Application of Key Technologies for Multi-Terminal Change of Frame-Double Core Tube Super High-Rise Building

Xu Chen*, Shimin Li, Ziqiang Yu, Jialin Xu, Lijian Wang, Yusheng Pei, Wei Zhang, Zhanxu Jing, Liuliang Min, Yaru Wang and Hui Zheng

The Northwest company of China Construction Third Engineering Bureau Group Co., Ltd.

*Corresponding author: chen_xu2020@foxmail.com

Abstract. Frame-double-core tube structure is a structural form suitable for super high-rise buildings with long or irregular standard floor plan. In this paper, the structural arrangement and structural member size of the double core tube are determined through the analysis of structural indexes such as stiffness calculation and torsion effect under rare earthquake. At the same time, through the research of all-steel climbing frame and aluminum formwork under the condition of super high-rise height and structural change, the application of all-steel climbing frame and multi-end aluminum formwork with super high-rise height change are solved, which speeds up the construction progress, greatly reduces the safety and quality risks in the construction process of super high-rise buildings, and at the same time, reduces the material and labor costs to meet the development requirements of green construction.

Keywords: Super high-rise frame-double core tube, Ultra-high-rise multi-terminal changes, All-steel climbing frame, Aluminum alloy template.

1. Introduction
Frame-core tube structure has been widely used in earthquake areas in China, and concrete core tube is a main structural element against lateral force. There are quite a few tall buildings with rectangular, oval or other special-shaped towers. In the architectural layout of long or special-shaped plane, some vertical traffic cores (stairwells and elevators) are offset to one side, while others are quite flat. If the common frame-core tube structure design is adopted, the stiffness of the structure in two main axis directions is greatly different due to the large difference in length or number of shear walls in two main axis directions, resulting in large difference in dynamic characteristics of the structure in two main axis directions, or concentrated stiffness in the middle of the structure plane and insufficient overall torsional capacity, which makes it difficult to control the torsional effect of the structure. Engineering practice shows that the increase of the aspect ratio of the building plane directly leads to the increase of the torsional effect of the structure, and many actual earthquake disasters reflect that the torsional effect is an important reason for the structural damage. In this project, the double-core tube is set in the plane of the long building, which solves the problem of large difference in stiffness between the two directions of the structure and effectively reduces the torsional effect of the main structure.
At present, all-steel climbing frame and aluminum formwork are widely used in high-rise residential projects, which has a certain application foundation. Ultra-high-rise all-steel climbing frame and aluminum alloy formwork are seldom used, mainly because the multi-terminal changes of beams, columns, core wall, floor thickness and floor height make the investment of all-steel climbing frame and aluminum formwork larger than that of ordinary high-rise residential buildings. By studying the use of aluminum formwork with varied height in climbing overhead, the application problems of super-high-rise climbing frame and aluminum formwork are solved. Compared with traditional cantilever frame and wooden formwork used in traditional super-high-rise outer frame and formwork support system, it will have the following beneficial effects: significantly improve the overall construction efficiency, safety effect, quality effect, economic benefit and environmental benefit, and provide strong technical support for the smooth application of super-high-rise climbing frame and aluminum formwork.

2. Engineering survey

Bao Li·Tianchen Bay Project is located in Matan Community, Qilihe District, Lanzhou City, on the northeast side of Yintan Bridge, near Nanbinhe West Road. 6# public building tower has 47 floors above ground and 2 floors underground, with a total construction area of 80908.83 m², including 1406.56 m² for commercial facilities (floors 1-2), 40020.90 m² for apartment-style hotels (floors 3-26), 35361.32 m² for office buildings (floors 28-47) and refuge buildings. The building has a length of 56.20m and a width of 33.30/29.20m, the standard floor height of the serviced apartment is 3.20m, and the standard office floor height is 4.20m. The structural height (the height difference between indoor and outdoor is 0.10m to the large roof of the structure) is 177.80m, and the highest point of the building is 197.70m.

