Influence of steel ratio on the vertical deformation of super high-rise building

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Abstract. Taking a super high-rise project as the research object, considering the shrinkage and creep characteristics of concrete and different steel ratio, MIDAS/Gen is used to simulate the construction process of the structure. The results show that different steel ratio has an impact on the vertical deformation and the vertical deformation difference. In the design stage, the reinforcement amount should be increased appropriately, so as to reduce the vertical deformation difference between the core tube and the outer frame column.

1. Introduction
The construction of super high-rise buildings in China is increasing, and the structural shape is becoming more and more complex [1]. With the increase of the height of super high-rise structure, the vertical deformation of core tube shear wall and outer frame column is increasing, and the cumulative effect of this deformation on the vertical deformation difference of the structure is increasing [2]. Structural deformation will make the actual position of the component deviate from the design position, which has a great impact on the subsequent installation work. If the components are processed and installed according to the design configuration during construction, the components cannot be installed, and there must be some deviation between the configuration of the structure and the design configuration after completion. The vertical accumulated deformation difference will also cause additional internal force of horizontal connecting members and outrigger truss, which will cause redistribution of internal force, and even lead to floor cracking, partition wall cracking, pipeline damage and other problems [3].

In this paper, a super high-rise project was taken as the research object, MIDAS/Gen software is used to simulate the construction process of the structure by considering the shrinkage and creep characteristics of concrete, the influence of different steel ratio on the vertical deformation difference is discussed and analyzed.

2. Project overview
A super high-rise project covers an area of 7030m², with a total building area of about 278000m², underground building area of 31000m² and aboveground building area of 247000m². It is composed of three floors underground and 90 floors above ground. The podium has 4 floors above ground. The structure height is 428m, and the building height is 445m. The structural type of the tower is a hybrid structure composed of concrete-filled steel tubular frame and reinforced concrete core tube with...
outrigger truss reinforcement layer. The outrigger truss is located on the 43rd and 70th floors. The architectural effect is shown in Figure 1.

Figure 1. Effect of the building.

3. Influence factors of vertical deformation difference
This paper mainly considers the shrinkage and creep characteristics of concrete and the influence of different steel ratio on the vertical deformation difference of super high-rise building.

3.1. Time varying characteristics of concrete materials
The shrinkage and creep characteristics of concrete are the main factors affecting the cumulative deformation analysis of vertical members of super high-rise structures. In this paper, the shrinkage and creep model of CEB-FIP1990 [4] is used to simulate the tower construction process by MIDAS/Gen.

For the parameters in CEB-FIP (1990) model, the annual average relative humidity is 70% for core tube shear wall, 90% for concrete-filled steel tubular column [5], the cement type is N, R: 0.25, and the concrete age at the beginning of calculating concrete shrinkage and creep is 3 days.

3.2. Steel ratio of structure
The influence of steel ratio on vertical deformation is mainly reflected in three aspects: (a) influence on vertical stiffness of structure, (b) influence on self-weight of structure, (c) influence on shrinkage and creep characteristics of concrete filled steel tubular column [6].

According to the different steel ratio, it is divided into four models for the construction simulation analysis. The four models are the basic model corresponding to the construction drawing (W₀-C₀), the model with the outer frame column all using concrete (W₀-C_fall), the model with the core tube all using concrete (W_fall-C₀), and the model with the outer frame column and the core tube all using concrete (W_fall-C_fall).

The values of steel ratio of four calculation models are listed in Table 1. The steel ratio defined in this paper is the ratio of the weight of steel in the structure to the total weight of the structure.

| Model         | Steel ratio (%) |
|---------------|-----------------|
| W₀-C₀         | 18.03           |
| W₀-C_fall     | 10.16           |
| W_fall-C₀     | 9.16            |
| W_fall-C_fall | 6.27            |

4. Load and construction stage
This paper mainly studies the influence of different steel ratio on the vertical deformation. In order to simplify the analysis, only the self-weight and shrinkage creep of the structure are considered, and the curtain wall load, construction live load and secondary structure load in the construction process are not considered.
According to the actual construction progress of the project, the construction simulation analysis is carried out. Five layers are taken as a construction step, and it takes seven days for each layer to complete the construction. The core tube is five layers ahead of the outer frame. The tower is divided into 19 construction steps. The calculation model of the sixth construction step is shown in Figure 2.

![Finite element model of the sixth construction step](image)

**Figure 2.** Finite element model of the sixth construction step.

5. **Analysis of calculation results**

Based on the construction simulation analysis of super high-rise structure, four outer frame columns (C1~C4) around the tower are selected as deformation control points, and four corner points (W1~W4) of core tube shear wall are selected as deformation control points, as shown in Figure 3.

![Vertical deformation control point](image)

**Figure 3.** Vertical deformation control point.

The calculated vertical deformation of the tower completion time is the average value of C1~C4 columns for the outer frame column and the average value of W1~W4 for the shear wall, as shown in Figure 3.

