Super High-rise Building Construction Simulation Analysis of the Iconic Tower

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Abstract. This paper takes the Iconic Tower as the background and combines the characteristics of overseas engineering projects. It mainly studies the influence of the leading layers of the super high-rise building’s corewall on the vertical displacement, and conducts construction simulation of the Iconic Tower based on the actual construction schedule. It analyzes in detail the vertical displacement and internal force variation laws of the corewall and frame column of the Iconic Tower, and studies the influence of concrete shrinkage and creep on the structure, which provides a reference for the project construction.

1. Introduction
Super high-rise buildings have high requirements for the technical strength of the general contractor due to their large investment, long construction period and difficult management. In particular, the construction simulation analysis technology has become a key technology to support safe and smooth construction of super high-rise buildings. The research on construction simulation technology of super high-rise frame-core tube construction simulation technology has been relatively mature. Gu Lei et al. [1] studied the influence of construction leveling on the vertical deformation of the structure, and Huang Xiangxiang et al. [2] analyzed the influence of concrete shrinkage-creep effect on the vertical deformation difference of the steel frame-core tube structure. Li Ye et al. [3] compared and evaluated different theoretical models and software applications in the construction simulation, and Jia Hongxue [4] analyzed the influence of the vertical deformation of the structure on the force of the outrigger truss during construction process. However, there are relatively few studies on the influence of height or layers of core tube leading outer frame on the structural behavior during construction process.

In the construction process of domestic super high-rise frame-core tube structure, the core tube construction usually leads the outer frame by 4 to 8 layers. However, domestic specification (JCJ3-2010) "Technical specification for concrete structures of tall building " [5] suggests that it should not exceed 14 stories. There are no mature research results showing the most reasonable leading layers at present.

The Iconic Tower project has poor controllability of construction schedule due to control factors of overseas engineering resources. According to construction schedule, the leading layers of the core tube of the project construction is at least 12 layers, and the maximum number of layers will reach 27. The difference in leading layers at different stages may cause large deformation and stress on the concrete cylinder. Based on this, this paper studies the influence of leading layers of the super high-rise building construction core tube on the vertical displacement of the super high-rise frame-core tube structure, and conducts a construction simulation analysis of the Iconic Tower to provide calculation data and control basis for the construction of the project.
2. Principles of structural construction simulation analysis

The state superposition method can be used for simulation analysis for rigid structures or structural systems with great rigidity during the construction stage and the schematic diagram of structural deformation is shown in Figure 1.

\[
\begin{align*}
\delta_1 &= \delta_{11} + \delta_{12} \\
\delta_2 &= \delta_{21} + \delta_{22} \\
\delta_i &= \delta_{i1} + \delta_{i2} \\
\delta_n &= \delta_{n1} + \delta_{n2}
\end{align*}
\]

Figure 1. Schematic diagram of vertical deformation of structure.

3. Engineering situation

The Iconic Tower is located in the central area of the CBD in the new capital of Egypt, with a total construction area of about 260,000 square meters, two floors underground, 79 floors above the ground, and a building height of 386m. The overall effect is shown in Figure 2.

The structural system of the Iconic Tower is a frame-core tube structure, with a steel frame outside and a reinforced concrete core tube inside, using a profiled steel plate and concrete composite floor system.

4. Calculation model of structure construction process

ETABS software is used to establish the construction simulation analysis model in this paper. The flow chart of construction simulation analysis is shown in Figure 3. The simulation calculation of the construction process established in this paper is shown in Figures 4-5. According to design requirements, the shrinkage-creep effect of the core tube wall concrete should be considered in the construction
simulation calculation of the project, and the time-related types should be selected according to ACI 209R-92. This paper selects only the typical outer frame column KZ1 and the outer wall Q1 of the core tube (as shown in Figure 6) from the structure for calculation and explanation.

5. Analysis of the influence of leading layers of the core tube

5.1 Analysis of working conditions
This section studies the influence of leading layers of the core tube on the mechanical performance of the super high-rise frame-core tube structure. The calculation results under four working conditions are compared and analyzed:(1) the core tube is leading the construction of 5 layers; (2) the core tube is leading 10 layers; (3) the core tube is leading 20 layers; (4) the core tube is leading 30 layers.

5.2 Vertical displacement analysis
As shown in Figure 7, as the number of leading layers of the core tube increases, the vertical displacement of the core tube wall gradually increases. The maximum vertical displacement of the wall is about 91.9mm when leading 5 layers and 143.2mm when leading 30 layers, an increase of about 55.8%. In addition, when the number of leading layers is large, the vertical displacement of the core tube is significantly reduced when the outer frame column starts construction.

It can be seen from Figure 8 that as the number of leading layers of the core tube increases, the vertical displacement of the outer frame column gradually decreases. The maximum vertical displacement of the outer frame column is about 70.2mm when leading 5 layers, and 51.7mm when leading 30 layers, a decrease of about 26.3%. This is mainly because the more layers the core tube leads, the later the outer frame column starts construction and the smaller the impact on its vertical displacement.

