creep and shrinkage induced deformations. As the height of the structure considered increases, consequences of above mentioned factors become more important. Creep can be simply defined as the deformation under sustained load. For the range of working stresses $\sigma_c<0.4f_{cm}$ creep and creep inducing stress may assumed to be proportional. Shrinkage is a phenomena observed in concrete which leads to volume reduction as the concrete cures. Both phenomena are complicated and difficult to evaluate. Creep and shrinkage are affected by various factors such as concrete properties, age of concrete, applied stress, loading history, environmental humidity, volume-surface ratio and amount of the reinforcement in the members.

Effect of construction sequence, rate of construction, and grade of concrete on axial shortening incorporating 10-40 story buildings was assessed in Jayasinghe and Jayasena [1] and it was concluded that differential shortening of vertical members become more crucial as the height of the structure increases. Construction sequence analysis of 20-80 story buildings were conducted in Yi and Tong [2] in order to observe differential column shortening behavior. Shen et al. [3] studied the long term deformations using a 60 story hybrid structure. Choo et al. [4] developed stress/strain models of concrete incorporating creep and shrinkage effects and investigated the influence of creep and shrinkage on the ultimate strength of reinforced concrete column cross sections. Schultz et al. [5] investigated the effect of sustained loading on the response of concrete columns. It was concluded that sustained loading results in a reduction of strength, stiffness and energy dissipation capacity when subjected to lateral loading. Vafai et al. [6] studied the creep and shrinkage effects in tall buildings using nonlinear staged construction analysis.

In this study, attempt is made to investigate the effect of 3 different analyses types on the overall response of a 25 story reinforced concrete building. First type is the conventional all-in-one analysis, second type is the staged construction analysis without creep and shrinkage effects and the last type is staged construction analysis with creep and shrinkage.

2 STRUCTURAL MODEL AND ANALYSIS

2.1 Structural Model

A 25 story reinforced concrete flat slab building was chosen for analysis and numerical model was created. The structural system is composed of circular columns, shear walls, and flat slabs. Reinforced concrete flat slab with 22 cm thickness were selected. 40 cm thick shear walls and circular columns with 45 cm radius were utilized in order to resist the lateral and vertical forces. The total height of the structure is 80 m with constant story height of 3.2 m. Concrete grade C50/60 was used in the analyses. Uniform constant live load (3 kN/m^2) was used for all the stories and live load reduction has not been taken into consideration. Dimensions of the members were decided in a way that the drift limit of H/500 was satisfied under the action of lateral forces. UBC [7] code was used in the computation of lateral seismic actions.

Quad elements and beam elements were used in order to model walls and slabs, columns respectively. The structural system and corresponding computer model created can be seen in Figures 1 and 2 respectively. First and second fundamental periods of the structure are found to be 3.70 and 3.33 sec respectively. 30% of the live load was added to the structure's self weight in the calculation of the fundamental periods.

