Finite element analysis of inclined wall construction process of super high-rise core tube

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Abstract. Xiamen Bailu West Tower is a super high-rise building, its core tube is designed to be retracted synchronously along the height of the peripheral shear wall, and the construction method of the core tube is the integral climbing steel platform formwork system + the formwork support system of the inclined wall of the core tube. In this paper, MIDAS Gen is used to simulate the whole construction process of the core tube inclined wall, analyze the deformation and stress state of each construction stage, and review the bearing capacity of the core tube structure. The simulation analysis shows that the construction scheme is feasible and the construction process is safe and controllable.

Keywords: Super high-rise building; Core tube; Inclined wall; Finite element analysis; Construction process

1 Introduction

Xiamen Bailu West Tower is a super high-rise building integrating high-end hotels, offices and commerce, located in Jimei District, Xiamen (As shown in Figure 1). The main tower of the project has 3 floors underground and 47 floors above ground. The total height of the building is 266.0 m (the crown of the tower). The above-ground part adopts concrete-filled steel tube frame-reinforced concrete core tube structure. The shear walls around the core tube on the 27th to 30th floors are inclined inward, and the core-tube shear walls on the north and south sides are inclined inward by 2000 mm at an inclination angle of 7.13 ° (the single-layer setback is 500 mm); the core-tube shear walls on the east and west sides are inclined inward by mm at an inclination angle of 10.27 ° (the single-layer setback is 500 mm). The thickness of the external wall of the core tube in relevant parts is 800 mm, as shown in Figure 2.

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2 Construction Technology and Difficulties Analysis of Inclined Wall

The construction process of the main structure is: Vertical members of core tube → frame structure outside core tube → horizontal members inside tube[1][2]. The construction of the inner wall of the core tube on the 27^{th} to 30^{th} floors is synchronized with the construction of the inclined wall section. The inner wall is constructed by using the integral climbing steel platform formwork system, and the inclined wall is constructed by using the formwork support system (As shown in Figure 3).

Fig. 1. Xiamen Bailu West Tower

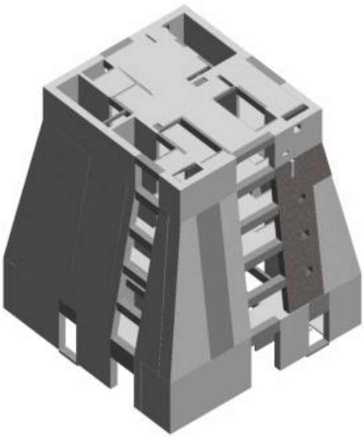


Fig. 2. Core tube model of the 26^{th} ~ 30^{th} floor

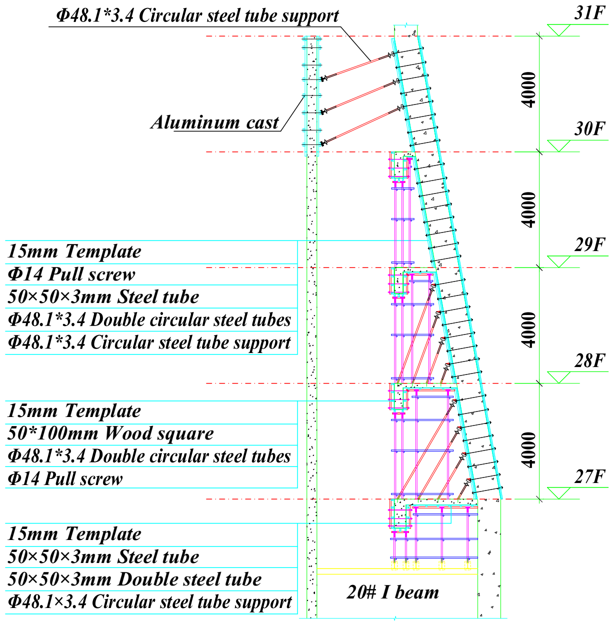
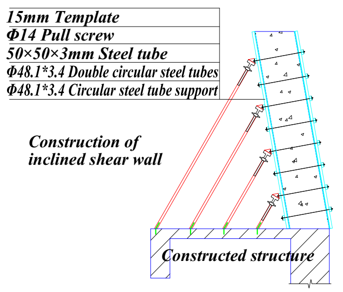
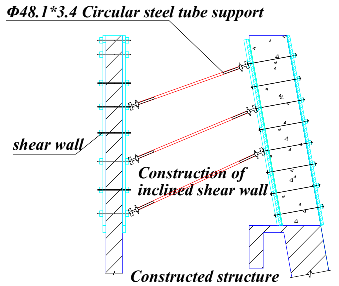


Fig. 3. Construction process diagram of inclined wall

The formwork support system of the inclined wall of the core tube on the 27th and 28th floors is supported on the constructed horizontal members, and the diagonal rod of the formwork support system of the inclined wall of the core tube on the 29th and 30th floors is supported on the constructed shear wall; Table 1 shows the parameters of the formwork support system.

