

Several Structural Concepts of Reinforcement of High-Rise Buildings

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Abstract: This paper puts forward that the appearance of unfinished buildings brings many difficult problems to the development of local urbanization, and explains that it is necessary to accurately evaluate the overall reliability of unfinished buildings and carry out structural reinforcement, in order to ensure the continuation of unfinished buildings, transformation and upgrading of the premise. This paper discusses the structural concept of structural reinforcement of high-rise buildings, the structural design problems caused by inclined column of high-rise building, the vertical deformation of suspension and continuous structure construction of high-rise building, and the mechanical behavior of beam and column under full-span wall of high-rise building transfer floor are discussed. In view of the corresponding problems, this paper proposes that measures should be taken to ensure the reliability of horizontal force transmission of beam-column joints, floor, wall-beam joints and core tubes. In addition, a simple method for calculating the moment of inertia conversion of beam-wall section is presented from the angle of beam-wall interaction, the correct method of realizing beam-wall interaction by common software is given, which provides reference for early structural analysis of complex engineering. It is hoped that these measures can solve the problems of unfinished buildings and promote the development of the city.

Keywords: Unfinished Building, Force Transmission Path, Vertical Deformation, Transfer Floor, JOINT Action

1. Introduction

"Unfinished buildings" often refer to construction projects that have gone through the land use and planning procedures, but have been suspended for more than one year after the project starts due to the inability of the builder to continue investing in construction, or because of debt disputes or unqualified project quality. Due to the existence of "unfinished buildings", it not only affects the economic life of the owners and causes social unrest, but also leads to the waste of urban resources and even damages the image of the city. Therefore, the renovation and continuation of the "unfinished buildings" is very important for urban development. Due to long-term exposure to the external environment, its building structural components and material properties are prone to damage or reduction, such as corrosion of steel bars, peeling of protective layers, carbonization of concrete or severe chemical ion corrosion, cracking and deformation of components, building settlement, inclination, and reduced strength of building materials. Wait. In order to find out the relevant parameters and

mechanical indicators of the existing building, provide a scientific basis for the continued construction, and ensure the safe use of the building, the construction quality inspection of the original project (existing building) must be carried out according to the design drawings and relevant specifications.

Only through structural inspection and analysis, the original construction quality of the unfinished building structure, the problems during the shutdown period and the evolution and quality status quo can be identified, and the current structural safety and quality problems can be determined according to the reasonable use requirements and current specifications. So as to provide the corresponding objective scientific basis for the follow-up work. Before carrying out structural analysis, it is necessary to grasp the concept of structural force in all aspects and system. This paper aims at the structural design problems caused by inclined columns in high-rise buildings, the vertical deformation problems of suspended and continued structures, and the full span of high-rise building transfer floors. The problem of the mechanical performance of beams and columns under the wall is developed to provide reference for the

structural analysis in the early stage of complex projects.

2. Structural Design Problems Caused by Inclined Columns of High-Rise Buildings

The axial force of the inclined column will generate a large horizontal force at the turning point of the floor. When the horizontal force is a tensile force, the tensile force will be transmitted in the beam-column node, the floor, the connection node between the tension beam and the core tube, and the core tube. The reliability of the path is a difficult point in the design of such complex structures [1], and there is still a lack of structural analysis and design methods related to this aspect in the current code. Wei Lian *et al.* [2, 3] gave a method for calculating the floor stress and considering the horizontal component of the vertical member.

Under the vertical load, the horizontal component force of the inclined column causes the structure to generate additional internal force, resulting in a certain horizontal deformation of the structure under the vertical load condition. Necessary construction simulation analysis should be carried out in the design, and the disadvantages brought by the inclined column should be fully considered, and take corresponding strengthening measures. In the over-limit design, it is suggested that the inclined column with large horizontal component force and related components connected to it can be defined as key components, and the seismic safety reserve can be appropriately improved. Analysis and other methods are used to analyze the reliability of the horizontal force transmission path in detail, and corresponding strengthening measures can be adopted with reference to the "Code for Design of Concrete Structures of High-rise Buildings" SJG98-2021 [4] (hereinafter referred to as "Shenzhen Concrete High Regulations"). In the design, when a composite floor is used, special attention should be paid to the connection node structure between the tension beam and the core tube. If hinged connection is used, the bearing capacity of the tension beam web and related connectors should be reviewed.

