

Analysis of the influence of the interlayer staggered zone in the basalt of Jinsha River Basin on the main buildings

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Abstract In this paper, the finite element software FEFLOW is used to simulate the seepage field of the interlayer staggered zone C₂ in the basalt of Jinsha River Basin. The influence of the interlayer staggered zone C₂ on the building is analyzed. Combined with the waterproof effect of current design scheme of anti-seepage curtain, the seepage field in the interlayer staggered zone C₂ is discussed under different design schemes. The optimal design scheme of anti-seepage curtain is put forward. The results showed that the case four can effectively reduce the head and hydraulic gradient of underground powerhouse area, and improve the groundwater seepage field in the plant area.

1. Introduction

In the study of last 20 years, the shape of fault is not described as only a single shear zone. It may has multiple parallel shear zones simultaneously, with the fracture zone around it (Wibberley et al, 2008). The primary lens may be even formed in the shear zone (Faulkner et al, 2003). The permeability of the shear zone is larger than that of the surrounding rock fracture zone. Recently, there are many numerical simulation methods for the development of the interlayer staggered zones and their hydraulic characteristic (Brown and Bruhn, 1998; Jourde et al., 2002; Matthai and Belayneh, 2004; Lunn et al., 2008). In these methods, the faults are considered as a collection of multiple fractures of different size. For example, Odling et al. (2004) simulated the faults using the discrete element method, based on the development and distribution of the main water conducting fracture.

It is particularly important to evaluate the permeability of the interlayer staggered zones of basalt, in order to analyze and evaluate the effect of groundwater movement on the engineering problem, such as the water gushing from the underground power house, seepage deformation of the interlayer staggered zones, and the slope stability, etc. The permeability of the interlayer staggered zone will affect the stability of the underground buildings. In this paper, the finite element software FEFLOW is used to simulate the seepage field of the interlayer staggered zone C₂ in the basalt of Jinsha River Basin. The influence of the interlayer staggered zone C₂ on the building is analyzed. Combined with the waterproof effect of current design scheme of anti-seepage curtain, the seepage field in the interlayer staggered zone C₂ is discussed under different design schemes. The optimal design scheme of anti-seepage curtain is put forward.

2. Geology and Hydrogeology

The Jinsha River flows through the Yunnan plateau and Sichuan basin, which is located in the upper reaches of the Yangtze River, with a total length of 2316 km and an area of 340 thousand square kilometers. The Jinsha River canyon is one of the deepest canyons in the world. The average annual



flow is 4750 cubic meters per second. The water level difference of the reach of Jinsha River is 3300m. There are four large cascade hydropower stations built in the lower reaches of Jinsha River, including the hydropower stations named Wudongde, Baihetan, Xiluodu and Xiangjiaba. The Baihetan hydropower station is taken as an example (Figure 1). The Emeishan Basalt of early Late Permian occur in the Jinsha River Basin, with the thickness of the basalt ranging from 490 to 520m. The two hydropower stations of Baihetan and Xiluodu are located on the Emeishan Basalt($P_2\beta$). The Emeishan basalt is volcanic rock flow of continental face, and the eruption of it has intermittent multi-phase. It presents discordance or unconformable contact with the lower Maokou formation, and conformable contact or discordance with the overlying Xuanwei formation.

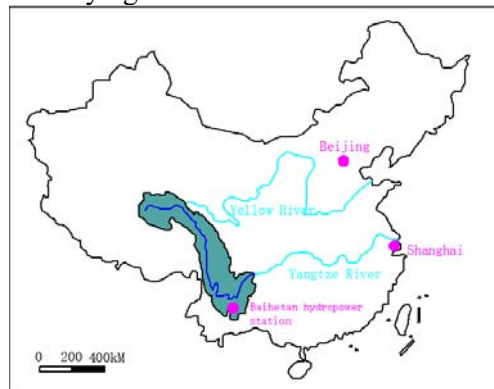


Figure 1 The location of the study area.

