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Abstract: (1) The studies on the influence of rainfall on slope stability mainly focus on rainfall characteristics and the variation of strength parameters. Few studies pay attention to the microstructure changes of rock mass under long-term rainfall conditions, and the influence of failure mode. (2) Based on nuclear magnetic resonance (NMR) and electron microscopic imaging (Emmi) technology, the microstructure changes and macro deformation characteristics of the schist, under long-term immersion in different liquids are analyzed. (3) After soaking in the deionized water, the uniaxial compression strength of the intact specimen is slightly lower than that of the untreated specimens, but the test process in the elastic compression stage is considerably prolonged, and the failure modes show both shear and slip at the same time. While after soaking in acid solution, the fracture of rock samples with initial cracks can be obviously reduced and healed, which is consistent with the change of micro pore structure. The uniaxial strength and modulus of the intact samples are significantly lower, and only slip failure mode occurred. (4) It shows that water–rock interaction is an important factor influencing the stability of slope besides the external rainfall force, which affects the structural characteristics and mechanical properties of rock.

Keywords: rainfall; nuclear magnetic resonance (NMR); schist slope; microstructural characteristics; failure mode; water–rock interaction

1. Introduction

Rainfall has a significant effect on the stability of slopes, and slope deformation can occur during processes of a long period of rain. Under the most serious conditions, this can lead to the triggering of large-scale landslides and cause significant damage to infrastructure and loss of life, which is not conducive to the sustainable development of social economy.

There have been numerous studies on slope stability associated with rainfall. Two approaches are commonly used to characterize the effects of rainfall on slope deformation: Numerical analysis or model testing. For numerical analysis, limit equilibrium method and strength reduction method, which are originated in the soil slope and then modified for rock slope, were commonly used. The influence of rainfall on slope is mainly through simulating infiltration or reducing strength parameters. Paul et al. [1] proposed a simultaneous reduction method for overhanging rock slopes. Mao et al. [2] used limit equilibrium method and strength reduction finite element method to evaluate slope stability under rainfall infiltration. Wu et al. [3] used intensity reduction method to analyze slope seepage and stability, considering the different rainfall intensity and duration, and concluded that
rainfall intensity and rainfall duration have the most significant impact on slope, which is consistent with Chen’s conclusion [4]. Camera [5] and Ng [6], using finite element software, studied the influence of groundwater level, pore water pressure, and response characteristics of groundwater under different rainfall patterns and durations on slope. For model testing, the influence of rainfall on slope is mainly simulated by different rainfall intensity or rainfall time, and then the deformation characteristics and failure modes of slope under rainfall conditions are analyzed. Vedie et al. [7] conducted model testing on a landslide triggered by rainfall, and the typical failure mode of slope instability in the permafrost region was revealed under different slope conditions. Ray [8] studied the stability of rock slope by modeling the impact of rainfall variations and management interventions on the groundwater. Chueasamat et al. [9] conducted model tests to investigate experimentally the effects of surface sand layer density and rainfall intensity on the slope failure due to rainfall. Experimental tests using physical models have also been conducted by Damiano and Olivares [10] to observe the slope failure mechanism, and the role of infiltration processes in steep slopes stability.

By means of laboratory tests, model tests, and numerical calculations, scholars worldwide have studied the issues including rainfall characteristics (rainfall pattern) [11,12], movement characteristics and failure types of different landslides [13], influence mechanism of rainfall on different types of slopes [14], landslide hydrology [15]. In fact, the influence of rainfall on slope stability is strongly related with the composition and properties of slope rock. With the development of testing technology and testing methods, more and more scholars begin to pay attention to the influence of water–rock interaction on rock properties after rainwater enters into the rock mass. Liu et al. [16] discussed two typical flow patterns on the softening of red sandstone and pointed out that dynamic water–rock interactions have a great effect on rock softening and breaking. Xu et al. [17,18] studied the effect of periodic water circulation on rock mass by P-Wave Velocity and found that the water–rock interaction changed the porosity of the rock pores and then affected its mechanical properties. Mu [19] studied the triggering mechanism and reactivation probability of a loess-mudstone landslide induced by rainwater infiltration, and concluded that shear strength of media is very sensitive to water content because of water–rock interaction, and landslide reactivation is controlled by the water sensitivity of media, especially the original sliding zone.

