The Design and Load Experiment Study on Corbel of Moving Sinking hanging Scaffold for Ultra-deep Shaft

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\textbf{Abstract.} Aiming at the difficulty of suspending the hanging scaffold of ultra-deep shafts, the corbel suspension device was designed by analyzing the needs of the moving type sinking hanging scaffold, and the strength check calculation was carried out to theoretically verify that the corbel can withstand the pressure of the sinking hanging scaffold. At the same time, through the no-load and heavy-load experiment of the moving type sinking hanging scaffold, the working status, force and overall load of each corbel of the moving type sinking hanging scaffold were monitored in real time. According to the experiment, it is concluded that the corbels can meet the conditions of use under the most unfavorable working conditions, which further improves the structural design theory of the sinking hanging scaffold and ensures the safe construction of the moving type sinking hanging scaffold.

\textbf{Keywords.} moving type; sinking hanging scaffold; corbel; load experiment

1. Introduction

In construction of ultra-deep vertical shafts in coal mines, suspension of sinking equipment is the key that restricts the construction of deep shafts. The moving type sinking hanging scaffold developed by the research group can achieve moving lift of the deep shaft, so that fewer suspension wire ropes are required for shaft sinking process, thus lowering load of the shaft derrick. With simple layout, the sinking equipment can solve the problem of difficult suspension of hanging scaffold in ultra-deep shaft [1-3]. Corbel, as the main hanging force-bearing device of moving type sinking hanging scaffold, supports the weight of the sinking hanging scaffold, its upper equipment and the suspended template. The overall load is transmitted to the multiple beam nest boxes pre-buried in the wall through multiple corbels. Through expansion and contraction control of the corbel, vertical lifting movement of the sinking hanging scaffold is possible along the shaft wall, thereby completing cliff building. Moreover, the corbel expansion and contraction control and its strength directly affect safety of the integral sinking hanging scaffold. In this paper, corbel design and load experiment of sinking hanging scaffold are studied.

2. Corbel suspension device and structure of moving type sinking hanging scaffold

The moving type sinking hanging scaffold is composed of an upper plate, a reinforcement ring, a stepping plate, a lower plate, a corbel, a column, a cylinder (step and corbel), and a control system [4]. Where, the corbel of the moving type sinking hanging scaffold is installed under the upper plate and
stepping plate, and 8 are arranged along the ring direction. Control of its expansion and contraction can complete the stepping function of the overall hanging scaffold. After calculation, it is determined that the corbel adopts a combined box structure with a cross-section of 200mm*260mm. Each corbel has consistent structure, as shown in Figure 1. To facilitate expansion and contraction of the corbel, a corbel hydraulic cylinder is installed in the box. A plurality of bolt holes are arranged at the corbel of the moving type sinking hanging scaffold in the outward direction from the center of the hanging scaffold to fix the corbel seat, which can be adapted to construction of shaft of different diameters.

![Figure 1. Corbel of moving type sinking hanging scaffold](image1)

![Figure 2. Layout of the corbel and the stepping cylinder](image2)

The upper plate corbels and stepping corbels are welded under the hanging scaffold. The expansion and contraction direction and the stepping cylinder position are shown in Figure 2. The corbels are arranged in positions other than the main column, stepping cylinder, bell mouth, part of the wire rope, etc. Considering its future use as permanent facilities, the embedded box reserved on the well wall can be used, and the eight corbels are symmetrically arranged around the center point.

3. Corbel strength check of moving type sinking hanging scaffold
3.1 Main technical parameters

Hanging scaffold weight: 60t; weight on plate: 30t; template weight: 30t; number of corbels: 8.

The total weight on the corbel \( m = (60 + 30 + 30) \times 10^3 \text{kg} = 12 \times 10^4 \text{kg} \).

The force on the corbel \( F_{\text{total}} = mg = 12 \times 10^4 \times 10 = 12 \times 10^5 \text{N} \).

