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Safety Analysis of Formwork Fystem in Core Tube Construction of Super High-rise Building

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Abstract:
Taking the formwork system in core tube construction of a super high-rise building project as the research background, taking the fixed load combination value according to the Load Code for the Design of Building Structures, combined with different construction stages and wind load directions, considering the failure and sinking of a single-piston rod by 100mm, 45 working conditions are determined. The finite element model of the jacking formwork system is established on ANSYS. The permanent load, live load , wind load are determined in detail. The safety of the formwork system during the construction of the core tube is evaluated from the three aspects of strength, stiffness ,stability. According to the analysis results, it is determined that the formwork system is safe during the construction process. The support reaction of the model structure is extracted. Based on the analysis results, the suggestions in the construction process are put forward, which lays a foundation for the safe design and construction of the core tube formwork system.

***Keywords**: Mold base system, Wind load, Safety analysis, Core tube, Super high rise building.*

I. INTRODUCTION

In the construction process of super high-rise buildings, there are some obvious problems, such as concrete transportation, material hoisting, template construction technology, construction accuracy control, etc. Super high-rise buildings are generally standard layers, and the vertical structure changes slightly. The integral construction formwork system has the advantages of fast construction speed, good sealing performance of steel platform, good construction safety, easy quality assurance, which is widely used in the construction of concrete core tubes of super high-rise buildings. It has been successfully applied in Shanghai Jinmao Building, Global Financial Center, Nanjing Zifeng Building, Guangzhou New TV Tower core tube structure, Shanghai Center Building, Shanghai Jing'an Dazhongli T2 Main Building, Shanghai International Aviation Service Center core tube, Shanghai Shimao International Plaza.

The construction formwork system in super high-rise buildings is mostly in the form of integral jacking, low support, electronically controlled hydraulic control. With large tonnage and long stroke cylinder as the power, the number of supporting systems supporting the structure of the next two layers is 3-4. Under the action of the lifting cylinder, the hanging scaffold and template system are lifted together with the steel

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platform, and the lifting synchronization of each supporting point is ensured by hydraulic electronic control device [1], as shown in Figure 1. Based on the development history of traditional integral steel platform formwork and intelligent control integral steel platform formwork[2][3][4] focus on the technical development of integral steel platform formwork equipment supported by inner tube and outer frame, temporary steel column support integral steel platform formwork equipment, rigid steel column support integral steel platform formwork equipment, steel beam and cylinder frame alternative support integral steel platform formwork equipment, steel column and cylinder frame alternative support integral steel platform formwork equipment.

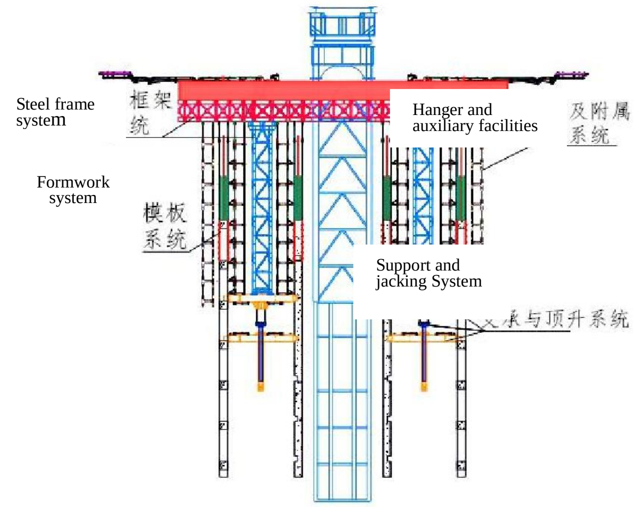

Fig. 1: Lifting formwork system of super high-rise building

The jacking formwork is mainly composed of a support system, platform system, hanging frame system, template system, intelligent hydraulic control system[5][6]. The key technology of steel support column attachment of irregular core tube climbing formwork frame is put forward. Based on the high-efficiency construction requirements of super high-rise concrete core tube structure, an intelligent jack-up formwork system is proposed, which can realize unmanned independent climbing and automatic opening and closing of formwork[7]. Starting from the analysis of the basic methods of the selection and design, installation and use, and demolition of the hydraulic climbing formwork system, combined with the calculation and analysis of the structural stress, the hydraulic climbing formwork system of the super high-rise special-shaped shear wall structure was systematically optimized[8].

The numerical simulation and field test of the steel platform was carried out by Midas Gen software to study the integral jacking steel platform used in the construction of the core tube of a super high-rise building[9]. With the help of SAP2000, the structure of the system is optimized and analyzed, and the whole system of the lifting template is optimized. The fuzzy mathematics analysis method is introduced into the technical and economic comparison selection with construction technical parameters[10]. Using the method of numerical simulation analysis, the mechanical performance of the construction integrated platform used in the core tube construction of a super high-rise building is studied. Taking the integral jacking formwork system of a super high-rise building as the research object, considering the dynamic characteristics of the

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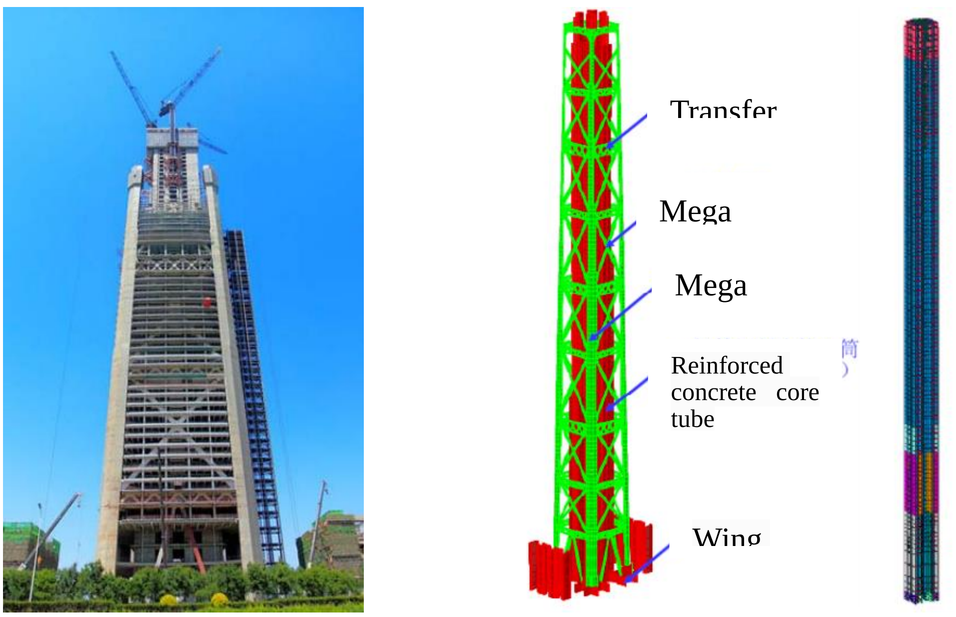
main structure changing with the construction stage and other factors, the dynamic time history analysis of the structure under earthquake action is carried out by finite element software SAP2000[11].

