Original Research Article

Analysis and Research on the Surrounding Rock Stability of Deep and Large Working Shaft of Long Shaft Deep Well Pump

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Abstract: The design of deep and large shaft excavation and support is not only related to the safety of personnel and machinery during construction, but also directly affects the safe and stable operation of the long-axis deep well pumping pump station in the later period. Therefore, the design of the surrounding rock support of the working shaft is very important. This paper makes full use of the advantages of Midas GTS NX geotechnical finite element analysis software and FLAC3D finite element analysis software to analyze and calculate the primary and secondary support of deep and large working shafts, verifies the rationality of the primary support measures, and provides specific design parameters for the secondary support design, which has a good practical guiding significance for the actual engineering design.

Keywords: Vertical shaft; Stability of surrounding rock; Force analysis; Midas.

1. Introduction

The working shaft is an essential structural component of a long axis deep well pump pumping station that extracts water from underground. If the number of units is large and the head is large, it will cause the working shaft to have a “deep and large” structure with a large cross-sectional size, which poses a certain test to the stability of the engineering structure. Vertical shafts have been applied in many industries, and scholars at home and abroad have conducted extensive research on the design, construction, and surrounding rock stability of vertical shafts[1]. Arild P conducted research on the design of unlined structure water diversion shaft engineering; Auld A conducted research on the structural form and construction methods of vertical shafts in deep and large coal mines; Danye Hiroshi et al. summarized the construction technology of the ventilation shaft of the Anfang Highway Tunnel located in the National Park area; Rehdocksander M provided an overview of the design of the vertical shaft for the New Santa Fe railway tunnel; Lv Kangcheng and others discussed the selection of design schemes and construction methods for vertical and inclined shafts in highway tunnels; Chen Youjie summarized the design technology of ultra deep copper mines. Due to the different geological conditions, uses, operating conditions, and service life of ventilation shafts in industries such as transportation, hydropower, and coal mining, the construction technology focus of different industries also varies. However, with the rapid development of science and technology, the design and construction experience of shaft engineering in different industries is also worth learning from[2-5].

By summarizing the design and construction techniques of different industries, this article will combine the geological conditions, operating conditions, construction steps, and other factors of the long axis deep well pump working shaft engineering of a water diversion project in Yunnan Province. It will fully utilize the advantages of Midas GTS NX geotechnical finite element analysis software and FLAC3D finite element analysis software to analyze and calculate the primary and secondary support of the deep and large working shaft shaft, Verified the rationality of the primary support measures and provided specific design parameters for the secondary support design, in order to better apply the research results to specific engineering designs.

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2. Project Overview

The pumping station of this project is located on a gentle slope next to the road on the left bank of a certain river valley, with a ground elevation of EL.1966.000m. It consists of two levels of pumping stations, including underground cylindrical vertical shaft inlet water tank, primary pump station main room, secondary pump station main room, underground inlet water tank, ground main pump room, electrical auxiliary plant building, and other buildings. The inner diameter of the cylindrical vertical shaft (inlet pool) of the first stage pump station is 14m. Above the vertical shaft is the main engine room of the first and second level pump stations, with a floor elevation of 1962.300m. On the east side, 8 deep well axial flow pump machines (6 in use and 2 as backup) are arranged, and the effluent finally enters the shared water tank. Four centrifugal pump machines (3 in use and 1 as backup) are arranged on the west side to take water from the shared pool.

The rectangular shared water tank type is determined to be semi underground. The bottom elevation is 1962.300m, the lowest operating water level is 1968.400m, the highest and design operating water level is 1971.900m, and the effective volume is 1050m^3.

The primary and secondary pump stations share the main pump room and installation room. The bottom plate elevation of the installation room is 1966.3m, and the length and width dimensions are 18.1m×14m. The main pump room adopts a reinforced concrete truss structure, with a total size (length, width, height) of 69.6m ×20.5m×11m. (Figure 1)