Table 1. Parameters of Inclined wall Formwork Support System

level number	Floor 27-28	Floor 29-30
Template	15mm Plywood	
Joist system	Main beam: φ 48.3 mm × 3.6mm, double circular steel tubes; Distance:457 mm Minor beam: 50 mm × 50 mm × 3.5 mm, square steel pipe; Distance: 220 mm	
Pull screw	φ14mm pull screw; Distance:457 mm	
Supported bar	φ 48.3 mm × 3.6 mm; Distance: 500 mm	φ 48.3 mm × 3.6 mm; Distance: 500 mm
Schematic diagram		

Construction characteristics and difficulties of inclined wall:

(1) The core tube shear wall moves inward along the height (the wall thickness is 800mm), and the formwork support system bears a large unbalanced force, so the requirements for the strength, stiffness and stability of the formwork support system are higher.

(2) Due to the construction of the horizontal members inside the core tube and the steel frame outside the core tube after the construction of shear walls within core tube, the formwork support system of some horizontal members in the core tube of the 27th floor lacks the support structure.

(3) With the construction of inclined wall, the construction load and self-weight of inclined wall produce additional torque to the Constructed structure (The concrete of the constructed structure is in the curing stage, and the concrete strength does not reach the strength standard value.). Therefore, it is necessary to analyze the relevant storeys of the construction process [3][4][5].

(4) The load of the 29th to 30th floor formwork support system is transmitted to the core tube shear wall of the same floor through the slant Beams. Because the inner wall of the core tube shear wall is constructed before the surrounding external wall, the edge of the inner wall is in an unconstrained state, and the bearing capacity and crack width of the inner wall need to be checked.

3 Finite element analysis of formwork support system

3.1 Model introduction and load analysis

In this paper, MIDAS Gen is used to analyze the formwork support system of the inclined wall from the 27 th to 30 th floors. The template adopts plate element ; the main beam, minor beam and slant beams adopt beam element; The connection adopts elastic connection, and the support limits the translational constraint. The model is established as follows Figure 4 and Figure 5.

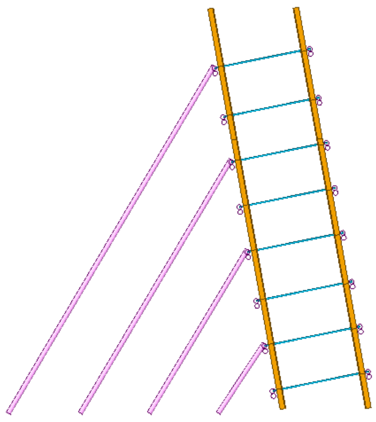


Fig. 4. Template support system model of the 27th and 28th floors

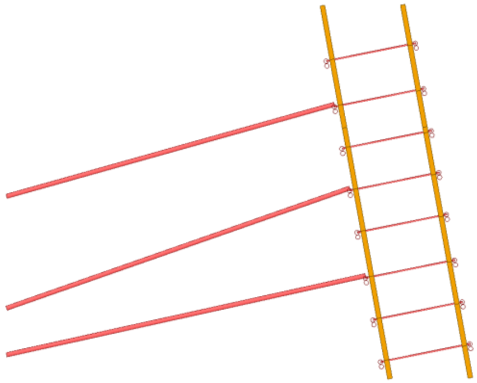


Fig. 5. Template support system model of the 29th and 30th floors

The constant load of the formwork support system includes the self-weight of the formwork and its support, the self-weight of the new concrete, the self-weight of the steel bar, and the lateral pressure of the new concrete acting on the formwork. The live load includes the load generated when vibrating the concrete and the horizontal load generated when dumping the concrete [6]. The stress calculation diagram of the inclined wall formwork support system is shown in Figure 6.