Figure 1 The renderings of Bao Li·Tianchen bay project

3. Selection of frame-double core tube structure system

3.1. Select background

Frame-core tube structure has been widely used in earthquake areas in China, and concrete core tube is a main structural element against lateral force. Quite a few super high-rise buildings have rectangular, oval or other special-shaped towers. In the architectural layout of long or special-shaped plane, some vertical traffic cores (stairwells and elevators) are offset to one side, while others are quite flat. If ordinary frame-core tube structure design is adopted, the stiffness of the structure in the two main axis directions is greatly different due to the large difference in length or number of shear walls in the two main axis directions, resulting in large difference in dynamic characteristics of the structure in the two
main axis directions, or concentrated stiffness in the middle of the structure plane and insufficient overall torsional capacity, which makes the torsional effect of the structure difficult to control [1]. The construction safety level of this project is Grade II, the seismic fortification category of the building is Standard Fortification (C) [2], the seismic fortification level is Grade I, and the foundation design level is Grade A. The length and width of the building are 56.20m and 33.30m/29.20m, and the aspect ratio of the building plane is large. The increase of the aspect ratio of the building plane directly leads to the increase of the torsional effect of the structure, and many actual earthquake disasters reflect that the torsional effect is an important cause of structural damage.

3.2. Selection of structural system
This project plans to adopt reinforced concrete frame-double-core tube structure system, and use vertical traffic boxes such as elevator shaft and stairwell to arrange shear walls, which are the main lateral resistance members of the structure, and work together with the outer frame to obtain good seismic and wind resistance performance.

![Figure 2](image1.png)

**Figure. 2** Axonometric drawing of single core tube

![Figure 3](image2.png)

**Figure. 3** Axonometric drawing of double core tube

![Figure 4](image3.png)

**Figure. 4** Schematic diagram of structural system composition
4. Seismic analysis of frame-double core tube

4.1. Dynamic elastoplastic analysis of rare earthquakes

4.1.1. Analytical method. At present, the commonly used elastic-plastic analysis methods can be divided into static elastic-plastic and dynamic elastic-plastic theoretically, and implicit integral and explicit integral numerically. The elastic-plastic analysis of this project will adopt the dynamic elastic-plastic analysis method based on explicit integration, which directly simulates the nonlinear response of the structure under earthquake force without any theoretical simplification, and has the following advantages:

1. Complete dynamic time-history characteristics: direct input of seismic waves into the structure for elastic-plastic time-history analysis can better reflect the internal force distribution of members under different phase differences, especially the repeated tension and compression stress state of the floor;
2. Geometric nonlinearity: the dynamic equilibrium equation of the structure is based on the geometric state of the structure after deformation, and the P-∆ effect and nonlinear buckling effect are accurately considered;
3. Material nonlinearity: directly simulated at the level of material stress-strain constitutive relation;
4. By using explicit integration, the failure of the structure can be accurately simulated until it collapses.

4.1.2. Analysis software. The new generation of "GPU+CPU" high-performance structural dynamic elastoplastic calculation software PKPM-SAUSAGE (PKPM Seismic Analysis Usage) developed by Jianyan Shuli Construction Technology Co.; Ltd. is adopted as the calculation software. It can accurately simulate the nonlinear performance of structural members such as beams, columns, braces, shear walls (concrete shear walls and shear walls with steel plates) and floors by using a set of new calculation methods, so that the large earthquake analysis of actual structures has the characteristics of high calculation efficiency, fine model and good convergence. It is characterized in that:

1. Without theoretical simplification, the dynamic differential equation derived from the principle of structural virtual work is directly solved, and the solution result is more accurate and reliable;
2. A fine model of material stress-strain hierarchy, one-dimensional member adopts nonlinear fiber beam element, which is integrated along section and length direction respectively. Two-dimensional shell-and-plate element adopts nonlinear layered element, which is integrated in plane and thickness direction respectively. In particular, the floor is also simulated by two-dimensional shell element;
3. High-performance solver: Pardiso solver is used for vertical construction simulation analysis, and explicit solver is used for dynamic elastoplastic analysis of large earthquakes;
4. The damping calculation in dynamic elastoplastic analysis creatively puts forward the "pseudo-modal damping calculation method", which is more reasonable than the usual Rayleigh damping form.