The basalt can be divided into fourteen rock layers, according to the intermittent eruption. The thickness of each rock layer varies greatly, with an average thickness ranging from 82.6m to 13.3m. There are thirteen discontinuity eruption in the fourteen rock flow layers, and the deposition is continuous. A tuff interlayer is formed between each two rock flow layers, and it changes to an interlayer staggered zone with different widths under the effect of tectonic stress. The basalt is a low permeable rock mass, however, the impact of interlayer staggered zone developed between the rock layers on the hydrogeological conditions is particularly significant. The interlayer staggered zones often run through the whole engineering area, and have wide spatial distribution. The hydrogeological characteristics of interlayer staggered zones are different from those of bedrock under the condition of high water level and pressure, which play an important role in controlling the seepage flow field. Therefore, the interlayer staggered zone is the main structural plane controlling water in this area. It is necessary to make a thorough study of its hydrogeological characteristics.

3. The structure characteristics of the interlayer staggered zone

The width of the interlayer staggered zone of basalt in Baihetan hydropower station varies greatly. The particle size and distribution of the filling material are not uniform, but there are some structural rules. The permeability characteristics of different fillings are different, for example, the permeability of mud filling of continuous distribution is weak, while that of the rock debris filling is strong. Due to the inhomogeneity of the distribution of filling in the interlayer staggered zone, the permeability of the same interlayer staggered zone is different at different positions.

At the same time, the surrounding rock on both sides of the interlayer staggered zone will produce micro unloading, and even strong unloading, because of the influence of tectonic movement and stress concentration. As a result, the permeability of the surrounding rock is greater than that of the bedrock. Therefore, the structure of the surrounding rock is also an important factor in studying the permeability characteristics of the interlayer staggered zone. According to the particle size and development characteristics of the fillings and broken surrounding rock, the fillings in the interlayer staggered zone are divided into four types, including the intercalated mud, rock debris with intercalated mud, particles and rock. According to the field and laboratory tests of the interlayer

staggered zone in Baihetan hydropower station engineering, the hydraulic conductivity of it is estimated to be $1.94 \times 10^{-4} \text{cm/s}$.

4. Methods

The interlayer staggered zone C_2 intersects the important buildings, such as the main-transformed cavern and the underground powerhouse in the left bank. However, the outcrop height of the interlayer staggered zone C_2 decreases gradually on the right bank, which does not intersect with the important underground structures. The height of the bottom line of the curtain grouting is lower than that of the outcrop position of the interlayer staggered zone C_2 . However, at the other locations, the bottom line height of the curtain grouting is higher than that of the interlayer staggered zone C_2 . The finite element software FEFLOW is used to simulate the seepage field of the interlayer staggered zone C_2 . The influence of the interlayer staggered zone C_2 on the building is analyzed under the condition of storage of reservoir. It is assumed that the interlayer staggered zone C_2 is horizontal. It is a homogeneous isotropic confined aquifer. The basalt in the upper and lower parts of the aquifer has no hydraulic connection with the interlayer staggered zone C_2 .

The simulated area of the interlayer staggered zone C_2 is shown in Figure 2. Taking the dam body as the center, the north and south sides of the dam extend to the upstream and downstream for 760m and 740m, respectively. The east and west sides of the dam extend eastward and westward for 1250m and 1600m, respectively. The heads on the south and north boundaries are 825m and 590m, respectively. The fluxes on the east and west boundaries are zero. The effective width of curtain is assumed to be 5m, and the hydraulic conductivity of it is $1.0 \times 10^{-5} \text{cm/s}$. The hydraulic conductivity of the interlayer staggered zone C_2 is $1.94 \times 10^{-4} \text{cm/s}$. The thickness of the interlayer staggered zone C_2 is 29.10cm. Thus, the value of the transmissivity is $5.65 \times 10^{-3} \text{cm}^2/\text{s}$. The critical hydraulic gradient is 1.9~6.6 for the interlayer staggered zone C_2 . In order to ensure the seepage stability of the engineering area, the safety factor is 5. The maximum hydraulic gradient equal to be the simulated value multiplied by the safety factor.