The vertical loads of each floor are transferred to the outer frame and core along the in-plane beam-slab system. Due to the existence of the inclined column, the vertical load transmitted to the outer frame is decomposed into two components along the axial direction of the column and along the horizontal direction at the beam-column node. Radial frame beams, and then transmitted to the floor through these beams (as shown in Figure 1); when the floor system is a cast-in-place reinforced concrete structure, the horizontal tension is transmitted to the core tube through the combined action of the beams and plates. The horizontal tension is generally transmitted to the core by the steel beams. As shown in Figure 2, for the frame-core tube structure with inclined columns, the horizontal component of the axial force of the inclined columns is transmitted to the core tube in the form of floor tension and compression on the relevant floors. When the horizontal tensile force is large, in order to ensure that the concrete floor does not crack under

normal use, it is necessary to take measures such as pouring after construction or adding prestressed steel bars to resist part of the tensile force; if necessary, steel columns and steel beams should be set in the core tube to ensure the horizontal Reliability of force transmission in the core.

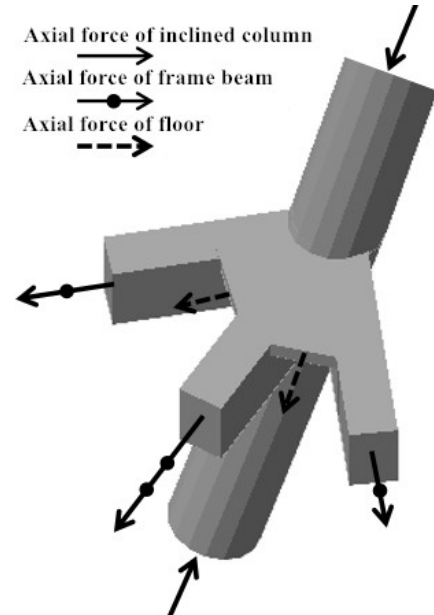


Figure 1. Force transmission between inclined column, slab and beam.

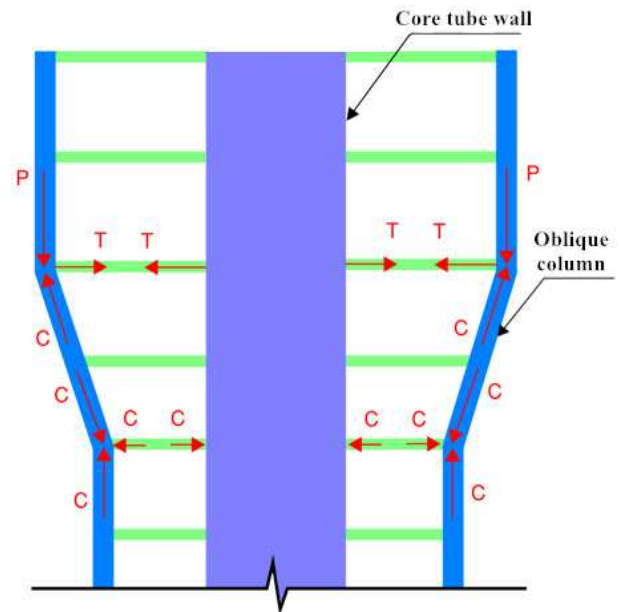


Figure 2. Horizontal force transmission under gravity load of frame-core wall structure with inclined column.

