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ORIGINAL ARTICLE

The weakening mechanisms of the rock mechanics of marlite bank slopes under water–rock interaction conditions

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Abstract
Karst-related issues have become serious in the Three Gorges reservoir area, where the bank slopes consist of marlite. In this paper, the mineralogical and petrological properties and internal micro-structure development mechanism of the marlite were analyzed to determine its dissolution and weathering characteristics. In addition, the application of high-power electron microscopy identified micro-cracks in the marlite and micro-dissolution vugs on both sides of the micro-cracks. Montmorillonite was shown to be the dominant clay mineral accumulated at the edges of the vugs. Based on the test results of the rock mechanics and the natural dissolution processes, the concept of dissolution coefficient was proposed to describe the strength change pattern of the marlite. Next, the change pattern between the dissolution and strength weakening of the marlite was characterized with the typical four stages of rock compression and deformations. It was also shown that long-term water–rock interactions resulted in unique deformation characteristics in the slopes, while, vertically, the slope bodies could be divided into a strong dissolution zone, medium dissolution zone, and weak dissolution zone.

Keywords Marlite bank slopes · Water–rock interactions · Weakened strength · Three Gorges reservoir area

Introduction

During the processes of water–rock interactions, the material composition and structures of the rock change over time, as direct results of physical and chemical actions. In terms of engineering geology, this causes changes in the mechanical strength of the rock, especially in areas where limestone is present. The strength of limestone rock tends to decrease due to water–rock interactions. It has been found that, both in China and internationally, dam foundation seepages and reservoir slope instability problems have become frequent disaster events (Eang et al. 2018; Shen 2014; Wang et al. 2015; Cheng 2016; Chen 2006; Duperret et al. 2005; Zhang 2004; He et al. 2003; Tugrul and Zarif 2000). Therefore, at present, an increasing number of researchers are paying closer attention to the study to the weakening strength levels of rock masses resulting from water–rock interactions. In soft rock engineering particularly, water weakening effects are one of the important reasons for large deformations and failure occurrences. Therefore, it is important to establish constitutive models of rock masses under weak water effect conditions. The mechanical properties of rock mass structures are required to be effectively analyzed to solve the mechanical mechanisms of soft rock structures (Bao et al. 2019; Bian et al. 2019; Xu et al. 2019; Deng et al. 2017; Lu et al. 2017; Liu et al. 2016; Lebedev et al. 2014; Wu et al. 2013; Erguler and Ulusay 2009; Patrick et al. 2000). In recent years, some researchers have studied the mechanism of parameter degradation of soft rock under immersion conditions from a microscopic perspective, and established a damage constitutive model (Bian et al. 2019). It was found that the pore growth rate of Glauconite in fresh water is several to several hundred times higher than that in salt water (Yang et al. 2014).

Marlite is a soluble rock belonging to one of the soft rock types, and the processes of water–rock interactions involving marlite are known to be complex. There are many factors affecting the strength properties of marlite. Previous research

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studies have pointed out that the main factors leading to the strength reduction of marlite include chemical corrosion, karst and weathering, water pressure, scale effects, acid, and water content (Guo et al. 2014; He and Guo 2013; Zhang et al. 2012; Yao et al. 2009a, b; Zhang 2004). Conventional triaxial compression tests have been used to determine the strength characteristics of hard brittle limestone immersed in chemical corrosive liquids at different pH values. The results indicated that limestone tends to transform from brittleness to ductility, and the degrees of the deterioration of the mechanical parameters of the limestone have positive correlations with the ionic concentrations dissolved from the limestone (Yao et al. 2009a, b). It has been observed that different corrosive liquids have varying effects on the structures of rock masses. Among these effects, large numbers of dissolution vugs are often formed in rock cores after gelling acid reactions. Meanwhile, the variable-load acids are generally dominated by uniform corrosion, which causes less damage to the internal structures of the rock cores. The differences in the corrosive structures caused by acidic liquids are the fundamental reasons for difference in the mechanical strength (He and Guo 2013). Also, scale effects are important factors affecting the mechanical properties of rock masses (Zhang et al. 2012).

The karst-related problems of the marl–limestone rock masses in the Three Gorges area are currently considered to be serious. The long-term interactions of water and rock have significant impacts on the stability levels of the bank slopes (Zhang et al. 2008, 2016, 2017, 2018; Huang and Gu 2017; Sun et al. 2016). Under the combined actions of water-level fluctuations and rainfall in the reservoir area, the calcareous components of the marlite are generally dissolved, while the argillaceous components become weathered. This situation causes the lithology and structure of the rock masses to change, resulting in the continuous decrease of the mechanical strength (Zhang 2004). In addition, significant promoting effects of the occurrences of landslide hazards in the reservoir area have been observed (Zhang et al. 2016). The authors of this study have also conducted many research investigations in the Three Gorges Reservoir area, and have found that the dissolution processes of the marlite on the slope surfaces have the characteristics of rapid and integral collapse (Liu et al. 2008). At present with the rapid development of engineering construction projects, the unloading effect of a large number of high-cut slopes on the surface has a significant influence on the weakening of rock mechanical properties (Wang et al. 2010; Gao et al. 2012), and the types of rock masses in many engineering sites include soluble limestone. The surface slope is severely damaged. However, there have been a few studies to date regarding the water–rock interaction processes of marlite or detailed analyses results of the strength weakening mechanism of marlite. Therefore, to address these issues, this study selected the rock masses of marlite slopes of the bank surfaces of the Fengjie area of the Three Gorges Reservoir as the research object for the purpose of exploring the special weathering regularity of the marlite masses during the processes of long-term water–rock interactions.