The key technologies and design methods of standardized connection of integral steel platform are studied[12]. Starting from the modification and optimization of modular low-lift formwork system, the modification and optimization were carried out based on Fuzhou Shimao Project, and successfully applied to the process of Yuyang Project[13]. By using the method of theoretical analysis, field monitoring, numerical simulation, the wind environment distribution of 600 m super high-rise buildings under strong wind during the construction period, the wind-induced response law of incomplete structures, the safety step of unequal height synchronous climbing construction and construction measures are systematically studied[14]. The complex climbing conditions in the construction of super high-rise hydraulic climbing formwork are analyzed, and the measures of installing a variable cross-section cushion plate between the upper wall attachment device and the wall are adopted. The bottom design and installation of the hanging platform solve the problem of connection between climbing formwork and elevator[15]. ·

II. ENGINEERING OVERVIEW

The total building area of the building is about 370,000 m^2, a total of 117 floors, and the structural height is 597 m. The tower plane is square. The floor plane gradually decreases with the oblique facade. The plane size of the first floor of the tower is about 65 m×65 m, and when it gradually changes to the top floor, the plane size is about 45 m×45 m, and the height-width ratio is 9.7. The central concrete core tube is rectangular, and the plane size is about 34 m× 37 m. It is mainly used for high-speed elevator rooms, equipment rooms, service rooms. As shown in Figure 2, it is the actual construction drawings and the overall structure. Figure 3 is the overall dynamic characteristics of the structure. The first two modes are translation and the third mode is rotation.



a Core tube in construction b Overall structure system c Core tube

Fig.2:The actual construction drawing and the overall diagram of structure

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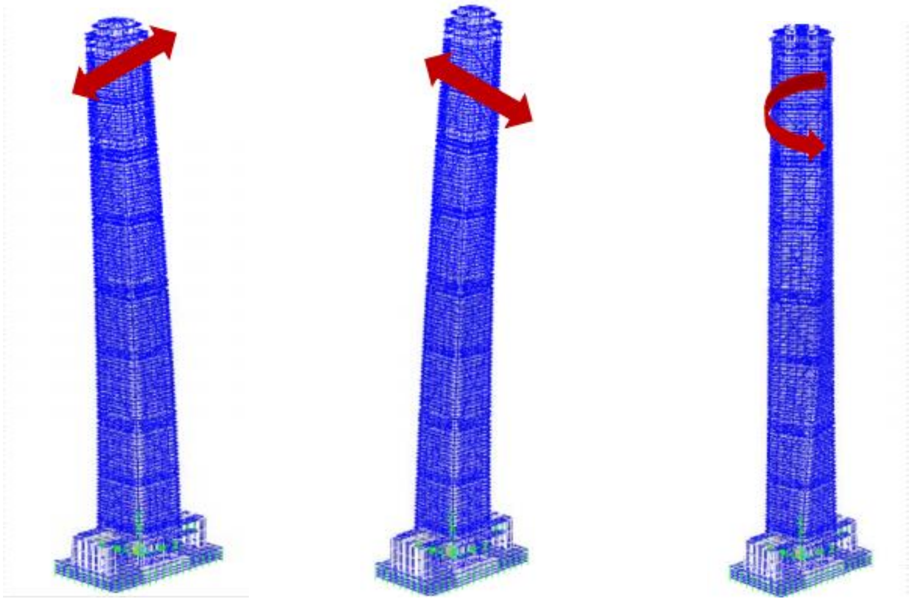
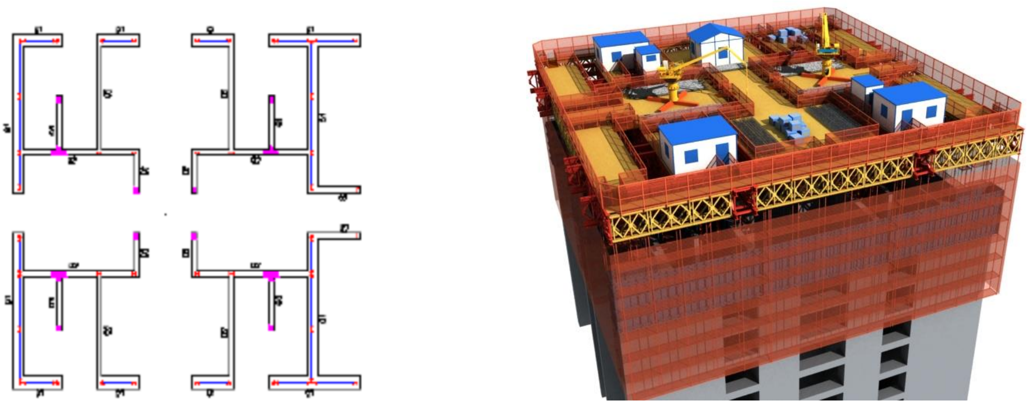


a T1 = 9.255 s (X- translation) b T2 = 9.135 s (Y-translation) c T3 = 3.573 (Z- rotation)
Fig. 3:Dynamic characteristics of structure

A low-level jack-up steel platform formwork system is adopted in core tube construction, including support and jack-up system, steel platform system, hanging frame and safety protection system, formwork system. The support and jack-up system consist of four large-scale, large-tonnage, hydraulic jack-up cylinders, supporting box girder, supporting column. The bracket of the supporting box girder extends into the reserved hole of the inner wall of the core tube to support the whole formwork system. Hanging frame and safety protection system hanging in steel platform truss bottom chord provides working face. The template adopts a steel-span wood formwork system with an activator and tension screw. The formwork climbs together with the formwork platform, and the construction speed is up to 4-5 days per floor. Fig. 4 shows the overall distribution of core tube shear wall and formwork system.



a Overall effect drawing of core shear wall distribution b Formwork system
Fig. 4:Overall effect of core tube shear wall distribution and formwork system

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III. Finite element model of formwork system

The general finite element software ANSYS was used to analyze the safety of the structure. The finite element models of the support and lifting system, the steel platform system were established. BEAM188 element was selected for all the members. The finite element model is shown in Fig. 5.

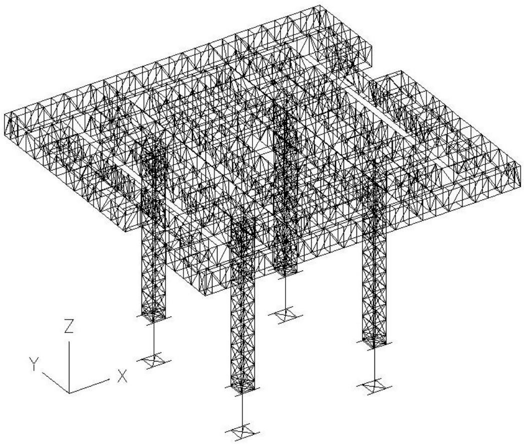

Fig. 5: Finite element model of formwork system

Modal analysis was carried out on the core tube, hanger (taking one piece for calculation) , steel platform. These provide the basis for the wind vibration coefficient value of wind load. Table 1 shows the period, frequency, vibration mode characteristics of the core tube, hanger (taking a piece for calculation), steel platform.

Table 3.1 Structural vibration characteristics

structure	vibration mode	cycle	frequency	modal characteristics
Core tube	1	17.40	0.057	translation
	2	16.89	0.059	translation
	3	10.37	0.96	torsion
Hangers	1	0.89	1.12	translation
	2	0.87	1.14	translation
	3	0.65	1.53	torsion
Steel platform	1	1.75	0.57	Torsion (overall)
	2	1.52	0.66	translation
	3	1.39	0.72	translation

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IV.DETERMINATION OF LOAD VALUE

4.1 Load of formwork system

The constant load includes the dead weight of the structure itself, the constant load of the hanger, the constant load of the template, the load of the cage, other fixed equipment facilities. Among them, the hanger constant load and template constant load are simplified as linear load according to the actual situation and loaded according to the design position. The load standard value is as follows.

Outside hanger system : 5.57 kN / m

Inside of the hanger system (including steel formwork) : 9.10 kN / m

Elevator cage : 11 t

Concrete spreader : 10 t

The live load on the top of the steel platform includes construction materials, personnel, machinery, hangers, other loads. Taking full account of the actual construction situation, 1.5 kN / m^2 is taken outside the core tube concrete, 10 kN / m^2 is taken in the center of the core tube, and 7.0 kN / m^2 is taken between the two parts. 6 kN / m^2 for live load of the hanger system based on two-layer full load.

