Study on the treatment materials of urban rail transit water-containing caves

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Abstract. With the sustained and rapid development of the national economy and the accelerating urbanization process, the contradiction between urban basic design, especially urban transportation facilities and urbanization, has become increasingly prominent. Rail transit has become the main public transport in major cities with its advantages of large capacity, fast speed, safety and reliability, and on-time comfort. Most of the rail transit lines are underground tunnels. When the tunnel crosses the karst area, it may encounter caves with different sizes, different locations, different filling levels and different water content. The existence of these caves will seriously affect the surrounding rock in tunnel construction. To carry out research on the typical disaster of water-filled caves, different types of filling materials were compared and analysed. And the applicable scope, advantages and disadvantages of various filling materials were also analyzed. Aiming at the treatment method of cement-water glass as filling material for the water-soluble cave, the relationship between the setting time of cement-water glass and the water inflow time was studied. The research shows that the effect of injecting the cave near the cement-water glass is the best.

1. Introduction

During the construction of the subway tunnel, there are many cases of karst caves, especially in the karst areas of southwest China. The karst development along the line is strong and the karst encounter rate is high. To ensure the smooth construction of the subway tunnel, stable operation and prevention of land subsidence and collapse, many scholars have studied the treatment of caves[1]. It is divided by the relative position of the cave and the subway tunnel, including the upper cave of the tunnel, the lower cave and the caves on both sides, and these caves are far and near. The farther the cave is from the subway tunnel, the smaller the impact on the subway tunnel. According to the engineering geological hydrology and the construction requirements, the caves are divided into the following four types: the first, the cave is a dry cave, no filling; second, the cave filling is saturated water; third, the cave filling is cemented mud; fourth, the filling is mud sand folder Block stone. Different types of karst treatment measures are also different, and the filling materials and filling processes used are vastly different and cannot be generalized. For example, for water-filled caves, it is necessary to fill with a material that is quick-setting and anti-scouring. For a non-water-filled cave, if it is an empty cave, it can be filled by filling the aggregate and filling it with a cementitious material. For the upper cave of the subway tunnel, it is necessary to fill with light materials. For the lower cave, the vibration of the subway train needs to be considered. It is necessary to consider the use of materials with high strength and certain toughness for filling. The filling processes corresponding to
Different materials are different. Therefore, different methods of karst caves need to be treated differently.

![Figure 1. Ground collapse caused by subway construction in karst areas.](image)

2. Research status of filling materials

In terms of filling materials, more research has been done on filling materials in coal mine goaf[2-6]. In the aspect of karst filling, Tijin Mountain has taken materials locally, and loess-cement filling materials have been developed using local loess, and various materials have been studied. Performance, and applied to the treatment of the hidden caves in Guangzhou Metro, greatly reducing the cost of cave filling. Yang conducted an indoor experimental study on the karst grouting materials, and discussed the unfilled karst grouting material, the karst grouting material filled with sand, the karst grouting material filled with flow plasticity clay and the filling material of the gushing water cave[7]. The best ratio of conventional filling materials for different filling medium caves is obtained. Wang used loess and fly ash as the main materials, and used cement and lime alkaline materials as auxiliary materials to study the performance, setting time, seed set rate and compressive strength of loess paste filling materials[8]. Zhou conducted a full-grained crushed stone cement filling material and pumping test study, and obtained the best ratio and the pumping pressure under the ratio[9]. Wang studied the optimum ratio and application of crushed stone and phosphogypsum cemented filler[10]. The strength of the filling body increased with the increase of the mass fraction of the paste-like paste. Phosphorus was added to the aggregate of gravel with a particle size below 10 mm. The uniaxial compressive strength of gypsum and filling body is significantly improved; the addition of phosphogypsum to gravel aggregate can improve the fluidity of the slurry, which is beneficial to reduce the amount of cement and save costs. The conventional karst grout drilling layout is shown in Figure 2.

![Figure 2. Cavity grout drilling plane layout.](image)
3. Comparison of water-filled type cave filling materials
Water-filled (over-water) karst caves account for a large proportion of all karst caves, and water-soluble caves tend to have large water flows, fast water flow rates, and difficult filling and treatment. At present, cement-water glass filling materials, modified cement-water glass filling materials and organic swelling materials are mainly used in the treatment of water-filled (over-water) karst caves.