4.1.3. Nonlinear seismic response analysis model. In the nonlinear seismic response analysis model of this project, all structural members that contribute to structural stiffness are simulated according to actual conditions. The nonlinear seismic response analysis model can be divided into three levels: (1) material model; (2) Component model; (3) Overall model. The component model is obtained by adding the constitutive characteristics of the material and the geometric parameters of the cross section of the component, and the whole model is formed by the geometric connection of the nodes.

1. Material model
   1) Steel products

The dynamic hardening model of steel is shown in the following figure, and the nonlinear material model of steel adopts bilinear follow-up hardening model, which has no stiffness degradation and
considers Bauschinger effect during the cycle. The yield ratio of steel is set at 1.2, and the ultimate plastic strain corresponding to the ultimate stress is 0.025.

Figure 5 Dynamic hardening model of steel

2) Concrete material
The one-dimensional concrete material model adopts the uniaxial constitutive model specified in the code, which can reflect the hysteretic, stiffness degradation and strength degradation of concrete. The standard values of axial compressive strength and axial tensile strength are adopted according to Table 4.1.4. Of Code for Design of Concrete Structures. The stress-strain curve equation of concrete under uniaxial tension is calculated according to the formulas 1-1-1-4.

\[ \sigma = (1 - d_i)E_i \varepsilon \]  

\[ d_i = \begin{cases} 1 - \rho_i [1.2 - 0.2x^3] & x \leq 1 \\ 1 - \frac{\rho_i}{\sigma_i(x-1)^3 + x} & x > 1 \end{cases} \]  

\[ x = \frac{\varepsilon}{\varepsilon_{t,r}} \]  

\[ \rho_i = \frac{f_{t,r}}{E_i \varepsilon_{t,r}} \]  

In which \( \alpha_i \) and \( \varepsilon_{t,r} \) are the parameters.
The stress-strain curve equation of concrete under uniaxial compression is calculated according to the formulas 1-5-1-9.

\[ \sigma = (1 - d_i)E_i \varepsilon \]
In which $\alpha_r$ and $\varepsilon_{r,c}$ are the parameters.

When concrete material enters plastic state, its stiffness decreases. As shown in the stress-strain and damage diagram, the stiffness damage is expressed by tensile damage parameter $d_t$ and compressive damage parameter $d_c$ respectively, and $d_t$ and $d_c$ are determined by the degree of plastic state of concrete material.

Two-dimensional concrete constitutive model adopts elastic-plastic damage model, which can consider the strength difference between tension and compression, stiffness and strength degradation of concrete materials, and stiffness recovery caused by cyclic crack closure in tension and compression.

When the load changes from tension to compression, the crack of concrete material closes and the compressive stiffness returns to the original compressive stiffness; When the load changes from compression to tension, the tensile stiffness of concrete does not recover, as shown in the following figure.

$$d_c = \begin{cases} \frac{1 - \frac{\rho_c}{n-1+x^n}}{\alpha_c(x-1) + x} & x \leq 1 \\ \frac{1 - \frac{\rho_c}{n-1+x^n}}{\alpha_c(x-1) + x} & x > 1 \end{cases} \quad (1-6)$$

$$\rho_c = \frac{f_{c,c}}{E_c \varepsilon_{s,c}} \quad (1-7)$$

$$n = \frac{E_c \varepsilon_{s,c}}{E_c \varepsilon_{s,c} - f_{s,c}} \quad (1-8)$$

$$x = \frac{\varepsilon}{\varepsilon_{s,c}} \quad (1-9)$$

Figure. 6 Tensile stress-strain curve and damage diagram of concrete
Figure 7 Stress-strain curve and damage diagram of concrete under compression

Figure 8 Schematic diagrams for restoring tensile and compressive stiffness of concrete

(2) Elastic-plastic model of bar

Fiber bundle model is used as the nonlinear model of members, as shown in the following figure, which is mainly used to simulate beams, columns, braces and trusses.

