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Application of concrete filled steel tube column for differential axial shortening control

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ABSTRACT

In this paper, numerical analysis is performed to predict and control the axial shortening of columns. Due to the difference in load according to the position of the column, the axial shortening value of the column is not constant for each floor. This is differential axial shortening, affecting non-structural elements. In order to accurately predict and control this differential axial shortening, numerical analysis is performed in consideration of the creep and construction sequence of the structure in this study. Finally, in this paper, the differential axial shortening of the structure is further reduced by applying concrete filled steel tube.

1. INTRODUCTION

Axial shortening of columns due to axial loads should be considered most fundamentally to ensure that the behavior of the structure is not affected even when it is subjected to loads such as dead and live loads generated within the structure. It is essential to confirm axial shortening through a numerical analysis model that can apply the time effect due to the huge size of high-rise buildings that are difficult to verify through experiments and the material properties of concrete that change over time when using concrete materials.

Differential axial shortening occurs in the same floor due to the difference in load applied to the inside and outside columns of the structure. When differential axial shortening increases, it induces torsion between floors and between columns, affecting non-structural elements (plumbing, fire protection systems, doors and windows, floors and ceilings). Therefore, the safety and usability of the structure can be guaranteed only when the differential axial shortening, which increases in high-rise/high-load buildings, is appropriately controlled

The time-dependent effect of concrete additionally causes axial shortening because it causes additional deformation due to long-term creep and shrinkage after sufficient expression of concrete strength and strength, which were relatively low during column construction in the early stage. In order to accurately identify differential axial shortening, a numerical analysis model considering the actual construction sequence is also required.

Otherwise, as can be seen in the paper by Kwak and Kim [1], a structure that does not consider the construction order increases the construction cost of the structure by having an excessive safety factor throughout the structure.
When adjusting the cross section to reduce this axial shortening, using CFT members for columns is an appropriate alternative. CFT has significantly less axial shortening than RC members because the shrinkage and creep of concrete, which have a great effect on the axial shortening of the structure, are blocked from exposure of the internal concrete by the external steel pipe [2]. In high-rise buildings where differential axial shortening is increasing, CFT has various advantages such as relatively small section size, excellent buckling control due to high steel ratio, increase in strength of internal concrete due to confinement effect, and excellent fireproof and seismic performance, so it is an excellent substitute for RC members. [3]
In order to accurately understand the differential axial shortening of a structure, it is essential to introduce a numerical analysis model due to the size of the structure and the time required for actual construction. In this process, it is necessary to accurately reflect the effects of time and construction sequence in order to confirm the criteria and tendency for accurate column section setting. Finally, improvements to ensure the safety of structures from differential axial shortening effects will be presented.

2. METHOD

In order to infer accurate differential axial shortening, it is necessary to consider creep and construction sequences. As the basic process of nonlinear structural analysis, the routine to analyze the load acting on the members constituting the structure is as follows. : (1) Assemble the stiffness matrix of the element and make it into a global stiffness matrix. (2) Calculate the nodal displacement using the combination of the stiffness matrix and the external force. (3) Calculate the internal force of the members. (4) Check convergence. Through this numerical analysis process, the state of each member can be checked. In order to additionally consider the time-dependent properties of concrete and the influence of the construction sequence, several steps should be added to the above numerical analysis process. First, in order to explain the time-dependent process of concrete, it is necessary to consider creep and shrinkage. Calculate the $\varepsilon_n$value, which is the sum of $\varepsilon_{\mathrm{cr}}$ and $\varepsilon_{\mathrm{sh}}$, which are the strains of creep and shrinkage described in the previous chapter, and convert it into a force through Equation (1). If this force is reflected in the previous numerical analysis routine, the time-dependent effect of concrete can be expressed.

$$dR^{nm} = \int_V B^T E d\varepsilon^{nm} dr \qquad (1)$$

In order to implement the construction sequence of the structure, the weight for each construction stage should be set appropriately. In this study, as shown in Fig. 1, three states of Active, Deactive, and Inactive are assumed at the construction stage. The active state is the state of the floor where structural analysis is performed, and it has its stiffness and receives a load corresponding to its own weight and the axial force of the column immediately above its floor, deactive floor. The deactive state corresponds to the floor above the active state and is modeled only with the load acting on the active floor, and is converted to the active state as construction progresses. Inactive is the previously active floor, and the load is not activated when the active floor is analyzed. At this time, the inactive floor acts as an elastic support for the active floor above. Excluding the dead weight effect of the inactive floor in the active floor analysis serves to consider the construction sequence in this analysis. In this way, by giving different roles of each floor for each construction sequence, this numerical analysis model can consider the construction sequence. In this study, numerical analysis of the structure is conducted while understanding the time effect of concrete members and the behavior according to the construction stage of the structure, and the overall structural analysis sequence is as shown in Fig. 2.