3.1. Cement-water glass filling material
The cement water glass slurry is mainly composed of cement water glass, and the two are injected by a two-liquid grouting method according to a certain ratio, and the utility model has the advantages of wide application and good injection effect. The chemical principle of C-S slurry is that the main components of cement are 3CaO·SiO$_2$, 3CaO·Al$_2$O$_3$, 4CaO·Al$_2$O$_3$ and Fe$_2$O$_3$, while the former two accounts for 70%-80% of the total cement.

The initial setting time of the cement-water glass slurry is short, and the initial injection can be poorly injected. The grouting operation is required to be high, and the diffusion range can be controlled by the grouting filling pressure and has a remarkable effect on blocking the moving water. However, it is not suitable for long-distance grout filling.

3.2. Modified cement-water glass filling material
Although the cement-water glass filling material has certain advantages, it still cannot meet the requirements in terms of setting time control, erosion resistance and pumping performance. Therefore, many scholars have studied the modified cement-water glass.

To extend the setting time of the filling material, it is necessary to add a retarder. The most commonly used retarder for cement-water glass filling slurries is Na$_2$HPO$_4$. In addition, in order to increase the anti-scour property of the filling material, it is necessary to add an appropriate amount of a viscous substance such as cellulose, gum or the like in the material. To ensure the long-term plasticity of the filling material, it is also necessary to add an appropriate amount of dispersing agent to ensure that the viscosity of the filling material is stable for a long time.

Therefore, by modifying the cement-water glass slurry, the performance of the filling material can be effectively enhanced, making it more applicable.

4. Comparison of water-filled type cave filling materials
For water-filled (water-moving) caves, the problem of water-washing of the slurry should be considered when filling. Therefore, when filling such caves, different anti-scouring quick-filling materials should be selected according to different conditions.

For caves with a small water flow velocity and a small volume, a 5:1 cement-water glass slurry can be used for filling, while for larger caves, sandblasting can be performed first, followed by 5:1 cement-water. The glass slurry is filled. For caves with a high water flow rate, the gravel aggregates must be filled first, and then filled with a suitable ratio of cement-water glass slurry. There is a difference in the initial setting time of cement-water glass with different ratios. If the water-water velocity is large, if the cement-water glass enters the water before initial setting, the retention rate of the slurry is difficult to ensure. To study the proper water infusion time of cement-water glass slurry, we studied the failure time of cement-water glass and the optimal water inflow time.

In this experiment, P.O32.5R ordinary Portland cement was used to prepare cement slurry, and the water glass used was Be. To control the initial conditions, the slurry treatment adopts the principle of ready-to-use. By adjusting the water-cement ratio of the cement slurry and the ratio of the cement slurry to the water glass, the CS double-liquid slurry under different working conditions can be obtained. Under the different working conditions, the C-S double-liquid slurry can be cured under the condition of no water entering state and water in the state. Glue time is tested.

The experimental conditions in this paper are mainly divided into two categories, one is the CS double slurry without water conservation. In this state experimental condition, the cement slurry and the water glass are mixed in different proportions, and the laboratory is at a temperature of 20 °C and
a humidity of 90%. The gel time was tested under the conditions. The gel time was measured by the inverted cup method and the Vicat method. The other type is the CS double-slurry gel time test in the water inlet state. The cement slurry and the water glass are mixed in different proportions, and then the C-S double is mixed in the three time states of "20s, 30s and the time of the current loss" after mixing. The slurry was poured into the water of 2 times the volume of the C-S double slurry to construct the water state to simulate the working condition of the C-S slurry injected into the blocked water body at different times in the real project. The initial setting and final setting time were tested with a Vicat instrument under laboratory conditions of a temperature of 20°C and a humidity of 90%.

For the initial setting and final setting time of C-S double-liquid slurry under the no-water curing and water-in-water curing, the paper uses the Vicat method to determine the Vika instrument used in this test as the new standard cement consistency meter STWKY-1.