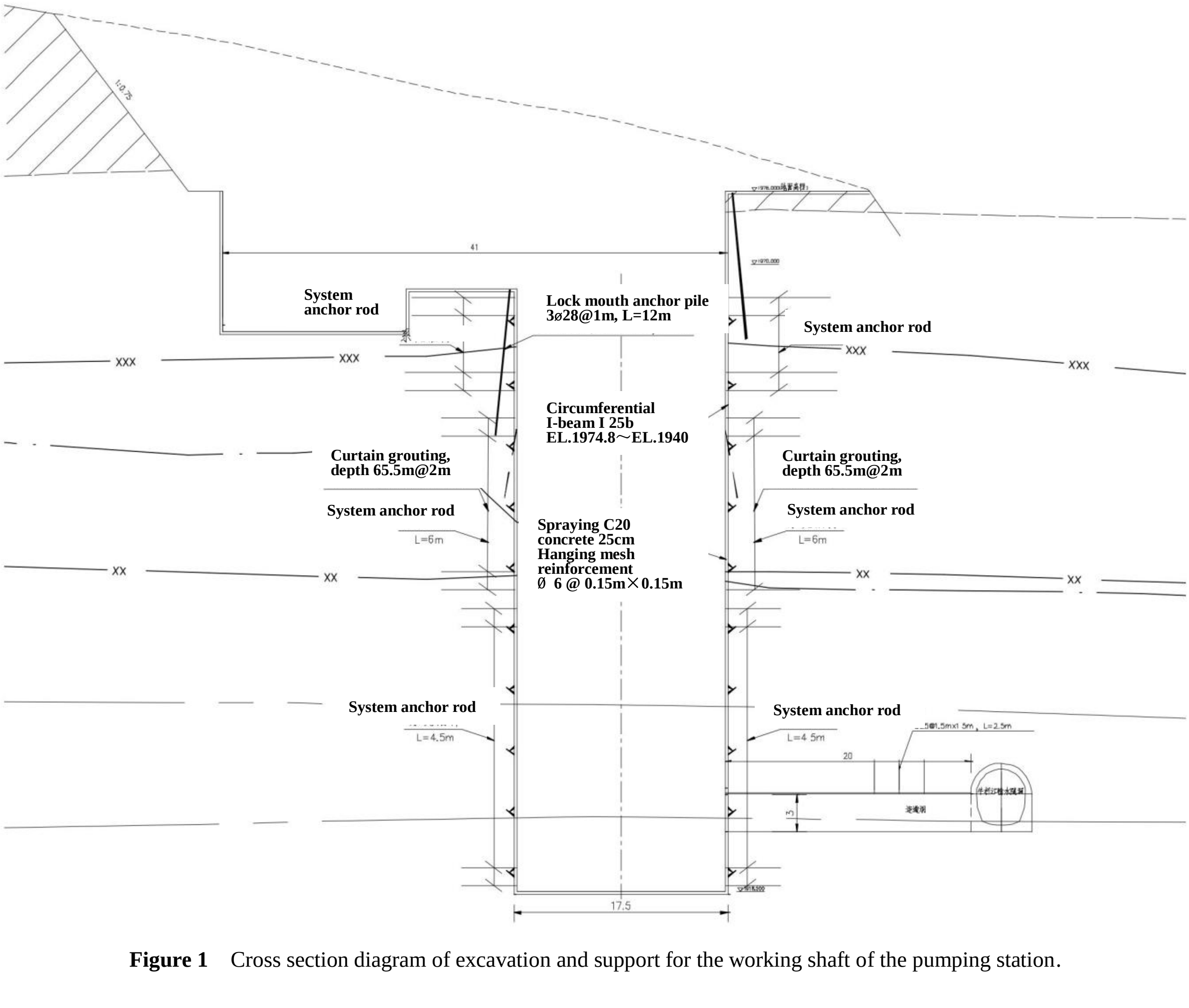


Figure 1 Cross section diagram of excavation and support for the working shaft of the pumping station.

3. Support Parameters

The shaft of the first level pump station was excavated from the foundation pit elevation of 1960.700m in the main engine room to an elevation of EL.1918.200m. Two curtain grouting holes are arranged around the wellbore, with a spacing of 2m and a depth of 47.5m.

The excavation diameter and support parameters of the wellbore are divided into three sections from top to bottom: EL.1960.70m~EL.1950.70m, with an excavation diameter of 19.3m. Before excavation, lock the wellhead with anchor pile support, and the parameters of the anchor pile are 3ø32@1m L=12m, exposed 0.4m, 2.5m away from the wellhead. Consolidation grouting is arranged for excavation of the shaft wall, with a spacing of between grouting holes 3m×3m, with holes penetrating 8.0m into the rock, arranged in a plum blossom shape. The support method for the wellbore wall is hanging net, spraying anchor, and locking reinforced concrete wall protection. The support parameters are: system anchor rod ø28, L= 9m@1.5m × 1.5m, exposed 0.5m, arranged in a plum blossom shape; Spray C20 concrete with a thickness of 0.15m; Hanging steel mesh ø6@0.15m× 0.15m; The reinforced C25 concrete for the retaining wall lock adopts a thickness of 1m.

