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Corrosion investigation of groundwater for underground tunnel

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Abstract

Underground tunnel becomes the common engineering for human activities in recent years. The groundwater corrosion cause significant casualties and economic loss for the tunnel. Hydrology investigation, chemical analysis, and water resistance analysis were carried out to study the corrosion effect of an hydropower tunnel in West China in this paper. First, the groundwater in the study area mainly consists of the bedrock fissure water, fault fissure water and the pore water. Then ten group representative samples of spring point were took to make chemical analysis separately. The SO4 of two points near the big fault are more than 250 mg/l. Results show that it have weak corrosive action to the ordinary cement, the proposal measures should be considered for the tunnel design. The corrosion effect of the groundwater is clarified clearly by the tests. At last, some controlling measures and suggestions for tunnel design were present.

Keywords: Regional environment, Groundwater corrosion, Chemical test, Underground tunnel

Introduction

With the development of economy and the increase of population in China, many districts began to build subway, tunnel and other underground engineering. A series of underground tunnels cause significant casualties and economic loss due to the fragile environment and groundwater corrosion. Large underground engineering must implement regional environmental assessment before the construction begins. Groundwater has a great influence on underground engineering, especially the corrosive action of the groundwater on the tunnel. Groundwater will seriously affect the service life of concrete tunnel. Therefore, it has important significance to evaluate its corrosion to the concrete.

In recent years, there is a lot of corrosion for underground engineering. Degradations regarding the corrosion of Bucharest metro structures of concrete steel are studied by corrosion of steel rebars of reinforced concrete structures 1. Pipeline corrosion will influence on the tunnel Management because of the corrosion on the pipeline 2-4. The corrosion of ferrous metals poses a serious threat on underground engineering, such as the rock bolts 5-8, high pH for crack growth 9-10, and so on.

Groundwater plays an important role on the regional environment 11-14. In addition, it has an effect on the tunnel corrosions. Effect of wash water and underground water will corrode the properties of concrete 15-16. Groundwater and its make-up water are important triggering factors to failure because of the corrosion for concrete 17-18.

The above researches take good explanation about the impact of corrosion on underground tunnel, but the methods are mainly based on the phenomenon explain. The related regional environmental test of groundwater corrosion for tunnel is still less. In order to better study the effect of groundwater corrosion on the tunnel, the physical and chemical properties of groundwater in a tunnel region were studied. The regional environmental analysis and water resistance test of groundwater were carried out independently. The tests show that the water has corrosion for the concrete tunnel. The result provides a basis for design of the underground tunnel.

Regional environmental analysis

The Danba Hydropower Station is located on the main stream of the Dadu River which flows through the Ganzi Tibetan Autonomous Prefecture, Sichuan Danba County. The main buildings of the hydropower station
include sluice, water diversion system, power house and switch station, etc. The average total length of water diversion system is about 17.4km, and two of the diversion tunnel lengths are respectively about 16.5km and 16.7km. The full length of the diversion system uses reinforced concrete lining, and lining after the cross section is a circular diameter of 12.4m. Dadu River is the main stream of the project area water system. The rainfall of valley region is about 606.8mm, so surface water resources are more abundant. And groundwater mainly contains three types which are bedrock fissure water, fault fissure water and loose layer of pore water. Therefore, it is very important to research the corrosive action of water to diversion tunnel concrete. We have researched the hydrogeological conditions and the water chemistry characteristics in this region.

**Hydrogeological condition**

A. Bedrock fissure water

The region is located in Erosional structures which are characterized as high mountains, steep terrain, strong cutting mountain genus. Left bank of the Quaternary cover is thin, poor infiltration of precipitation conditions, groundwater runoff conditions, and multi valley excretion, agenesis of pore water, groundwater poor storage conditions. Groundwater becomes mainly the bedrock fissure water. The main source of the groundwater recharge comes from atmospheric precipitation and snow melt water, the size of water is affected by seasonal effects. Main excretion form of the groundwater is springs, such as the east side of fractured spring and the fissure spring.

B. Fault fissure water

This area is of fault development, mainly containing F1, F5, F6, F7 shear fault, visible fractured zones contained by the tectonic breccia, mylonite, etc. Crushed zone is intruded by pegmatite and felsic dykes, and rock mass is broken. So, it has certain ability of groundwater storage and migration. But a lot of ground water gushed out is in no sight, only the strands form water flowing out is seen in the fault F6 place.