3. The Problem of Vertical Deformation of High-Rise Buildings Suspended and Continued Construction

3.1. The Main Influencing Factors of Vertical Deformation

With the continuous emergence of complex high-rise

building structures, cast-in-place concrete has attracted more and more attention due to its low strength and stiffness, and the vertical deformation caused by concrete shrinkage and creep. Correspondingly, the strength and stiffness of prefabricated and steel structures have little influence [5], which can effectively avoid such problems, but the disadvantages of their integrity and seismic resistance increase in reverse.

The construction period of high-rise buildings is usually relatively longer than that of general buildings, so that the shrinkage and creep of concrete can be better developed and stabilized [6]. Usually, for the structural calculation and analysis of vertical deformation, the structural calculation and analysis are added as a whole at one time after the structure is built, which is also called the calculation method of one-time loading [7]. The external load and boundary conditions of the building structure will change with time during the construction period [8-10]. For the structure of high-rise buildings that have been suspended for a long time and then rebuilt, due to the long construction period and many influencing factors, Therefore, it is necessary to comprehensively consider all aspects of the entire construction process, and conduct a whole-process calculation and study of its continued construction, so as to formulate a feasible construction plan and fully consider the safety of construction. Due to the long downtime of the continued construction, the construction simulation should fully consider the shrinkage and creep effects and strength changes of concrete materials. The calculation formula of the inelastic shortening caused by the creep and shrinkage of the compression member was proposed; KWAK H G et al. [11] proposed the importance of considering the time-varying effects of the creep and shrinkage of concrete when simulating the actual performance of the reinforced concrete frame structure; Cai Jian et al. [12] conducted a construction simulation of a super high-rise in Guangzhou and studied the influence of the shrinkage and creep effect of its concrete materials; Zhang Jianliang et al. studied the long-term deformation and the influence of deformation differences on the main structure of a super high-rise building with reinforcement layers..

Combined with the vertical deformation and deformation difference caused by frames and shear walls in high-rise buildings and complex structures, as well as the internal force redistribution and different damage effects caused by the vertical deformation difference, along with the loads applied during construction on the structure. The complex process of layer-by-layer formation; focuses on different loading methods of construction simulation, aiming to provide reference for similar projects.

3.2. Simplified Analysis of Vertical Deformation Calculation Method

In general, in the structural design analysis, engineers rarely consider the influence of the vertical deformation and deformation difference generated during the construction process on the internal force of the structural design. On a deeper level, in

the design of general building structures, the impact of structural fittings in the construction process, the stiffness integration of the overall structure, and the load loading method on the structural design is often considered poorly by engineers. For projects that are suspended and continued, it may be suspended for several years after completion of a certain height, and the stiffness integration and vertical deformation of this floor and below have been stabilized.

(1) One-time loading simplified calculation model

For the one-time loading calculation model, there is distortion because the influence of the stiffness integration process, the influence of the applied load sequence, and the layer-by-layer construction process factors are not fully considered. That is, in the analysis process of the complex structure of high-rise buildings, in order to simplify the calculation, after the overall structural model is completed, the overall structural stiffness is formed at one time, and the load is loaded at one time. For high-rise buildings and complex structures, the stiffness integration with the actual structure and the distortion of the load loading process are relatively large, causing cumulative effects on the redistribution of internal forces and even potential safety hazards.

The simplified calculation model of one-time loading is that the overall structural stiffness can be simplified as $K_1 + K_2 + \dots + K_n$ one-time integration, the load $Q_1 + Q_2 + \dots + Q_n$ is formed by one-time loading, and there is no other quantitative change in the middle. Its calculation model is shown in Figure 3.

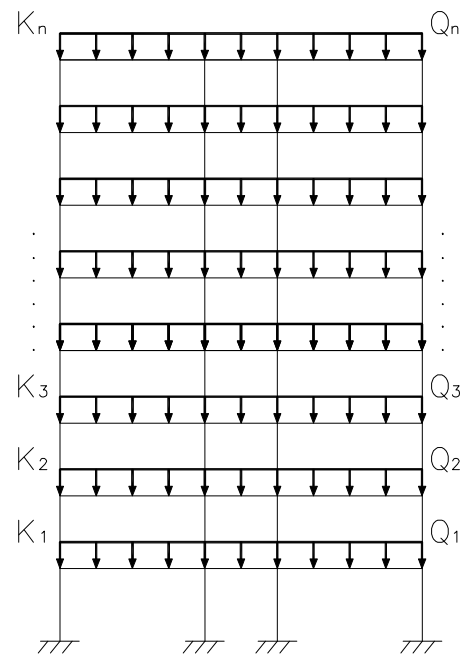


Figure 3. One-time loading calculation model.