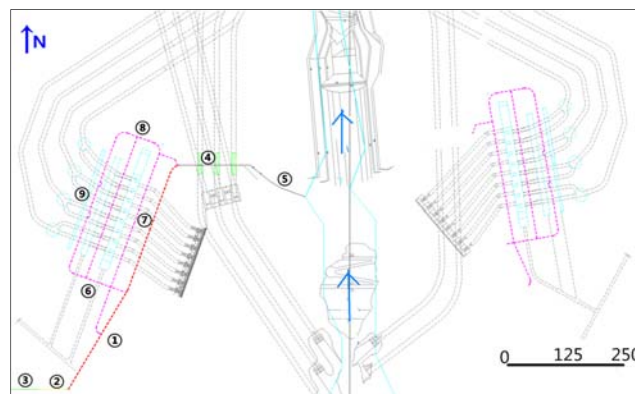


Figure 2 The simulated area of the interlayer staggered zone C_2 .

The curtain of the interlayer staggered zone C_2 is designed into nine sections. The section ① is the current design scheme, and the sections ⑥~⑨ represent the drainage hole in the powerhouse area. The sections ②~⑤ are the simulated design scheme, which indicates that the curtain extend westward for 750m, and eastward to the left dam abutment. The seepage field in the interlayer staggered zone C_2 under different conditions is simulated.

5. Results and discussion

The case 1 is the current design scheme, which includes the sections ① and ⑥~⑨. The impounded water level of the upstream is 825m, and the water level of the downstream is 590m. From Figure 3a, one can see that the water level on the left of grouting curtain decreases, and the direction

of seepage tend to the underground building. The water level on the upstream and downstream is 562m and 556m, respectively. The maximum water pressure around the underground powerhouse is zero. There is no leakage phenomenon in the underground powerhouse and main underground cavern. The discharge value of the drainage gallery is $258.1\text{cm}^3/\text{s}$. The upstream equipotential line of the underground building area is dense, and the hydraulic gradient is large. The seepage deformation is easily to occur. The maximum hydraulic gradient is 5.15, and the critical hydraulic gradient ranges from 1.9 to 6.6. The value of the thickness and hydraulic conductivity of the structural plane is mean value under ideal conditions. However, the maximum hydraulic gradient is close to the upper limit of critical hydraulic gradient, and the local area has seepage deformation.

Based on the case 1, the case 2 considered the scheme of extending the curtain, which includes the sections ①~⑤. From Figure 3b, one can see that the direction of the equipotential line in the lower reaches tend to be gentle, which indicates that the water pressure in the powerhouse area becomes smaller. The maximum hydraulic gradient is 3.95, within the critical hydraulic gradient ranging from 1.9 to 6.6. Compared with the case 1, case 2 can effectively reduce the head and hydraulic gradient of underground powerhouse, and improve the seepage field in the powerhouse area (Figure 3c). The case 3 replaced the grouting curtain on the basis of case 1. The hydraulic conductivity of the grouting curtain is $1.0 \times 10^{-9} \text{ cm/s}$. After calculation, the maximum hydraulic gradient in the upper reach of the underground powerhouse area is 4.25, which meets the critical hydraulic gradient 1.9~6.6. There is no leakage in the underground powerhouse area, and the quantity of discharge of the drainage gallery is $143.46\text{cm}^3/\text{s}$. Based on case 3, the case 4 considered the scheme of extending and replacing the grouting curtain, and the hydraulic conductivity of the grouting curtain is $1.0 \times 10^{-9} \text{ cm/s}$. Figure 3d shows that the water level on the left side of the curtain decreases, and the seepage direction near the powerhouse tends to be near the underground building area. The upstream and downstream water level of the underground powerhouse area is 555m, and the maximum external water pressure is 0 m. The quantity of discharge of the drainage gallery is $36.58\text{cm}^3/\text{s}$, and there is no leakage around the underground powerhouse. The upstream equipotential line of the underground building is sparse. The maximum hydraulic gradient is calculated to be 0.23, which is far less than the critical hydraulic gradient 1.9~6.6, and the seepage deformation can not occur. In summary, the scheme of case 4 can effectively reduce the hydraulic gradient of underground powerhouse. The discharge of the drainage gallery is reduced. The groundwater seepage field is improved.