The section from EL.1950.70m to EL.1930.00m has an excavation diameter of 17.5m. Consolidation grouting is arranged for excavation of the shaft wall, with a spacing of between grouting holes3m×3m, with holes penetrating 8.0m into the rock, arranged in a plum blossom shape. The wellbore support method adopts circumferential I-beam+hanging net+spray anchor support. The support parameters are: circumferential I-beam support: i25b@1m ; System anchor rod ø28, L= 6m@1.5m×1.5m, exposed 0.5m, arranged in a plum blossom shape; Spray C20 concrete with a thickness of 0.25m; Hanging steel mesh ø6@0.15m×0.15m.

EL.1930.00m~EL.1918.20m section, excavation diameter 17.3m. The wellbore support method adopts hanging net+spray anchor support. The support parameters are: system anchor rod ø28, L= 4.5m@1.5m×1.5m, exposed 0.5m, arranged in a plum blossom shape; Spray C20 concrete with a thickness of 0.15m; Hanging steel mesh ø6@0.15m×0.15m.

Anchor piles are arranged on the bottom plate, with the following parameters: 3ø32@3m×3m, L=9m, 6.67m into the rock, arranged in a plum blossom shape.

Table 1 Table of primary support parameters for working vertical shafts.

Part	Support parameters
Wellbore EL.1960.70m ~Wellbore EL.1950.70m	System anchor rod: C28, L= 9m@1.5 × 1.5m, exposed 0.5m plum blossom layout
	Shotcrete: C20, thickness 0.15m
	Hanging steel mesh: q6@0.15m × 0.15m
	Locked reinforced concrete retaining wall: C25 with a thickness of 1m
	Consolidation grouting: @ 3.0 × 3.0m into the rock for 8m, arranged in a plum blossom shape
Wellbore EL.1950.70m ~Wellbore EL.1930.00m	System anchor rod: C28, L= 9m@1.5 × 1.5m, exposed 0.5m plum blossom layout
	Circular I-beam support i25b@1.0m
	Shotcrete: C20, thickness 0.15m
	Hanging steel mesh: q6@0.15m × 0.15m
	Locked reinforced concrete retaining wall: C25 with a thickness of 1m
	Consolidation grouting: @ 3.0 × 3.0m into the rock for 8m, arranged in a plum blossom shape

4. Calculation Parameters and Operating Conditions

Due to the large scale of the project wellbore and the importance of safety, three-dimensional finite element analysis is used for the stability analysis of the surrounding rock of the wellbore in this stage. The calculations were carried out using Midas GTS NX geotechnical finite element analysis software and FLAC3D finite element analysis software. The physical and mechanical parameters of each rock layer in the surrounding rock were provided by geological reports. The final calculation parameters are shown in Table 2.

Table 2 Calculation of surrounding rock material parameters.

Rock layer	Thickness /m	Severe /kPa	Elastic modulus/GPa	Poisson's ratio	Internal friction angle	Cohesion force/MPa
Strong solubility	18	24	2	0.35	0.3	0.05
Weakly soluble	27	26	3	0.3	0.7	0.25
Weixin	105	27	6.5	0.25	0.85	0.35

The calculation conditions are divided into construction conditions and operating conditions. During the construction period, the stability of the surrounding rock excavation is mainly analyzed in a step-by-step manner. The operating conditions mainly calculate the stress and reinforcement of the inner lining concrete structure.

The construction conditions mainly simulate the excavation and support process of the vertical shaft, and the solid units of each layer of rock mass are balanced according to the rock mass parameters and the displacement is reset to zero; Crown beam (2.5m) at the top×1.5m) Construction; Layered excavation depth of 1.5m; Hanging nets and spraying anchors, and using I-beam internal supports for construction; Then excavate 1.5m in each cycle until the vertical shaft excavation is completed.

5. Calculation Model

Calculate model size 300m×300m×150m, divided into 62500 units. The calculation model and results are shown in Figures 2 and 3.

