Analysis on surrounding rock masses' stabilities for underground cavern group

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Abstract. Surrounding rock masses' stabilities of cavities and crane beams of the hydropower station were studied using $FLAC^{3D}$. Results show that, due to the large excavation span and height, the main powerhouse and tail water hole have larger plastic zones after the excavation, and the same as 1 # unit and 2 # unit affected by the alteration belt; after the excavation, the plastic zones of the main powerhouse and main transformer hole appear connected and it is reduced obviously after support; from the comprehensive consideration of cavities' stabilities and economic benefits, scheme 3 (bolts and nineteen cables) is the optimal supporting plan, apt to ensure the overall stability of surrounding rock; displacements of surrounding rock and bolts' axial forces of crane beams are caused mainly by excavation, while the parts caused by wheel pressure are small. This offers a reliable basis for stability analysis and supporting design for underground cavern group.

Introduction

The hydropower station is located in Sichuan province, China. Its total installed capacity is 219.7 million m^3. The underground powerhouse systems are mainly composed of main powerhouse, main transformer hole, tail water hole, bus tunnel and tail pipes. The main powerhouse's excavation size is 170 m × 23.4 m × 60.7 m (length × width × height) and the roof's excavation elevation is 2024.8m, its largest excavation span is 24.9 m and its largest excavation height is 60.7 m. The tail pipe bottom's excavation elevation is 1964.1 m. The main transformer hole is located between the main powerhouse and the tail water hole, it is 40 m far away from the main powerhouse and its excavation size is 114.7 m × 17.3 m × 22.2 m (length × width × height). The main powerhouse and the main transformer hole is connected by the bus tunnel and its net section size is 7.5 m × 6.8 m (width × height).

Overlying rock's thickness of The underground cavern group is 112~339m, the surrounding rock masses are mainly quartzite and marble, giving priority to $Ⅲ_1$ class and locality class, there are some small faults such as f1, f3, f4, f17 etc. The engineering geological conditions are comprehensively analyzed of underground powerhouse area, it is good and most surrounding rock is stable, the area has the condition of building underground caverns with large span, of course, local parts with bad stability or instability need to be supported.

The hydropower station is deep in the rock mass, the cavities have complex layout and the stability of cavern surrounding rock after excavation needs to be targeted researched. With reference to the design and construction experience of similar underground engineering at home and abroad[1-4], the mechanical analysis model is established in this paper combined with complex topography and geology condition, rock mass structure, physical and mechanical characteristics of surrounding rock. Surrounding rock masses' stabilities of cavities, crane beam's stabilities are studied using $FLAC^{3D}$, which offers a reliable basis for the stability analysis and supporting design for underground powerhouse cavern group.

Analysis on reasonable supports of underground cavern group

The calculation coordinate system is the right-handed coordinate system, defined as follows: X axis is perpendicular to the workshops' longitudinal direction, the positive direction is from upstream to downstream; Y axis is the vertical direction and the positive direction is upward and Z axis is parallel to the workshops' longitudinal direction. During the modeling process, faults with larger effect on the stability of caverns, such as f1, f3, f4, f17 and alteration belt are considered. The three dimensional model is divided into 324391 units and 55407 nodes, three dimensional element subdivision graph and the hydraulic structure model are shown as Fig. 1 and Fig. 2. Z coordinates of 1 #, 2 #, 3 # and 4 # units are 106.35 m, 81.35 m, 56.35 m, 31.35 m, respectively.

