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Column Shortening Analysis with Lumped Construction Sequences

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Abstract

An analysis method with lumped construction sequences for the column shortening of tall buildings is proposed and its efficiency is investigated. The lumped model shows results that are close to the exact model in post-installation shortening as well as total shortening. The saw-tooth shape of post-installation shortening can be modified by curve fitting and the modified shortenings show good agreement with the exact values. The effect of the size of the lumping is studied and about 1/15 of the total stories of the building is recommended considering the accuracy of the results and the reduction in computing time. The proposed method is expected to be used effectively at the design stage of a tall building when repetitive analysis is required.

Keywords: Column Shortening; Long-Term Analysis; Tall Building; Construction Sequence.

1. INTRODUCTION

Several studies have been made over the past few decades on the prediction and compensation method for the differential column shortening of tall buildings (Fintel et al. 1987; Kwak and Kim 2006; Sharma and Kagpal 2007). The most widely used method in practice is that proposed by Fintel et al (1987), which predicts the total and post-installation shortening of each column. It calculates not only elastic shortening but inelastic shortening due to creep and shrinkage considering the construction sequence of a tall building. The method, which is based on RCM (Rate of Creep Method), one of the long-term analysis methods, gives nearly exact shortening of the columns connected with simple shear joints. However, the analysis methods with the free standing columns are not able to calculate the exact shortening of columns

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in a rigid frame because it cannot consider the restraining effect of the rigidly connected horizontal members (Kim 2008).

Column shortening analysis should adapt one of the long-term analysis methods which have been studied extensively for the last few decades. The analysis methods include EMM (Effective Modulus Method), RCM (Rate of Creep Method), AEMM (Age Adjusted Modulus Method), and SSM (Step by Step Method) (Bazant and Wittmann, 1982). Among these methods, SSM is the most exact method for the column shortening of tall buildings in that it can deal with any creep function and any complexity of the tall building structure (Bazant and Wittmann, 1982). For the purpose of analysis, the total time is divided into a number of time steps, the lengths of which should increase with time. The disadvantage of the SSM is that it requires considerable computation and takes a long time to perform the analysis of a complex structure such as a tall building.

The intention of this paper is to investigate the effect of lumped construction sequences on the column shortening. Here, the lumped construction sequence means that several building stories are lumped into one construction unit and the lumped units are assumed to be constructed at a time. The lumped construction sequence is proposed to reduce the computing time because the computing time for the column shortening analysis considerably increased as the number of stories of the tall building increases. The analysis results and the computing time of the lumped construction sequence are compared with those of the non-lumped construction sequence. The proposed method is expected to be used effectively at the design stage of a tall building when repetitive analysis is required under the condition that the detailed construction method, the material properties and the loading data are not yet fixed. Also, the proposed method can be used in the optimum design for the control of the differential shortening, which requires considerable repetition of the column shortening analysis.

2. LUMPED CONSTRUCTION SEQUENCES

Figure 1-(a) shows a column shortening analysis of an RC frame with the construction sequence representing every floor and it is expected to yield the most exact analysis results. A lumped construction sequence is shown in Figure 1-(b) in which 3 floors are lumped into one constructing unit and only two construction stages are required for the 6-story frame, while six construction stages are used in Figure 1-(a).

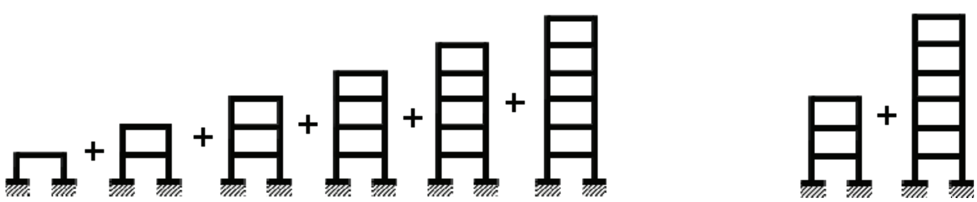

Figure 1(a): Conventional model; (b): Lumped model for construction sequence for column shortening analysis

2.1. Pre-installation and Post-installation Shortening

In cast-in-place reinforced concrete structures, the amount of shortening before the slab installation is of no importance because the forms are usually leveled when the concrete is placed for each floor slab, which means that the shortening compensation is completed automatically (Fintel et al, 1987). However, information is needed on how much the slab changes its position after the placement of the concrete due to subsequent loads and subsequent changes in volume. This information can then be used to tilt the formwork in the opposite direction so that the slab is eventually in the desired position. In steel structures where columns are fabricated to exact lengths, the total shortening, which is the sum of the pre-installation and post-installation column shortening, is of importance because the slabs are placed at a predetermined position.