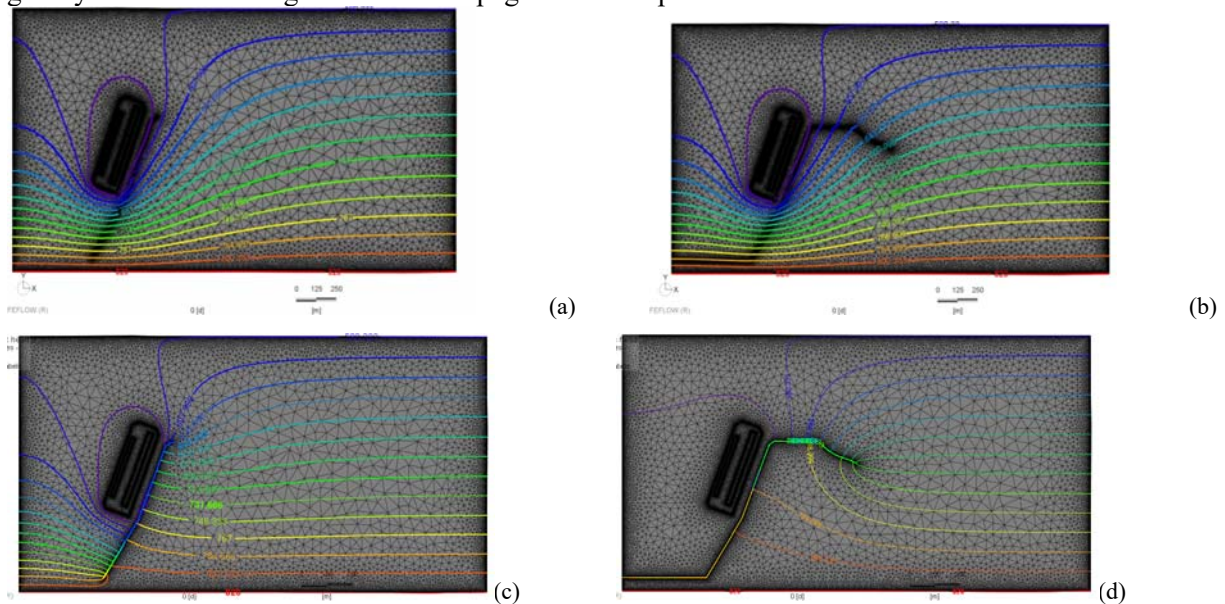


Figure 3 The seepage field in the interlayer staggered zone C_2 under four conditions. (a)Case 1, (b)Case 2, (c)Case 3, and (d) Case 4.

Compared with the case 1, the results of case 2 show that the maximum hydraulic gradient decreases gradually with the increase of anti-seepage curtain. The hydraulic gradient in the upstream of the underground powerhouse area is large, and the seepage deformation is easy to occur. The maximum hydraulic gradient for the basic scheme (case 1) fitted the critical hydraulic gradient, however, it is close to the upper limit of the recommended value. The curtain extension for case 2 can reduce the head and hydraulic gradient near the underground powerhouse area, and effectively improve the groundwater seepage field. The case 3 shows that the hydraulic gradient and the discharge of drainage gallery decreases with the decrease of hydraulic conductivity of the curtain. Similar to the case 2, as the hydraulic conductivity of the grouting curtain decreases, the hydraulic gradient and the discharge of drainage gallery decrease for the case 4. Under the four cases, the hydraulic gradient for the case 4 is lower, and the discharge of drainage gallery is much smaller than other cases.

6. Conclusions

The permeability of the interlayer staggered zone can affect the stability of the underground buildings in the hydropower station. In this paper, the finite element software FEFLOW is used to simulate the seepage field of the interlayer staggered zone C_2 in the basalt of Jinsha River Basin. The influence of the interlayer staggered zone C_2 on the building is analyzed. Combined with the waterproof effect of current design scheme of anti-seepage curtain, the seepage field in the interlayer staggered zone C_2 is discussed under different design schemes. The optimal design scheme of anti-seepage curtain is put forward. The results showed that the case 4 can effectively reduce the head and hydraulic gradient of underground powerhouse area, and improve the groundwater seepage field around the powerhouse area.

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