4.2 Wind load value

The tower formwork system is located at the top of the core tube of a project, which is the auxiliary structure for construction. According to the "Load Code for Building Structures"[16], the wind load is calculated by the basic wind pressure W_0 = 0.3kN / m^2. The hanging frame is not completely connected with the steel platform, so the wind load on the windward side of the hanging frame is undertaken by the core tube, and half of the horizontal wind load is transferred to the steel platform, while the wind load on the bottom, side, back of the hanging system is all transferred to the steel platform. In order to determine the windshield coefficient of the hanging frame, the opening ratio of the aluminum plate punching network is set to 0.5.

The height of the core tube of the building is close to 600m. Because the wind around the top of the structure is complex at high altitude (400m-600m), it is necessary to consider the upward lift effect and the downward pressure effect of the wind load on the steel truss platform plate, and the wind load in X and Y directions is considered respectively.

Taking the wind load along the X direction as an example, it is explained in detail.

1) The horizontal wind load on the steel platform truss is distributed on the first three trusses closest to

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the windward surface.

2) As shown in Figure 6a, the hangers (locations of zones 1, 2, 3, 4, 6, 7, 8 , 9 outside the steel truss platform) are not structurally considered, all wind loads (only half of the horizontal load of the windward hangers) are applied to the members of the corresponding lower chord of the steel truss.

3) The vertical wind load on the steel truss platform is applied to the steel truss platform plate .

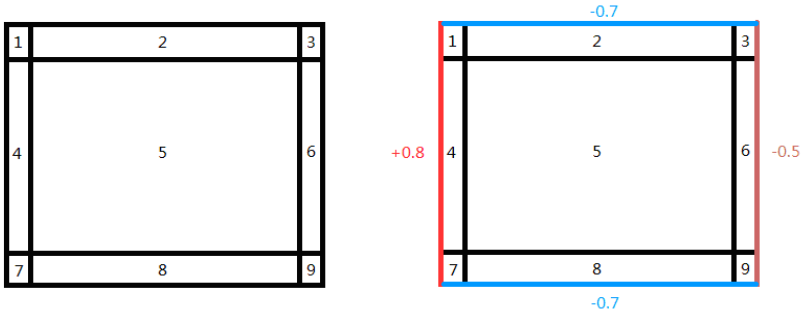
According to the standard wind load calculation formula :

$$\omega_k = \beta_z \mu_s \mu_z \omega_0$$

Formula : ω_k , wind load standard value ; β_z , wind vibration coefficient at height z ; μ_s , wind load shape coefficient ; μ_z , wind pressure height variation coefficient ; ω_0 , basic wind pressure.

According to the above calculation, the natural vibration period of the core tube frame structure is 17.4s, and the natural vibration period of the steel platform formwork system is 0.89s. The natural vibration period of the steel platform and the hanger is smaller than that of the core tube structure. The steel platform and the hanger are finally attached to the core tube structure. Therefore, the natural vibration period of the core tube should be selected when calculating the wind load vibration coefficient of the tower formwork system.

The shape coefficient of each side of the hanger, the shape coefficient of each bottom, and the shape coefficient of the steel platform plate are shown in Fig. 6, b, c, and d, respectively. The internal value of brackets in Fig. d represents the shape coefficient corresponding to the upward suction effect of wind load on the steel truss platform plate.



a Partition diagram of wind load on steel platform   b Shape coefficient of cind load on lateral face

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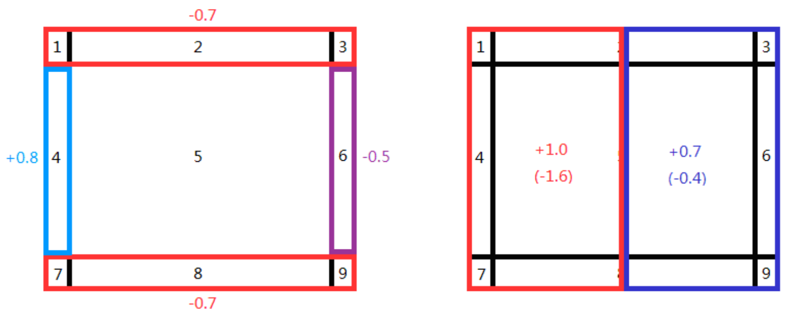

c Shape coefficient of wind load on bottom   d Shape coefficient of wind load on top

Fig 6 Structure partition and shape coefficient

4.3 Load summary

Permanent load standard value : 1058 t, including steel platform : 478 t, hanger and template : 580 t

Live load standard value : 563 t, including hanger live load 222 t, steel platform live load 341 t

Total load standard value : 1621 t

Horizontal wind load standard value X direction : 58.9 t

Steel platform top vertical wind load (pressure) standard value : 90.0 t

Steel platform top vertical wind load (suction) standard value : 91.7 t

4.4 Condition determination

During the construction process, the operation mode of the formwork system mainly includes two types: one is the jacking process of the formwork itself; the second is the process of auxiliary pouring concrete of the main structure after lifting the formwork. In the first kind of process, for completing the construction of the top of the main structure, the formwork system rises to the highest position (the upper supporting box girder of the formwork system has just risen in place, has not been fixed, and all the load is borne by the lower box girder). At this time, it is one of the most dangerous states for the formwork system, and this state is referred to as 'the stage of jacking to the highest position'. In the second process, when the formwork system rises to the highest position (the highest position where the formwork system can be located throughout the construction period) and is fixed in place, it is also one of the most dangerous states for the formwork system. This state is referred to as 'the stage of concrete construction'.

In addition, during the lifting process of the formwork system, it is considered that a jack may fail and cause the lifting asynchronous. Therefore, another structural state is set in this paper, which is referred to as 'single-piston rod sinking 100 mm' for simulating the situation that the vertical displacement at the bottom of

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the corresponding column is 100 mm more than that of the column when a jack fails.

According to the above description, the number combination of each condition, as table 2 shows the basic combination of load condition, table 3 shows the standard combination of load condition table. For the convenience of expression, for the number of box girder support, the specific node position is shown in Fig. 7. In the figure, the lower box girder support is represented by IA0J, the upper box girder support is represented by IB0J, and the column lateral constraint support is represented by IC0J. Here I refers to the column number, and J refers to the bracket number under the column, which is numbered in clockwise order.

Condition constraints are as follows :

1) Working conditions 1~12: 1A0J, 2A0J, 3A0J, 4A0J (J = 1,2,3,4) of the lower box girder bearing are constrained, including16 nodes translational degrees of freedom along X, Y, Z directions ; the constraint of the anti-side device corresponds to the translational degrees of freedom along X and Y directions is implemented.

2) Working conditions 13~20: Constraint upper box girder bearing 1B0J, 2B0J, 3B0J, 4B0J (J = 1,2,3,4), a total of 16 nodes along the X, Y, Z direction of translational freedom; the constraint anti-side device corresponds to the translational degrees of freedom of all bearings along with X and Y directions.

3) Working conditions 21~25: The translational degrees of freedom are constrained at the same constraint position as working conditions 1~12, but 100 mm displacement constraint is applied in Z direction under one pillar; the constraint anti-side device corresponds to the translational degrees of freedom of all bearings along with X and Y directions.

4) Working conditions 26~29: the same constraints as operating conditions 1~12.

5) Working conditions 30~37: the same constraints as operating conditions 1~12.

6) Working conditions 38~45: the same constraints as working conditions 13~20.

From the perspective of structural strength, stiffness and stability, the safety of jacking to the highest position, concrete construction state and single jack failure state are checked, and the data of bearing reaction, stress, displacement and buckling eigenvalue are extracted.