With the continuous increase of the floor height and the influence of the vertical component of the inclined rod of the complex structure, the vertical deformation amount and the deformation difference of the top floor components will be much larger than the actual situation, and the distortion phenomenon is serious. When more extreme considerations

are taken, there may be a large settlement of the support of the top floor under a large span, resulting in a large bending moment of the beam connected to it but not being redistributed in time, resulting in an abnormal phenomenon of tension in individual columns.

(2) Layered loading simplified calculation model

Considering that the approximate calculation method of the loading model for the construction sequence of each floor is closer to the actual situation, that is, under the assumption that

the overall stiffness matrix is integrated, for a building structure with n floors, when constructing a floor, the floor elevations of 1 to $i-1$ floors below it, All have been adjusted to the design elevation through on-site construction measures. With the advancement of the construction sequence, the internal force of the first layer components is generated by the vertical load of the first layer and the upper layers after the construction is completed. The simplified calculation model is shown in Figure 4.

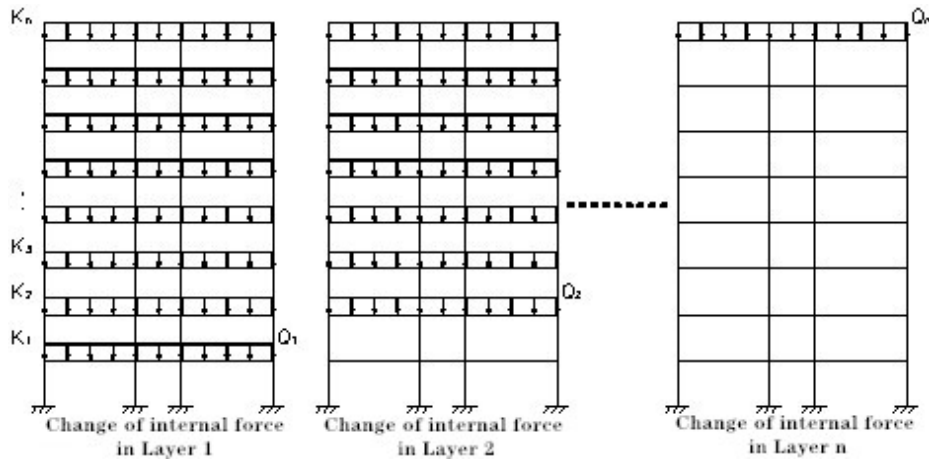


Figure 4. Layered loading calculation model.

The calculation principle expression of the hierarchical loading calculation model is:

$$[K][\Delta] = \begin{bmatrix} q_n & q_n & \dots & q_n & \dots & q_n \\ q_{n-1} & q_{n-1} & \dots & q_{n-1} & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ q_i & q_i & \dots & q_i & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ q_1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (1)$$

With the upgrade of computing software and the development of numerical simulation, this method has been implemented in some analysis software and has been well applied, such as software Satwe, MIDAS/Gen, Etabs, etc., which requires high computer memory. In conclusion, this layered loading model and stiffness integration process is more in line with engineering practice than the one-time

loading model calculation method. However, because each calculation is based on the overall structural stiffness, it is not reflected that the structural stiffness integration is a process of gradual integration with the change of the construction sequence, so there is still a certain difference with the actual situation.