Characteristics of the marlite slopes of the bank surfaces in the Fengjie area of the Three Gorges reservoir

Argillaceous limestone and marlite bank slopes are widely distributed throughout the Three Gorges Reservoir area. These types of rock mainly occur in the Triassic Badong Formation strata, and are roughly symmetrically distributed on the eastern and western sides of the Huangling anticline (Fig. 1). It has been generally observed in the field that after rock has been subjected to karstification, a wide range of dissolution cracks and small karst caves tend to occur. The diameters of dissolved pores vary from several millimeters to several tens of cm. In some marlite banks, large karst caves with diameters of more than 10 m are developed. The rock layers become thinner and the rock becomes increasingly fragmented. Also, it is particularly noticeable that the rock masses change in color (Fig. 2a), which is mainly due to the fact that the FeO oxidizes into Fe_2O_3, thereby resulting in the affected rock changing from dark grey to dark green → grey green → yellow green → pink → brown red as the argillaceous components become weathered. For example, on a hexahedron cut with joints and beddings, the central part will tend to be dark grey; the surrounding parts will appear to be grey green; and the adjacent joints will be yellowish brown to muddy yellow. These color variations indicate that the dissolution and corrosion from the center of the block to the joint surface has been gradually enhanced. However, on a vertical section, it may be observed that the lower part of the section will be dark grey; turn grey green in an upward direction; then change to muddy yellow as it continues upward; and finally become visible as brown red calcareous mudstone or mudstone at the top. The described color changes indicate that the dissolution and corrosion effects are gradually enhanced from the bottom to the top of the section.

Dark grey muddy limestone and marlite are known to be hard and fragile after weathering. When hammered, they easily break into 1 cm sized slags (Fig. 2b). Due to the existence of expansive clay minerals in the rock, the rock cores taken from the deeper sections will burst 1 or 2 days after being exposed to the surface, even in the cases of the dark grey argillaceous limestone cores. The fragility levels indicate that the rock joints are susceptible to changes in external geological conditions under alternating wet and dry conditions. The bursting actions are beneficial to the karstification process, resulting in the speed of the karst development in

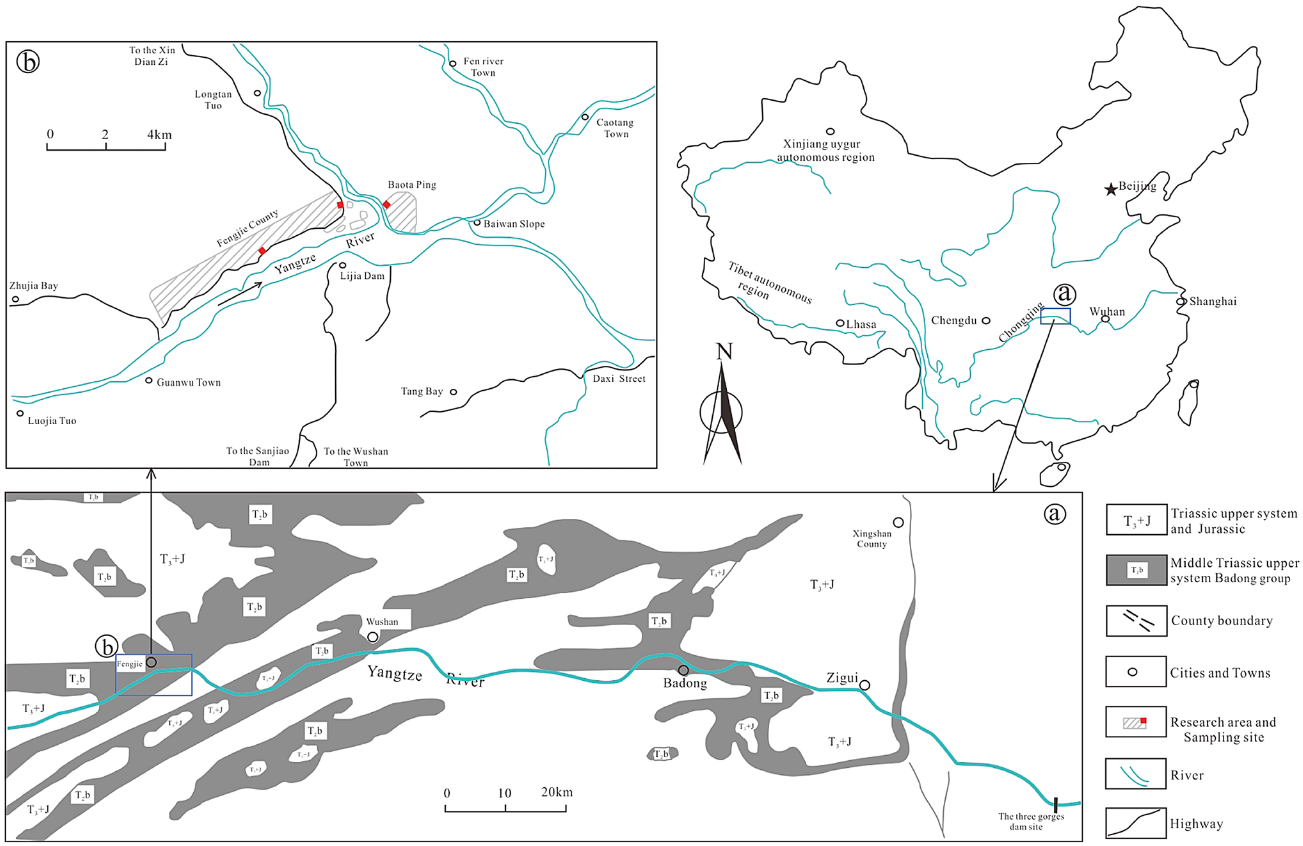

Fig. 1 Distribution of the Triassic marlite in the Yangtze River (Zhang 2005; modified). ⓐ The Three Gorges reservoir area scope and the marlite stratigraphic distribution; ⓑ Marlite sample collection sites in Fengjie area