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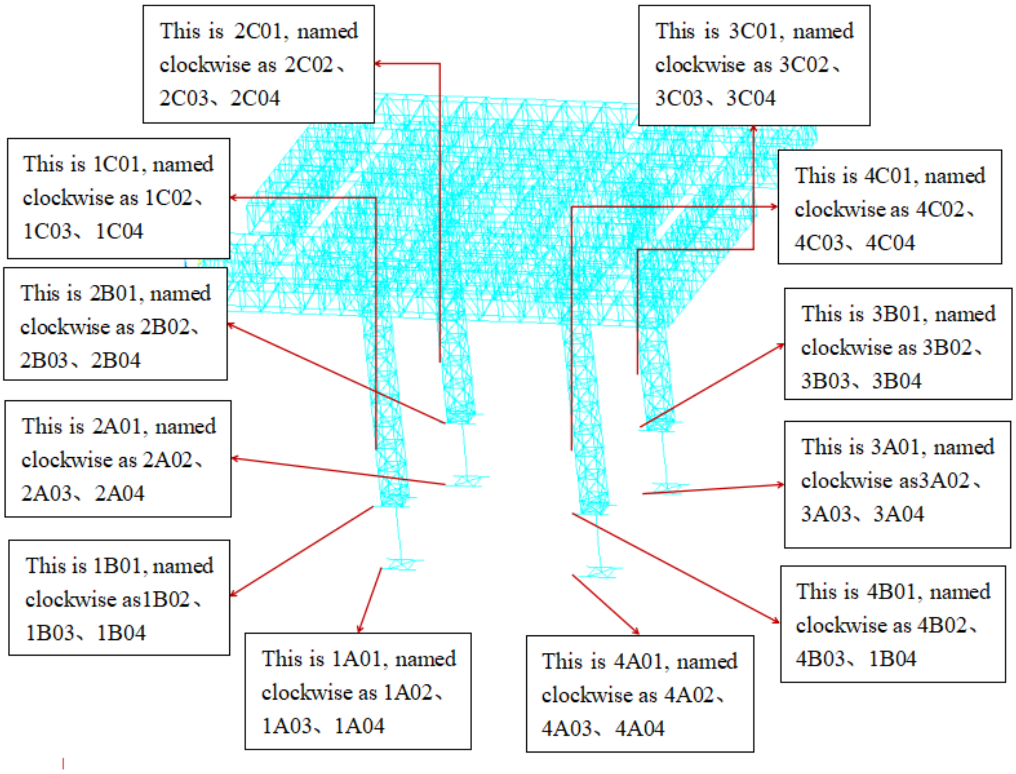

Fig 7 Schematic diagram of formwork support system

Table 2 Table of basic load combinations
（D is permanent load, L is live load and W is wind load）

Number	**Content**	**Working condition combination**	**Load details**		
			Combined content	**wind direction**	**Wind load effect**
1	Lift to the highest position	Variable load effect control (live load plays a leading role)	1.2D+1.4L+0.6×1.4W	X	Platform compression
2				Y	Platform compression
3		Permanent load effect control	1.35D+0.7×1.4L+0.6×1.4W	X	Platform compression
4				Y	Platform compression
5		Variable load effect	1D+1.4L+0.6×1.4W	X	Platform

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					tension
6		control (live load dominates and permanent load is beneficial to the structure)		Y	Platform tension
7		Permanent load effect control (permanent load is beneficial to the structure)	1D+0.7×1.4L+0.6×1.4W	X	Platform tension
8				Y	Platform tension
9		Variable load effect control (wind load plays a leading role)	1.2D+1.4W+0.7×1.4L	X	Platform compression
10				Y	Platform compression
11		Variable load effect control (wind load dominates, permanent load is beneficial to the structure, and live load is not considered)	1.0D+1.4W	X	Platform tension
12				Y	Platform tension
13	Concrete construction stage	Variable load effect control (live load plays a leading role)	1.2D+1.4L+0.6×1.4W	X	Platform compression
14				Y	Platform compression
15		Variable load effect control (wind load plays a leading role)	1.2D+1.4W+0.7×1.4L	X	Platform compression
16				X	Platform tension
17				Y	Platform compression
18				Y	platform tension
19		Variable load effect	1D+1.4W+0.7×1.4L	X	platform

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					tension
20		control (wind load dominates and permanent load is beneficial to the structure)		Y	Platform tension
21	Sinking of single-piston rod during jacking 100mm	Variable load effect control (wind load dominates, permanent load is beneficial to the structure, and live load is not considered)	1.0D+1.4W	X	Platform tension
22				Y	Platform tension
23		Permanent load effect control	1.35D+0.7×1.4L+0.6×1.4W	X	Platform compression
24		Variable load effect control (live load plays a leading role)	1.2D+1.4L+0.6×1.4W	X	Platform compression
25		Variable load effect control (wind load plays a leading role)	1.2D+1.4W+0.7×1.4L	X	Platform compression
26	Single calculation condition	Only wind load is considered	W	X	Platform compression
27				X	Platform tension
28		Only Permanent load is considered	D		
29		Live load only	L		

Table 3 The load standard combination conditions

Number	Content	Working condition combination	Load details		
			Combined content	Wind load effect	wind direction
30	Lift to the highest position	The live load effect controlling is wind load	1.0D+0.7L+1.0W	Platform tension	X
31					Y
32				Platform compres	X
33					Y

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				sion	
34		The live load effect that plays a controlling role is other live loads other than wind load	1.0D+1.0L+0.7W	Platform tension	X
35					Y
36				Platform compression	X
37					Y
38	Concrete construction stage	The live load effect controlling is wind load	1.0D+0.7L+1.0W	Platform tension	X
39					Y
40				Platform compression	X
41					Y
42		The live load effect that plays a controlling role is other live loads other than wind load	1.0D+1.0L+0.7W	Platform tension	X
43					Y
44				Platform compression	X
45					Y

V. STRUCTURAL ANALYSIS RESULTS

5.1 The stage of jacking to the highest position

To express the analysis clearly, the steel truss platform system is divided into four parts: main truss, secondary truss, column and box girder.

Fig. 8 shows the maximum stress ratio of each part of the bar at the maximum stage of lifting. Figure 9 shows the maximum displacements of X, Y, Z under different working conditions. The stress ratio refers to the ratio of the maximum normal stress at the edge of the section under the combined action of axial force and bending moment to the design value of steel strength[17]. The strength is calculated according to the basic combination, and the displacement is calculated according to the standard combination.

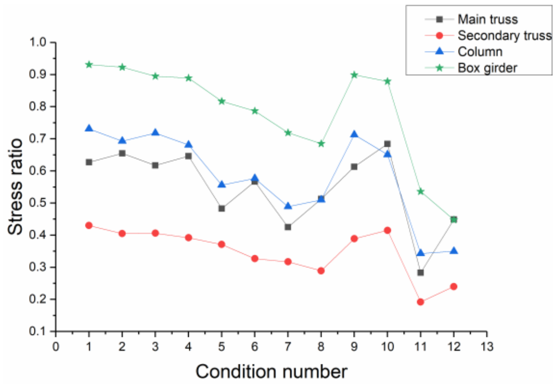

Fig. 8:The maximum stress ratio of each part

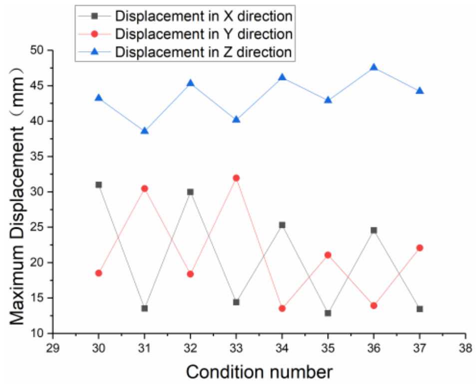

Fig. 9:The maximum displacements of X, Y, Z

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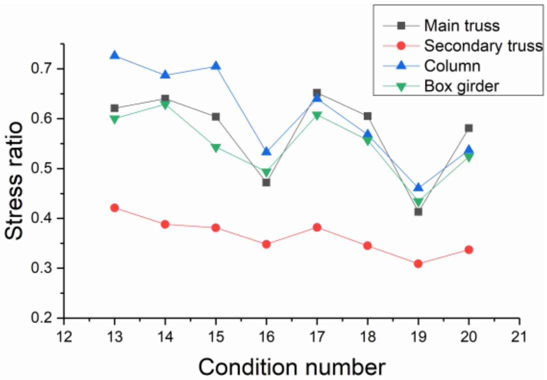
5.2 Concrete construction stage

Fig. 10 and Fig. 11 show the maximum stress ratio and the maximum displacement of X, Y, Z under different working conditions of each part of the structure in the concrete construction stage.