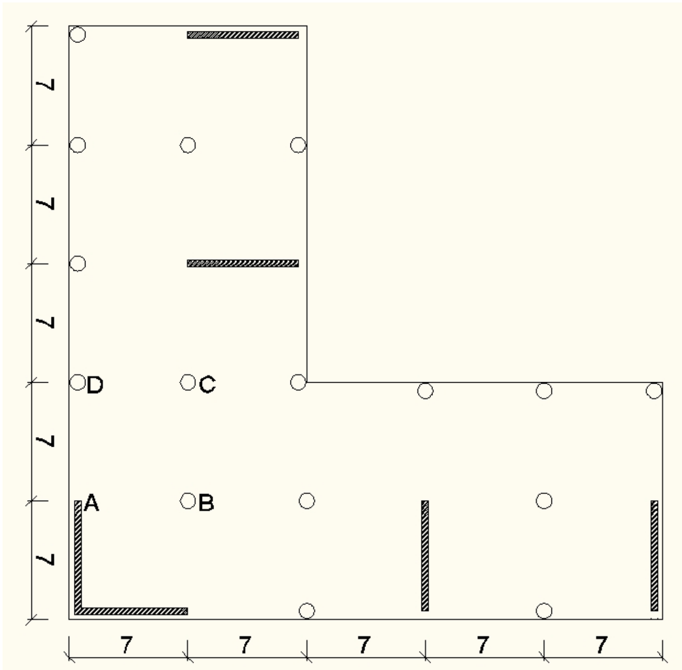

Figure 1 Structural System

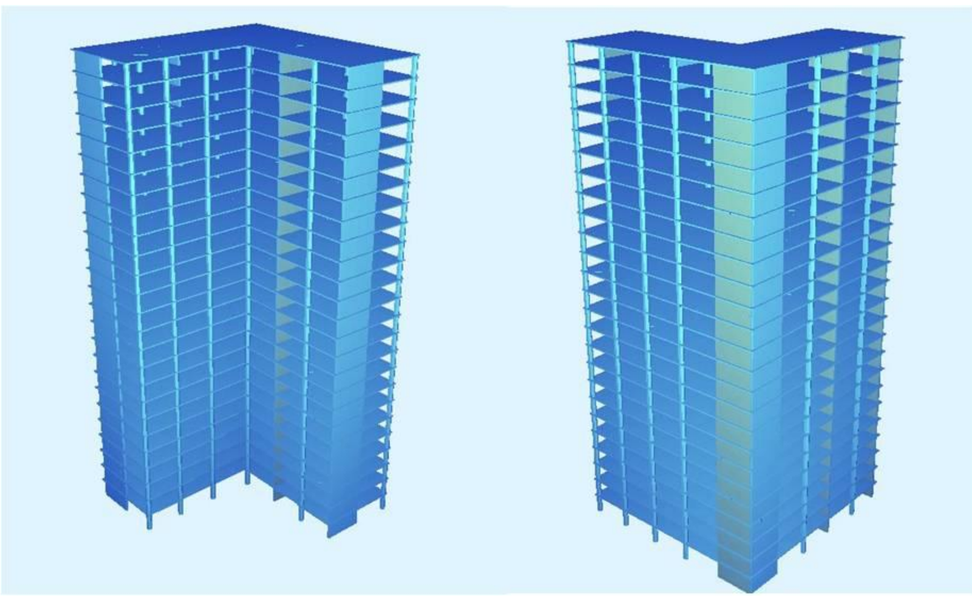

Figure 2 Computer Model

2.2 Analysis

Three different analyses were conducted in order to investigate the consequences of construction stages, creep and shrinkage. Conventional all-in-one analysis (Analysis 1) was run in the first analysis type where the structure is assumed to be built in a second. In the second analysis (Analysis 2), construction stages of the building were simulated. At each construction stage, a complete story was added to the system. The complete construction was simulated in 25 construction stages. In the last type of analysis (Analysis 3), together with the construction sequence analysis, creep and shrinkage effect were also activated. After addition of each story, the constructed part of the structure was subjected to 7 days of time dependent effects. After the completion of the construction, 10 years of long term effect were recorded. Only the loads arising from structure's own weight was utilized in all three analyses. Figure 3 shows the construction sequence for the first 4 stories for Analysis 2 and 3.

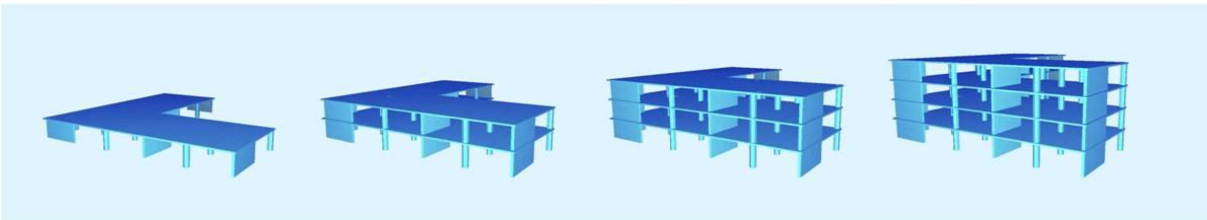

Figure 3 Construction Stages (1st-4th Story)