the rock masses increasing. It has been observed in the field that after 1 or 2 years of exposure to the surface, the grey marlite became weathered into grey–green or brown–red formations, indicating that the oxidation of the rock has transformed Fe^{2+} into $Fe(OH)_3$ due to exposure on the surface. According to Zhang (2004), dark grey marlite outcrops tend to turn grey–green after becoming exposed to rain and sunshine, and the rock excavated from the ground will decompose into soil after exposure on field ridges for 2 to 3 years.

The marlite strata in the Fengjie area are affected by subsidence and the unloading and loosening of underlying rock masses in the Yangtze River Gorge area. They are generally considered to exhibit loosening phenomena. The tensile fissures on the vertical bank slopes are well developed. However, these existing fissures have been eroded by both surface water and underground water to form broad dissolution fractures. The dissolution actions are affected by microstratification to form different dissolution vugs (Fig. 2c, d). Along the fissure surfaces, the phenomena of honeycomb vugs, dissolution ditches, troughs, and pits are often formed, which have been observed to be relatively developed in the Baotaping section of the Fengjie area (Fig. 2e, f). The scale of the karst caves is small, such as the dissolution vugs at the east side of Chenjiagou, their diameters vary from 0.2 to 1 cm (Fig. 2d), and the diameters of the dissolution ditches and dissolution troughs at Baotaping vary from 3 to 10 cm (Fig. 2e, f). However, in the West Bank karst cave of the Meixi River (Fig. 2g), the karst caves are also highly developed, and their diameters vary from 1 to 10 m. The surfaces of reservoir banks T_2b^3 marmite fissure rock masses are basically affected by the corrosion effects, and the corrosion characteristics of the slope surfaces are obvious.

Sampling and testing methods

The samples for this study were collected from the argillaceous limestone and marlite of Triassic Badong Formation in the Fengjie area. The sampling points were located at three different sites on the bank slopes. For example, samples were taken from the roadside section on the north side of the Fujun Bridge in Baotaping; an eastern section of the Yufu Gas Station in Baotaping; and an excavation cave in the old county town of Fengjie itself (Fig. 1).

The selected experimental items were mainly examined in the Shandong Provincial Key Laboratory of Depositional Mineralization and Sedimentary of Shandong University of