C. Loose layer pore water

The main outcrop is on the right bank and the river bed coverage. The right bank of the Quaternary overburden widely distributes colluvium and residual sediment. Loose structure and strong water permeability provide good conditions for groundwater storage and transportation of water. The supply is mainly rain and snow melt water during the rainy season. Pore water seeps in rain season, groundwater level and flow change with the seasons, excrete into the valley. The body of accumulation landslide and so on can see pore springs outcrop (Fig. 1). Rich water of river is in bed cover, so the ascending spring outcrops (Fig. 2) in the floodplain of the Dadu River when water level continues to drop.

**Chemical property**

Ten group representative samples of spring point were took to make chemical analysis separately, the analysis results can be seen in Table 1.
A. Salinity

Groundwater which salinity is generally low is fresh water, anionic is mainly made up of HCO$_3^-$, cationic is mainly made up of Ca$^{2+}$, salinity range 122~314 mg/l, belong to low salt. There are three place of water with high salinity, exposed in Russia full landslide, tie families and armor in landslides respectively, anion is given priority to SO$_4^{2-}$, cationic is mainly given priority to Ca$^{2+}$, genera of mineralized water.

B. The main ion

There are four water types in the ten groups of water, anionic is mainly given priority to HCO$_3^-$, followed by SO$_4^{2-}$, and cationic is mainly given priority to Ca$^{2+}$.

C. pH value

pH value is partial neutral, the range between 7.2 and 8.2, only pH in one place is under 7.0, and exposed in an abandoned mine at east slope.

Mineral analysis

Appraisal analysis equipment of rock minerals composition is transmission-reflection optical microscope which type is Jiangnan XP-213, and photographic equipment is Nikon EVLIPSE LV100POL. Environmental parameters of the tests include test temperature and test humidity, and the value is 25 °C and 55% respectively. There are respectively mineral composition analyses of rock which are come from ten positions, and the analysis results such as shown in Table 2. The texts of the ten mineral can be seen in Fig. 3.
<p>| | | |</p>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>(8%) Packing granular, size is 0.03~0.85mm</td>
<td>Hornblende (76%) Long column, granulous, size is 0.04~1.55mm</td>
</tr>
<tr>
<td>7</td>
<td>(56%) Directional alignment, size is 0.03~0.65mm</td>
<td>(13%) Schistose, directional alignment, size is 0.06~2.2mm</td>
</tr>
<tr>
<td>8</td>
<td>Hornblende (84%) short columnar granular size is 0.05~1.97mm</td>
<td>Calcite (8%): size is 0.05~2mm</td>
</tr>
<tr>
<td>9</td>
<td>(46%) Particle at the intersection of plane is 120, size is 0.05~0.7mm</td>
<td>(17%) Schistose, thin strip, size is 0.04~2.1mm</td>
</tr>
<tr>
<td>10</td>
<td>(47%) Stretched, directional arrangement, size is 0.06~0.9mm</td>
<td>(23%) Schistose, directional arrangement, size is 0.1~3mm</td>
</tr>
</tbody>
</table>

Figure 3 The texts of the ten mineral

From the Fig.4 and Fig.5, with the increase of the hole deep, quartz content in the mica schist shows a holistic slight upward trend, the corresponding mica content declined. Among the pile number from K0+924 to K1+050, the schist is Mica quartz schist, and its quartz content significantly increases more than 50%. According to the field investigation of the whole exploratory hole, with the increase of pile number (after K0+900), the surrounding rock strength has a tendency of increase. The reasons of the surrounding rock strength increases is mainly the following several aspects.

Firstly, the increase of the rock quartz content and the decrease of the mica content give rise to the increase of the rock strength; Secondly, in the hole section after the pile number K0+900, the surrounding rock strength increases due to the decrease of the fault, the extrusion broken belt, the joint etc. Moreover, with the shortening excavation time than the first half and the weakening of the unloading relaxation of surrounding rock, the effect of the groundwater and the stress release is relatively small, and so that the strength of surrounding rock is enhanced. Chemical property and the mineral analysis of the ten groups showed that the corrosion
of groundwater near the F6 is strong. So, the corrosion effect needs further research.

Figure 4 Quartz content in the mineral

Figure 5 Mica content in the mineral

The water resistance analysis

Method

Generally, considering from the chemical reaction between the corrosiveness of groundwater with concrete and reinforced concrete, the chemical corrosion of groundwater can be divided three kinds, including decomposition type corrosion, crystal type corrosion and crystallization decomposition composite category corrosion. The corrosion mechanism classification according to the investigation of different, here introduces the classification scheme of the Ministry of Communications.

