Stability Analysis of Connecting-tunnel Sealing Plug in Underground Storage Cavern

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Abstract. Connecting tunnel sealing plug is one of the important structures in water sealed cavern. The plugs ensure the safety of main cavern and water seal effect. This paper uses the finite element software doing several calculation steps including geometry model, underground stress distribution, boundary condition and assumption, to analysis the connecting plugs and rock mass’ stability. On the basis of no-relative-slip assumption, it can reach the conclusion that the sealing plugs and rock mass are in safety conditions. Thus to make sure close and tight relation between plugs and rock mass, a variety of grouting measures are promoted and fulfilled.

Introduction

Connecting tunnel plug is one of important structures in water sealed cavern, which is made to ensure the whole main caverns sealing effects. All those plugs are arranged in the middle of two storage caverns, to separate various types of liquid chemical materials. Connecting plug is one irregular shape of steel-reinforced concrete structure, and the boundaries approach to rock mass remains big gaps. Thus various types of slurries should be injected into the contact gaps to make sure good sealing effects.

Setup Modals

Geology Shapes

Sealing plug is one irregular shape with middle large body and two small ends. It is one reinforced concrete structure embedded in the rock mass, with plane view and side view showed as the following figures.

Underground Stress

The in-situ stress test was carried out in field, with maximum horizontal principal stress 6.19~11.50Mpa, the minimum horizontal principal stress 3.63~9.02Mpa. In this FEM modal vertical stress is the weight of rock mass, and the smaller horizontal in-situ stress is 2.4 times of vertical stress the larger horizontal in-situ stress is 4 times of vertical stress.

Boundary Condition

This paper takes 5 times the range within the span of cavern rock mass as research object, with upper line as free surface, the rest lines as zero displacement. In order to effectively utilize calculation resources, take half of general rock mass and sealing plug as the research objects.
Figure 1. Plane view and side view of connecting-tunnel plug.

Assumption on Contact Boundary

The bounding effects of contact surface between sealing plug and rock mass related calculation results. There are two assumptions about the contact relations.

1) The sealing plug is in good contact with the surrounding rock mass and no relative sliding is produced, which is the form of consolidation.

2) Friction between sealing plug and surrounding rock mass cannot resist the hydraulic pressure on one side of plug. Then a relative slip occurred at the interface, and finally the embedding shaping effects prevent plug off from groove.

The interface mechanical behavior is in accordance with Mohr-coulomb principle. According to survey data, the cohesive strength of $C=0.83\text{MPa}$, and the friction coefficient $f=0.67$.

When the horizontal static friction force is bigger than hydraulic horizontal force generated by operation pressure, the sealing plug is in consolidation situation, and vice versa. The horizontal static friction generated by cohesive strength and underground stress. Calculation shows the friction force is bigger than hydraulic force, then proves plug is in consolidation condition.

FEM Calculation

Geology Modal

The software ANSYS is used to make the FEM modal, as showing in fig.2. Based on the consolidation assumption, mechanical parameters selected are the following.

- Hydraulic pressure on one (back) side of plug is $0.84\text{MPa}$
- Underground horizontal stress is $5.2\text{MPa}$
- Rock mass modulus of elasticity is $9\text{GPa}$, Poisson’s ratio is $0.2$
- Sealing plug modulus of elasticity is $11.5\text{GPa}$, Poisson’s ratio is $0.2$
Calculation Result

The maximum displacement of sealing plug is 0.70mm, and the maximum combined stress (Von Misses) is 1.77MPa, which occurred in the back shoulder of plug. The maximum combined stress of surrounding rock mass is 0.88Mpa, located in the center position of front face.

The maximum stress of plug is far smaller than C30 concrete’s design strength, so it can be considered the sealing structure is safe. The maximum stress of rock mass is far smaller than original uniaxial compressive strength of rock mass, which is 160MPa. So the rock mass is safe too.

The plug’s surrounding face’s displacement is close to zero, all that shows the consolidation assumption is reasonable. Results show that both plug and rock mass are all in safe condition.
Grouting Measures

In order to ensure the surrounding rock mass’ stability, system blots supporting and reinforce grouting should be do timely after connecting-tunnel excavated. After plug keyway is dug out, the interface should be also reinforced. To make sure the fresh interface between rock mass and plug, spraying concrete was forbidden.

Smooth interface between rock mass and plug is bad for bonding effects. To make sure the good bonding effects of interface, three times of grouting should be fulfilled. Three steps grouting job includes filling grouting, hole-sealing grouting and contact grouting. All the grouting parameters are as Tab.1.

Table 1. Parameters of grouting of rock mass and plug.

| NO. | Grouting types     | Grouting location                                      | Aims of grouting                                | Material       | Grouting pressure /MPa |
|-----|--------------------|-------------------------------------------------------|------------------------------------------------|----------------|------------------------|
| 1   | Rock mass grouting | A range of rock mass before and behind the plug       | Reinforce the rock mass and increase the resistance to penetration. | Cement past   | 0.5                    |
| 2   | Filling grouting   | Upper part of plug                                    | Fulfill the upper part of plug                  | Concrete       | 0.5                    |
| 3   | Hole-sealing grouting | Cooling pipe, exhaust pipe, grouting pipe and manhole | Fulfill all the pipes                          | Cement past/concrete | 0.5            |
| 4   | Contact grouting   | Interface between plug and rock mass                  | Make sure the interface bonding effect          | Cement slurry  | 1.5                    |

Conclusion

This paper established FEM to simulate the connecting-tunnel sealing plug and rock mass. Analysis result shows that the two parts’ relationship is consolidation, and all in stability condition. Finally all types of grouting measurement are put forward to ensure the interface bonds tightly.

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