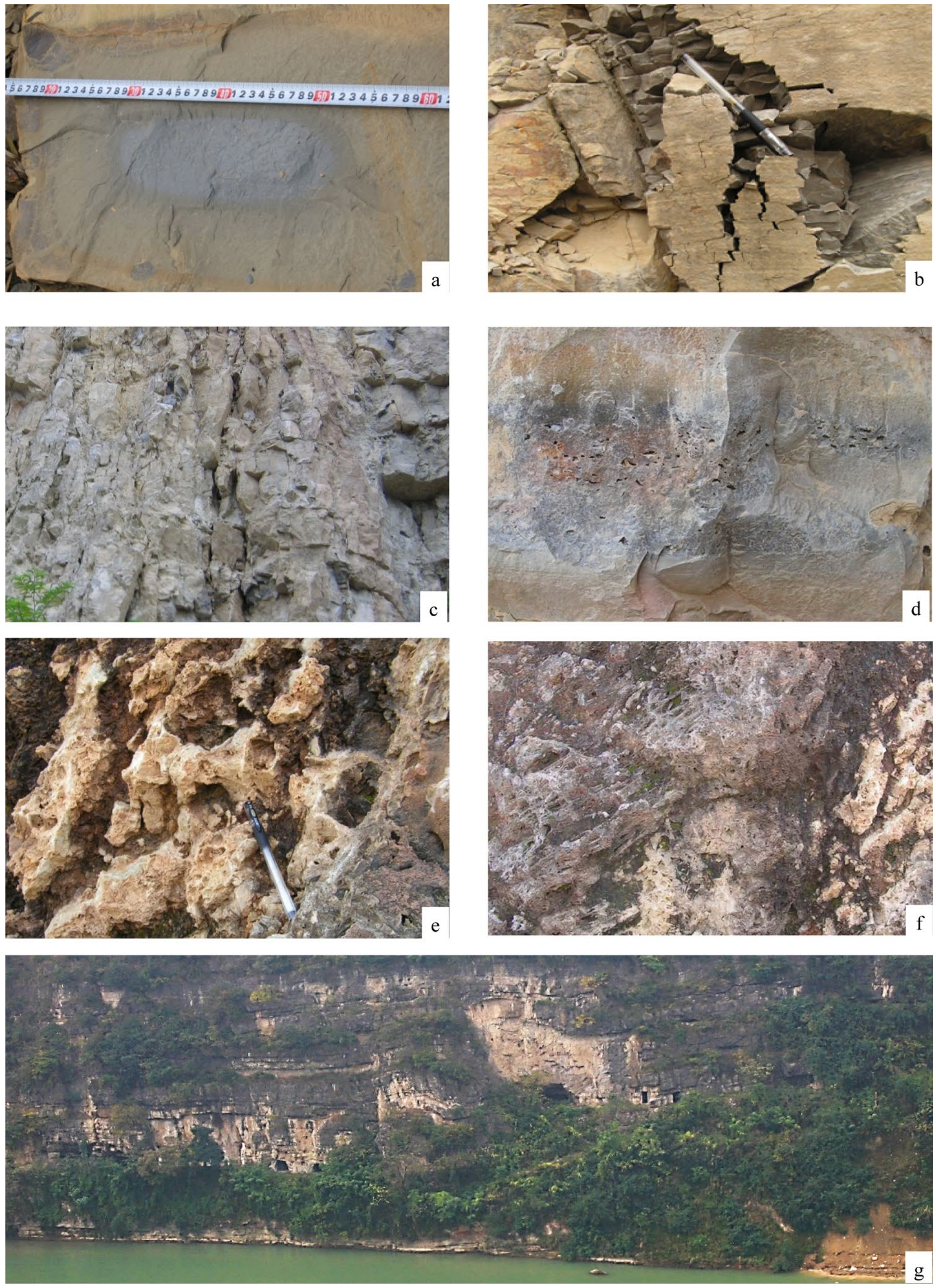

Fig. 2 Various karst characteristics of the marlite band slopes as observed in the field. **a** Weathering halo phenomenon (Wangjiabao). **b** Fragmentation phenomenon (Wangjiabao). **c** Vertical dissolution and corrosion band (east slope of Chenjiagou). **d** Horizontal dissolution and corrosion band (east side of Chenjiagou). **e** Dissolution ditch and dissolution trough (Baotaping). **f** Peak pit dissolution vugs (Baotaping). **g** Horizontal dissolution vugs on the west bank of the Meixi River

Science and Technology. The processes included an analysis of the physical properties of the rock samples. The details are shown in Table 1. This study used a block density test to determine the natural density, and the dry density and saturation density of the rock samples were measured using a volume method. In addition, the natural water content and saturation water content of the samples were measured at the same time. This study's mineral composition analysis was mainly completed by observations made using an indoor microscopy. A polarizing microscope (BX53-P) produced by OLYMPUS Co. (Japan) and a scanning electron microscope (LEO 1450VP) obtained from Leo Co. (Germany) were adopted in this study to perform comprehensive analyses of the composition and microstructures of the samples. The rock mechanics tests included a uniaxial compression test and a triaxial compression test. The instruments used in the rock mechanics tests included a TAW-2000 microcomputer-controlled electro-hydraulic servo rock testing machine. Therefore, this study's testing machinery had the ability to reliably complete uniaxial compression and triaxial compression tests under different confining pressures. The saturated state and dissolution state samples were processed into

Table 1 Basic physical properties of the Argillaceous limestone samples

Grouping of the samples	Group A	Group B	Group C
Natural density (g/cm^3)	2.67	2.60	2.54
Dry density (g/cm^3)	2.67	2.59	2.52
Wet density (g/cm^3)	2.68	2.63	2.58
Natural water content (%)	0.25	0.50	0.76
Saturated water content (%)	0.37	1.58	2.29
Lithological characteristics	Dark grey argillaceous limestone; compact; low porosity; less-developed fissures	Grey–yellow marlite containing clay minerals; weak sample properties	Muddy yellow marlite containing a large amount of argillaceous material; microscopic micro-fissures

50 mm × 25 mm cylindrical samples in the early stage, and then, after their size and quality were measured, they were placed in cups. Then, 140 ml diluted hydrochloric acid with concentration of 0.5% was added, the diluted hydrochloric acid was replaced with the same concentration and volume after 24 h, and observations and records were made. This process was repeated until 120 h and then ceased. The specific requirements referenced those described by Liu et al. (2008). Many assorted tests were carried out using the three sample groups. The mechanical properties of each group of the samples were tested under a natural state, water saturation state, and dissolution state. Then, five rock samples were taken for uniaxial testing under each of the aforementioned states, and the average values were taken from the experimental results, as detailed in Table 2.

Research results

Physical and structural properties of the marlite under water–rock interaction conditions

It has been found that marlite differs from pure limestone due to its dual characteristics of both limestone and mudstone. During the process of water–rock interactions, the calcareous components of the marlite are dissolved and the mudstone components become weathered. This process changed the lithology and structure of the rock and continuously reduced the mechanical strength (Zhang 2004). Some of the marlite was already considered to belong to the category of soft rock.

According to this study's surface observations and identification analyses of the samples, the surface coloration of the Group A samples was grey–black and appeared dark under the polarizing microscope. In addition, the rock structure was compact. The main mineral composition in Group A was calcite, followed by dolomite, with trace amounts of limonite, mica, quartz, and biological debris also observed.

Table 2 Mechanical property contrast table sorted by the uniaxial compression test results in different states

Group no.	Sample state	Uniaxial compressive strength, σ_1 (MPa)	Modulus of deformation, E (GPa)	Poisson's ratio, u	Cohesion C, (MPa)	Angle of internal friction φ, (°)	Deterioration coefficient	Dissolution coefficient
A	Natural	91.752	24.328	0.340	31.45	47	1	1.224
	Saturated	80.677	19.877	0.252			0.879	1
	Dissolved	57.491	10.565	0.343			0.626	0.532
B	Natural	89.088	15.781	0.242	16.34	53	1	0.953
	Saturated	67.342	16.567	0.157			0.733	1
	Dissolved	49.428	9.543	0.26			0.555	0.576
C	Natural	71.371	12.251	0.240	–	–	1	1.118
	Saturated	52.299	10.958	0.166			0.734	1
	Dissolved	39.198	6.868	0.246			0.549	0.610

The test property was a uniaxial compression test; sample size: the sample diameter 25 mm and height 50 mm; deterioration coefficient refers to the ratio of the compressive strength after saturation (dissolution) to the compressive strength of the sample in a natural state; dissolution coefficient refers to the ratio of the deformation modulus in a natural (dissolution) state to that in a saturated state

The overall appearance was that of muddy cementation. The results of this study's scanning electron microscopy revealed that mineral grains were closely arranged in the fresh marlite (Fig. 3a, b), with clear margins and no signs of alterations or disturbances. Also, from the perspective of the structural morphology, the cleavage surfaces of the calcite were arranged in layers and sheets which displayed directional characteristics. Therefore, the microstructures of the fresh marlite of the Badong Formation were determined to be relatively stable (Fig. 4a, b).