Decomposition type corrosion is that the Ca(OH)2 of cement with H+, CO2, H2CO3 of water neutralizing and dissolving, making cement broken down. So concrete has a soft saw and honeycomb structure.

\[
\begin{align*}
\text{CO}_2 + \text{Ca(OH)}_2 & \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} \\
\text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O} & \rightarrow \text{Ca(HCO}_3\text{)}_2 \\
\text{2NH}_4\text{Cl} + \text{Ca(OH)}_2 & \rightarrow \text{2NH}_3 + \text{CaCl}_2 + \text{2H}_2\text{O}
\end{align*}
\]

Crystal type corrosion through the contact with the salt of water and concrete forms a new aqueous crystal from the composition of concrete. These crystals are in the process of forming swelling action, so that the concrete appearance is in the bursting destruction, such as:

\[
\begin{align*}
\text{MgSO}_4 + \text{Ca(OH)}_2 + \text{H}_2\text{O} & \rightarrow \text{Mg(OH)}_2 + \text{CaSO}_4 \cdot \text{H}_2\text{O} \\
\text{3CaSO}_4 + 3\text{CaO} \cdot \text{Al}_2\text{O}_3 + 3\text{H}_2\text{O} & \rightarrow 3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{CaSO}_4 \cdot 3\text{H}_2\text{O}
\end{align*}
\]

The operability is poor although the concept is clear. For example, it can not only produce crystal type corrosion, but also produce crystallization decomposition composite category corrosion. Different corrosion probably is generated by the same factors, and same kind of erosion probably is produced by a variety of factors.

Tunnel erosion includes dissolve out erosion (HCO3−), carbonate erosion (aggressive CO2), general acid corrosion (H+), sulfate corrosion (SO42−), magnesium salt corrosion (Mg2+), and etc. According to the discriminate standard of corrosion the water of environment to concrete, the chemical corrosion types of concrete influence by environmental water mainly include: decomposition, decomposition crystalline compound and crystal. According to the degree of erosion, it can be divided into four grades: no erosion, weak erosion, medium erosion and strong erosion.

In accordance with the evaluation standard in China “the geological investigation specification of water conservancy and hydropower engineering”(GB50487-2008), the environmental evaluation criteria of influence on concrete corrosion is as fellows.

The result

A. According to the evaluation about fissure water of environment to tunnel sulfate: the index of the ordinary cement have weak corrosive is that the SO42− concentration should be greater than 250 mg/l, the index of against sulfate cement have weak corrosive is that the SO42− concentration should be greater than 3000 mg/l; And the value of SO42− are far less than 3000 mg/l, it have no effect against sulfate cement. SO42− value is less than 250 mg/l in most of the
water, there is not exist crystalline corrosion problems for the ordinary cement. It is only 7 # water sample (and full landslide) and 8 # water sample (tie families ore in the adit) SO$_4^{2-}$ value more than 250 mg/l, it have weak corrosive action to the ordinary cement, the proposal design should be considered (see Table 3).

B. The pH value of the evaluation criteria is: pH > 6.5 no corrosion, 6.5 ≥ pH > 6.0 weak corrosion, 6.0 ≥ pH > 5.5 moderate corrosion, pH ≤ 5.5 strong corrosion. The groundwater has acid corrosive effect, when its pH value less than 6.5. But as the result of the water quality analysis from water samples, the groundwater pH is substantially greater than 6.5, so it has no acid problem to the concrete. According to the decomposability-corrosion evaluation of the concrete affected by osmosis water.

C. If HCO$_3^-$ > 1.07, there is no corrosion, if 1.07 ≥ HCO$_3^-$ > 0.70 there is weak corrosion, if HCO$_3^-$ ≤ 0.70 there is strong corrosion. It shows that the smaller concentration has the greater erosiveness. From the result of water quality of water samples, all the concentration of HCO$_3^-$ are far more than 1.07 mmol/L. Therefore, there exist no dissolution properties of corrosion.

Under the function of osmosis water, the Ca (OH)$_2$ successively loses with water in the concrete which reduce the concentration of solution CaO, when HCO$_3^-$ in water content is too low. When the concentration lower than 1.3 mg/l, the crystal Ca (OH)$_2$ in concrete will run off while dissolve into water, CaO in C$_3$S (tricalcium silicate) and C$_3$A (tricalcium aluminate) is successively resolved and dissolved into water, which let the structure of the concrete become loose, and the strength decrease.

