Analysis of the influence of erection of scissor braces on the bearing capacity of the wheel-buckled steel pipe supporting formwork system

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Abstract. The supporting formwork system as one of the most commonly used temporary structures in the process of building construction, its safety accidents frequently occur. The wheel-buckled steel pipe supporting formwork system is a new type of system developed under this background, and scissor brace as a kind of component in the system, have played an important role in improving the bearing capacity of the system. This paper uses ABAQUS finite element analysis software to establish an accurate simulation model of the foundational frame, and on the basis of this model, explores the influence of different erection methods of vertical and horizontal scissor braces on the overall bearing capacity of the frame. When erecting vertical scissor braces to reinforce the foundational frame, priority should be given to erect on the outer facades around the frame, and secondly consider satisfying the arrangement on the three facades. In the process of erecting horizontal scissor brace, the priority of the erected horizontal layer should be considered, that is the sub-bottom horizontal layer, sweeping rod horizontal layer, middle horizontal layer, sub-top horizontal layer, top horizontal layer.

1. Introduction
The main force-bearing structure in the wheel-buckled steel pipe supporting formwork system is the vertical pole, one wheel-buckled plate is welded every fixed module on the pole, insert the plugs welded on both ends of the horizontal rod into the wheel-buckled socket, so as to realize the connection between two poles. And for all kinds of supporting formwork systems, the erection of scissor braces is particularly important to the bearing capacity of the supporting formwork, because the scissor brace is the last support before the system is broken. The wheel-buckled plate does not have any special socket reserved for the installation of scissor braces, so the setting method of scissor braces of the wheel-buckled steel pipe supporting formwork draw on the method of fastener-type steel pipe supporting formwork, rotating fasteners are used to fix the scissor braces with the rods of the frame [1]. This paper is to research how the arrangement of the vertical scissor braces is combined in the four decades elevations to maximize the reinforcement to the frame, and to research when only one horizontal scissor brace can be set, which part of the frame has the best effect on the overall bearing capacity improvement, in order to achieve economic and reasonable goals.
2. Materials and methods

This research uses ABAQUS software to establish a simulation model of the foundational frame, and on the basis of this model, realizes the erection of vertical and horizontal scissor braces in various ways, uses the eigenvalue buckling analysis method to calculate the eigenvalues of the first-order buckling mode, in order to calculate the ultimate bearing capacity of the frame under each working condition, and the data obtained provides a basis for the subsequent analysis and summary of the law.

2.1. Foundational frame model establishment

The vertical or horizontal spacing of the vertical poles in the frame model are equal, both are 1200mm, the number of vertical or horizontal spans of the frame are 4. The height difference between two adjacent layers of horizontal rods in the frame is the step distance, is 1200mm, and the number of steps in the vertical direction of the frame is 4. The height from the bottom horizontal rod to the ground is the height of the sweeping rod, which is 400mm. The length of the vertical pole extending from the top horizontal layer is the length of the free end of the vertical pole, is 400mm. A plane model is established on the top of the frame and the grid is divided, it is set as a rigid body, and the plane model is also the acting surface of the vertical load.

The following basic assumptions are set. The rods are all straight rods with equal cross-section, ignoring the existence of the vertical rod sleeve, jacking and backing plate, and does not consider the influence of the initial defects of the rods. The vertical and horizontal rods intersect at one point, ignoring the eccentricity caused by the low accuracy of the vertical cross of two rods. The model does not consider the impact of foundational settlement, ignores all other horizontal loads such as earthquake loads and wind loads [2], regardless of the torsion effect of the frame body, and there is no restriction around the frame.

All materials in this model use Q235 ordinary steel, and the section of the steel pipes in this model is φ48mm×3.5mm.

| Elastic Modulus | Poisson's ratio | Yield Strength |
|-----------------|----------------|---------------|
| 2.06×10¹¹Pa     | 0.3            | 2.35×10⁸Pa    |

| Outer diameter | Wall thickness | Moment of inertia | Cross-sectional area | Section modulus | Density | Radius of gyration |
|----------------|----------------|-------------------|----------------------|-----------------|---------|-------------------|
| 0.048m         | 0.0035m        | 1.3×10⁻⁷m⁴       | 4.89×10⁻⁴m²         | 5.08×10⁻⁴m³    | 7.85×10³ kg/m³ | 1.58×10⁻²m       |
The connection between the pole and the ground is set as a hinged joint, which is simulated by a fixed hinged support [3]. The connection between the vertical pole and the horizontal pole is set as a semi-rigid connection, and the rotational stiffness is 30kN-m/rad [4]. The connection between the top of the pole and the template is set as a hinged joint. The scissor braces and the horizontal rod or the vertical rod are connected by a rotating fastener, and the connection mode is set as a hinged joint.