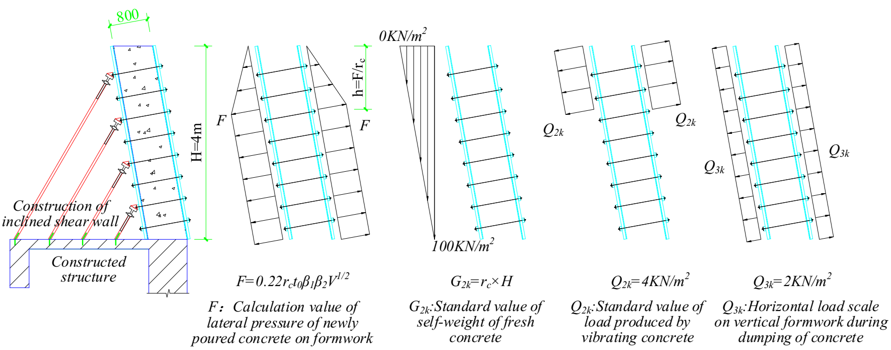


Fig. 6. The stress calculation diagram of formwork support system

The standard value of wind load is calculated according to the specification of the *Code for Design of Concrete Structures* (GB50009-2012). The load combination is carried out according to Article 4.3 of the *Technical Code for Safety of Building Construction Formwork*.

3.2 The checking results of formwork support system

The strength, stability and deformation of the inclined wall formwork support system of the 27 th to 30 th floors of the core tube are checked in turn. The results are shown in Table 2:

Table 2. The checking results of formwork support system

Content	Component name	Check the calculation results
force calculation	Main beam, minor beam and diagonal rod (material: Q235)	Bending strength < 205 MPa Shear strength < 120 MPa
	Pull screw (material: HPB300)	Tensile strength < 270 MPa
	Formwork (material: bamboo plywood)	Bending strength < 35 MPa
Deformation calculation	Main and minor beams (material: Q235); formwork (material: bamboo plywood)	Mid-span deflection < L/250
	Skew Rod	Component stability calculation < 1

4 Finite element analysis considering the joint action of permanent structure space in construction process

4.1 Construction step division and load

According to the structural construction progress and concrete pouring sequence, five construction conditions are considered: temporary steel structure support structure is set up during the construction of the 26th floor structure (platform beam section: 20 # I-shape-beam, in order to enhance the overall stability of the temporary steel structure support structure, inclined support is added and 14 # channel steel is laid on the platform beam). Erect the 27th floor slab formwork support system on the temporary platform and pour concrete; erect the core tube external inclined wall formwork support system on the main structure, bind reinforcement and pour concrete; repeat the above process for the 28th to 30th floors; the calculation model of construction steps is shown in Figure 7.

(A)Condition I (B) Condition II (C) Condition III

(D) Condition IV (E) Condition V

Fig. 7. Models of each working condition

Temporary scaffolding is erected on the inner side of the four-sided shear wall of the core tube on the 27th and 28th floors by using the horizontal floor slab, and the diagonal rod of the four-sided shear wall support system of the core tube on the 29th and 30th floors is supported on the inner wall of the core wall; when the inclined wall is converted and retracted, part of concrete is vertically pressed on the formwork during concrete pouring, which produces vertical pressure on the formwork, and the overall vertical load is triangular. Figure 8 shows the force calculation diagram of the conversion and retreat construction of the core tube inclined wall.

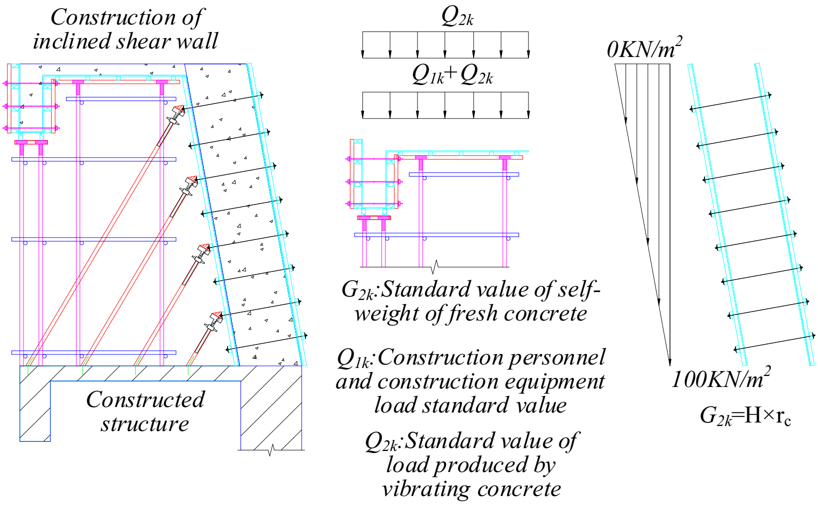


Fig. 8. The stress calculation diagram of the core tube inclined wall during construction

The strength and elastic modulus of high-fluidity pumping concrete develop very fast within 3 days, and gradually slow down after 7 days [7]. According to the construction schedule and concrete curing conditions of the project, the standard value of concrete strength of the constructed structure can reach 75%.