The surfaces of the Group B and Group C samples were greyish yellow, and the results obtained using polarizing microscopy determined that calcite was still the main mineral component. However, the content levels of clay minerals were observed to have significantly increased (Fig. 3c–f). The results of this study's scanning electron microscopy showed that there were a large number of micro-cracks in the samples, which displayed directional characteristics and were found to often be developed around the edges of the calcite particles. In addition, strong dissolutions were found to have locally occurred, with a large number of vugs and loose structural characteristics. The long axis directions of the multiple extensions of the vugs often traced the extension directions of the micro-cracks (Fig. 4c, d). The concentrated lamellar clay minerals surrounding the dissolution caves were determined to be mainly montmorillonite clay minerals according to their mineral morphological characteristics. This was mainly due to the fact that during the weathering process, the argillaceous components produced a large number of new montmorillonite (Fig. 3d, e).

Mechanisms of the strength weakening of the marlite rock masses following long-term water–rock interactions

Through the analysis of the uniaxial test results of the rock mechanics completed in the laboratory, the mechanical strengths of each group of rock were found to obviously

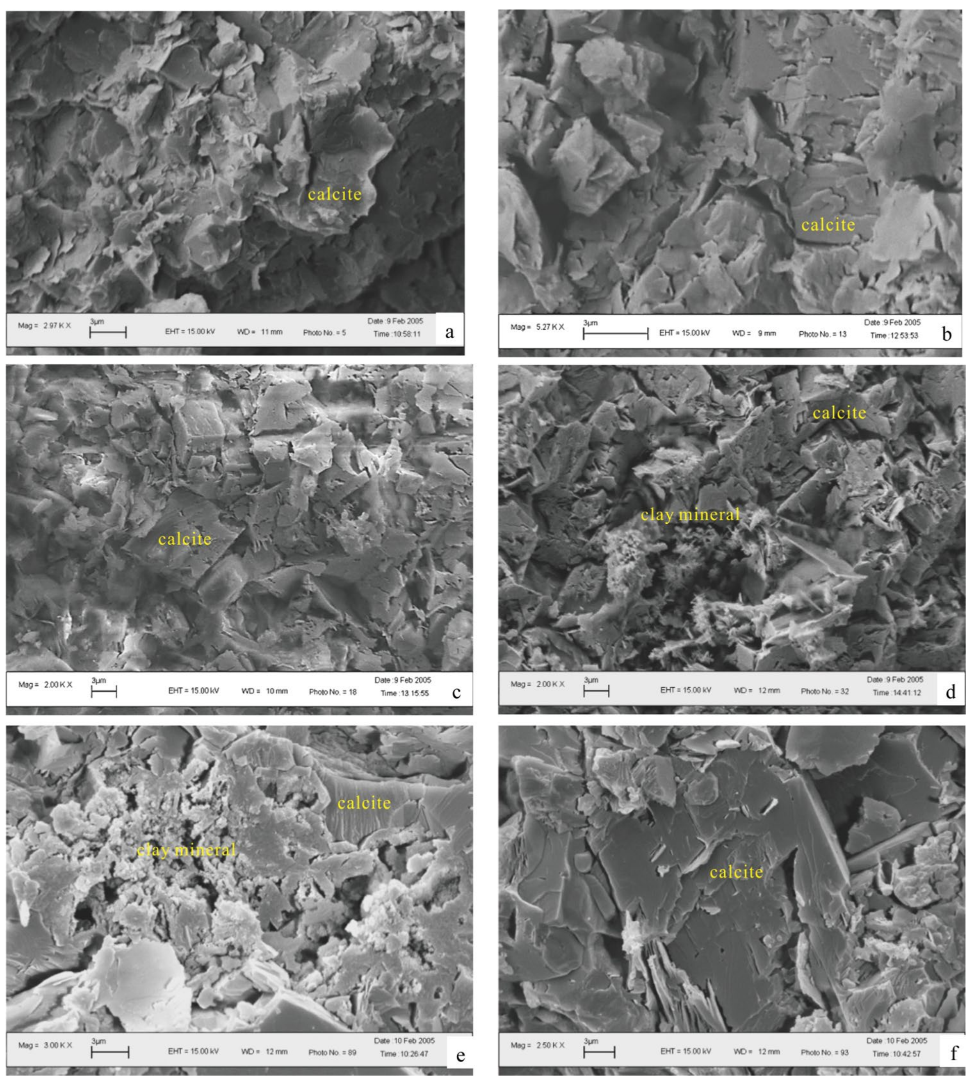

Fig. 3 Mineral compositions of the marlite samples under water–rock interaction conditions