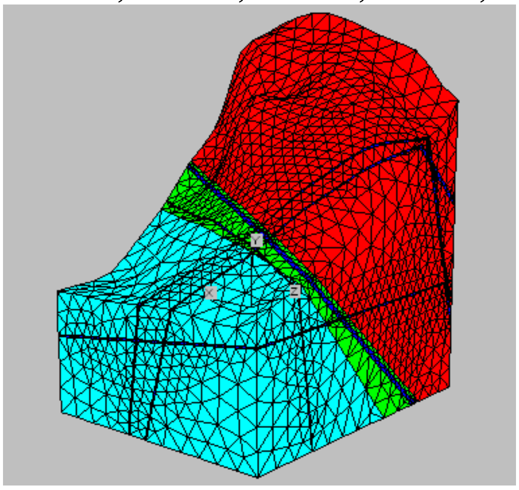

Fig. 1 Three dimensional element subdivision graph

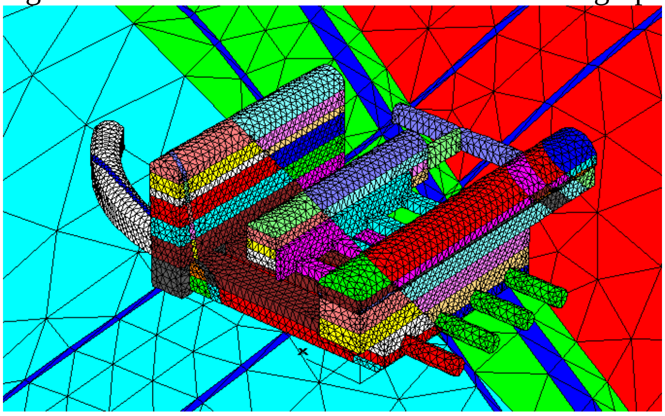

Fig. 2 Three dimensional hydraulic structure model

Take 2 # unit model for designing supporting parameters of underground caverns. Four support schemes have been designed[5-7]:

(1) scheme 1 (only bolt supports and there are no cables). Scheme 2, 3 and 4 have increased cables based on the scheme1, and the layouts of cables are as follows:

(2) scheme 2

There are four rows of cables in the upstream of the main powerhouse and three rows of cables in the downstream; there are only one row of cable in both the upstream and downstream of the main transformer hole; there are three rows of cables in the crown of the tail water hole, and six rows of cables in both the upstream and downstream.

(3) scheme 3

There are four rows of cables in the upstream of the main powerhouse and five rows of cables in the downstream; there are five rows of cables in both the upstream and downstream of the tail water hole.

(4) scheme 4

There are five rows of cables in the upstream of the main powerhouse and seven rows of cables in the downstream; there are five rows of cables in both the upstream and downstream of the tail water hole.

The plastic zone sizes of these four support schemes are shown in Table 1. From it we can see that: the total plastic zone size of scheme 2 is 39878.0 m^3, and has reduced by 14.6%, compared to 46681.8 m^3 of scheme 1, the plastic zone size of main powerhouse has reduced by 11.6%, the plastic zone size of main transformer hole has reduced by 6.75%, the plastic zone size of tail water hole has reduced by 32.0%; the total plastic zone size of scheme 3 is 38687.4 m^3, and has reduced by 17.1%, compared to 46681.8 m^3 of scheme 1, the plastic zone size of main powerhouse has reduced by 28.4%, the plastic zone size of main transformer hole has reduced by 13.5%, the plastic zone size of tail water hole has reduced by 17.4%; the total plastic zone size of scheme 4 is 38463.1 m^3, and has reduced by 17.6%, compared to 46681.8 m^3 of scheme 1, the plastic zone size of main powerhouse has reduced by 29.7%, the plastic zone size of main transformer hole has reduced by 13.5%, the plastic zone size of tail water hole has reduced by 17.7%. From the point of supporting effect, scheme 3 and scheme 4 are better than scheme 2, while, considering the restriction of economics, scheme 3 is the best of these four support schemes due to its good supporting effect and less cables.

Table 1 Plastic zone sizes of four support schemes [m^3]

Parts	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Total plastic zone sizes	46681.8	39878.0/-14.6%	38687.4/-17.1%	38463.1/-17.6%
Main powerhouse	14693.6	12984.3/-11.6%	10522.4/-28.4%	10331.5/-29.7%
Main transformer hole	10965.5	10224.9/-6.75%	9490.1/-13.5%	9490.2/-13.5%
Tail water hole	13440.3	9136.7/-32.0%	11098.8/-17.4%	11065.3/-17.7%

Stability analysis of crane beam on rock wall

There are eight wheels on each side of the crane beam on rock wall of the hydropower station. In the excavation and normal operation period, the wheel pressure value is 580 KN and the horizontal force is 110 KN. The wheel pressure is 640 KN and the horizontal force is neglected in the overload operation period. Crane beam on rock wall is shown in Fig. 3. There are three bolts near the abutment at each side of the crane beam, bolt spacing is 0.75 m.