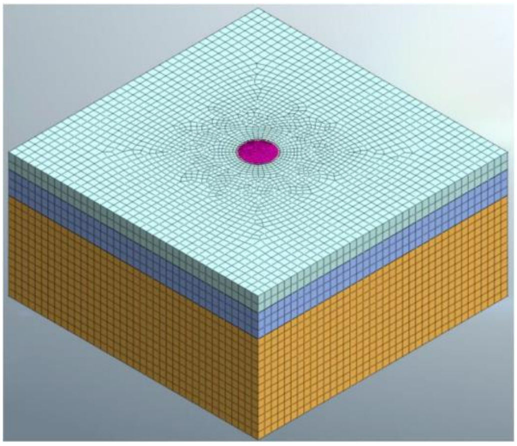
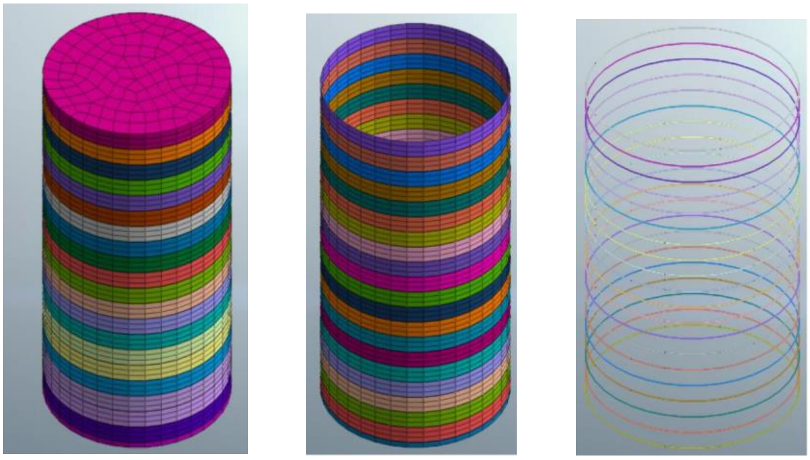


Figure 2 Calculation model diagram (1).



(a) Excavation of rock mass **(b) Shotcrete** **(c) I-beam**

Figure 3 Calculation model diagram (2).

6. Calculation Results

We used Midas GTS NX geotechnical finite element analysis software and FLAC3D finite element analysis software for analysis and calculation.

(1) The calculation results of the displacement of the cylinder wall and the stress of the steel support after a single support are shown in Figures 4 and 5.

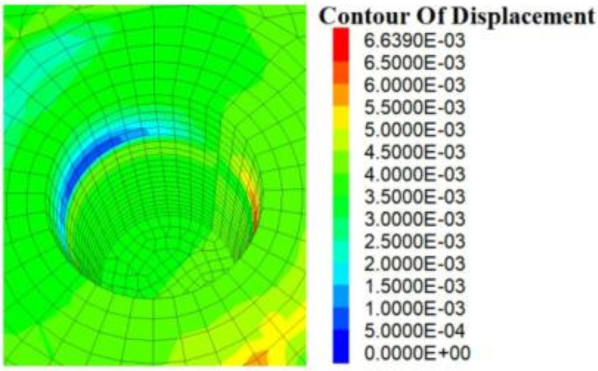


Figure 4 Cloud map of surrounding rock displacement with support measures.

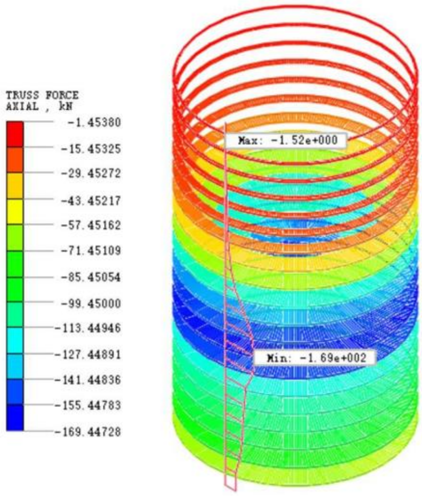
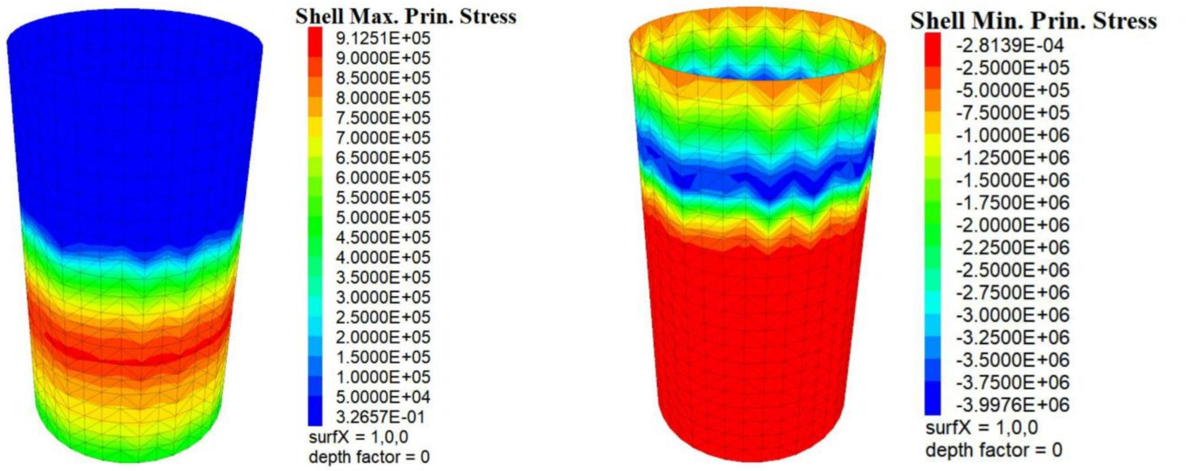