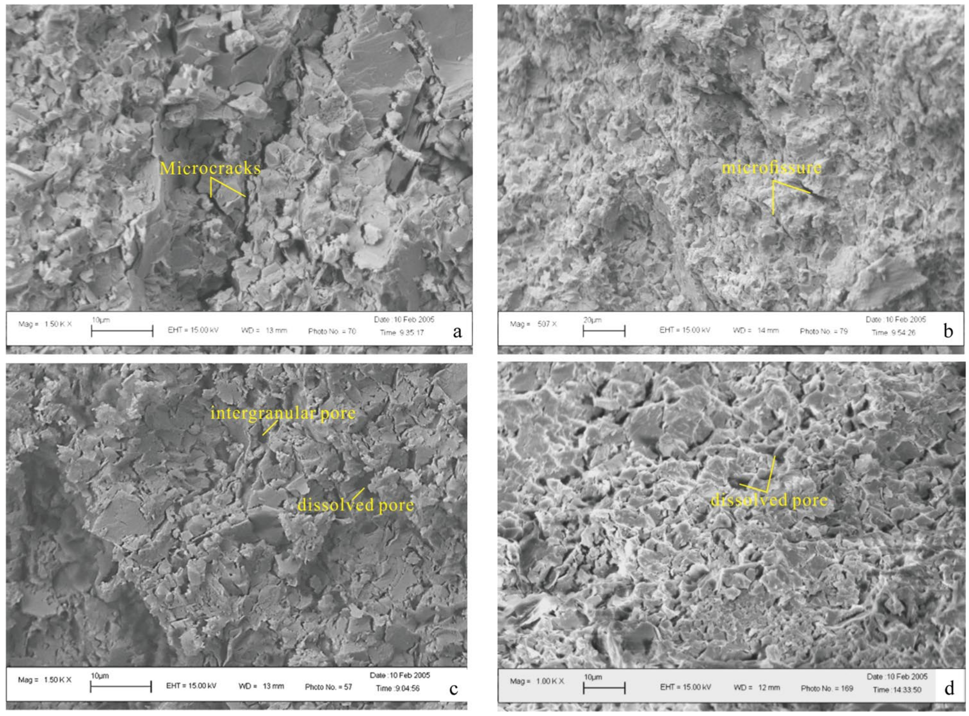

Fig. 4 Internal karstic fractures of the developed marlite samples under water–rock interaction conditions

change following the natural, saturation, and dissolution processes (Table 2). The strength levels of each group of rock decreased slightly following water absorption and saturation. However, those decreases were observed to be minimal. The dissolution process destroyed the original composition and structural characteristics of the rock samples, and the mechanical properties of the samples were obviously weakened. Then, according to the analysis results of the uniaxial test processes and the stress–strain data, the uniaxial compressive strengths of Group A were determined to be higher, and the weakening of the properties of the original rock was found to be less significant. Meanwhile, the strength levels of the Group B and Group C samples were observed to be significantly weakened during the process of the bank slope evolution following the effects of weathering and corrosion (Fig. 5). The maximum deformation modulus was 24.328 GPa in the test results, and the minimum deformation modulus was only 6.868 GPa. In addition, according to the analysis results of the dissolution coefficients of the three groups of samples, the deformation moduli of the rock samples decreased greatly after the dissolution conditions occurred. At the same time, the deterioration coefficient analysis results showed that the strength levels of the three groups of samples decreased to almost 50% of the original after the dissolution. It was found that, due to the differences in the microstructures of the samples, the dissolution process had greatly changed the compositions of the samples, as well as the state of the internal micro-structures, which subsequently led to obvious weakening in the strength levels of the rock.

In the present study, in accordance with the variation law of the mechanical strength and the shape characteristics of the stress–strain curves of the rock samples following this study's uniaxial laboratory strength tests of the natural, saturation, and dissolution processes, the compression deformation processes could be summarized into four stages as follows: ① compaction stage, ② elastic deformation stage, ③ microfissure expansion stage, and ④ failure stage (the serial numbers of each stage in Fig. 5 are represented by the results of samples in the natural state). The compaction stage of rock structure was more typical when the rock was dissolved. The initial stages of the compression curves of the three groups of dissolution samples were concave. The main reason for this was that some of the interbeds, cracks, and micro-pores in the rock samples had gradually compacted, deformed, and closed with the increases in pressure. The second stage was the elastic deformation stage of the sample, namely after all the cracks in the rock were closed, the curves showed near linear growth. The third stage was a development and expansion stage for the rock microfissure. In other words, the processes before and after the stress–strain curves reached their peak values, which often exhibited the characteristics of multiple peak values. At that time, the internal structures of the rock samples changed, with the micro-cracks beginning to expand, and the internal lattices and interfaces fracturing, separating, and dislocating. The results were that the earlier processing stages of the rock samples had transformed from micro-structuring to macro-destruction processes. The fourth stage was the