Construction Stage Manager (CSM) module was used for analyses. Required CSM module input was prepared as a TEDDY input file. Construction stages, activation of groups and loads can be easily defined and controlled with a TEDDY input file. Code based creep and shrinkage parameters are used in CSM [8]. While preparing the input file for CSM analysis, a parameter called CANT that is related to the activation of new groups in construction sequence needs to be defined. In order to observe the differences of different CANT values, a simple frame were studied. Second story was added on top of first story, which has already been deflected, using different CANT values. Resulting construction can be seen in Figure 4 for a simple frame. CANT value of 1 was used in the scope of this study.

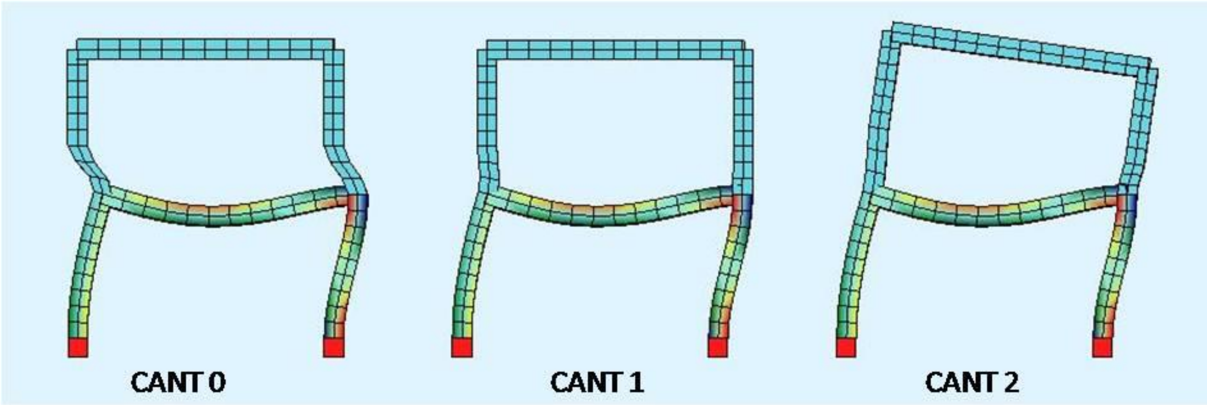

Figure 4 CANT Values 0, 1 and 2

As it was stated in the previous section, creep and shrinkage are affected by many factors such as concrete properties, age of concrete, applied stress, loading history, environmental humidity, volume-surface ratio and amount of the reinforcement in the members. The effect of the reinforcement was not considered in this study. Temperature difference of indoor and outdoor was not taken into account. Among these factors, influence of volume-surface ratio, concrete strength and the age of concrete at the loading for a simple 6 m high reinforced concrete column, analyzed under the action of its own weight for 10 years, can be observed in Figure 5. Three different cross sections were assigned to column as rectangle (20x80 cm), square (40x40) and circular (D=22.45 cm) section. It is important to note that all these sections have the same cross sectional area but different volume-ratio. Figure 5 shows the long term deformation (after 10 years) of the column having different sections, concrete grades and age of concrete at loading. As seen from the figure, as the concrete grade and the age of concrete at the loading increases, creep and shrinkage related deformations tend to decrease. Rectangle section, having the highest surface area, experiences the highest long term deformation.