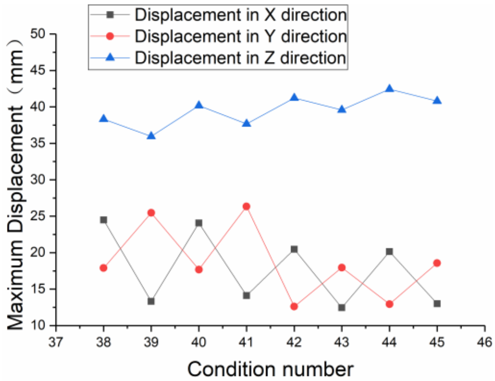
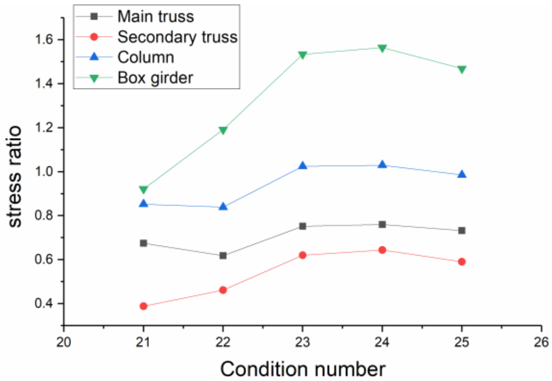


Fig.10:The maximum stress ratio of each part Fig. 11:The maximum displacements of X, Y, Z

5.3 single-piston rod sink 100 mm

Fig. 12 and Fig. 13 show the maximum stress ratio and the maximum displacement of X, Y and Z of the structure with a single-piston rod sinking 100 mm under different working conditions.



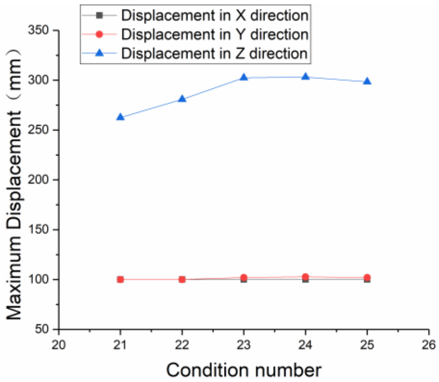


Fig.12:The maximum stress ratio of each part Fig.13:The maximum displacements of X, Y, Z

5.4 Stability analysis

Fig. 14 shows the stability characteristic values of each working condition. Condition 4, condition 14, condition 23 are the minimum buckling eigenvalues under three different conditions: the stage of jacking to the highest position, the stage of concrete construction, single-piston rod sinking 100 mm. Fig. 15 shows the instability mode diagram of condition 4, condition 14 and condition 23.

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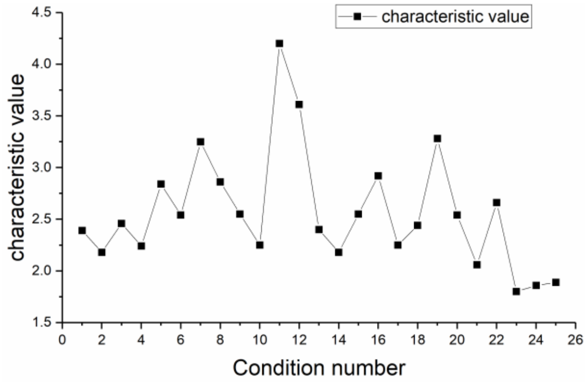
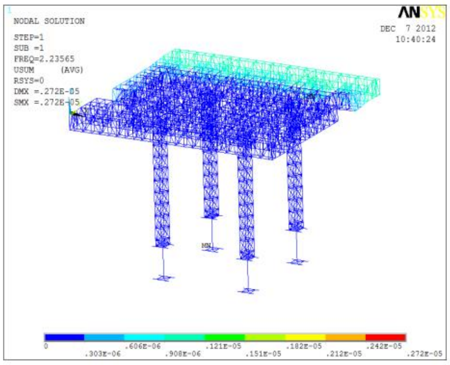
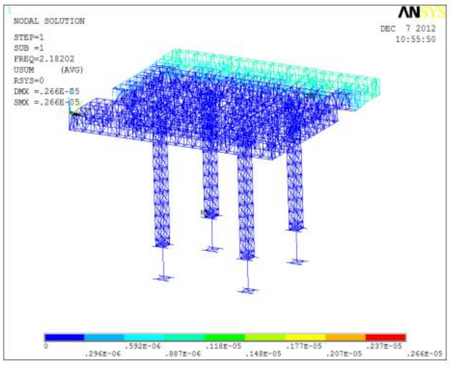


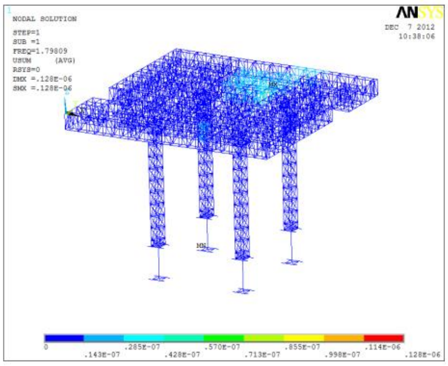
Fig 14 Eigenvalues of buckling stability under various working conditions



Condition 4



Condition14



Condition 23

Fig. 15 Instability mode diagram of formwork system

5.5 Nephogram of displacement and stress ratio

According to the analysis results, the maximum stress ratio appears in condition 9 in each working condition during the stage of jacking to the highest position, the maximum stress ratio in the stage of concrete construction is 15, the maximum displacement condition during the stage of jacking to the highest position is 32, the maximum displacement condition during the concrete construction stage is 40, and the maximum failure stress of a single-piston rod appears in condition 24. Figures 16 and 17 show the maximum stress ratio and displacement nephogram of the stage of jacking to the highest position and the stage of

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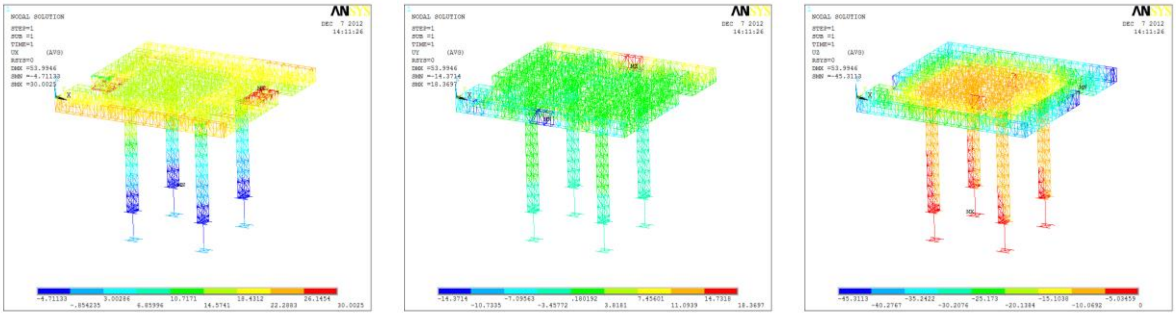
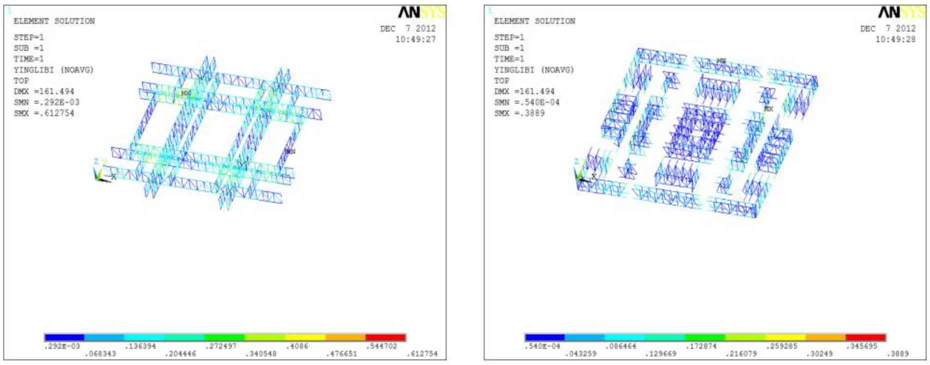
concrete construction, respectively. Figure 18 shows the maximum stress ratio nephogram of single-piston rod sinking 100 mm.