While mechanical properties of rock based on local microstructure [20–22] show that any macroscopic damage of rock is the ultimate embodiment of its micro damage accumulation, studying the microstructural characteristics of rock in the process of water–rock interaction is also the basis of revealing the mechanism of rainfall-induced slope instability.

There is a large area of metamorphic rocks in Shiyan City, Hubei Province, according to the survey data of geological disasters released by Shiyan Municipal Bureau of Land and Resources in 2016. There have been 1889 geological disasters in Zhushan, Zhuxi, and Fangxian counties in Duhe River Basin in Hubei, including 1801 landslides. As a result of geological disasters, 31 people died, and the direct economic loss was about 225 million yuan. There are still 48,800 people and about 3.7 billion RMB worth of property safety under threat [23], as well as priceless cultural heritage resources. We have conducted a lot of investigations into this area, a thorough statistical analysis of metamorphic rock slope, a kind of rock that is distinctly anisotropic, in Shiyan is shown in Table 1. These examples showed the evidence of long-time rainfall acting as a trigger for landslides. In this paper, Zhushan landslide was considered in view of the specific engineering geological conditions. Microstructural evolution characteristics of schist during water–rock interaction was revealed, using low field nuclear magnetic resonance (NMR) and electron microscopy, considering the effects of seasonal acid rain, to analyze the structural changes of schist under the action of long time soaking from the perspective of micro view. The results of this work can provide a supplementary reference for accurately analyzing and evaluating the effect of long-term rain on slope.
Table 1. The landside caused by rainfall in Shiyan.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name</th>
<th>Location in Hubei Province</th>
<th>Incentive</th>
<th>Lithologic Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yeda landslide</td>
<td>Yunxian county</td>
<td>Rainfall and impoundment</td>
<td>Quartz schist</td>
</tr>
<tr>
<td>2</td>
<td>Yetan landslide</td>
<td>Yunxian county</td>
<td>Rainfall and impoundment</td>
<td>schist</td>
</tr>
<tr>
<td>3</td>
<td>Daoshiping landslide</td>
<td>Zhushan county</td>
<td>Rainfall</td>
<td>Quartz-mica schist</td>
</tr>
<tr>
<td>4</td>
<td>Machanghe landslide</td>
<td>Zhushan county</td>
<td>Rainfall</td>
<td>Quartz-Muscovite schist</td>
</tr>
<tr>
<td>5</td>
<td>Hongjiaopo landslide</td>
<td>Zhushan county</td>
<td>Rainfall</td>
<td>Quartz-mica schist</td>
</tr>
<tr>
<td>6</td>
<td>Daqjayan landslide</td>
<td>Fang county</td>
<td>Rainfall and impoundment</td>
<td>Quartz-mica schist</td>
</tr>
<tr>
<td>7</td>
<td>Daijiawan landslide</td>
<td>Fang county</td>
<td>Rainfall and impoundment</td>
<td>Chlorite mica schist</td>
</tr>
<tr>
<td>8</td>
<td>Longtangpo landslide</td>
<td>Fang county</td>
<td>Rainfall</td>
<td>Quartz-mica schist</td>
</tr>
<tr>
<td>9</td>
<td>E’ping school landslide</td>
<td>Zhuxi county</td>
<td>Rainfall</td>
<td>Chlorite mica schist</td>
</tr>
<tr>
<td>10</td>
<td>Hongjiashan landslide</td>
<td>Zhuxi county</td>
<td>Rainfall</td>
<td>Quartz-sericite schist</td>
</tr>
</tbody>
</table>

2. Overview of Zhushan Landslide

Zhushan Landslide is located on the left side of Section K155+854-K156+178 of Gucheng–Zhuxi Expressway, which is a single expressway construction project with the longest construction mileage and the largest investment scale, as well as the first engineering project to implement standardized construction management in Hubei Province. It is of great significance to the implementation of the two major strategies of the rise of the central region and the development of the western region, and the construction of the ecological and cultural tourism circle in Western Hubei. Once damaged by natural disasters, it will directly affect the contact and communication between the central and western regions and affect the traffic conditions in the mountainous areas of central and Western Hubei. During the construction of the expressway in 2012, part of the landslide collapsed, and anti-slide piles were immediately set up along the road. In 2013, a retaining wall was set between anti-slide pile and expressway. However, the creep deformation of landslide gradually accumulates in each rainy season, which has begun to reduce the function of the support structure and affect the stability of retaining walls, as shown in Figure 1.