Figure 9 One-dimensional fiber bundle unit

The fiber bundle can be made of steel or concrete. According to the known $Q$, $\kappa_1$ and $\varepsilon_0$, the strain of the fiber bundle $i$ can be obtained as $\varepsilon_i = \kappa_1 x_i + \varepsilon_0 + \kappa_2 x_i V_i$, and its sectional bending moment $M$ and axial force $N$ are:
In which $f(\varepsilon_i)$ is the fiber stress obtained from the material constitutive relation described above. It should be pointed out that after entering the plastic state, the axial force and axial expansion of the beam element are quite obvious and cannot be ignored. Therefore, the coupling effect of bending and axial force should be considered for beams and columns.

Because the fiber plastic zone model is adopted instead of the concentrated plastic hinge model, the stiffness of the member is obtained by dynamic integration in the cross section and in the length direction, and the hysteretic performance of bi-directional bending and tension can be accurately expressed by the hysteretic property of the material. As shown in the following figure, the fiber of the same cross section gradually enters plasticity, and also gradually enters plasticity in the length direction.

![Figure 10: Schematic diagram of plastic zone development of one-dimensional element](image)

In addition to the fiber plastic zone model, the one-dimensional elastic-plastic element of bar has the following characteristics:

1. Shear deformation of Timoshenko beam;
2. For C0 unit, the rotation angle and displacement are interpolated separately.
3. Nonlinear model of shear wall and floor

Elastic-plastic layered shell element is adopted for shear wall and floor slab, which has the following characteristics:

The constitutive relation of elastic-plastic damage model can be adopted;

Rebar-layer can be superimposed to consider the effect of multi-layer distributed reinforcement;

It is suitable for simulating the nonlinear state of shear walls and floors under the action of large earthquakes.

4. Overall analysis model

In order to reduce the calculation workload in the finite element analysis of building structures, the assumption of rigid floor is usually adopted for the floor. The essence of the assumption is to constrain the relative distance of X and Y of each node in the same floor to be constant by the method of node coupling. This assumption is acceptable in the stage of small deformation and elasticity. However, in the elastic-plastic stage considering large deformation, especially for super high-rise buildings, the vertex displacement is more than 1m, and the upper floor slab of the structure has obvious dip angle. At this time, if each node in the same floor still assumes the relative horizontal distance of X and Y at the beginning of analysis, it will make the node deviate from its position, which will lead to analysis error.

In addition, in the nonlinear process, the floor will crack and its in-plane stiffness will decrease, which will also have a certain impact on the stiffness distribution and shear transfer of the lateral force
resisting members of the structure. Therefore, the assumption of rigid floor will not be adopted in the nonlinear analysis of this project, and all floors will be divided into shell elements for analysis.

(6) Damping model

In the process of structural dynamic time-history analysis, the damping value has great influence on the amplitude of structural dynamic response. In elastic analysis, vibration damping ξ is usually used to express the damping ratio, while in elastic-plastic analysis, vibration damping cannot be directly substituted because the equation is solved by direct integration method, and the structural stiffness and vibration mode are in height change. The common practice is to use Rayleigh damping to simulate vibration mode damping. Rayleigh damping is divided into two parts: mass damping α and stiffness damping β, and the conversion relationship between Rayleigh damping and vibration mode damping is as follows:

\[ C = \alpha[M] + \beta[K] \]

\[ \xi = \frac{\alpha}{2\omega_1} + \frac{\beta\omega_1}{2} = \frac{\alpha}{2\omega_2} + \frac{\beta\omega_2}{2} \]

In the above formula, [C] is the structural damping matrix, [M] and [K] are the structural mass matrix and stiffness matrix respectively, and \( \omega_1 \) and \( \omega_2 \) are the first and second periods of the structure respectively.