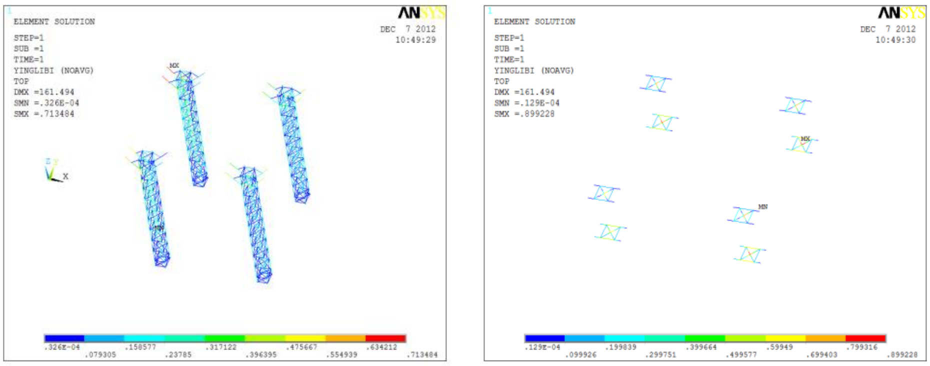


X direction Ydirection Z direction

(a) Displacement nephogram under working condition number 32



Main truss Secondary truss



Column Column supporting box girder

(b) Stress ratio distribution nephogram under No.9

Fig. 16: Displacement and maximum stress ratio in the stage of jacking to the highest position

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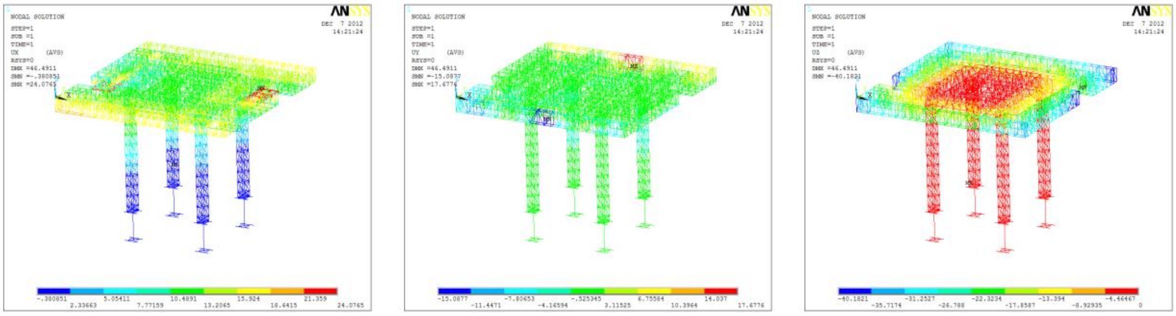
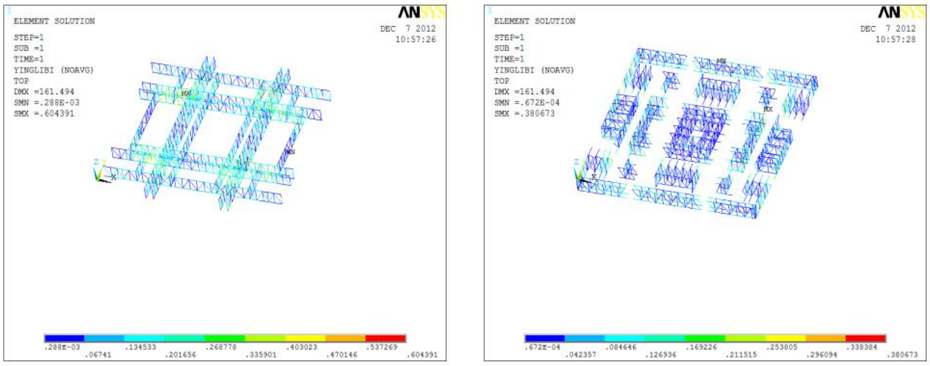
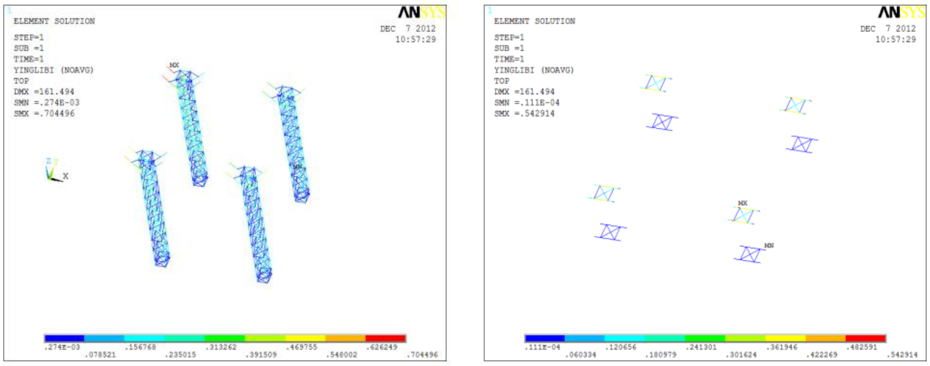


X direction Y direction Z direction

（a）Displacement nephogram under working condition number40



Main truss secondary truss



Column Column supporting box girder

(b) Stress ratio distribution map under condition number 15

Fig.17:The maximum displacement and stress ratio nephogram of the stage of concrete construction

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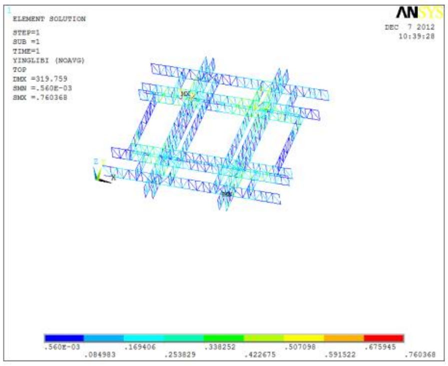
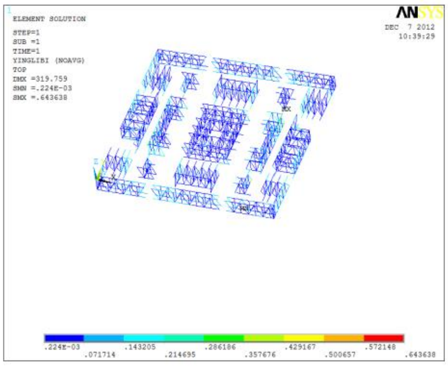
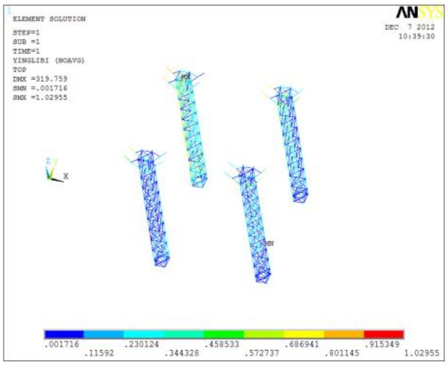
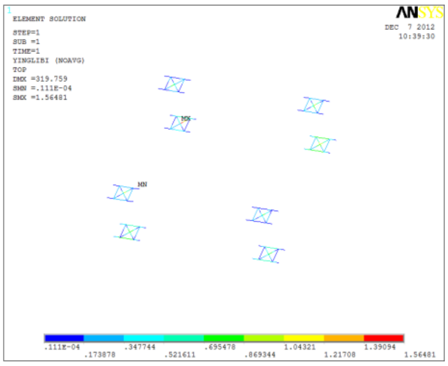