(3) Stage loading simplified calculation model

The staged loading model is assumed to be based on the one-time loading model and the layered loading calculation model, combined with actual requirements. The calculation diagram is shown in Figure 5, that is, an n -storey building under vertical load is regarded as a whole composed of n sub-structures in the calculation and analysis of structural deformation. The number of layers of the substructure varies continuously from 1 to n layers, and the method that only bears the corresponding top load is called the stage loading calculation model analysis method.

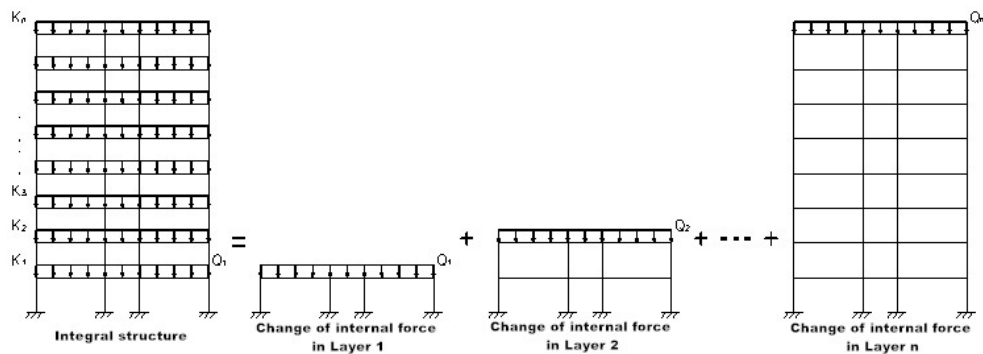


Figure 5. Stage loading calculation model.

When the construction of the structural layer is completed, the relationship between the vertical displacement and the load can be expressed by the following formula:

$$\{F_i(t)\} = \{K_i(t)\} \times \{\Delta_i\} \quad (2)$$

As the construction process enters the end stage, the internal forces and displacements of the structure will also tend to stabilize. At the same time, for the stiffness integration, the internal force and displacement are also redistributed, which is closer to the engineering practice.

4. Mechanical Performance Problems of Beams and Columns Under Full Span Walls of High-Rise Building Transfer Floors

Beginning in the 1970s, due to the requirements of building functions, my country began to try to adopt the large-space shear wall structure at the bottom, that is, the transfer layer structure. This structural arrangement is likely to cause structural problems such as discontinuity of vertical members, lateral stiffness of floors and sudden changes in shear bearing capacity of floors, which is unfavorable for the calculation of the overall index of the structure, especially for the dynamic response and failure process of the structure under the action of strong earthquakes. In order to avoid the formation of weak links in the transfer layer during an earthquake, which is unfavorable to the overall seismic resistance of the structure, it is often required to reduce the vertical members that need structural transformation, the position of the transfer layer should be low rather than high, strengthen the lower part, weaken the upper part, and control the stiffness ratio, etc. measure.

In recent years, the engineering application and technology of high-rise building transfer layer structure have developed rapidly. At present, there are many types of conversion beams in high-rise building structures, which are divided into beam-type conversion and plate-type conversion according to the conversion form; single-span conversion beam, double-span conversion beam and even multi-span conversion beam according to the span of plane connection; according to the upper part of the conversion beam Whether the wall is arranged with full-span shear wall conversion beams and non-full-span shear wall conversion beams along the full length of the conversion beams; according to whether the upper wall of the conversion beams has holes, it can be divided into non-opening shear wall conversion beams and non-full-span shear wall conversion beams. Opening Shear Wall Conversion Beams. The beam-type conversion has the advantages of direct and fast force transmission path, safety and reliability, and simple structure. It is often widely used, and accounts for up to 80% of many conversion forms.

In the beam type conversion, the different layout forms of the upper shear wall of the conversion beam can be divided

into full-span type, two-end type, 3/4-span type, 1/2-span type, and 1/4-span type, as shown in Figure 6. Show. The research focuses on the mechanical performance of beams and columns under the full span wall of the upper shear wall of the transfer beam when the first floor of the high-rise building is converted.