It can be seen that Rayleigh damping can only ensure that the damping ratio of the first and second periods of the structure is equal to the vibration mode damping, and the damping ratio of each period after that is higher than the vibration mode damping, and the shorter the period, the greater the damping. Therefore, even in elastic time history analysis, using constant Rayleigh damping will lead to smaller dynamic response, especially in the high frequency part, which makes the results unsafe.

![Figure 11](image-url)

**Figure 11** Comparison of periodic damping ratio of structures corresponding to array damping and constant Rayleigh damping

In SAUSAGE, considering the insufficient consideration of α damping for structural damping, another damping system-pseudo-modal damping system is provided, which is more reasonable than the usual Rayleigh damping form. The brief introduction is as follows:

\[ [C] = [\Phi^T]^{-1}[\tilde{C}][\Phi]^{-1} = [M]^{-1}[\Phi][\tilde{M}]^{-1}[\tilde{C}][\tilde{M}]^{-1}[\Phi][M] \]
\[
\begin{bmatrix}
\frac{2\zeta_\omega \Omega}{M_i} & 0 & \ldots & 0 \\
0 & \frac{2\zeta_\omega \Omega}{M_1} & \ldots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
0 & 0 & \ldots & \frac{2\zeta_\omega \Omega}{M_n}
\end{bmatrix}
\]

Therefore, the complete time-domain damping matrix can be simplified as:

\[
[C] = [M][\Phi][\bar{\xi}][\Phi]^T[M]
\]

It can be used in explicit dynamic time history analysis.

In which \([\bar{\xi}]\) is the inverse matrix of generalized mass matrix, \([\Phi]\) is vibration mode matrix, \([C]\) is time domain damping matrix and \([M]\) is generalized damping matrix.

4.2. Evaluation method of seismic performance of structures

4.2.1. Overall deformation of structure. (1) The whole elastoplastic time history analysis process can be completed without divergence; 
(2) The final state of the structure is still erect; 
(3) The maximum inter-story displacement angle of the main structure is less than the code limit, and the frame-core tube structure is 1/100.

4.2.2. Component performance objectives. This project is a super B-class high-rise building. According to the General Rules for Seismic Behavior Design of Building Engineering, the performance objectives of this project under rare earthquakes are: "Allow moderate damage to key components, allow serious damage to some ordinary vertical components, and yield to energy-consuming components with obvious cracks". This performance target corresponds to the evaluation criteria of components in sausage elastic-plastic analysis as follows:

(1) Shear wall member: It is allowed to crack the shear wall, and some shear walls are damaged by compression (i.e., the compression elastic modulus is degraded), but the area where the compression plastic damage of the main bearing wall limb reaches 0.9 should not exceed 1/2 of the section height to ensure that it still has vertical bearing capacity. Plastic strain (i.e., partial yield) of steel bars and steel ribs in the edge members of shear walls is allowed, but the maximum plastic strain should be less than 0.025 (i.e., plastic strain can be recovered);
(2) Concrete beams and columns: tensile cracking and compression damage of beam concrete are allowed, but the degradation value of compressive elastic modulus of concrete should not exceed 80%, so as to avoid complete crushing of beam ends, and concrete members on the same floor cannot form a mechanism due to compression damage. Plastic strain of beam reinforcement should be less than 0.025;

4.2.3. Analytical procedure. The basic steps for dynamic elastoplastic analysis of this structure are as follows:

(1) Considering the structural construction process, the structural gravity loading analysis is carried out to form the initial internal force and deformation state of the structure; 
(2) Calculate the natural vibration characteristics of the structure and other basic information, and compare it with the original structural design model to ensure that the elastic-plastic analysis structural model is consistent with the original model; 
(3) Input earthquake records to analyze the dynamic response of the structure under large earthquakes.
4.3. Calculation results of elastic-plastic analysis model