<table>
<thead>
<tr>
<th>NO.</th>
<th>SO$_4^{2-}$ (mg/l)</th>
<th>pH</th>
<th>HCO$_3^-$ (mg/l)</th>
<th>Mg$^{2+}$ (mg/l)</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.8</td>
<td>7.2</td>
<td>215.6</td>
<td>114.3</td>
<td>No crrosion</td>
</tr>
<tr>
<td>2</td>
<td>69.1</td>
<td>7.5</td>
<td>173.9</td>
<td>124.0</td>
<td>No crrosion</td>
</tr>
<tr>
<td>3</td>
<td>73.0</td>
<td>7.7</td>
<td>141.4</td>
<td>115.2</td>
<td>No crrosion</td>
</tr>
</tbody>
</table>

The evaluation indicator of corrosive concrete is that action Mg$^{2+}$ concentration should be greater than 1000 mg/l. In the tunnel areas, according to 10 test results of analysis water samples, the maximum concentration of Mg$^{2+}$ is 343 mg/l, which is far less than the predetermined value. Therefore, the groundwater in the study area can not corrode the concrete with decomposition of complex crystal according to the standard evaluation of compound corrosion affected by decomposition of crystalline.

Based on the above analysis, when diversion tunnel build through bedrock, groundwater quality is basically not adversely affect the lining concrete. Currently, “Acid erosion occurs while Calcium ion concentration>1mg/l, pH<11.63”, generally lower limit of the concentration of sulfate ion erosion is defined as 250 mg/l, pH as 10.24. According to the view, the concentration of sulfate ion of 7# water sample (the full Russian landslides), 8# water samples (Zakho mine adit within), respectively are 280 mg/l and 380 mg/l, pH value are 6.66 and 7.2, Calcium ion concentration are 102 mg/l and 173 mg/l, all of them meet the conditions of acid erosion occur.

Combined with the emersion of the water sample in the vicinity of the fault F6, the acidic erosion will oozed fault fillings, generate loose amorphous substances without gelling and strength, loose the concrete structure, prevent concrete tunnel lining corrosion damage by groundwater, and determine the need for concrete protection and protective measures.
Anticorrosive suggestions

When cement varieties is slight erosion, it can use ordinary Portland cement or resistant cement; and when the degree of erosion is medium or strong erosion, it can use ordinary Portland cement or resistance and high sulfate cement (Table 4). If it is eroded that the degree is moderate and strong, it should use reinforced concrete. If it is eroded which is slight, it can use plain concrete.

<table>
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<th>Soil erosion grade</th>
<th>slight</th>
<th>moderate</th>
<th>strong</th>
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<tr>
<td>Plain concrete</td>
<td>C25</td>
<td>C30</td>
<td>C35</td>
</tr>
<tr>
<td>Reinforced concrete</td>
<td>C30</td>
<td>C35</td>
<td>C40</td>
</tr>
</tbody>
</table>

In addition, for the cement in the cementitious materials of concrete, it can also mix with fly ash and silica fume, and the type of admixture is better to choose multifunctional composite admixture.

Determine the value $C$ of concrete thickness is another issue. That is to say that the thickness of the protective layer of reinforced concrete.

Distance value is from the outer reinforcement (add stirrups) to the concrete surface as follows: the value of $C$ should be more than 40mm under the conditions of slight erosion, and under the condition of medium erosion and strong erosion, it should be more than 45mm.

Conclusions

(1) The groundwater in the study area mainly consists of the bedrock fissure water, fault fissure water and the pore water which is in the loose layer. The former two types are mainly located on the left bank, the last one is mainly distributed on the right bank where the Karst is not development.

(2) Surrounding rock of tunnel is mainly two-mica schist which is weakly weathered. The integrity of rock mass is well on the whole and rock mass is mainly weakly permeable. The activity of groundwater is weak, and there is no large gushing generally.

(3) Fracture zone develop in the zone which have fault, especially the zone which the fault $F_6$ passes though have the outcrop of groundwater along. The covering layer of the right bank is thick, especially the thickest area is more than one hundred meters in the accumulation area of landslide. Digging tunnels may cause the water gushing because of the thin top of the cave.

(4) The groundwater of bedrock which is in the area of tunnel passes through does not adversely affect the lining concrete by the resistance analysis. There is a certain degree of acid erosion in $F_6$ because the content of sulfate ion of groundwater is high.

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