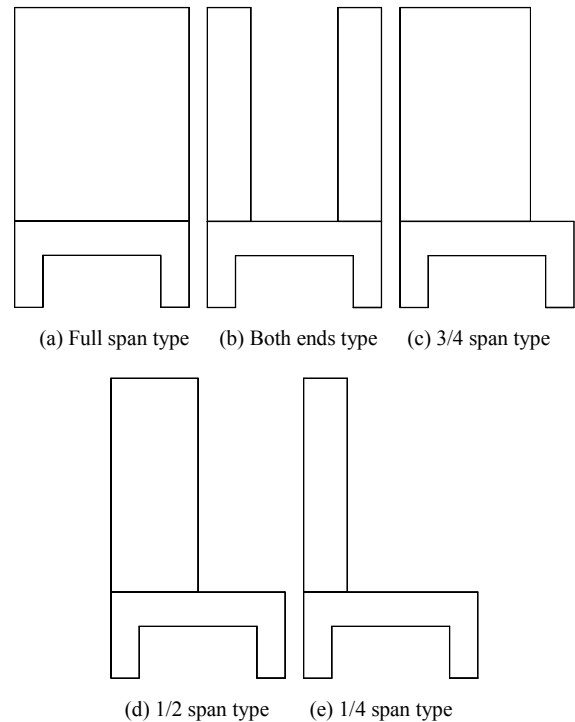


Figure 6. Different layouts of the shear wall on the upper part of the transfer beam.

4.1. Calculation of the Stiffness of Beam-Wall Section Considering the Upper Wall of the Transfer Floor

4.1.1. Theoretical Calculation of Beam-Wall Section Stiffness

Solve the definition of static distance. For any finite plane figure shown in Figure 7, take its unit dA , whole graph pair y , x the static distances of the axes are:

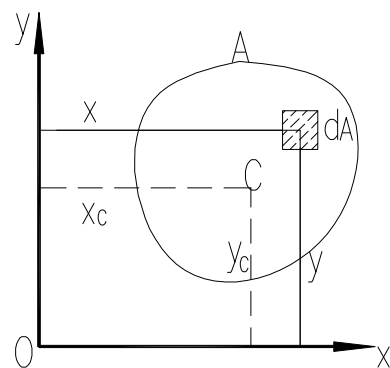


Figure 7. Finite plane figure.

$$S_y = \int_A x dA \quad (3)$$

$$S_x = \int_A y dA \quad (4)$$

The relationship between the centroid and the static distance: let the coordinates of the centroid C of the plane figure be x_c , y_c ,

$$x_c = \frac{S_y}{A} \quad (5)$$

$$y_c = \frac{S_x}{A} \quad (6)$$

Correspondingly, let the cross-section figure be given by n the areas are $A_1, A_2, A_3, \dots, A_n$ is composed of simple graphics, and the centroid coordinates of each family of graphics are respectively,, the static distances of the figure to the y axis and the x axis are:

$$x_n = \frac{\sum_{i=1}^n A_i x_{ci}}{\sum_{i=1}^n A_i} \quad (7)$$

$$y_n = \frac{\sum_{i=1}^n A_i y_{ci}}{\sum_{i=1}^n A_i} \quad (8)$$

Considering that the upper wall of the conversion layer is fully covered (as shown in Figure 8), the cross-sectional area is $bb \times hb + bq \times hq$, The moment of inertia I_x of the x axis is:

$$I_x = \frac{1}{3} [b_b y_2^3 + b_q y_1^3 + (b_b - b_q)(h_b - y_2)^3] \quad (9)$$

For the quasi-permanent load combination considered when the beam-type transfer of the transfer floor is fully covered with the upper wall, its stiffness under long-term load B is

$$B = \frac{B_s}{\theta} = \frac{E_s A_s h_o^2}{\theta (1.15\phi + 0.2 + \frac{6\alpha_E \rho}{1 + 3.5\gamma_f})} \propto E_s I_x \quad (10)$$

Combined with equations (9~10), the change of stiffness caused by the joint action of the transfer beam B and the upper wall can be calculated.