![Figure 1. The deformation of support structures.](image_url)

The slope is fan-shaped with a main sliding direction of $10^\circ$, the longitudinal length is about 60–90 m, and the transverse length is about 100–160 m (as shown in Figure 2). The bedrock of the landslide is mainly grayish green and grayish black sericite schist, with a single thickness of 1–3 mm. The occurrence of schistosity are the strike $200^\circ$–$340^\circ$ with the dip angle of $21^\circ$–$33^\circ$, separation state with aperture distance less than 3 mm, clean without filling and poor combination, which can be defined as weak structural surface. The annual average precipitation in this area is about 990 mm, which is characterized by frequent rainstorms, continuous rainy days, and uneven spatial and temporal
distribution. The overall terrain of the landslide area is high in the south and low in the north. A part of atmospheric precipitation is automatically discharged to the southeast in the form of slope flow. While some of it infiltrates the slope overburden and enters the bedrock fissures, and finally flows into the slope bottom. The monitoring data of borehole displacement on the landslide in Figure 3 show that the landslide will have obvious displacement after the rainy season, and there is a significant lag between the occurrence of deformation and rainfall. Therefore, this paper mainly considers the influence of time effect after rainfall on slope stability and sets long-term immersion experiment to study the influence of physical and mechanical properties of schist under water–rock interaction.

Figure 2. Overview of the Zhushan slope.

Figure 3. The monitoring data of borehole displacement on the main landslide section.
3. Indoor Test and Result Analysis

3.1. Test Preparation and Test Plan

In order to study the influence of water–rock interaction on the stability of schist slope, the schist blocks taken from the landslide area are processed into samples of different scales, and the samples with obvious defects and large discreteness are screened and removed by ultrasonic testing. The mineral composition is mainly composed of quartz, feldspar, muscovite, and clinochlore. The natural density is 2.53 g/cm$^3$ and the saturated density is 2.76 g/cm$^3$. The test scheme is set as follows, and the instruments used are also shown in Figure 4.

1. Take out the selected rock samples after drying at 45 °C, put them into a dryer to cool them down to room temperature and weigh them. Repeat the drying until the difference between the two adjacent masses does not exceed 0.1% of the later weight, indicating that the initial drying is completed. Then measure and record the size and wave velocity of each rock sample, and group them to undergo different test conditions.

2. Considering the influence of acid rain as it is reported, the rock samples after initial drying are soaked in H$_2$SO$_4$ solution with pH = 4 and deionized water, respectively.

3. In each group of tests, a number of control rock samples were set up, and the samples were taken regularly every day after immersion for scanning the local surface morphology by electron microscope, and the quality, wave velocity, and micro pore structure of the complete rock samples were tested at the same time.

4. After each day’s immersion, the solution and control group samples are taken to test the composition and content of mineral in liquid and solid, respectively.

5. The strength test was carried out on the samples undergoing different test conditions.

![Figure 4. The test scheme and main instruments used in the test.](image)

3.2. Analysis of Pore Structure in Samples

After soaking in different solutions for the same time, the low field nuclear magnetic resonance (NMR) test was carried out. The NMR T2 spectrum is the measurement of hydrogen atom bearing water in rock pores. The distribution of pores will affect the test results and the change of T2 spectrum was used to analyze the change of micro pore structure under different solution conditions. The shorter the relaxation time of transverse axis, the smaller the micro pore diameter, and the position of T2
The T2 spectrum of typical rock samples after immersion in deionized water for a number of days is bimodal distribution, as shown in Figure 5. With the increase of soaking time, the main wave peak shifted to the left only when soaking for five days. After soaking for 10 days, the main wave peak shifted to the right by a large margin, and a new wave peak appeared at the relaxation time of 1000 ms. After soaking for 15 to 30 days, the main wave peak shifted to the right again. This shows that the pore size of the schist sample decreases during the five-day soaking process. However, the pore structure of schist becomes larger with the prolongation of soaking time, and larger pore size is formed with the breakthrough of small pore.

![Figure 5. The T2 spectrum of typical rock samples soaked in deionized water.](image)

Figure 6 shows the change of T2 spectrum of typical rock samples soaked in the solution with pH = 4 for a number of days. It can be seen from the figure that the change of the position of the two main wave peaks occurred in 5 days and 10 days, respectively. After soaking for five days, the position of the main wave peak did not change obviously, while the range of the secondary wave peak expanded to the right side, which indicated that five days soaking in acid solution had a great influence on the macropore. When the immersion time is prolonged, the main wave peak of the sample shifts to the right obviously after immersion for 10 days, which indicates that the pores with smaller size in the sample become larger. However, the process of soaking for 10 days to 30 days does not change the position of the main wave peak of the sample, but makes the secondary wave peak shifts to the left, indicating that the long-term soaking under acid conditions does not change the small pores of the sample obviously, and it is even helpful for the repair of the large pores to a certain extent.