There is uneven force on the corbel when the moving type sinking hanging scaffold is working [5]. Considering corbel imbalance, unbalance coefficient is chosen as 2. Then, corbel strength is calculated for 4 corbels, and the force on each corbel is \( F_{\text{Corbel}} = F_{\text{total}} \div 4 = 12 \times 10^5 \div 4 = 3 \times 10^5 \text{N} \).

3.2 Corbel strength calculation

3.2.1 Draw calculation diagram

The corbel is welded with Q345B steel plate, and its sectional view is shown in Figure 3.

![Figure 3. Sectional view of corbel](image)

The corbel can be simplified as a simply supported beam in operation, and the bearing force is shown in Figure 4.

![Figure 4. Corbel force diagram](image)

3.2.2 List shear force equation and bending moment equation

i. Calculate support reaction

\[
\sum M_A(F) = F_{\text{Corbel}} \cdot AD/2 + F_{RB} \cdot AB = 0
\]

Substitute the data into equation (1) and get: \( F_{RB} = 75kN \)

\[
\sum F_y = F_{RA} + F_{RB} - F_{\text{Corbel}} = 0
\]

Substitute the data into equation (2) and get: \( F_{RA} = 225kN \)

ii. List shear force equation and bending moment equation, take any section \( x_1 \), then there is

For AD section:

\[
F_{Q1}(x) = F_{RA} - qx_1 = 225 \times 10^3N - 1.5 \times \frac{10^6N}{m} \cdot x_1
\]

\[
= 2.25 \times 10^5N - 15 \times \frac{10^6N}{m} \cdot x_1 (0 < x_1 < 200mm)
\]

\[
M_1(x) = F_{RA} \cdot x_1 - qx_1 \frac{x_1}{2} = 225 \times 10^3N \cdot x_1 - 1.5 \times \frac{10^6N}{m} \cdot \frac{x_1^2}{2}
\]

\[
= 2.25 \times 10^5N \cdot x_1 - 7.5 \times \frac{10^6N}{m} \cdot x_1^2 (0 \leq x_1 \leq 200mm)
\]

For BD section:
\[ F_{Q2}(x) = F_{RA} - F_{Corbel} = 225 \times 10^3 N - 3 \times 10^5 N = -75 \times 10^3 N \quad (200mm \leq x_2 \leq 400mm) \]  
\[ M_2(x) = F_{RA} \cdot x_2 - F \cdot BC = 225 \times 10^3 N \cdot x_2 - 3 \times 10^5 N \times 300 \times 10^{-3} m \]  
\[ = 225 \times 10^3 N \cdot x_2 - 90 \times 10^3 N \cdot m (200mm \leq x_2 \leq 400mm) \]  
\[ (5) \]  
\[ (6) \]

3.2.3 Draw shear force diagram and bending moment diagram

Draw the corresponding shear force diagram and bending moment diagram from the above equations, as shown in Figure 5 and Figure 6.

iii. Check using normal stress intensity

From the bending moment diagram, there is
\[ M_{max} = 45 \times 10^3 N \cdot m \]  
\[ \sigma_{max} = \frac{M_{max}}{W_z} = \frac{4.5 \times 10^4 \times 10^3}{926976} \quad MPa = 46MPa < [\sigma] \]  
\[ (7) \]  
\[ (8) \]  
\[ (9) \]

Therefore, a corbel of 260mm*200mm is strong enough.

4. Load experiment

To fully understand working performance of hydraulic hanging scaffold, especially reliability of hanging scaffold lifting and safety control technology, it is necessary to conduct ground experimental study on its overall work performance. At the same time, actual measurement of mechanical properties of the hanging scaffold structure can provide a comprehensive understanding of force bearing status of the hanging scaffold structure under various working conditions. Combining structural design analysis and research of the hanging scaffold, the structural design theory of the sinking hanging scaffold can be further enriched, thus ensuring safe construction of the hydraulic hanging scaffold. Li Shushan et al. [6] studied calculation method of shear capacity of the high-strength steel fiber concrete corbel through the shear performance test. There has been no precedent of study on the corbel load test of sinking hanging scaffold.