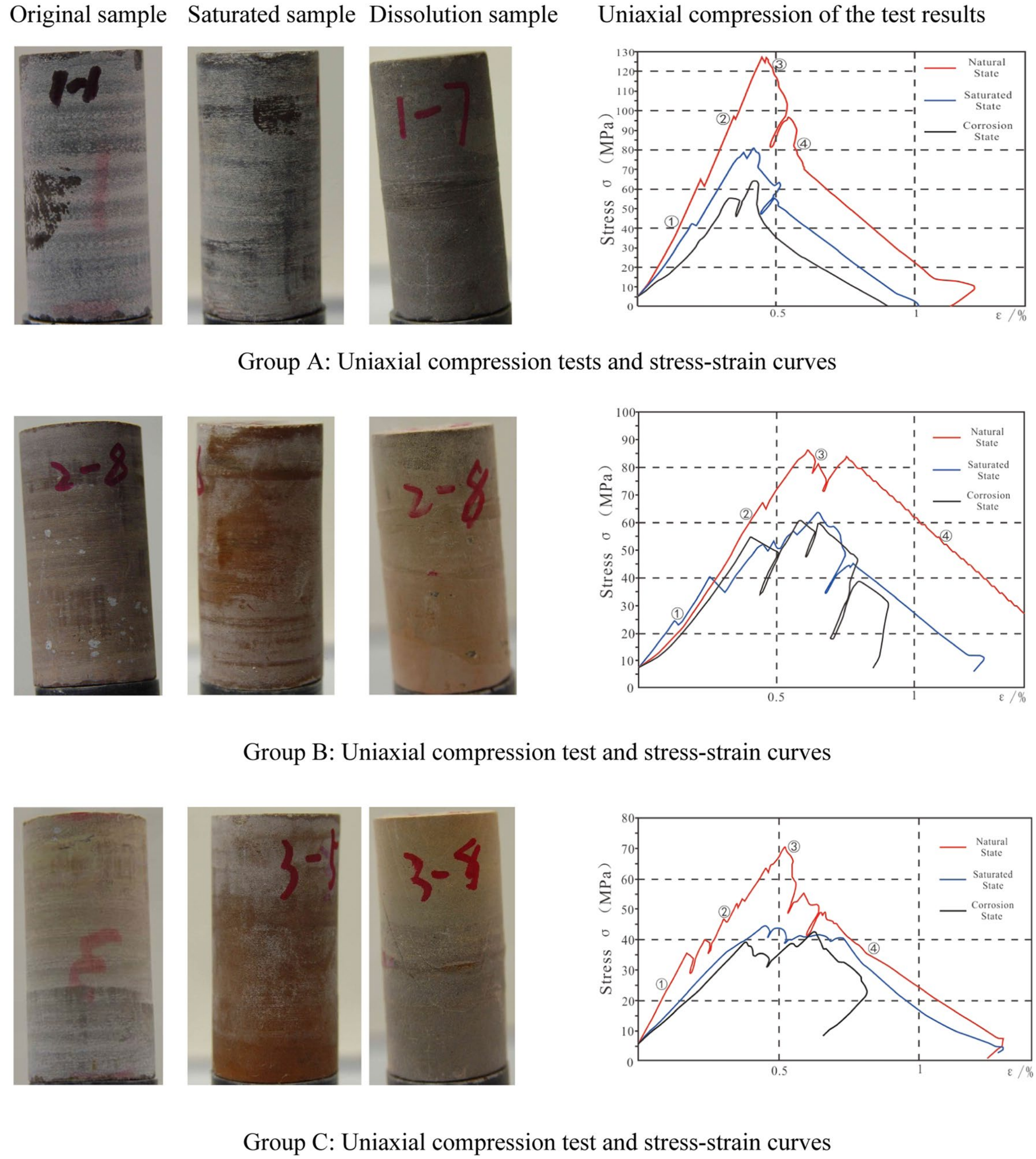

Fig. 5 Uniaxial compression tests of the three sample groups in the natural, full water, and dissolution states. ① The compaction stage of rock structure. ② The elastic deformation stage of the sample. ③ The development and expansion stage for the rock microfissure. ④ The macro-fracture failure stage of the rock samples

macro-fracture failure stage of the rock samples, in which the macro-performance characteristics of the micro-cracks had changed after the cracks had extended to certain extents. The stress levels in the stress–strain curves were observed to begin to fall from the highest point, and the initial speeds were relatively slow. Then, after the stress levels had fallen to a certain degree, the samples were found to lose their bearing capacities. At that point, the strength capacities of the samples rapidly dropped. The micro-cracks in the rock samples rapidly expanded into macro-cracks, and the scope of the damages noticeably enlarged.

Analysis results and discussion

The processes involved in the examined water–rock interactions were found to significantly alter the compositions and structural properties of the marlite. The strength levels of the rock masses became weakened and exhibited certain regularities. During the processes of the water–rock interactions, not only did the chemical elements of the rock masses become redistributed between the rock masses and water, but changes had also occurred in the microstructures of the rock masses. Therefore, it was necessary to comprehensively analyze the mechanical properties and deformation and failure characteristics of the marlite after the dissolution from the perspectives of chemistry, physics, and mechanics.

Karstification is a geological process in which soluble rocks (such as carbonate rocks, gypsum, rock salts, etc.) are subjected to chemical dissolution by water, supplemented by mechanical action such as erosion, subduction, and collapsed by flowing water. However, marlite has a relatively complex rock composition, and clay minerals are sensitive to water, which causes corrosive water to react with soluble rock composition by penetrating to the rock surface. At the same time, the erosion and subduction of flowing water are more intense than those of common soluble rocks in the process of dissolution. It has been determined that the marlite components on the bank slopes of the Three Gorges Reservoir area are complex. Marlite is considered to be a transitional type of rock between limestone and mudstone, which possesses both limestone and mudstone characteristics. The most important features of the coupling of these two types of rock characteristics are the strong effects of karstification under certain conditions (Zhang 2004), and that the initial dissolution during the early stages of the water–rock interactions first occurs on the rock surfaces. The solutions gradually infiltrate into the interior areas of the rock masses along the surfaces of the micro-structural cracks. Then, following dissolution, clear crack notches have been observed to form on the rock surfaces, along with small visible solution vugs. Ultimately, the internal compositions and structures of the rock masses change due to the water–rock interaction processes, and the integrity and firmness characteristics of the rock become greatly reduced. In this study, the alignments of the calcite crystals in the rock were characterized by their orientations using a microscopic electron microscopy method, which reduced the mechanical properties of the rock in the direction of the parallel joints, and was conducive to the dissolution process. It could be seen from the microscopic electron microscopy results that the dissolution in the contact zones between the soluble and non-soluble rock material was often more obvious. Dissolution vugs and other karst formations were easily formed near the soluble rock material. Meanwhile, such insoluble impurities as the siliceous and argillaceous components were found to be concentrated around the karst vugs. In accordance with the analysis results of the structural characteristics of the examined rock samples, the distribution areas of the joint fissures and cracks, especially near the ends of the fissures, were the activation areas of the dissolution. Those activation areas were the destruction first occurred, before gradually extending to the surrounding rock. The effects of the dissolution of the rock promoted the interactions of the cracks. Then, the effects of the crack aggregation effectively reduced the strength of rock masses. At the same time, the aggregation and expansions of the cracks provided a more favorable environment for hydro-chemical actions and permeation of fluids. It is worth noting that when we discuss the karstification of slope and the weakening of slope strength, we must consider the scale effect of the experimental results in this paper, as they were observed under actual circumstances.