5.3 Analysis of the influence of internal force
As shown in Table 1, in order to study the influence of leading layers of the core tube on the internal forces of the vertical components of the structure, the total vertical base reaction force of the core tube and the outer frame column at the completion of the construction is taken under each working condition.
It can be seen that as leading layers increase, the vertical deformation and the internal force sharing of the core tube gradually increase while the vertical deformation and internal force sharing of the outer frame column gradually decrease. Therefore, when formulating the construction schedule, it is necessary to select leading layers reasonably to avoid excessive deformation and internal force of the components.

6. Simulation analysis of the entire construction process of the Iconic Tower

6.1 Loading conditions
This calculation mainly analyzes the construction process and shrinkage-creep effect of concrete on the vertical deformation of the frame-core tube structure. Loading considerations during construction are as follows: (1) The weight of the structure is mainly considered in the construction process; (2) the weight of the structure and additional constant load are considered after completion of construction. (3) the shrinkage-creep effect of concrete is considered throughout the process.

6.2 Analysis of working conditions
As shown in Table 2, the following three working conditions are considered.

| Table 2. Simulation of construction process. |
|------------------------------------------|
| working condition | construction process | shrinkage-creep |
| Condition 1       | consider              | consider       |
| Condition 2       | consider              | not consider   |
| Condition 3       | not consider          | not consider   |

6.3 Construction progress
The construction process simulation is carried out according to the construction schedule plan made on site, and the typical construction process is shown in Figure 9. After completion of construction, the load was continued to the 10-year stage to analyze the long-term effect of shrinkage-creep.

| Layer 10 | Layer 30 | Layer 50 (Construction completed) |

Figure 9. Typical construction process.
6.4 Analysis results

6.4.1 Vertical deformation analysis of frame-core tube
The maximum vertical displacement of external frame column and core tube shear wall for different construction steps in various working conditions are listed in Table 3. The vertical displacement of the core tube wall increases significantly when considering shrinkage-creep effect, and the vertical displacement of the outer frame is also increased accordingly when the core tube wall is affected.

| Working condition                  | Core tube | Frame column |
|-----------------------------------|-----------|--------------|
| Construction of the outer frame to layer 10 | Condition 1 | 36.0 | 3.0 |
|                                   | Condition 2 | 15.0 | 3.0 |
| Construction of the outer frame to layer 30 | Condition 1 | 54.0 | 14.0 |
|                                   | Condition 2 | 28.0 | 13.0 |
| Construction of the outer frame to layer 50 | Condition 1 | 78.0 | 33.0 |
|                                   | Condition 2 | 41.0 | 31.0 |
| Construction of the outer frame to layer 70 | Condition 1 | 111.0 | 59.0 |
|                                   | Condition 2 | 57.0 | 46.0 |

It can be seen from Figure 10 that the maximum vertical deformation is 96.1mm when considering the shrinkage-creep effect of concrete, and the maximum vertical deformation is 51.8mm without considering the shrinkage-creep effect of concrete, an increase of about 85.5%. The maximum vertical deformation of the wall under one-time loading occurs on the top floor, and the maximum value is 106.5mm; while the maximum vertical displacement of the wall occurs on the middle floor when considering the leveling during construction.
As shown in Figure 11, although there is no shrinkage-creep in the steel frame column itself, it is affected by the shrinkage-creep of the concrete core wall. Vertical deformation of the steel column will also increase by about 31.1% due to the redistribution of internal forces. The maximum vertical deformation under one-time loading occurs on the top floor and the maximum value is 111.8mm; while the maximum vertical displacement occurs on the middle floor when considering the leveling during construction.

It can be seen from Figure 12 that under the influence of concrete shrinkage and creep, although the vertical deformation of the core tube wall and the outer frame steel column both increase, the increase of the core tube wall is greater than the other. The vertical displacement difference between the wall and the outer frame steel column increases and the maximum increase is about 30mm. When loading at one time, the vertical deformation of the outer frame steel column is greater than that of the core tube wall. While the vertical deformation of the core tube wall is greater than that of the outer frame steel column, and the vertical displacement difference changes significantly when considering the leveling during the construction process.