The sinking hanging scaffold is a special steel structure for mines. The hanging scaffold is mainly
made of section steel, steel pipe and steel plate connected by welding or bolts. To measure bearing force of the structure under various working conditions, an appropriate test method should be selected based on fore-bearing nature of the main structure of the hanging scaffold. Actual measurement of the total load of the hanging scaffold requires installation of load sensors on beam nests of the 16 corbels on the upper plate and step plate. The bearing force of the corbels can be measured through the strain gauge to obtain the actual load of the working hanging scaffold on the well wall.

4.1 Test system and main equipment

Working condition test of the sinking hanging scaffold is arranged on the ground test frame, and the load is triggered by the corbel force on the test frame when the sinking hanging scaffold runs [4]. According to the actual working conditions of the sinking hanging scaffold in ground test and considering its working status in the ground test, uniform equipment should be chosen for mechanical performance testing. To this end, resistance strain measurement system is adopted, whose main testing system and equipment are shown in Figure 7.

![Figure 7](image_url)

**Figure 7.** The mechanical performance test system and equipment for hanging scaffold

Corbel measuring points are arranged mainly based on bearing force of the corbel, and a load sensor is directly installed inside the corbel nest to test the load on the corbel. According to the column corbel nest structure, the selected resistance strain load sensor is arranged as shown in Figure 8.

![Figure 8](image_url)

**Figure 8.** Load sensor arrangement in the corbel beam nest

1—load sensor; 2—positioning block; 3—load transmission element; 4—bearing column

When placing sensors in the corbel beam nest, it is necessary to modify the original structure of the hanging scaffold test frame column. In addition, it is necessary to specially process and manufacture load transmission elements. This work needs to be carried out simultaneously with the processing and manufacturing of the test frame. In addition, holes should be made at suitable positions on the test
frame beam nest to facilitate the installation and laying of sensors and test cables.

4.2 The ground industrial test is divided into no-load test and heavy-load test data analysis

The actual measurement results of bearing force of the sinking hanging scaffold corbel are shown in Figure 9. As the corbel contacts the test frame beam nest, the corbel force increases to a certain value from the initial zero value. At this time, the corbel is in contact with the beam nest, but the sinking hanging scaffold weight is borne by the 16 corbels of the stepping plate and the upper plate. With the further movement of the stepping cylinder, corbel has gradually increased contact with the beam nest, and the corbel’s bearing force is gradually increased until finally reaching a constant. In this way, the hanging scaffold supports alternate movement of corbel.

![Figure 9. Force bearing process of the corbel](image)

A total of 3 tests were monitored for force bearing status of the hanging scaffold corbel, as shown in Figure 4. Each corbel supports about 85 tons, which is basically consistent with the calculated weight of the hanging scaffold and template. The 8 corbels support about 14.5 tons at the maximum and about 2.0 tons at the minimum. The corbel bearing force is uneven in a way related to the grid structure of the hanging scaffold and the horizontal position of the beam nest, which is in line with expectations (Figure 10).

![Figure 10. Bearing force of the corbel](image)

5. Conclusion:
- Bearing force analysis and verification are performed for corbel design of the sinking hanging
scaffold. It is theoretically verified that the corbel can withstand the pressure of the sinking hanging scaffold, which provides theoretical basis for the manufacture of sinking hanging scaffold.

- Ground bearing force test is carried out on corbel of the sinking hanging scaffold to monitor the working status, bearing force and overall load of each corbel of the sinking hanging scaffold in real time. For corbel of the developed sinking hanging scaffold, its bearing force is verified in real object test. It is concluded that the corbel can meet conditions of use under the most unfavorable conditions, which further improves structural design theory of the sinking hanging scaffold and guarantees its safety construction.

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