4.3.1. Basic information of model

**Table. 1** Sausage and yingjianke calculate the total quality of structure

| Computing software | Total mass produced by dead load(t) | Total mass produced by live load(t) | Total mass of structure(t) |
|--------------------|-----------------------------------|-----------------------------------|---------------------------|
| Sausage            | 125792.6                          | 8992.3                            | 134784.9                  |
| Yingjianke         | 123045.4                          | 9189.0                            | 132234.4                  |

**Table. 2** Sausage and Yingjianke calculate the main cycle

| Computing software | The first mode shape | Second mode shape | The third mode shape |
|--------------------|----------------------|-------------------|----------------------|
| Sausage            | 3.68(Y)              | 3.22(X)           | 2.50(T)              |
| Yingjianke         | 3.63(Y)              | 3.15(X)           | 2.70(T)              |

It can be seen from the above results that the initial analysis and calculation results (structural quality and modal) of SAUSAGE software are similar to those of Yingjianke software, which ensures that the plastic analysis structure model is consistent with the original model.

![Figure. 12 Plane graph](image)

4.3.2. Damage of shear wall and frame. The following figure shows the relationship between compressive stress and strain of shear wall concrete and the relationship between compressive damage factor and strain. By using the concept of compressive damage factor, the damage and failure of shear wall under large earthquake is given. In the figure, the abscissa is the compressive strain of concrete, and the ordinate is the ratio of compressive stress to peak value of concrete, that is, the compressive stress-strain curve normalized according to the peak pressure of concrete; For the relationship between compressive damage factor and compressive strain of concrete, the ordinate is the compressive damage factor of concrete. It can be seen from the figure that when the concrete reaches the peak value of compressive stress, the compressive damage factor is basically between 0.2 and 0.3. Therefore, when the compressive damage factor of concrete is below 0.3, the concrete does not reach the peak value of bearing capacity, and it can basically be judged that the shear wall concrete has not been crushed.
Figure. 13 Three-dimensional model

Figure. 14 Curve of stress-strain relationship of concrete

4.4. Suggestion
Through the above analysis, the structural layout of frame-double core tube and the size of structural members are determined. However, the height of this monomer is high, and the overall bending moment deformation is large under the earthquake action. Therefore, thin floor heating is adopted in
the hotel floor, and light wallboard is adopted in the internal partition wall of the office, so as to minimize the dead weight of the structure and reduce the earthquake response; Check the elastic-plastic deformation of the structure under the action of rare earthquake, meet the requirements of the code for failure under rare earthquake, understand the damage situation of the structure and the formation law of plastic hinge, find out the weak parts, and optimize the structure layout pertinently.

(1) In addition to the above conceptual design and analysis and calculation of specific components, in view of the fact that the height exceeds the B-level height limit of reinforced concrete frame-core tube, the ductility standard should be appropriately improved structurally, and the proposed measures are as follows:

1) Section steel is added to the double-core wall limb to reduce the reinforcement of the constraint edge member and resist the axial tensile stress under the action of bidirectional horizontal earthquake during moderate earthquake, and the set section steel is anchored in the foundation;
2) In view of the shear-compression ratio exceeding the limit, the shear resistance of the coupling beam is improved by setting diagonal diagonal diagonal reinforcement or cross reinforcement;
3) In view of the discontinuity of the first floor, take the following strengthening measures:

The stress of the floor under rare earthquake is analyzed, and the reinforcement of the floor is adjusted and strengthened according to the stress situation, so as to ensure that the floor can effectively transmit the seismic force under the earthquake, the thickness of the floor is not less than 120mm, and double-layer bidirectional reinforcement is carried out according to the reinforcement ratio of 0.25%.