2.2. Ultra Tall Building Analysis Model

The column shortening analysis of an ultra tall building is performed to investigate the effect of the lumped construction sequence. The example is a 151-story building of which the structural system includes composite mega columns and a concrete core wall connected with outriggers and belt trusses at 4 locations on floors 36-40, 57-61, 84-88, 116-120 and 150-151 as shown in Figure 2. A CEB model (CEB 1993) is used for the concrete model. The relative humidity is 60%. The construction time for each floor is 5 days and the age at the first loading is 3 days. The 10F-unit model, the 30F-unit model and 50F-unit model, which corresponds to about 1/15, 1/5 and 1/3 respectively of the number of the total stories, are compared with the 1F-unit model.

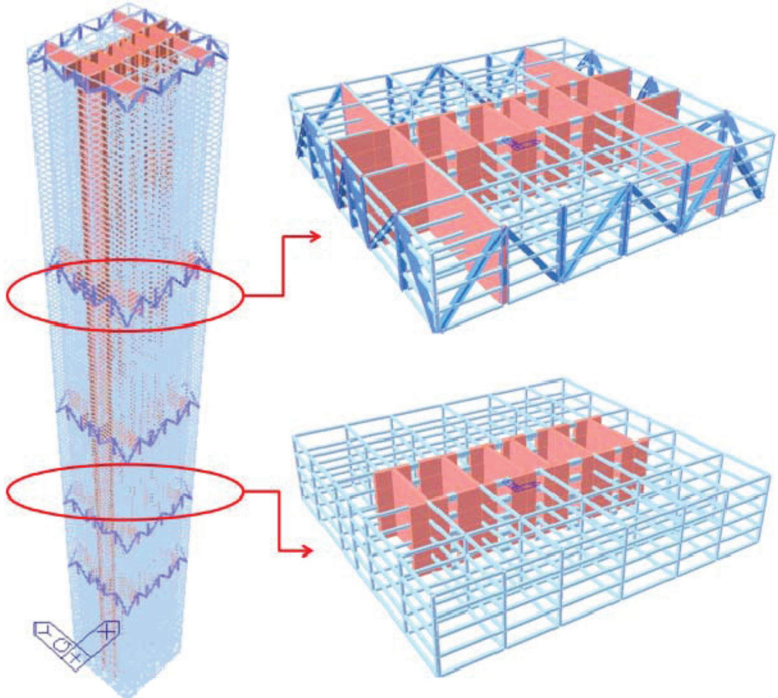

Figure 2: Ultra tall building example for column shortening analysis

2.3. Computing Time

The computing times for each model are shown in Figure 3. The 1F-unit model takes 2 hours and 21 minutes to complete. The 10F-unit model takes 28 minutes, which corresponds to only 20% of the time required for the 1F-unit model. The time for the 30F-unit model is 24 minutes, which corresponds to 17%. Though the size of lumping of the 30F-unit model is three times larger than that of the 10F-unit model, only 4 minutes, which corresponds to as little as 2.8% of the time of the 1F-unit model, is reduced. The time for the 50F-unit model is 17 minutes, which corresponds to 12%. From the result, it can be concluded that the lumped models are very effective in reducing the computing time.