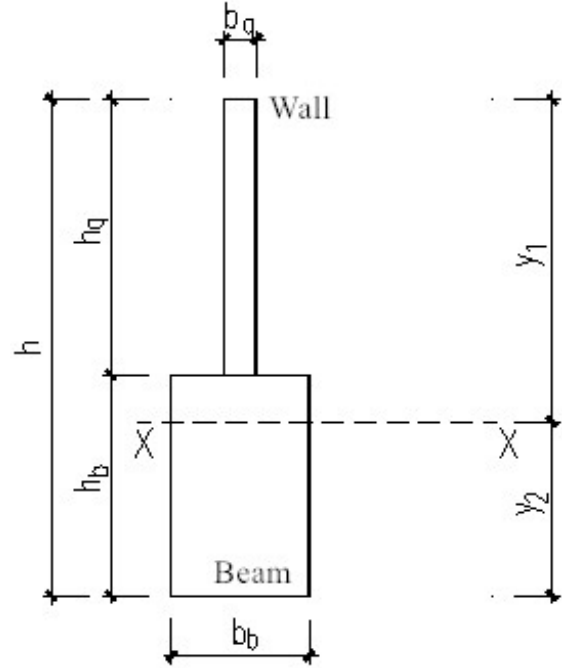


Figure 8. Schematic diagram of transfer beam and shear wall.

4.1.2. Engineering Calculation of Transfer Beam and Upper Wall

For the conversion beam size is 1500×2400mm, the thickness of the upper shear wall is 350mm, the standard layer height is 3.0m, and there are 44 floors above ground. According to formulas (9~10), the moment of inertia is calculated and the ratio of the stiffness of the transfer beam acting alone is listed. The results of the five layers on the transfer beam are listed in Table 1.

Table 1. Variation of stiffness of five layers on the transfer layer.

Operating mode	moment of inertia I_x / m^4	Ratio of stiffness acting alone to the transfer beam
Conversion beam acting alone	1.73	1.00
Works with the 1st layer above	8.44	4.89
Works with the 2st layer above	31.42	18.19
Works with the 3st layer above	77.57	44.89
Works with the 4st layer above	152.62	88.32
Works with the 5st layer above	261.81	151.51

For the transfer story structure of high-rise buildings, the height of the reinforcement part at the bottom of the shear wall should be taken to two floors above the transfer story. For reasons such as small size, when considering the joint action of the transfer beam and the upper wall (that is, the deformation coordination), its stiffness B increases by 4.89 times under the action of the arch effect. If in the actual project, there are more things to consider about the influence and

deviation from the actual value, and it needs to be supported by actual test and engineering practice data.

4.1.3. Influence of Beam Stiffness Amplification on the Lateral Stiffness of the Overall Structure

At present, the calculation methods of the overall stiffness of the structure are not the same. According to the method proposed in the literature [13], the lateral stiffness of the

high-rise building structure is calculated by the ratio between the floor shear force and the inter-story displacement under the action of earthquake. The calculation formula is::

$$K_i = \frac{V_i}{\Delta_i} \quad (11)$$

The Guangdong provincial standard "Technical Regulations for Concrete Structures of High-rise Buildings" (DBJ15-92-2013) [14] stipulates that the lateral stiffness of the floors of high-rise building structures is calculated by the ratio of the floor shear force under the action of the earthquake to the inter-story displacement angle. The formula is:

$$K_i = \frac{V_i}{\theta_i} = \frac{V_i h_i}{\Delta_i} \quad (12)$$

Equations (11) and (12) both need to obtain the lateral stiffness of the structure under the action of external force. On this basis, the literature [15] systematically studied the calculation principle of lateral stiffness, and combined with the "shape constant" to perfectly explain the essential properties of lateral stiffness. That is, it is only related to the geometric, physical and mechanical properties of the structural member and the constraints at both ends, but has nothing to do with the external load. For the transfer layer (or standard layer) under the action of horizontal load, assuming the beam-column joint rotation angle is equal (D value method), the lateral D stiffness of the column is:

$$D = \alpha \frac{12i_c}{h^2} \quad (13)$$

where: α is the correction coefficient of the lateral stiffness of the column; i_c is the linear stiffness of the column; h is the storey height.