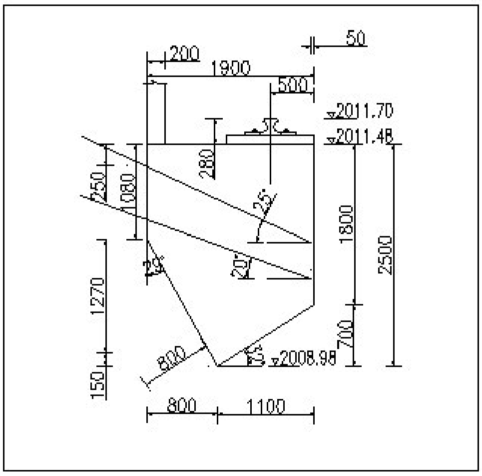

Fig. 3 Layouts of crane beam

Take 2 # unit for example, the calculation model is divided into 170728 elements and 30881 nodes, and the grids of crane beam is refined. Loads are applied to the crane beam when the eight excavation and support is finished. The wheel pressure applied to the crane beam is equivalent to uniform load[8,9]. The calculation parameters are shown in Table 2.

Table 2 Physical and mechanical parameters of crane beam and surrounding rock

Rock type	Density [g/cm^3]	Elastic modulus [Gpa]	Poisson ratio	Cohesion [Mpa]	Friction angle [°]	Tensile strength [Mpa]
Surrounding rock	2.81	7	0.28	0.8	40	5.0
concrete	2.50	30	0.167	1.75	20	1.4

Table 3 Displacements and bolts' axial forces of crane beam

		Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Normal operation	Overload operation
Displacements of crane beam/mm	Upstream	4.60	8.91	18.57	23.65	32.20	35.90	38.80	39.52	39.79	39.80
	Downstream	1.89	5.14	6.04	6.63	7.09	8.33	10.34	10.63	11.01	11.03
Bolts' axial forces of crane beam/KN	First row of upstream			111.5	111.9	124.0	127.3	129.5	130.7	131.2	131.2
	Second row of upstream			109.3	110.2	120.7	123.4	125.7	127.2	127.5	127.5
	Third row of upstream			61.6	61.6	61.7	61.8	62.0	62.2	62.6	63.1
	First row of downstream			98.3	103.6	103.7	103.8	105.5	105.7	106.9	106.9
	Second row of downstream			98.3	102.5	103.6	103.7	103.8	105.5	105.7	106.9
	Third row of downstream			37.4	37.4	37.5	37.5	37.6	37.6	37.7	37.9

What we can conclude from Table 3 are as follows, crane beam load has little effect on the overall stability of surrounding rock, and the influence is focus on areas near the crane beam. During the normal operation, the maximal displacement increment of upstream surrounding rock is 0.27 mm, and that of downstream surrounding rock is 0.38 mm. During the overload operation, the maximal displacement increment of upstream surrounding rock is only 0.28 mm, and that of downstream surrounding rock is only 0.40 mm. The displacements of surrounding rock and bolts' axial forces during the normal operation and overload operation are both roughly the same with those without load. Therefore, the displacements of surrounding rock and bolts' axial forces of crane beam are mainly caused by excavation, and parts caused by the wheel pressure are small.

Conclusion

(1) Four support schemes of the hydropower station are analyzed using the bolt element and equivalent anchoring formula of FLAC^{3D}, from the comprehensive consideration of cavities' stabilities and economic benefits, scheme 3 (bolts and nineteen cables) is the optimal supporting plan, apt to ensure the overall stability of surrounding rock.

(2) After the caverns 'excavation, due to the large excavation span and height, the main powerhouse and tail water hole have larger plastic zones, and the same as 1 # unit and 2 # unit affected by the alteration belt; the plastic zones of the main powerhouse and main transformer hole appear connected and it is reduced obviously after support; the plastic zones of 3 # unit and 4 # unit are relatively small.

(3) The displacements of surrounding rock and bolts' axial forces of crane beam are mainly caused by excavation, and parts caused by the wheel pressure are small, and they are both in the engineering allowable range, so the support scheme of crane beam is reasonable.

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