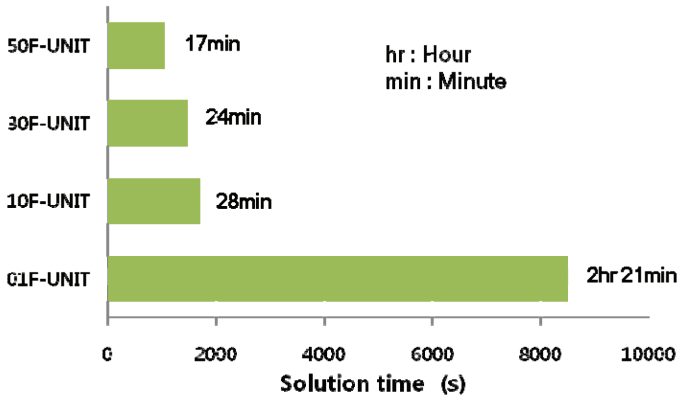

Figure 3: Computing time for analysis example

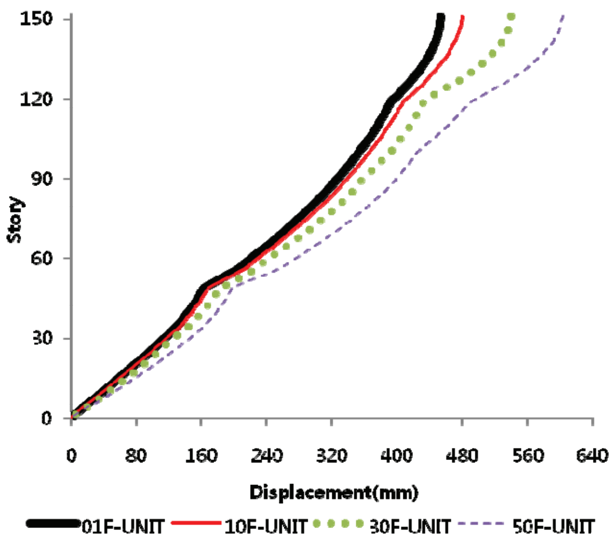

Figure 4: Total shortening of 151-story building example

2.4. Total Shortening

Figure 4 shows the total shortening developed on one of the perimeter columns at 1,000 days. The shortenings of the three lumped models are greater than that of the non-lumped model. The reason for this overestimation is that all the dead loads of the lumped unit are applied simultaneously 3 days after the lumped unit was constructed. As expected, the shortening of the 10F-unit model is the most identical to that of the 1F-unit model and the differences increase as the size of lumping increases. The errors at the top are 5.7%, 18.9% and 32.8% for the 15F-unit, 30F-unit and 50F-unit models, respectively. The total shortenings in this building are of no consequence because the pre-installation shortenings would be automatically compensated.

2.5. Post-installation Shortening

The post-installation shortenings of the same columns after 1,000 days are shown in Figure 5. It is observed that the post-installation shortenings of the lumped models are saw-tooth shaped and they show considerable discrepancy except for the first stories of the lumped units. The saw-tooth shape occurs because the pre-installation shortenings are compensated simultaneously for the lumped stories which are lumped into a unit while the automatic compensations occur for every single story in the 1F-unit model. Therefore, a correction is needed for the post-installation shortening of the lumped models.

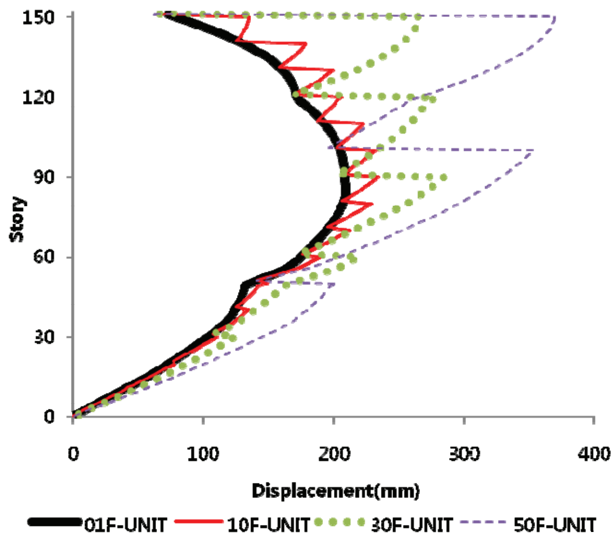

Figure 5: Post-installation shortening of 151-story building example

Utilizing the fact that the shortenings at the first story of the lumped units are quite close to the exact results, the fitted curve using only the first story of the lumped units (shown in circled points in Figure 6) is compared with the exact results. It should be noted that one single story unit for the top story, which is the 151th floor in the analysis model, is used to include the last point for the curve fitting.