2.2. Setting method of scissor braces

Mark the established foundational frame model as MJ-0. On the basis of this model, the vertical and horizontal scissor braces can be erected, and the methods are as follows.

| Model number | Setting method (Based on the original frame MJ-0) |
|--------------|--------------------------------------------------|
| MJ-1         | Set one vertical scissor brace on one of the four facades |
| MJ-2         | Set two vertical scissor braces on two opposite of the four facades each |
| MJ-3         | Set two vertical scissor braces on two adjacent of the four facades each |
| MJ-4         | Set three vertical scissor braces on three of the four facades each |
| MJ-5         | Set four vertical scissor braces on four of the four facades each |
| MJ-6         | Set one horizontal scissor brace on the sweeping rod horizontal layer |
| MJ-7         | Set one horizontal scissor brace on the sub-bottom horizontal layer |
| MJ-8         | Set one horizontal scissor brace on the middle horizontal layer |
| MJ-9         | Set one horizontal scissor brace on the sub-top horizontal layer |
| MJ-10        | Set one horizontal scissor brace on the top horizontal layer |

2.3. Analysis method of frame model

This article uses the buckling analysis method to analyze the frame model. Eigenvalue buckling analysis can generate multiple buckling modes at the same time, but the first-order buckling mode has the greatest impact on the entire frame structure [5]. As to this model, the vertical rods are compressed rods, when the entire system is in an unstable state, the corresponding axial pressure is the overall stable bearing capacity of the stent. A vertical load of 1N is applied to the main node of the rigid body on the top of the frame, at this time the load will be uniformly applied to the platform through the rigid body element, to realize the effect of applying uniformly distributed load. The linear elastic buckling analysis in ABAQUS is used to solve the eigenvalues of the first-order modal linear buckling of the frame, the calculation method for the critical load is to multiply the eigenvalues of this order and the load in the model and the number of applied loads in the model. The load which is set in the model is 1N, and the number of the load is 1, so the value of the first-order critical load is the bearing capacity value of this model.
3. Results and Discussion

Table 4. Bearing capacity value of scissor bracing control group.

| Model number | MJ-0  | MJ-1  | MJ-2  | MJ-3  | MJ-4  | MJ-5  |
|--------------|-------|-------|-------|-------|-------|-------|
| Bearing capacity | 739.2 kN | 741.5 kN | 743.7 kN | 791.9 kN | 1185.2 kN | 1216.7 kN |

Compared with the bearing capacity of foundational frame MJ-0, the bearing capacity of MJ-1 has increased by 0.31%, that of MJ-2 has increased by 0.61%, that of MJ-3 has increased by 7.13%, that of MJ-4 has increased by 60.33%, and that of MJ-5 has increased by 64.60%. It can be seen that adding vertical scissor braces on one of the four sides and on two opposite sides have minimal improvement, but when adding vertical scissor braces on two adjacent sides, the value increases a little. Under two conditions with vertical scissor braces on three sides or on four sides, their values have a great leap, both more than 60%. Compared with the bearing capacity of MJ-0, the bearing capacity of MJ-6 has increased by 0.55%, that of MJ-7 has increased by 0.68%, that of MJ-8 has increased by 0.51%, that of MJ-9 has increased by 0.23%, and that of MJ-10 has increased by 0.01%. Setting up horizontal scissor braces can improve the overall bearing capacity of the frame. The bearing capacity of the frame model from large to small is MJ-7, MJ-6, MJ-8, MJ-9, MJ-10, that is the sub-bottom horizontal layer, sweeping rod horizontal layer, middle horizontal layer, sub-top horizontal layer, top horizontal layer.

4. Conclusions

Through research, it proves that when erecting vertical scissor braces, if objective conditions permit, it should be given priority to set up vertical scissor braces on the outer facades to achieve the best reinforcement effect. If it cannot be achieved, vertical scissor braces should be erected on three facades. When vertical scissor braces can be erected on only two facades, the lifting effect when erecting two adjacent facades is better than that of two opposite facades. When laying horizontal scissor braces on the foundational frame, priority should be given to ensure that horizontal scissor braces are set up at the bottom, lower middle, middle, upper middle, and top of the frame body. If it cannot be met, the priority of the horizontal layer which will be erected should be considered, that is the sub-bottom horizontal layer, sweeping rod horizontal layer, middle horizontal layer, sub-top horizontal layer, top horizontal layer. For the erection of vertical scissor braces, the situation of erecting on only one elevation should be avoided, and for the erection of horizontal scissor braces, the situation of erecting in only one horizontal layer should be avoided, because these two conditions do not greatly improve the overall bearing capacity of the frame, so that it can cause unnecessary waste.

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