5.1. **Comparison of vertical deformation**

Considering the shrinkage and creep of concrete, the vertical deformation of outer frame column and core tube shear wall under different steel ratio is shown in Figure 4 and Figure 5.
As shown in Figure 4a, it can be seen that the vertical deformation of the outer frame column becomes larger with the decrease of the steel content of the outer frame column and the same steel content of the core tube under the action of dead load. Under the same steel content of the outer frame column, the change of the steel content of the core tube has little effect on the deformation of the outer frame column. It can be seen from Figure 4b that the deformation of the outer frame column becomes smaller with the decrease of the steel content of the outer frame column and the same steel content of the core tube under the action of shrinkage and creep. Under the same steel content of the outer frame column, the change of the steel content of the core tube has little effect on the deformation of the outer frame column.

It can be seen from Figure 5a that the deformation of the core tube below the middle of the floor increases with the decrease of the steel content of the core tube and the same steel content of the outer frame column under the action of dead load; the deformation of the core tube above the middle of the floor increases with the decrease of the steel content of the outer frame column and the same steel content of the core tube. It can be seen from Figure 5b that the deformation of the core tube below the middle of the floor increases with the decrease of the steel content of the core tube and the same steel content of the outer frame column under the action of shrinkage and creep; the vertical deformation of the core tube decreases with the decrease of the steel content of the outer frame column and the same steel content of the core tube.
5.2. **Comparison of vertical deformation difference**
Considering the shrinkage and creep of concrete, the vertical deformation difference between the outer frame column and the core tube shear wall under different steel ratio is shown in Figure 6.

![Figure 6. Comparison of vertical deformation of outer frame column and core tube.](image)

It can be seen from Figure 6a that the deformation difference between the core tube and the outer frame column becomes larger with the decrease of the steel content of the outer frame column and the same steel content of the core tube under the action of dead load; the deformation difference between the core tube and the outer frame column becomes smaller below the middle of the floor with the decrease of the steel content of the core tube and the same steel content of the outer frame column. It can be seen from Figure 6b that the deformation difference between the core tube and the outer frame column increases with the decrease of the steel content in the outer frame column and the same steel content in the core tube under the action of shrinkage and creep; the deformation difference between the core tube and the outer frame column increases below the middle of the floor with the decrease of the steel content in the core tube and the same steel content in the outer frame column.

5.3. **Comparison with the basic model deformation**
Considering the action of dead load, concrete shrinkage and creep, and the different steel ratio, the differences between the vertical deformation of outer frame column and core tube of the other four models and that of the basic model are shown in Figure 7 and Figure 8 respectively.

![Figure 7. Comparison of vertical deformation with the basic model (Outer frame column).](image)

![Figure 8. Comparison of vertical deformation with the basic model (Core tube).](image)
It can be seen from Figure 7 that the vertical deformation of the outer frame column is basically the same as that of the basic model \((W_{0-C_0})\) with the steel content of the outer frame column is the same as that of the basic model and the steel content of the core tube is less than that of the basic model; the outer frame column difference of vertical deformation between the model \((W_{\text{full-C}_0})\) and the basic model becomes larger when the steel content of the core tube is the same as that of the basic model and the steel content of the outer frame column is less than that of the basic model; the outer frame column difference of vertical deformation between the model \((W_{\text{full-C}_0})\) and the basic model becomes larger when the steel content of the outer frame column and the core tube is less than that of the basic model.

It can be seen from Figure 8 that the vertical deformation of the core tube is basically the same as that of the basic model when the steel content of the core tube is the same as that of the basic model \((W_{0-C_0})\) and the steel content of the outer frame column is less than that of the basic model; the core tube difference of vertical deformation between the model \((W_{\text{full-C}_0})\) and the basic model under 100m becomes larger when the steel content of the outer frame column is the same as that of the basic model and the core tube is less than that of the basic model, and the core tube difference of the vertical deformation between the model \((W_{\text{full-C}_0})\) and the basic model for under 100m becomes larger when the steel content of the outer frame column and the core tube is less than that of the basic model.

6. Conclusions

In this paper, MIDAS/Gen finite element software is used to simulate the construction of a super high-rise building with different steel ratio. The main conclusions are as follows:

1. Considering the action of dead load, shrinkage and creep, the vertical deformation of outer frame column is mainly related to the change of steel content of outer frame column; the change of steel content of outer frame column and core tube has little effect on the deformation of core tube.

2. Considering the action of dead load, shrinkage and creep, the vertical deformation difference between outer frame column and core tube is mainly related to the change of steel content of outer frame column.

3. The total vertical deformation of outer frame column and core tube is mainly related to the change of steel content of outer frame column.

4. In the design stage, when the minimum reinforcement ratio is met, the reinforcement amount should be increased appropriately according to the results of construction simulation analysis, so as to reduce the vertical deformation difference between the core tube and the outer frame column.

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