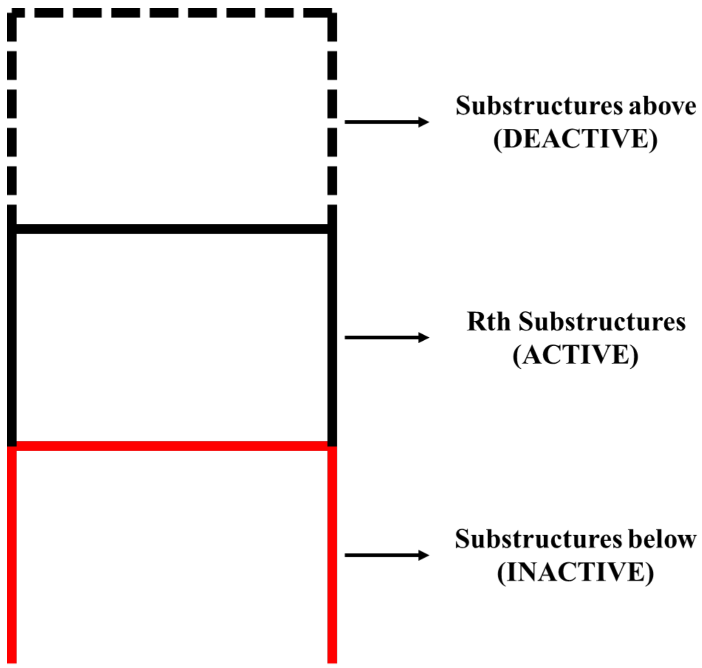

Fig. 1 Substructure arrangement for frame analysis

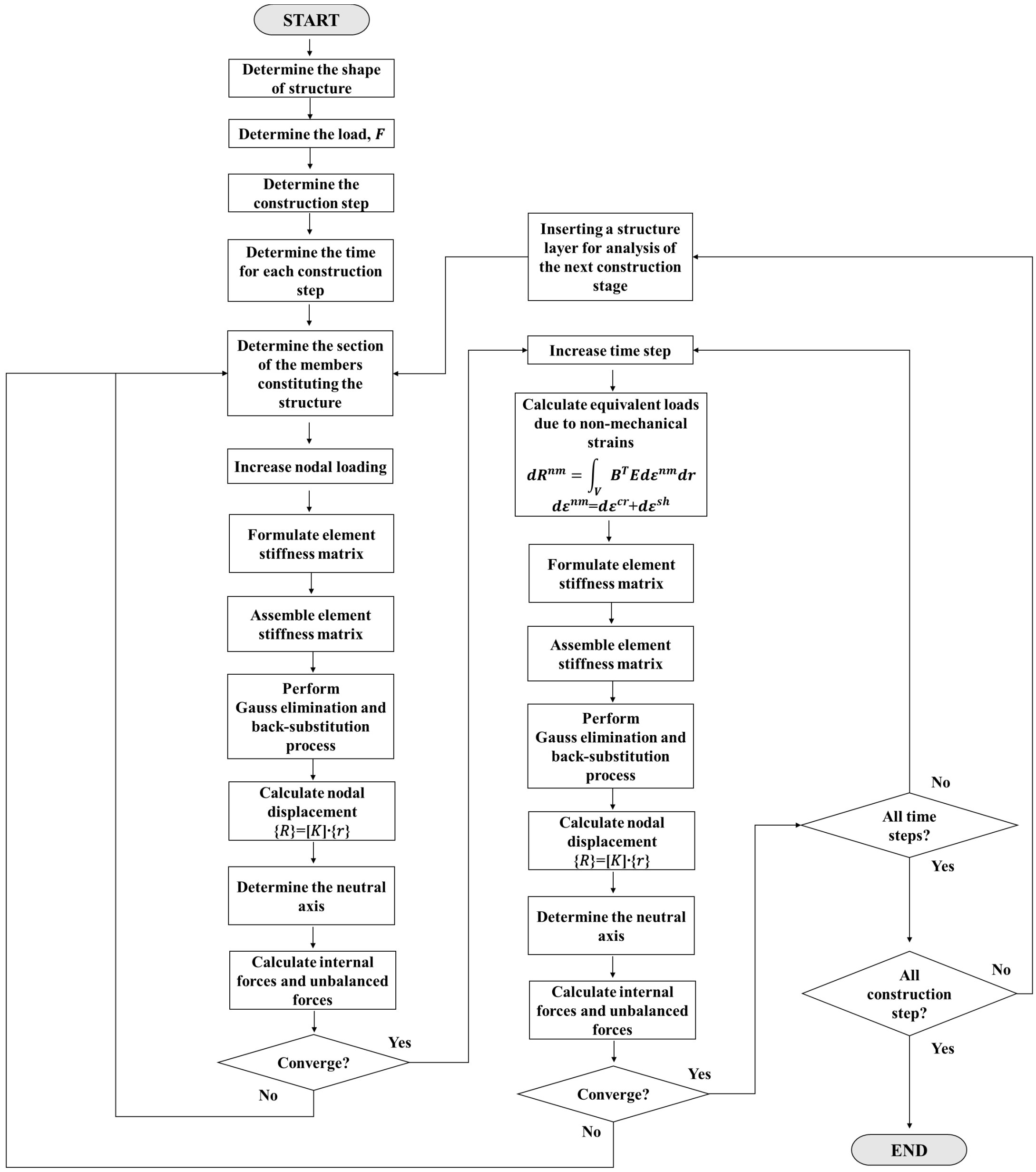

Figure 2: Solution Procedure

3. RESULTS

Based on RC columns, in a high-rise building with 4 bays and 40 floors, (1) Structure analysis considering the construction stage in the overall structure analysis (2) Structure analysis considering the time stage additionally in the structure analysis considering the construction stage (3) Analysis considering the flattening effect in addition to the structure analysis considering the construction stage and time stage was conducted. As a result, the change in maximum differential axial shortening of the

structure was shown in Table.1. Additionally, numerical analysis was performed in the same way as RC through CFT, and the results were the same as those in Table. 2.
The 5 mm reference value for differential axial shortening can be exceeded if an RC column carries a total dead load (F_d) exceeding 20% of its ultimate axial force capacity (F_u). The differential axial shortening increases as the carried dead load increases. RC columns are expected to have larger differential axial shortening than CFT columns due to their larger creep deformation, resulting in a difference of about 7-13% in differential axial shortening between the two types of columns. Figure 3 shows the variation of cross-sectional areas concerning the differential axial shortening. The total sectional area of A_{total} is considered a reference value for the normalization of the cross-sectional area determined at each evaluation. This figure can be used to select