Figure 7 shows the post-installation shortenings of the 1F-unit model and the lumped models, the curves of which are corrected by curve fitting. It is noted that the shortenings of the lumped models are somewhat less than the values from the 1F-unit model. The reason for this underestimation can be explained using the same reason as that for the overestimation in the total shortening. The overestimated shortening due to the dead loads applied at the early age of the lumped stories constitutes pre-installation shortening and is subtracted from the total shortening to yield the post-installation shortening.

It is observed that the shortening of the 10F-unit model is remarkably close to that of the 1F-unit model along all the stories while the 30F-unit and 50F-unit models do not show good approximation, except for floors 31, 61, 91, 121 and 151 which are the sampled points for the curve fitting. The 30F-unit and 50F-unit models is too coarse to predict the column shortening for the example building because it is not able to reflect the effect of outriggers and belt trusses. However, the 10F-unit model, which corresponds to 1/15 of the total stories, shows sufficient approximation (less than 5%) to the exact model with more than an 80% reduction in computing time.

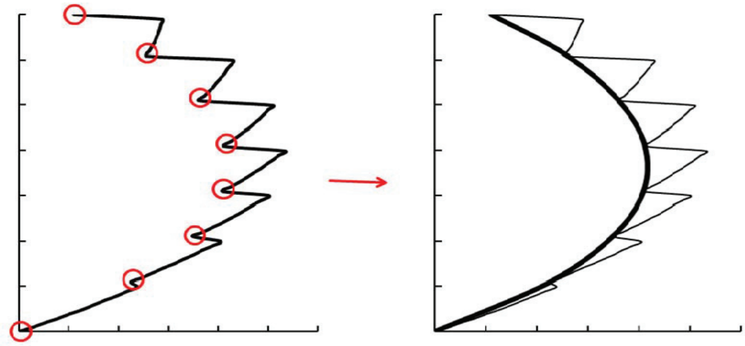

Figure 6: Curve fitting for post-installation shortening

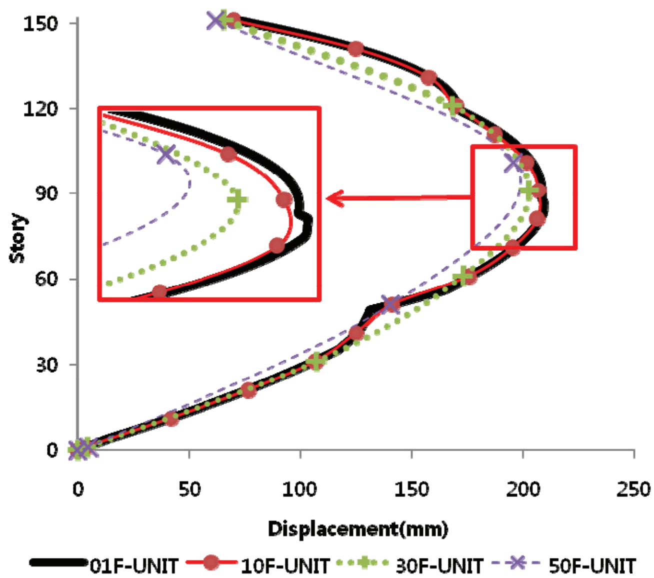

Figure 7: Fitted post-installation shortening of 151-story building example

2.6. Plane Frame Analysis Model

The column shortening analysis of a rigidly connected plane frame is performed to verify the effectiveness of the proposed method. The analysis model is an 80-story reinforced concrete 2-bays frame structure with two perimeter columns and a core wall. The beams are rigidly connected to the column and wall. A CEB model (CEB, 1993) is used for the concrete model. The relative humidity is 60%. The construction time for each floor is 5 days and the age at the first loading is 3 days. The story height and the span are 3.5m and 8.0m, respectively, as shown in Figure 8. For clarity, Figure 8 shows only the ground story.