(2) To solve the problem of large displacement, the following structural measures are taken:

Section steel shall be set in columns with 13th floor and below, and the steel content shall not be less than 4%; 14~16 layers of columns are equipped with structural steel, and the steel content is not less than 2%; Core columns are set in frame columns with 17th floor and above, and the reinforcement ratio of core columns is not less than 0.5%, so as to improve the torsional bearing capacity and ductility of the whole structure.

5. Technology of climbing overhead and connecting high in super high-rise building with height change

5.1. Advantages of climbing frame construction technology

(1) All buildings above 45m are applicable. The higher the floor is, the more obvious the economy is, and the cost of each building can be saved by 30%~60%.

(2) It can be applied to building main bodies with various structures, and can actively prevent unsafe conditions. Multiple fall prevention devices are adopted to prevent failures such as failure of reset devices, which can ensure that the protective frame body is always in a safe state and effectively realize fall prevention.

(3) Achieve the function of low build and high use. It is assembled at the bottom of the main building at one time, attached to the building, and continuously promoted with the increase of floor height. The whole operation process does not occupy other hoisting machinery, which greatly improves the construction efficiency. Moreover, the site environment is more humanized, the management and maintenance are easier, and the civilized operation effect is more prominent.

(4) Break through the messy appearance of traditional scaffolding, make the overall image of the construction project more concise and regular, and show the safe and civilized image of the construction project more effectively and intuitively [3].

5.2. Problem analysis

Considering the application of building functions and safety design, the height of floors 3~26 and floors 27~47 of this project is 3.2m, and the height of the 10-12 axis crossing H-J axis is 4.2m. When the location is on the 13th floor, the whole structure shrinks, and the height and structure change, so the climbing frame needs to be connected in the air.
5.3. Construction method

In this project, the climbing frame is assembled from the 8th floor, and embedded at the bottom of the 9th floor. The height of the climbing frame from 8th to 27th floor is 15m. On the 13th floor, due to the structural changes, the configuration of the climbing frame also changes, so it is necessary to assemble the frame body of the retracted part layer by layer from the 13th floor. Since the 27th floor, the floor height has changed from 3.2m to 4.2m. In order to ensure the safe construction of the working floor, the corresponding climbing frame body needs to be raised by 4.5m to 19.5m the heightening part is assembled and raised on the 28th floor. The order of assembly and heightening is as follows: install the vertical pole → install the vertical walkway board → install the upper walkway board → install the guide rail extension joint.

Figure 15 Schematic diagram of frame heightening
After installing the 4.5-meter frame body, the cantilever height exceeds the allowable height of the code, which has great potential safety hazards. It is necessary to embed steel pipes on the 28th floor to tie the cantilever parts to ensure the stability of the frame body at the cantilever parts. Specific measures are as follows: Rachel steel pipes are set at the guide rails, and the number of Rachel is the same as that of the guide rails. Fasteners are used to connect the Rachel steel pipe with the guide rail, and two fasteners are installed at both ends to increase the anti-sliding ability; 10×30×5mm steel plates are welded at both ends of cable-stayed steel pipes to prevent fasteners from falling off.
5.4. **Summary experience**

The comprehensive promotion and use of climbing frame have become the trend of industry development, and the application of super-high-rise climbing frame has been widely used. By studying the construction method of climbing overhead with height change of super-high-rise building, the application problem of all-steel climbing frame in super-high-rise building with height change and
structure change is finally solved, avoiding dismantling and reassembling climbing frame, saving time and speeding up the project construction progress.

6. **Application of ultra-high-rise multi-terminal aluminum die**

6.1. **Advantages of aluminum formwork construction technology**

1. The aluminum formwork is convenient to install and dismantle, with high construction efficiency and good concrete forming effect, which can greatly improve the construction efficiency and engineering quality in the construction process.

2. All fittings of the aluminum formwork system can be reused, and each set of formworks can be turned over for more than 300 times in standard construction. The abandoned aluminum formwork can also be recycled, which can save the project investment cost.