the initial column sections. For example, if a maximum differential axial shortening of 0.8 is allowed, the total cross-sectional area of RC and CFT columns can be reduced to 54% and 47% of the maximum total cross-sectional area, respectively, with an additional reduction of 7% expected in CFT columns, assuming a smaller ratio of total dead load to ultimate axial force capacity implies the use of relatively larger columns.

Table 1: Maximum differential axial shortening of RC column structures

CASE	Maximum differential axial shortening
1	0.9724
2	1.2261
3	0.9280

Table 2: Maximum differential axial shortening of CFT column structures

CASE	Maximum differential axial shortening
1	0.8064
2	0.9921
3	0.8370

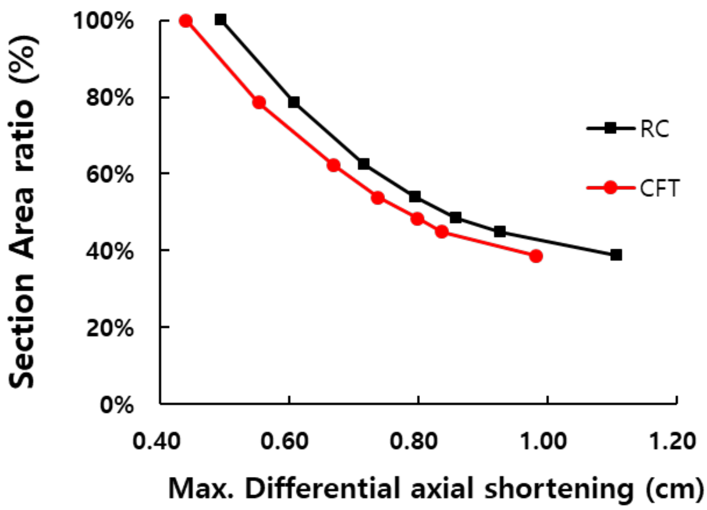

Figure 3 Difference in axial shortening compared to section area ratio

4. CONCLUSIONS

The study examines the impact of construction and design conditions on the differential axial shortening behavior of rigid frame structures. The numerical results show that the differential axial shortening effect can be eliminated if the design takes into account the construction sequence. For a 40-story rigid frame structure, the use of concrete-filled steel tube (CFT) columns reduces differential axial shortening more than reinforced concrete (RC) columns. However, to comply with safety limits, the portions of concrete and steel should be increased in both types of columns. The study proposes a relationship between differential axial shortening and the dead load portion to aid in the preliminary design of building structures.

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