According to literature and the D calculation principle of the α value method, it increases with the D increase of the beam-to-column stiffness ratio, which increases the overall stiffness of the floor. Correspondingly, from the perspective of conceptual design, for the transfer floor structure of high-rise buildings, when considering the joint action of wall beams, the stiffness of transfer beams increases, thereby increasing the overall lateral stiffness of the floors.

4.2. Modeling Methods of Current Major Software

At present, the main software for the simulation calculation of the conversion layer are Satwe, Midas-gen, and Etabs. Analysis software mainly includes Abaqus and Ansys. The frame method is used in Satwe, which is the beam-rod model analysis method. When directly using the three-dimensional space analysis program to calculate and analyze, the beams and columns are considered as general rod (line) elements, and the upper wall is only considered according to the vertical load, not considered Co-working of transfer beams with upper walls. Usually, the stiffness of the

transfer beam is amplified for calculation, but it is still necessary to study the specific amplification to match the actual situation. In general, the stiffness amplification factor is set to 100. At this time, the force and reinforcement of the transfer beam will be Increase by about 5% to 30%. In most cases, the span height of the conversion beam is relatively small, and if the rod element is considered compared with the actual situation, it is easy to produce distortion, and the relevant test data is relatively scarce, so it is difficult to find the true solution. Later, in the calculation software such as Yingjianke, it began to realize the addition of deformation coordination functions, which filled the shortcomings of rapid modeling and calculation.

Midas-gen and Etabs are finite element analysis methods, which consider the deformation coordination of column, beam, and wall element nodes or junctions during mesh division, which can play the effect of converting beams and upper shear walls. Among them, the deformation of the same node in Midas-gen, the finer the element division, the higher the simulation reality, and the higher the computer requirements, which need to be considered comprehensively. Etabs shows that the deformation at the junction of the beam and the wall is coordinated, and the calculation methods of the two are basically the same, and the difference is very small. Nodes are set at the end connection locations in order to obtain more accurate stress results. In Etabs and Midas-gen modeling, since the shape constant of the quadrilateral is higher than that of the triangle, it is advisable to use quadrilateral elements and less triangular elements for fine meshing of surface elements. At the same time, in order to improve the efficiency of calculation and analysis, for more For a regular shear wall, a larger grid size can be used. For example, a larger size shear wall can use a grid of 1.5m to 2m, and a small grid size of about 0.5m to 1m should be used for key parts.

5. Conclusion

"Unfinished buildings" often refer to construction projects that have gone through the land use and planning procedures, but have been suspended for more than one year after the project starts due to the inability of the builder to continue investing in construction, or because of debt disputes or unqualified project quality. Due to the existence of "unfinished buildings", it not only affects the economic life of the owners and causes social unrest, but also leads to the waste of urban resources and even damages the image of the city. Therefore, the renovation and continuation of the "unfinished buildings" is very important for urban development. Through the research, the main conclusions are as follows:

- (1) The structural design problems caused by the inclined columns of high-rise buildings are discussed, and it is pointed out that measures should be taken to ensure the reliability of the horizontal force transmission in beam-column joints, floors, wall-beam joints, and core tubes;

- (2) The vertical deformation problem of high-rise buildings suspended and continued construction is emphasized, and the simplified vertical deformation calculation models of one-time loading, layered loading and staged loading are summarized;
- (3) The mechanical performance of beams and columns under full-span walls of high-rise building transfer floors is introduced, and the simple calculation method of the moment of inertia of the transfer beam-wall section is given from the perspective of the interaction of beams and walls, and the commonly used software to realize beams is given. The correct way for walls is to work together.

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