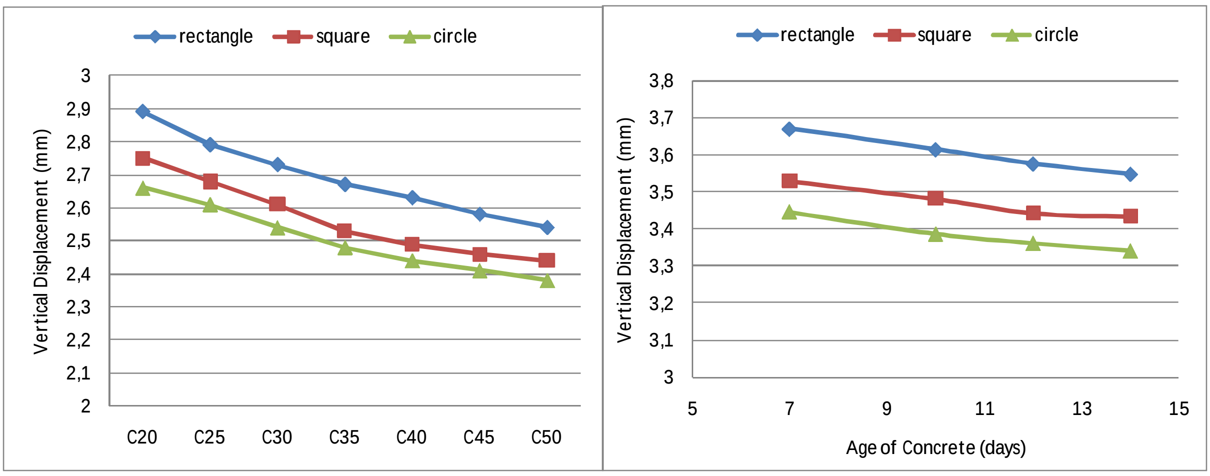

Figure 5 Long Term Vertical Displacement versus Concrete Grade and Age of Concrete at Loading

3 RESULTS

Axial shortening of vertical members due to instantaneous loading and long term creep and shrinkage is inevitable. Structural and non-structural members can be adversely affected by the relative movements of the vertical members. Creep and shrinkage induced displacements do not result in any stresses for the determinate structures whereas redistribution of forces occurs for indeterminate structures. Differential shortening between shear wall tip (Point A) and columns (Point B and C) was found to be the relevant engineering parameter to be observed in this study. Points A to C, can be seen in Figure 1. Vertical displacements of points A to C were recorded for all three analyses and results were compared. Yi and Tong [2] stated that the axial stress ratio between shear wall and columns varies between 0.2 and 0.5 for medium to high-rise buildings. This ratio is in the order of 0.4 for the points considered. Figures 6 and 7 show the relative vertical displacement results between points A-B and A-C respectively. As observed in both figures, all three analyses have different result which should be interpreted carefully. Maximum relative displacement occurs at the top floor for all in one result, whereas for Analysis 2 and 3 maximum value is around the midlevel of the structure. Jayasinghe and Jayasena [1] suggested similar results in their study. The differences in the results of the Analysis 1 and Analysis 2 are quite small up to the story level 7.

The axial loads obtained from Analysis 1 for columns at the ground floor at point B and C were 6680 and 7047 kN respectively. Axial loads for point B for the Analysis 2 and 3 were 7182 and 7043 kN. Axial loads obtained for point C were 7417 and 7319 kN for Analysis 2 and 3 respectively. When Figures 6 and 7 are compared for Analysis 3, it can be seen that higher axial load of column at point C resulted in higher relative displacement. Attention should be paid to the fact that adjacent vertical members should not have much difference in terms of stresses. Figure 8 shows the result of the vertical displacement of point B after the end of the construction recorded for 10 years together with results of Analysis 1 and 2. As shown in the figure the rate of increase in vertical displacement decreases as the time passes.

Figure 9 shows the change of the absolute moment values in ground floor column at point D after the end of construction (Analysis 1-3). Results in the figure are provided for the time range between the end of the construction and 10 years after the end of the construction (Analysis 3). As shown in the figure, moment values nearly doubles at the end of the 10 years. It is important to note that the results of this study are limited to the assumptions made. Further introduction of reinforcement and nonlinearity into the computation would produce different results.