Figure 5 Stress cloud map of I-beam.

According to the cloud map calculated in Figure 4, the displacement of the surrounding rock is relatively large at the boundary between the upper strongly weathered and weakly weathered rock layers, with a maximum displacement value of 6.6mm, which is within the allowable deformation range. The stability of the tunnel wall structure under a single support measure meets the design requirements.

According to the stress calculation results of I-beam in Figure 5, the I-beam structure mainly bears compressive stress, with a maximum stress value of 169kN, which also occurs at the boundary between strongly weathered and weakly weathered rock layers in the upper part. The average stress value of the I-beam between the wellbore EL.1950.70m and the wellbore EL.1930.00m is 85KN, indicating that the I-beam support structure has been fully utilized. However, for the wellbore EL.1950.70m and below, the I-beam support structure can be omitted to save investment.

(2) The stress calculation results of the secondary concrete lining are shown in Figure 6.



(a) Minimum principal stress cloud map
Maximum value: 0.91MPa (maximum tensile stress)

(b) Maximum principal stress cloud map
Maximum value: -4MPa (maximum compressive stress)

Figure 6 Stress cloud map of wellbore lining structure.

The cloud chart of the calculation results in Figure 6 shows that due to the large displacement at the boundary line of the rock layer, the lining structure is mainly subjected to circumferential compression, with a maximum compressive stress of no more than 4.0 MPa, and a tensile stress of no more than 0.2 MPa appears at the locking mouth of the second wellhead. The structural design of the wellhead, excluding the setting of locking concrete is reasonable.

The rock mass below EL.1950.00m in the lower shaft has good quality and mainly bears external water loads. The lining structure is mainly subjected to vertical tension, with local tensile stress exceeding 1.0MPa. Therefore, it is necessary to strengthen and reinforce the concrete lining between EL.1950.00m and EL.1930.00m in the shaft.

According to the cloud diagram of the calculation results of the shaft lining, the reinforcement of the shaft lining can be preliminarily proposed as shown in Table 3.

Table 3 Preliminary recommended reinforcement values for shaft lining.

Part	Vertical stressed steel bars	Circumferentially stressed steel bars	Remarks
Wellbore EL.1950.00m and above	C20@200	C25@200	
Wellbore EL.1950.00m~EL.1930.00m	C22@200	C28@150	
Wellbore below EL.1930.00m	C22@200	C28@200	

7. Conclusion and Suggestions

Based on the displacement and stress calculation cloud map results, the following conclusions can be drawn:

(1) The maximum displacement value of the surrounding rock under the primary support of the deep and large vertical shaft in this project occurs at the boundary between strong and weak weathered rock layers in the upper part, with a maximum displacement value of 6.6mm. The maximum displacement value meets the structural design requirements. However, due to the low degree of weathering of the surrounding rock and the constraint of the bottom plate of the shaft, the displacement value of the surrounding rock at this position is not significant.

(2) The stress calculation results of the I-beam for the primary support of the deep and large working shaft in this project indicate that the stress value of the I-beam in the middle of the shaft is relatively high, and the I-beam support structure has been well utilized. The lower stress value is relatively small, which can be replaced by strengthening the secondary lining. The I-beam support measures for the lower structure of the shaft can be taken.

(3) The calculation of secondary concrete lining stress shows that the maximum tensile stress of concrete lining also occurs in the middle of the shaft, but the maximum stress calculation value is around 1.0 MPa, mainly due to the combined effect of surrounding rock pressure and external water pressure. The low stress of the lining at the bottom of the well is mainly due to the constraint effect of the bottom plate. The design of concrete lining structure is relatively reasonable. This also indicates that the stress calculation results of concrete lining are reasonable and have a good distribution pattern, which plays a good guiding role in engineering design.

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