![Figure 6. The T2 spectrum of typical rock samples soaked in acid solution.](image)
The area of T2 spectrum after the first saturation is defined as the initial area, the ratio of T2 spectrum area to the initial area after each immersion is defined as the relative change rate of pore number. The change of the pore number of the sample, after immersion for different time under different solution conditions, is characterized by calculating the relative change rate of pore number, as shown in Table 2, which also shows the characteristic regions of typical spectrum changes during the soaking process.

### Table 2. Characteristics of chromatogram area of typical rock.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Soaking Time</th>
<th>Relative Change Rate of Pore Number</th>
<th>Chromatogram Area of Rock Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>deionized water</td>
<td>1</td>
<td>1.00</td>
<td><img src="image1.png" alt="Graph" /></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td>acid solution</td>
<td>1</td>
<td>1.00</td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0.97</td>
<td></td>
</tr>
</tbody>
</table>

It can be found that the spectrum area of rock sample decreases significantly on the fifth day of soaking in deionized water, and the area of T2 spectrum is the largest on the 10th day of soaking. After 20 days of soaking, the area of T2 spectrum almost rises to the initial state, and then the spectrum area decreases significantly, and the relative change rate of pore number is stable until 30 days of soaking. After soaking in acid solution for 10 days, the pore number decreases significantly, but after soaking for 15 days, it increases significantly. During soaking for 20–30 days, the pore number remained relatively stable.

### 3.3. Characteristics of Solution Properties and Minerals Content

The pH value of the solution and the content of minerals in the solution were tested in the process of soaking. The influence of soaking in different solutions was analyzed by the fluctuation of solution properties and minerals content in the soaking process. After immersion in deionized water, the contents of Mg, Al, and Si in the solution vary greatly, as shown in Figure 7a. After soaking for one day, the content of Mg reaches the peak, and then decreases in a fluctuation. The content of Si in the solution first increases gradually, and then decreases obviously after 20–25 days soaking, and then increase again. While the content of Al in the solution has been in a state of fluctuation. After soaking for 10 days, the increase of Fe content indicates that the iron salts in the mineral cement are largely dissolved. After soaking in acid solution (Figure 7b), the content of Si changes most violently. The content of silicon element in the solution after soaking for one day reaches the peak value, and then drops to the minimum after soaking for 10–15 days. It reaches a new peak value (much smaller than the initial peak value) after soaking for 20 days and 30 days, respectively. After soaking for 20 days, the content of Ca increases, indicating that the calcium cement in schist minerals begin to dissolve.
The change of minerals content in the solution corresponds to the reaction process of schist minerals in the solution. The solution reacts with the mineral composition in the pore to form transient solid or sediment, which is the main reason for the larger pore size getting smaller. The hydrolysis of transient solid and the gradual dissolution of minerals, including magnesium, calcium, and silicon, are the important factors for the formation of smaller new pores. It is worth noting that with the prolongation of immersion time, the pH of acid solution increases gradually and tends to be neutral, while even in neutral deionized water, the pH of solution fluctuates obviously during the immersion of schist samples.

3.4. Microstructural Characteristics of Schist

The joints of the test rock are developed well, and quartz, mica, and other minerals are arranged in a certain direction in the process of rock metamorphism, showing obvious anisotropic characteristics. The characteristics of schist parallel and vertical to joint surfaces were observed after soaking in different solutions, to analyze the effect of different solutions on the morphology and mineral crystal structure of schists. The original samples were cut along the vertical and parallel joint surfaces, respectively, and their microscopic images were shown in Figure 8. The vertical microscopic images show that the joints are parallel, the material in the layer is well cemented, and the fracture is ladder-like. After 2000 times magnification, the ladder-like fracture is mainly quartz intergranular fracture, and mica crystals are scattered on the steps (Figure 8a). While the integrity of the images parallel to the joint direction is good, and after 2000 times magnification, lamellar mica intergranular fracture can be seen locally (Figure 8b).