### 6.4.2 Analysis of the impact of the long-term shrinkage-creep effect on the vertical deformation

The vertical displacement of the outer wall of the core tube on the second floor is used for research to further analyze the long-term shrinkage-creep effect. It can be seen from Figure 13 that the shrinkage-creep of concrete develops relatively rapidly in the initial stage of loading. With the development of age, the development slows down and gradually stabilizes. When the construction was completed, the elastic deformation of concrete was completed, which was 11.1mm. At this time, the shrinkage-creep deformation was 9.3mm, accounting for 45.6% of the total deformation, which indicates that shrinkage-creep has a significant impact on the deformation of super high-rise concrete structures during the construction process. Two years after the completion, the shrinkage-creep deformation was 11.7mm, accounting for 51.3% and 10 years after the completion, the deformation was 12.4mm, accounting for 52.8%. That is, from 2 to 10 years after the construction, the shrinkage-creep development is very small and can be almost ignored. Therefore, the shrinkage-creep effect of the super high-rise frame-core tube structure should be considered at least two years after the completion of construction.
### Table 4. Total vertical base reaction force /kN.

|                | Condition 1 | Condition 2 | Variety (%) |
|----------------|-------------|-------------|-------------|
| Core tube      | 904961      | 953343      | -5.1        |
| Frame column   | 533511      | 508876      | 4.8         |

As shown in Table 4, after considering the shrinkage and creep of concrete, the reaction force of the core tube base is reduced by about 5.1%, while the base reaction force of the frame column is increased by about 4.8%. It follows that due to the redistribution of internal forces caused by vertical deformation, the total reaction force of the frame column base increases and the total reaction force of the core tube base decreases when considering the impact of concrete shrinkage and creep.

#### 6.5 Reserved length of typical vertical components

Based on the above analysis, working condition 1 is consistent with the actual construction situation. When the construction is completed for 2 years, the shrinkage-creep effect is already small, and the vertical deformation is basically completed. This stage is used as the calculation time point for the reserved length of vertical components.

This section takes the vertical deformation of the structure after 2 years of construction as the benchmark according to the working condition 1 and calculates and analyzes the reserved length required for the processing of typical vertical components, as shown in Figures 14-15. The calculation method of reserved length is detailed in reference [7].

The reserved length of the vertical component is greater than zero due to the long-term effect of shrinkage-creep and the gravity of the upper floor. The maximum reserved length of the outer frame column KZ1 is about 11.3mm, and the maximum reserved length of the wall Q1 is about 21.7mm. Close to the top of the structure, due to the impact of construction leveling, the actual height of the structure during construction is greater than the design value, so the reserved length of vertical component is less than zero. Considering the reserved length of the vertical component in construction can avoid the vertical deformation of the structure and additional internal force of the structural components caused by long-term effects such as shrinkage-creep.

![Figure 14. KZ1 reserved length of typical frame column on each floor.](image1)

![Figure 15. Q1 reserved length of typical wall on each floor.](image2)

#### 7. Conclusion

This paper analyzes and studies the construction process of the Iconic Tower. The following main conclusions are obtained through numerical simulation analysis:

1. The number of leading layers of core tube has a great impact on the vertical deformation and internal force of the structure. As the number of leading layers of the core tube increases, the vertical displacement of the core tube wall and the internal force sharing gradually increases; while the vertical displacement of the outer frame column and the internal force sharing gradually decreases.

2. Considering the shrinkage-creep effect during the construction process, the vertical displacement of the core tube wall increases significantly. The frame steel column is affected by the core tube wall, and the vertical displacement increases accordingly, but the increase is smaller than the core tube.
(3) The maximum vertical deformation of the structure occurs at the top floor when one-time loading, while after considering the leveling during construction, the maximum vertical displacement of the wall occurs at the middle floor, that is, the position of the maximum vertical displacement changes.

(4) The shrinkage-creep development of concrete is relatively rapid in the initial stage of loading. With the increase of age, the development gradually stabilizes. The impact of shrinkage-creep effect of super high-rise frame-core tube structure should be considered at least 2 years after the construction.

(5) When considering the shrinkage-creep effect of concrete, the total reaction force of frame column base increases due to the redistribution of internal forces caused by vertical deformation, and the total reaction force of core tube base decreases.

(6) It is advisable to consider the influence of leveling and shrinkage-creep of concrete in the calculation of reserved length of vertical components during construction. Two years of construction completion can be used as the calculation time point for the reserved length of vertical components.

References
[1] Gu, L., Li, X., et al. (2017) Influence of leveling methods to super high-rise building and the calculation of storey reserved length. Build. Struct., 47(21):30-35.
[2] Huang X.X., Zhou X.H. (2013) The long term effects of concrete shrinkage and creep on vertical differential shortening of hybrid structures. J. Hunan Univ. (Nat. Sci.), 40(5):1-6.
[3] Li Y., Wang J., Zhou J.L. (2012) Applying research on construction simulation analysis of non-load effect of high-rise building. Build. Struct., 42(5):159-163.
[4] Jia H.X. (2019) Construction simulation analysis of unilateral inclined super high-rise building based on different models. Build. Struct., 49(S2):246-250.
[5] (2011) Technical specification for concrete structures of tall building: JGJ3-2010. CABP Publishing, Beijing.
[6] Civil King Software Technology Co., Ltd. (2014) ETABS Chinese version user guide. CABP Publishing, Beijing.
[7] Fu X.Y., et al. (2014) Analysis and control on long-term deformation caused by gravity of the Shenzhen Pingan Finance Center. J. Build. Struct., 35(1):41-47.