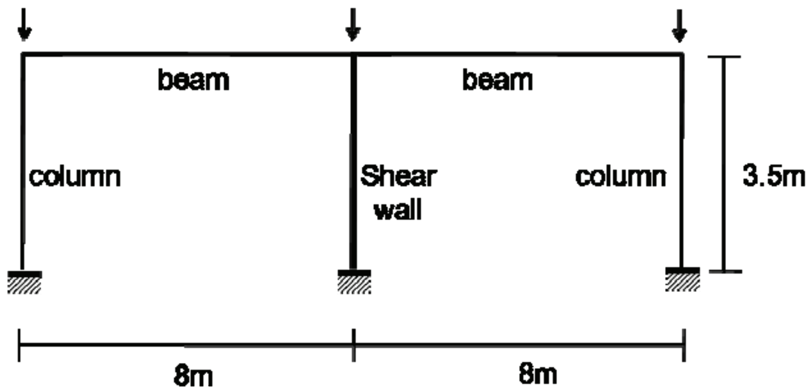

Figure 8: 80-story plane frame example (for clarity, only one story is shown)

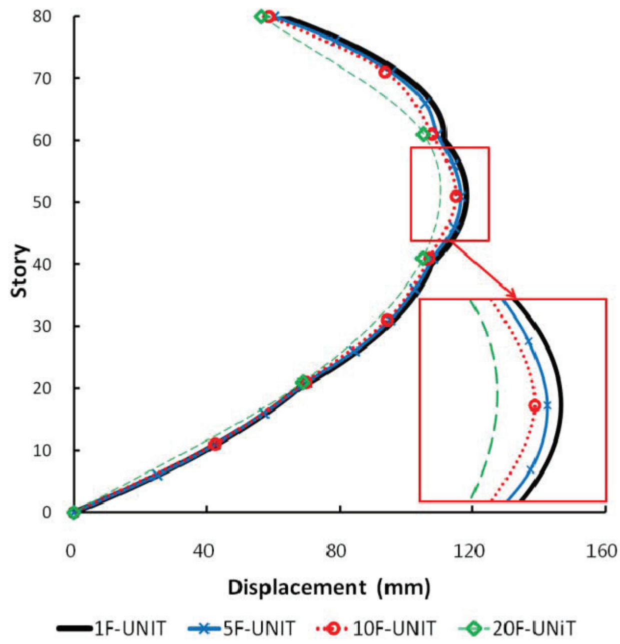

Figure 9: Fitted post-installation shortening of plane frame example

For computing, the 1F-unit model takes 87 seconds and the 5F-unit model takes 10 seconds, which corresponds to only 11.5% of the time required for the 1F-unit model. The times for the 10F-unit and the 20F-unit models are 4 seconds and 2 seconds, respectively, which are only 4.6% and 2.3% fractions of 87 seconds, respectively. The post-installation shortenings of the models are represented in Figure 9. The curves for the lumped models are fitted curves. The errors at the 51st story where the maximum post-installation shortening develops are 1.4%, 2.7% and 6.6% for the 5F-unit, 10F-unit and 20F-unit models, respectively. It can be said that the propose method yields sufficiently close results to the exact model in the plane frame example as well as the complex 3-dimensional example.

3. CONCLUSIONS

In this study, a simplified analysis method with lumped construction sequences for the column shortening of tall buildings is proposed and its efficiency is investigated. The method which lumps more than 2 stories into one constructing unit yields sufficiently close results to the exact model for use at the design stage of tall buildings while it reduces the computing time remarkably. The saw-tooth shape of post-installation shortening can be modified by curve fitting and the modified shortenings show good agreement with the exact values. The effect of the size of the lumping is studied and about 1/15 of the total stories of the building is recommended considering the accuracy of the results and the reduction in computing time. The proposed method can be used more effectively at the design stage of tall buildings when the data for the shortening analysis are not yet fixed and repetitive analysis is inevitable.

Acknowledgement

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