The mineral structure of the samples immersed in different solutions under single polarized light and orthogonal polarizing microscope was observed, to analyze the crystal structure characteristics of different minerals reacted with different solutions as shown in Table 3. The quartz in the original sample is colorless and transparent with wavy extinction. The particle size range in 0.02 to 0.25 mm, and the distribution is directional, concentrated in strip distribution, showing fold structure. There is an angle between the directional distribution direction and the strip direction of minerals. Muscovite is flaky, colorless, and the interference color is bright grade II to III, with parallel extinction and continuous directional arrangement. Biotite is flaky too, with obvious maroon brown yellow polychromism. The interference color is grade III, with parallel extinction, and mixed with Muscovite in a strip distribution. Iron is irregular granular, black, and opaque, with particle size of 0.02–0.15 mm. After soaking in solutions of different properties, cracks can be seen clearly. After soaking in deionized water, the fracture develops mainly along the direction of joint, and there are some holes left by particle hollowing out, and occasionally filled with small particles. After soaking in the acid solution, cracks along and perpendicular to the joint surface can be seen clearly, and small holes...
can be seen locally, and some of them have been connected. No matter which solution is soaked in, the microstructure of mica quartz schist will be affected, and the microcracks tend to expand along the edge of mica-oriented distribution, which is the main reason for slip failure mode.

![Microscopic images of original samples](image1)

![Microscopic images of original samples](image2)

(a)  (b)

**Figure 8.** The microscopic images of original samples (a) perpendicular to joint surfaces, (b) parallel to joint surfaces.

**Table 3.** Mineral structure under single-polarized and orthogonal polarized conditions.

<table>
<thead>
<tr>
<th>State</th>
<th>Structures under Single/Orthogonal Polarized Light</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original State</td>
<td><img src="image3" alt="Image" /> <img src="image4" alt="Image" /></td>
<td>Mineral grains closely arranged, and native tiny cracks can be seen</td>
</tr>
<tr>
<td>Acid solution</td>
<td><img src="image5" alt="Image" /> <img src="image6" alt="Image" /></td>
<td>Crack extension is visible along or vertical to the joint surface, local small holes appeared, and some holes have been connected</td>
</tr>
<tr>
<td>Deionized water</td>
<td><img src="image7" alt="Image" /> <img src="image8" alt="Image" /></td>
<td>Crack extension is visible along the direction of joint after soaking, local hollowed hole left by the particles, occasional small granular solid filler can be seen</td>
</tr>
</tbody>
</table>
3.5. Mechanical Properties of Soaked Schist

After soaking in different solutions, some specimens with primary cracks develop well in the stress-free state. Specifically, after immersion in deionized water, the extension of primary cracks and the initiation of new cracks are obvious with the increase of immersion time, as shown in Figure 9a. After immersion in the acid solution, only the local block spalling along the primary fracture occurred in the initial immersion stage. After the immersion time was prolonged, the original cracks on the surface are intermittently closed and opened, as shown in Figure 9b. The macroscopic phenomenon is almost consistent with the microscopic porosity results.

![Figure 9. The cracks of samples developed after soaking (a) in deionized water, (b) in acid solution.](image)

After immersion, uniaxial compression tests were performed on the intact specimens. The results show that the peak strength of the samples soaked in the two solutions is significantly lower than that of the original samples. However, the strength of the sample soaked in acid solution decreases more obviously. The soaking process prolonged the compression process of the sample in the elastic stage, and the elastic modulus of the sample showed different degrees of influence. Although immersion in deionized water has the greatest influence on the process of elastic compression, the influence on the magnitude of elastic modulus is less than that in acid solution, as shown in Figure 10.

![Figure 10. The stress-strain curve of samples.](image)
Although it seems the macroscopic fracture of schist is larger and more obvious after immersion in deionized water than that in acid solution, the results of strength test showed that the process of elastic compression of schist sample was prolonged after immersion in deionized water, but the influence on strength was not greater than that after immersion in acid solution. It is suggested that the deionized water is more likely to dissolve the filler between the framework particles of schist, resulting in more and more obvious macro cracks. However, after immersion in acid solution, the pH value of the solution itself increased, and the reduction of compressive strength was the largest, which indicated that the skeleton particles of schist minerals were more likely to be corroded after soaking in the acid solution, reducing the strength. At the same time, the retention of the reaction products filled the dissolved pores again, and the macro fracture of schist also showed partial closure.