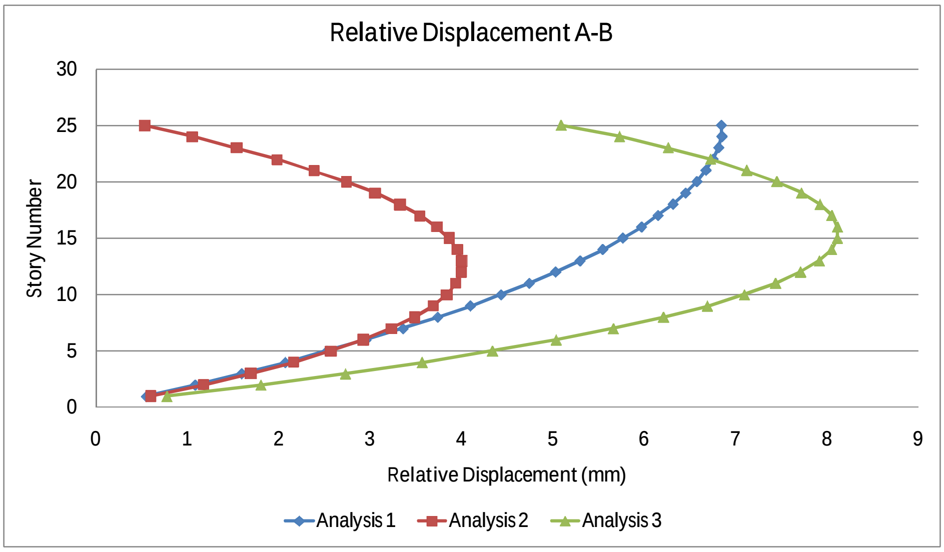

Figure 6 Relative Displacement Results (Analysis 1-3)

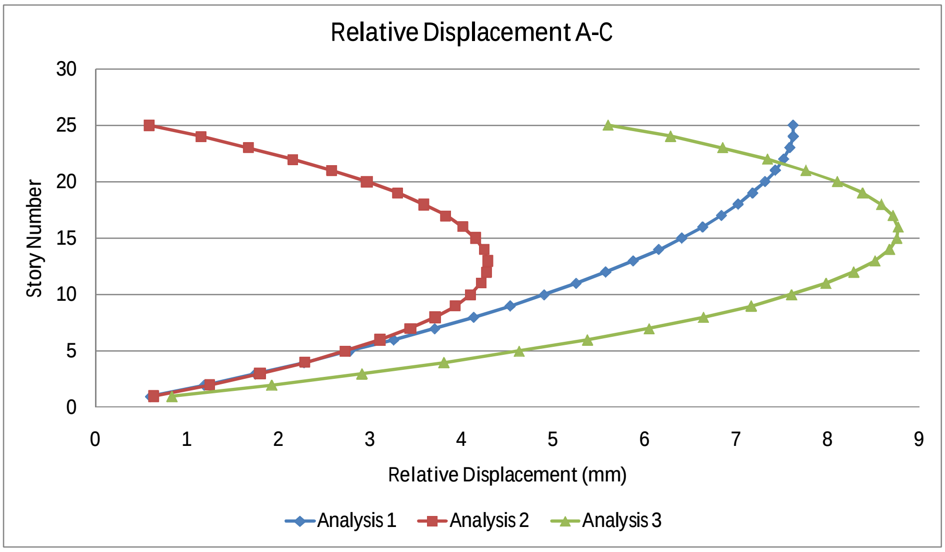

Figure 7 Relative Displacement Results (Analysis 1-3)