The C-S double slurry studied in this paper can not make the same test mode as the cement paste in the water state. Therefore, referring to the cement gel time measurement method, the initial setting time is taken when the test needle of the Vicat instrument enters the test body 36mm. When the needle sinks into the test piece at 0.5 mm, it is the final setting time. When testing in the water inlet state, the test needle enters the boundary between the water and the gel as the effective depth.

The gel time test results are shown in Figure 1, Figure 2 and Figure 3. The flow loss time of C-S double slurry under different water curing conditions under different cement slurry ash water ratio (C: W) is shown in Table 1.

Table 1. C-S double slurry flow loss time under water maintenance conditions.

| Condition | Grout C: W | Loss of time |
|-----------|-----------|--------------|
| 1         | 0.6:1     | 2min45s      |
| 2         | 0.6:1     | 1min40s      |
| 3         | 1:1       | 1min25s      |
| 4         | 1:1       | 1min10s      |
| 5         | 1:1       | 1min         |
| 6         | 1:1       | 52s          |
| 7         | 1:1       | 42s          |
| 8         | 1.5:1     | 36s          |
| 9         | 1.5:1     | 35s          |

Figure 3. Initial setting time (a) and Final setting time (b) of different slurries at C: W =0.6:1.
Figure 4. Initial setting time (a) and Final setting time (b) of different slurries at C: W =1:1.

Figure 5. Initial setting time (a) and Final setting time (b) of different slurries at C: W =1.5:1.

It can be seen that under the water inlet conditions, the difference of the water inflow time has a great influence on the gel time of the C-S double slurry. If the C-S double slurry is less than the flow loss time from the mixing to the influent water (such as 20s, 30s in this study), it will greatly increase the gel time of the C-S double slurry in the water, such as gray water. Compared with 0.6:1, C:S is 1:1, the initial setting time of non-water curing is only 25 minutes, and the initial setting time of 20s into water is 26 hours, which can not play the characteristics of C-S double-liquid fast gel, which is difficult to move. The effect of water blocking. If the C-S double slurry is too long from mixing to entering the water body and exceeds the flow loss time, it will bring difficulties to the transmission of C-S double slurry in the pipeline, and it is easy to cause the pipe blocking or blocking range to be too small. problem. It can be seen from the figure that the de-flow time obtained by the inverted cup method has an important guiding effect on grouting, and the gel time of the slurry entering the water near the time of the outflow is not much different from that in the non-water-retaining state. It can be seen that in the actual project, if the time from mixing to entering the plugged water body is controlled in the vicinity of the flow loss time, the C-S double liquid slurry can play the best sealing effect.
The water-cement ratio of the cement slurry has a greater influence on the gelation time of the C-S double-liquid slurry under the water inlet state, and the gel time of the C-S double-liquid slurry is shortened as the proportion of the cement in the water-cement ratio is increased. For example, in the case of C:W =0.6:1, the minimum initial setting time of the CS slurry for 20s into water is 18h (cement slurry: water glass = 3:1 condition); as the cement content in the water-cement ratio increases, when C:W =1.5:1, the minimum initial setting time of 20s into water is 50min (cement slurry: water glass = 3:1 condition), and the condensation time is large when the water is in the state of C:W =0.6:1.

It can be seen that in the actual project, the C-S slurry is controlled to enter the blocked water body near the time of the flow loss, which can achieve the best quick-setting and sealing effect. How to control the time from mixing to entering the plugged water body in the actual project can be realized by adjusting the length of the grouting line injected into the target water body or adjusting the pumping speed by adjusting the double slurry mixer.

It can be seen that no matter what kind of water entering time conditions, in order to realize the rapid setting requirement of C-S double slurry under water inlet conditions, it is an effective means to increase the cement slurry ash water ratio.

5. Conclusion
In view of the current situation of urban subway encountering water-filled caves, different types of filling materials were compared and analysed. And the applicable scope, advantages and disadvantages of various filling materials were also analyzed. The treatment method of cement-water glass as filling material was proposed for the water-soluble cave. The relationship between the setting time of cement-water glass and the water inflow time was studied. The research shows that the effect of injecting caves near the cement-water glass is the best.

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