On the other hand, the failure characteristics of the specimens soaked in different solutions are different from those of the original samples. Under uniaxial compression, the specimens without any treatment exhibit typical shear failure mode, as shown in Figure 11a, and the specimens immersed in acid solution for a long time show a sliding failure mode under uniaxial compression as shown in Figure 11c. However, the specimens immersed in deionized water for a long time contain both shear and sliding failure characteristics, as shown in Figure 11b.

Figure 11. The failure characteristics of the specimens (a) untreated samples, (b) after soaked in deionized water, (c) after soaked in acid solution.

4. Discussion

(1) It has been proved that for schist metamorphic rocks, the acidity of rainwater is an important factor affecting the slope stability. The effect of acid rain on schist is not only physical dissolution, but also chemical corrosion. Chemical corrosion causes the formation and dissolution of minerals around quartz, mica and other particles, forming microcracks distributed along the grain edge, which is the fundamental reason for the slip failure of schist immersed in acid solution under uniaxial stress. For this kind of slope, if the joint distribution is consistent with the sliding
direction of the slope, it is easier to produce sliding deformation than at any other time, as this engineering example, Zhushan slope, shows.

(2) The creep deformation of the slope occurs after long-term rainfall and stops after the rainy season, which indicates that the starting of the sliding process of the slope is sensitive to water with time effect. As a typical bedding slope, the sliding direction of Zhushan landslide is consistent with the direction of schist schistosity plane, which creates a decisive condition for the instability of the landslide. Rainfall infiltrates into the slope rock mass, and the water content increases, which not only increases the gravity component in sliding direction, but also softens the strength of the rock on the potential slip surface. Under the water–rock interaction, the failure mode of rock on the sliding surface changes from shear failure to sliding failure (or shear and sliding failure), which further reduces the requirement of external force for inducing sliding, and it is an essential condition for the deformation of Zhushan landslide. Based on this, the protection of the slope deformation in the rainy season can be carried out from three aspects. To deal with the sliding mass in sections, transferring the risk of forward sliding. To take measures related to surface protection, reducing the surface water infiltration and fissure water infiltration. To set up a retaining structure, decreasing the probability of sliding mass cutting out from the potential shear outlet.

(3) The experimental conditions designed in this study mainly consider the influence of long-term hydrostatic immersion on schist in slip zone, the pore water pressure of fracture water in schist and the dynamic water pressure of flow are ignored. However, under the condition of long-term rainfall, water enters the rock mass along the joint surface and primary micro cracks, and the granular quartz and flake mica are sandwiched between the schistose planes, which provides a good channel for the flow of water in the schistose plane. In turn, water acts as a lubricant between the particles. Once pore water pressure or hydrodynamic pressure increases, the friction and anti-force between schistosity will be reduced directly, which is not conducive to the overall stability of the slope.

5. Conclusions

Analyzing the formation and occurrence mechanism of slope disasters from a micro perspective is an important link to prevention and risk management for sustainable fruition, and also an important way to achieve disaster prevention and control. The main conclusions drawn from the present study can be summarized as follow:

(1) When the schist is soaked for a long time in deionized water, the pore size and the number of pores decrease temporarily in a short time. However, the change of pore number is little different from that of the initial state undergoing continuous immersion, even it makes the pore structure larger. The short-term immersion under acidic conditions will make the pore structure larger and extending the soaking time will help repair the larger pores, but the effect of the whole process on pores number is smaller than that of the former.

(2) The long-term immersion in solutions with different properties not only affects the peak strength of schists, but also changes the failure mode of schists under uniaxial loading. In particular, the peak strength of un-soaked specimens is the highest, and the failure mode of the rock mass is a typical shear failure. After soaking in acid solution for a long time, the peak strength and elastic modulus of the samples are greatly reduced, and sliding failure is the main failure mode. The long-term immersion in deionized water has little effect on the peak strength, but it greatly prolongs the test process of the elastic compression stage, which makes the failure of rock take into account the shear and slip modes.

(3) Under the condition of long-period and low-intensity rainfall, the dissolution of mineral particles and cementitious materials between particles changes the pore structure of schist. In particular, the early micro-cracks formed at the edge of mica particles, and gradually expanded and
penetrated during long-term immersion, which reduced the bearing capacity of rock mineral structure and affected the mechanical properties of schist (elastic modulus, peak strength, etc.). The instability of schist slope under rainfall is the result of the accumulation of minor damage and also the reflection of the interaction of rock mass structure and geological environment.

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