Main truss secondary truss

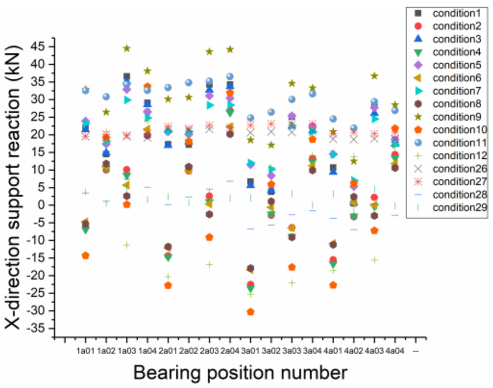



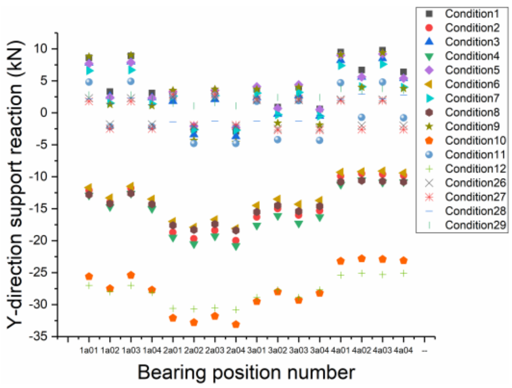
Column Column supporting box girder

Fig.18:Stress ratio distribution nephogram under working condition number 24

5.6 Bearing reaction

The load of the steel platform is transferred to the main structure of the concrete core tube through the column and the corbel support. There is a large stress concentration in the local area of the core tube concrete. Therefore, to check the local bearing capacity of the core concrete in the later stage, the constraint reaction force of all corbel support and lateral support is extracted. According to the basic combination bearing reactions under the condition of 1-29 are selected. Figure 19 - Figure 22 shows the distribution of the reaction force in the X, Y, Z directions of the bracket bearings under four columns under 1-29 working conditions.





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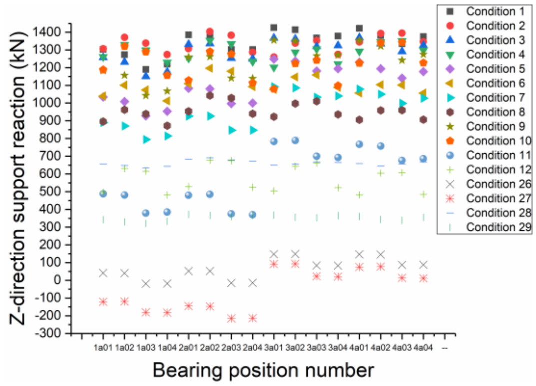


Fig.19: Reaction force of lower bracket support

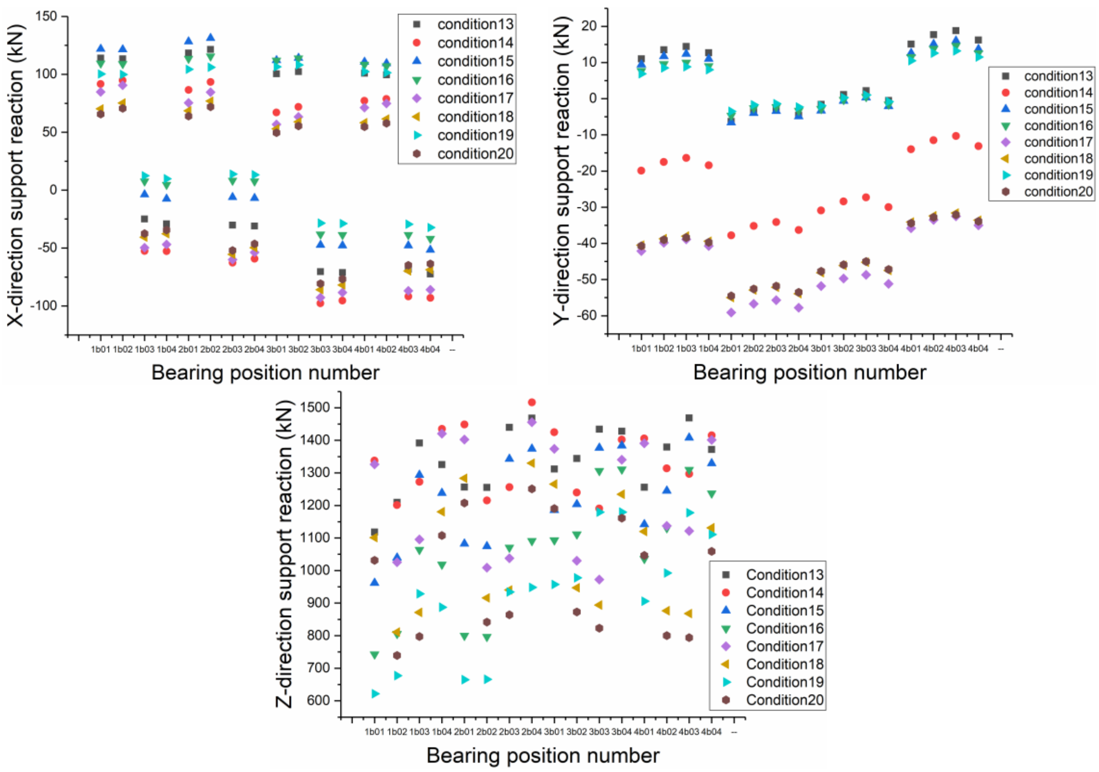
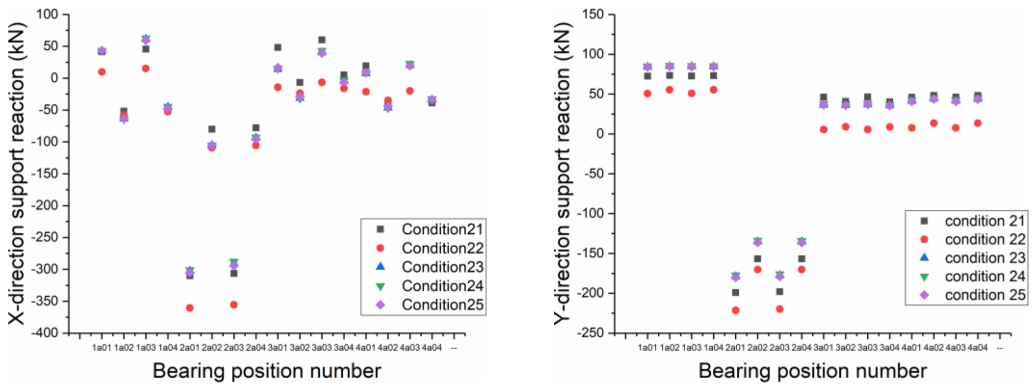