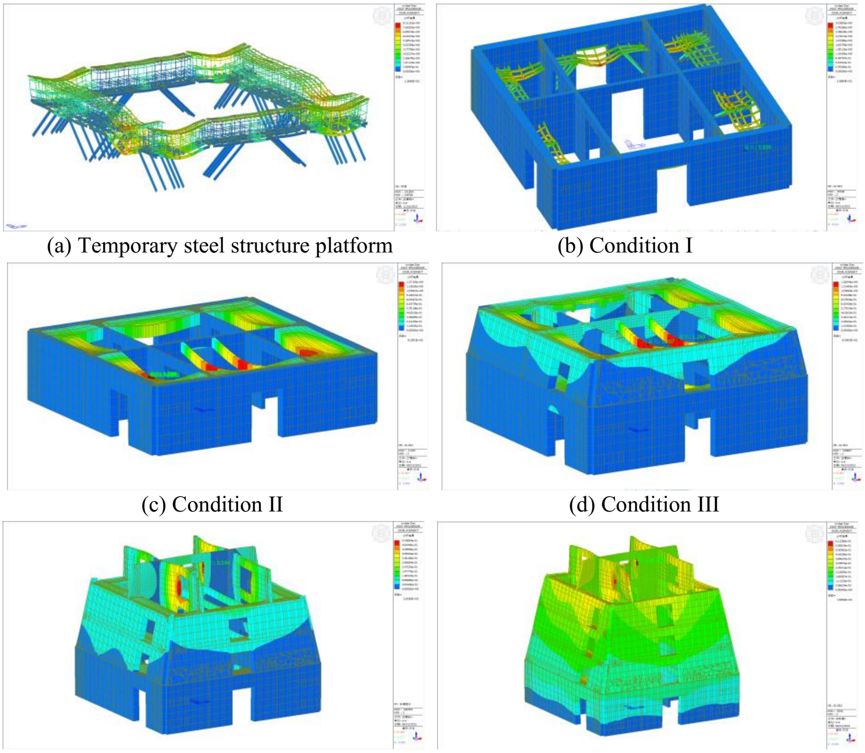
4.2 Analysis of construction simulation results

Table 3 shows the finite element analysis results of the different conditions according to the structural construction schedule and concrete pouring sequence. The displacement clouds of the different construction conditions of the core tube are shown in Figure 9.

Based on the application of the formwork support system of the core tube inclined wall, the crack width of the constructed structure is checked by using the *Code for Design of Concrete Structures* (GB50010-2010, 2015 edition) [8]. According to the formula:$\omega_{max} = \alpha_{cr}\psi\sigma_s/E_s\left(1.9C_s + 0.08d_{eq}/\rho_{te}\right)$. The crack width is checked to meet the requirements of the specification.

Table 3. Analysis Results of the Different Construction Conditions

conditions	Working condition I	Working conditions II - III	Working conditions IV - V
Check the calculation results	The maximum tensile stress of the temporary steel support system is 126.9Mpa, and the maximum vertical displacement is 3.04 mm, which meets the requirements of the specification.	The maximum vertical displacement of the 27th floor slab and beam is 1.27 mm, which meets the requirements of the specification. The maximum vertical displacement of the 28th floor slab and beam is 1.27 mm, which meets the requirements of the specification.	The maximum horizontal displacement of the inner wall of the core tube on the 29th floor is 0.54 mm, which meets the requirements of the code. The maximum horizontal displacement of the inner wall of the core tube on the 30th floor is 0.61 mm, which meets the requirements of the code.



(a) Temporary steel structure platform (b) Condition I

(c) Condition II (d) Condition III

(e) Condition IV (f) Condition V

Fig. 9. The displacement clouds of the different construction conditions of the core tube

5 Conclusion

Based on the complex construction technology of inclined wall of 27-30 floors in the core tube of Xiamen Bailu West Tower project, the paper uses MIDAS / Gen finite element software to simulate and analyze the construction process. The main conclusions are as follows:

(1) The finite element analysis of the formwork support system of the 27th to 30th floors is carried out respectively. All the stress indexes meet the requirements of the specification, and the inclined wall formwork support system is safe and reliable.

(2) The stress, deformation and stability of the temporary steel structure support system meet the requirements of the specification.

(3) Through the finite element analysis of the spatial interaction of the permanent structure in the construction process of the inclined wall, the stress of the temporary structure, the bearing capacity of the existing structure and the crack width meet the requirements of the specification, which ensures the safety of the construction process.

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