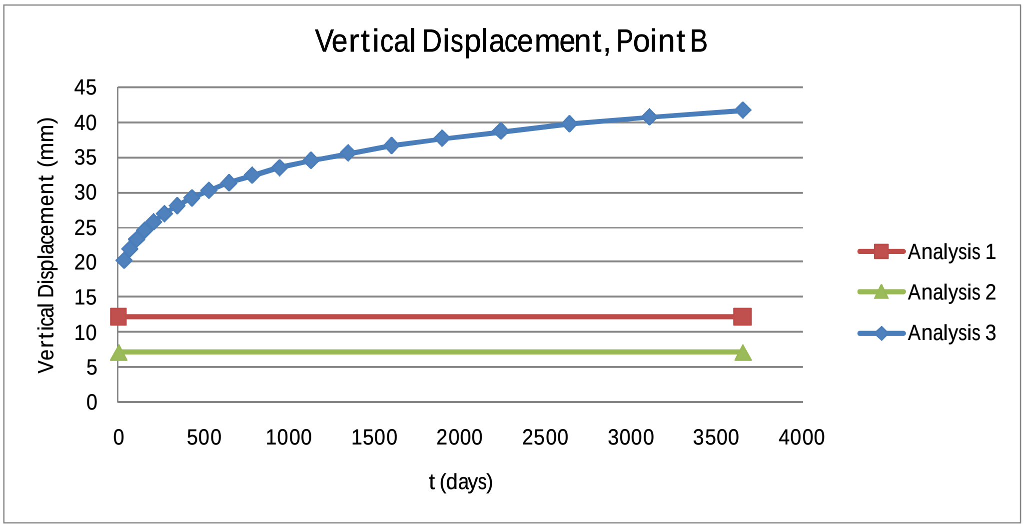

Figure 8 Vertical Displacement versus Time, Point B (Analysis 1-3)

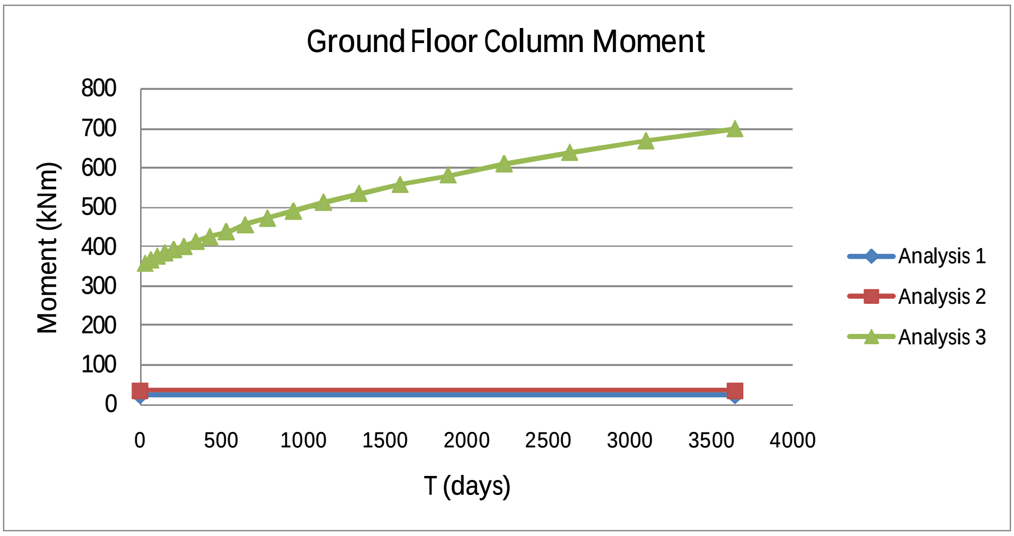

Figure 9 Ground Floor Column Moment versus Time (Analysis 1-3)

4 CONCLUSION

A comparative study has been conducted in order to investigate the consequences of construction sequences, creep and shrinkage incorporating Construction Stage Manager module of SOFISTIK software. A 25 story reinforced concrete flat slab building was analyzed conducting three different types of analyses. Based on the results of the numerical study, it was concluded that analysis and design of high rise buildings based on all-in-one models could be misleading and further steps should be taken to reflect the staged construction and long term effects.

5 REFERENCES

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