3. There is no construction waste on the construction site, and the construction is safer. After formwork removal, there is no construction waste on the site, and the construction site is clean and tidy. It will not produce a large amount of construction waste like using wooden formwork, which fully meets the green building construction standard [4].

6.2. **Problem analysis**

In this project, the first floor is 6.1m high, the second floor is 5.66m high, the third-26th floor is 3.2m high (13 floors are refuge floors, with a height of 4.2m), and the 27th-46th floor is 4.2m high. The cross sections of core tube shear wall and outer frame column are shrunk in the 3rd, 14th, 28th and 39th floors. When the 10-12 axis crosses the H-J axis on the 13th floor, the whole structure shrinks. The change of storey height, the shrinkage of structure and the shrinkage of wall column section increase the application difficulty of aluminum mold.

6.3. **Construction method**

The wall formwork with a standard height of 3.2m, the external wall adopts 2700mm standard formwork +200mm high formwork +300mmK board, and the internal wall adopts 2700mm standard formwork +200mm high formwork. When matching formwork for the wall column of 4.2m standard layer, the formwork of 200mm height extension shall be replaced with the formwork of 1200mm height extension for the outer wall and inner wall based on the formwork of 3.2m height extension.

![Figure. 20 3.2m-high BIM mold matching drawing](image)
When the cross section of wall column of standard floor frame and core tube structure changes, the allocation of aluminum formwork will also change. In order to save the cost and maximize the turnover of the aluminum template, when the aluminum template is deepened, the change value of the cross-section size is deepened into a single aluminum template, and when the cross-section changes, it is directly added or removed. For example, the cross-sectional dimension of the outer frame column is 1400×2200mm on the 28th floor, and 1200×2200mm on the 29th floor. Therefore, when deepening, a 200mm aluminum template will be deepened on the side where the size changes, and the 200mm aluminum template will be removed when the 29th floor is constructed.

6.4. Summarize experience
Through the research and analysis of the application of super high-rise aluminum formwork, the design is deepened from the aspects of mold matching when the height changes and the cross-section changes, and finally the optimal mold matching scheme is determined. Maximize the utilization rate of aluminum formwork, ensure the construction safety and construction standards of super high-rise buildings, and effectively save the construction period, control the cost, and save labor and materials [5]. Quality management and detail control should be done well in the construction process to ensure the effectiveness of aluminum alloy formwork in super high-rise construction.

Conclusions
Through elastic-plastic analysis under rare earthquake and bearing capacity analysis under fortification earthquake, the structural layout and structural member size of double-core tube are determined, which can better solve the problem of large difference in stiffness between two directions of the structure and effectively reduce the torsional effect of the main structure. By optimizing the construction technology
of all-steel climbing frame of super high-rise building, the safety problem of climbing frame in the application of height change of super high-rise building was solved [6]. By optimizing the matching scheme of super high-rise aluminum mold, the application of aluminum mold in the change of height and section of super high-rise building was solved.

By solving these difficulties, the construction progress is accelerated, the safety and quality risks in the construction process of super high-rise buildings are greatly reduced, and at the same time, the material and labor costs are reduced, so that the project can be implemented smoothly.

References
[1] Code for seismic design of buildings GB50011-2010(2016 edition)
[2] Classification standard for seismic fortification of building engineering GB50223-2008.
[3] Cai Xiaolong. Application analysis of aluminum formwork construction technology for super high-rise buildings. Engineering technology and building materials development orientation in April 2017.
[4] Application of aluminum alloy formwork in building construction. Building materials and decoration. 1673-0038(2016)23-0037-02.
[5] Li Jun. Application of climbing frame construction technology in high-rise buildings [J]. Shanxi Architecture, 2003,35: 92-93
[6] Zhang Lifeng. Construction Scheme of Aluminum Mould. China Academic Journal Network, 2013.