Marlite slopes are ubiquitous throughout the Three Gorges Reservoir area. According to this study's field observations, rock mass failures are gradually expanding from the outside to the inside of the slopes, displaying infiltrative disintegration processes during long-term water–rock interaction conditions. Some previous related research studies have pointed out that, after the excavations of a large number of high-cut slopes in the Three Gorges reservoir area, the surface marlite tends to become easily and rapidly decomposed into the soil, which greatly reduces the mechanical strength of the marlite (Qi et al. 2009). It has been observed that under the comprehensive actions of weathering, unloading, leaching, and dissolution of slope rock masses, many cracks and vugs become evident on the slope surfaces within a certain range, and the quality of the rock masses decreases. At the same time, the rock masses are compacted and

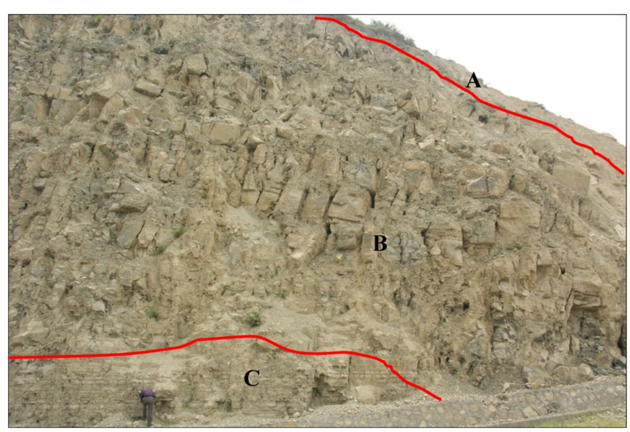

Fig. 6 Marlite bank slope deformation characteristics of the Fengjie Yufu gas station area

subsided under the actions of gravity. Following the marlite slope rock masses experiencing dissolution, the loose and deformed rock masses display typical zonation patterns from the outside surfaces to the inner layers, as illustrated in Fig. 6. Generally speaking, within the thickness range of 3–5 m from the slope surfaces tend to be strong influence zones of dissolution (Area A), and the rock becomes soil-like in character. Then, within the range of 30–50 m from the slope surfaces, or even more than 100 m below the surfaces, erosion influence zones occur (Area B). Therefore, after controlling the characteristics of the rock masses loosening deformation, the strength levels will be reduced and the rock masses will become relatively fragile. On the other hand, due to the adjustments of the structural networks in the rock masses, the strong loosening deformations tend to occur in larger ranges, forming thick "crisp" and "loose" bands. The rock strength and structural strength of those parts of the rock masses become significantly reduced, and "overall collapses" may very easily occur. In the interior regions of the rock masses, weak dissolution influence zones (Zone C) occur. These interior zones may also undergo some rock dissolution, but its performance will not be as strong as in the two zones. The strength levels of the rock masses continue to decrease to a certain extent, but the loosening of the rock mass structures will be weak. This study's comprehensive analysis results indicated that the collapsing actions of the slopes are weakened from the slope surfaces to the slope interior areas. The slope profile revealed a step-by-step downward fault along the fissure surface, which resulted in the examined bank slope in the Three Gorges area displaying the deformation characteristics of not being fully slipped and collapsed (Fig. 6). However, if the hydrodynamic conditions are good, the dissolution processes will be more intense, and the unloading cracks along the slopes will often form large-scale karst caves, resulting in karst-type collapses.

Conclusions

Through observation of the weathering and dissolution characteristics of marlite slope in the Three Gorges reservoir area, and analysis of the results of laboratory dissolution test of marl samples, the following conclusions were reached:

1. In the process of water–rock interaction, the dissolution water is permeable on the surface of marlite, which is due to the clay minerals in the rock composition, especially montmorillonite minerals.
2. The argillaceous composition results in the water more easily infiltrating into the interior of the marlite than the common limestone.
3. The dissolution liquid could not only dissolve the soluble components along with the micro-cracks, but also had a stronger erosion effect along the cracks.
4. The insoluble argillaceous components were easily lost after the liquid dissolution, resulting in strong weakening of the rock mass structure. The strength of dissolved samples had been reduced to the original 50–70%, and the strength of the marlite samples was more obviously weakened than the common limestone.
5. Under the same stress conditions, the plastic deformation of dissolved samples was greater than that before dissolution in the initial stress stage, which was more prominent in the marlite samples.

As is known, field conditions are more complicated than the laboratory conditions. When discussing the karstification of the slope and weakening of the slope strength, the scale effect of the test results in this paper should be considered, as the test was performed under actual conditions. In addition, karst development is strong in the tectonic belt area, and the influence of large structures such as faults and folds on dissolution is also a very important factor, yet these are not discussed in this article.

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