Fig. 20:Reaction force of upper bracket support



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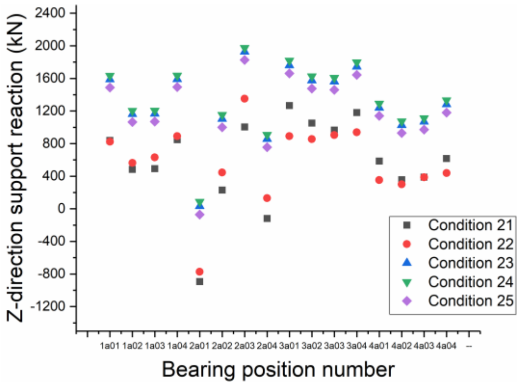

Fig.21:Reaction force of bracket support in single-piston rod sinking 100 mm

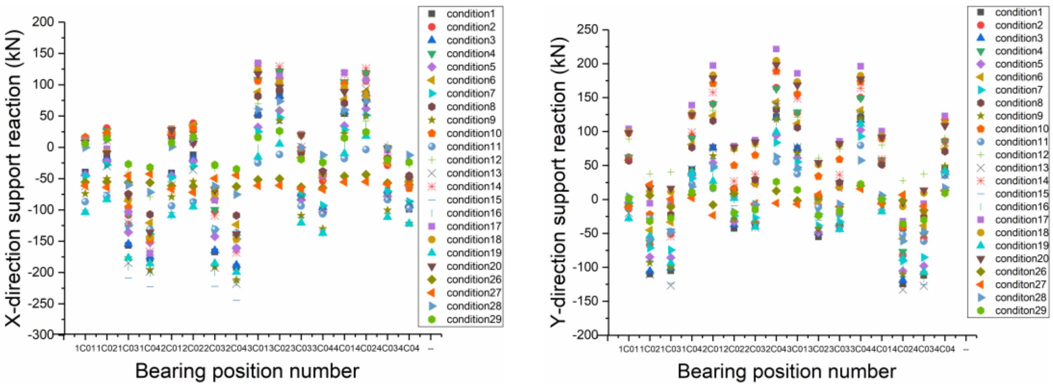

Fig. 22:Lateral bracket reaction force

5.7 Summary of checking results

Based on the above analysis, the following conclusions can be drawn.

5.7.1 The stage of jacking to the highest position

The stress ratio of the main truss is lower than 1.0, and the maximum stress ratio is 0.68, which occurs under working condition 10, and the strength meets the requirements. The stress ratio of the secondary truss is lower than 1.0, the maximum stress ratio is 0.43, which occurs in condition 1, the strength meets the requirements. The stress ratio of the column is less than 1.0, the maximum stress ratio is 0.73, which occurs in working condition 1, all in less than 0.5 except for the diagonal brace, the structural strength meets the requirements. The stress ratio of the box girder is lower than 1.0, the maximum stress ratio is 0.93 which occurs in working condition 1, where occurs in the central part of the column, the stress ratio is relatively high, and the corresponding nodes should be paid attention to. The buckling eigenvalue of condition 4 is the smallest, which is 2.24, greater than 1, and the overall instability will not occur.

The maximum displacement in X direction is 31.00 mm, which occurs in working condition 30; the maximum displacement in Y direction is 31.97 mm, which occurs in condition 33; the maximum

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displacement in Z direction is 47.56 mm, which occurs in working condition 36. The local fulcrum reaction force of the support system is close to 152 t, and the contact surface between the bracket and the support should be increased to meet the requirements. Lateral support X direction maximum support force is 21.2t, Y direction maximum support force 18.9 t.

5.7.2 The stage of concrete construction

The stress ratio of the main truss is less than 1.0, the maximum stress ratio is 0.65, which occurs in condition 17. The stress ratio of the secondary truss is less than 1.0, the maximum stress ratio is 0.42, which occurs in condition 13. The stress ratio of the column is lower than 1.0, the maximum stress ratio is 0.73, which occurs under condition 13. The stress ratio of the box girder is less than 1.0, the maximum stress ratio is 0.63, which occurs in working condition 14, the strength meets the requirements. Working condition 14 buckling eigenvalue is minimum, 2.18, greater than 1, the overall instability will not occur.

The maximum x-direction displacement is 24. 08 mm, which occurs in condition 40. The maximum displacement in Y direction is 25.46 mm, which occurs in condition 39. The maximum displacement in Z direction is 42.43 mm, which occurs in condition 44. The local fulcrum reaction force of the support system is close to 143 t. The maximum lateral support in X direction is 24.5 t, Y direction maximum support is 22.2 t.

5.7.3 The condition of single-piston rod sinking 100mm

The stress ratio of the main truss is less than 1.0, the maximum stress ratio is 0.76, which occurs in working condition 24, the strength meets the requirements. The stress ratio of the secondary truss is less than 1.0, the maximum stress ratio is 0.64, which occurs in working condition 24, the strength meets the requirements. The maximum stress ratio of the column is 1.03, which occurs in the second section of the column from top to bottom in working condition 24, and the structure is unsafe. The maximum stress ratio of the box girder is 1.57, which occurs in working condition 24, and the structure is unsafe. The buckling eigenvalue of condition 24 is the smallest, which is 1.80, greater than 1, and the overall instability will not occur.

The maximum displacement in Z direction is 303.0 mm, which occurs in condition 24. The local support reaction force of the support system is close to 200t, the maximum support force in the X direction of the lateral support is 31.7 t, and the maximum support force in the Y direction is 52.5 t. Therefore this phenomenon should be avoided.

XI. CONCLUSION

1. For the calculation of 'the stage of jacking to the highest position' and 'the stage of concrete construction' of the formwork system, the stress ratio is less than 1.0, and the eigenvalues obtained by eigenvalue buckling analysis are greater than 1.0. The structure is safe. For the calculation of the

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'single-piston rod sinking 100 mm' of the formwork system, the stress of the column and the supporting box girder of the column exceeds 1.0 under certain working conditions, the structure has potential safety hazards in this state.

Therefore, the safety of the jacking process of the formwork system is the key to the safety of the formwork system. In construction, the jacking accuracy should be guaranteed, and the monitoring in the jacking process of the formwork should be strengthened to ensure that the columns can be synchronously lifted to avoid the uncoordinated problem of the piston rod jacking. It is necessary to establish an effective management response mechanism to take measures in time for unexpected situations during lifting (such as cylinder oil leakage or column collision with core tube). The lifting process should be carried out strictly following the provisions at the moment of small wind level. During the lifting process, various live loads on the steel platform should be avoided.

2. Through multi-condition stress analysis, the reliability of connection joints such as column and box girder, jack and box girder, column and the lateral resisting device should be concerned. Under the relevant working conditions, the internal force of the jack of the lifting formwork system is large. It should be ensured that the jack of this part has sufficient bearing capacity.

3. The lateral resistant device in the middle of the column is installed, which is connected with the core tube of the main structure, and provides a certain lateral stiffness for the structure. To reflect the function of the anti-lateral device, the translational degrees of freedom of the corresponding nodes of the column along the horizontal direction are fully constrained. However, in practical work, when the core tube as the support of the lateral device is constructed to a certain height, it will have a large horizontal displacement itself. At the same time, the formwork system itself will also have horizontal displacement under horizontal load, and there will be a complex interaction between the core tube and the formwork. Therefore, the constraints imposed on the anti-side device cannot truly reflect this interaction. More careful research should be carried out on the collaborative work between the core tube and the mold base system.

4. The pre-arching steel platform to offset the displacement caused by gravity. Installation of steel platform should be considered In the installation process of steel platform. It is recommended to pay proper attention to the comfort of workers. From the bearing reaction calculation results, the maximum reaction force of a single corbel is nearly 1500kN. Therefore, special checking calculations should be carried out for the local pressure of concrete at the corbel in the structural design.

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