Field test on engineering characteristics of karst breccia

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Abstract. Karst breccia is a special kind of rock related to karst action with wide distribution. The karst breccia in the dam site area of a hydropower station in the Three Gorges reservoir is very representative. Field tests are carried out on the karst breccia at the dam site of the hydropower station, including in-situ deformation test, direct shear test, triaxial compressive test, large density test and particle analysis test. The test results show that the engineering characteristics of karst breccia in the dam site area is close to that of soil, and moisture content, gravel content and lateral pressure are important factors affecting deformation modulus. Water content has a weakening effect on the mechanical properties of karst breccia, and the higher the water content is, the lower the deformation modulus of the same kind of lithology is. The shear strength parameters of karst breccia determined by triaxial compression test are higher than that of the direct shear test.

1. Introduction
Karst breccia is a kind of karst sedimentary formation related to paleo-karst, and is a "fossil" that records the karst development environment and formation era [1-2]. The karst breccia is also a hosting ore for a variety of mineral deposits, and is closely related to engineering construction due to its wide distribution [3-4]. In China, karst breccia is developed from the pre-Sinian to the Tertiary [5].

With the socio-economic development, more and more engineering construction projects involve karst breccia, but also due to insufficient recognition, resulting in certain hazards and Losses. During the construction of Yichang - Wanxian Railway, Taihang Mountain Tunnel of Shijiazhuang - Taiyuan Passenger Dedicated Line Railway and Yuanliangshan Tunnel of Chongqing to Huaihua Railway, and so on, the engineering geological problems of karst breccia have been encountered [6-12]. Current research on karst breccia by domestic and foreign scholars is mainly in the field of mineral resources, archaeology and other fields [13-17]. The main research direction is the genetic mechanism, development characteristics and mineralization significance, little research on the engineering properties of karst breccia [8-13]. In China, Hongdan Y, Liming X, et al. have studied the engineering characteristics of karst breccia such as weathering and rheology, and carried out engineering classification to study the impact of karst breccia on the project [2, 5, 18-19].

The Triassic karst breccia is widely distributed in the dam site area of a hydropower station on the Wujiang River in the Three Gorges reservoir area of the Yangtze River, Chongqing, China. Karst breccia has great influence on slope stability, dam foundation stability and dam seepage control. For this reason, from the perspective of engineering safety, the exploration adit was excavated in the karst breccia with the worst properties at the dam site of this hydropower station. Through field tests, the physical properties, strength and deformation characteristics of karst breccia are studied.
2. Lithological characteristics of Karst breccia

The karst breccia strata in the dam site of the hydropower station is the upper part of section 4 of the Jialingjiang Formation in the Lower Triassic (T$_{1}$j$^{4-2}$), with stable production horizon. The karst breccia can be divided into two layers according to lithology difference:

A. The upper layer is yellow, brown-yellow, pinch a small amount of light gray, gray, mainly argillaceous cementation. The breccia diameter is relatively different with poor roundness. It is named Yellow Karst Breccia in the field;

B. The lower layer is dark-gray, gray-black, and the bottom part contains gypsum lensing, with calcium or calcium-argillaceous cementation mainly, a small amount of cementation is semi diagenetic, and the grain size of breccia is relatively homogeneous, with relatively good grinding roundness. It is named Gray Karst Breccia in the field.

The total thickness of karst breccia is about 52m. The thickness and distribution of the upper and lower layers are unstable, and the top and bottom interfaces fluctuate.

3. Test methods

3.1. Selection of test methods

For rock and soil mass, conventional in-situ tests include load test, cone penetration test (CPT), dynamic penetration test (DP), standard penetration test (SPT), vane shear test (VST), pressure meter test (PMT), flat dilatometer test (DMT), direct shear strength test and sonic measurement, etc.[20]. In this study, field test methods for karst breccia were selected on the basis of the following:

a. The lithologic characteristics of karst breccia in the project area. The karst breccia in the project area has different types of cement, such as argillaceous cementation and calcareous cementation, with disparity of gravel particle size, poor sorting and easily disintegrates, making it difficult to obtain specimens that meet the requirements for physical, hydraulic and mechanical property testing.

b. Meeting the engineering design requirements. In the karst breccia distribution area, there are some engineering geological problems such as slope stability of the dam shoulder, leakage of the dam foundation, anti-sliding stability and foundation deformation. In order to meet the requirements of slope support design, seepage control engineering design, anti-slip stability and deformation calculation of dam foundation, it is necessary to provide the corresponding parameters, which mainly including physical properties and particle composition, deformation parameters, strength parameters, hydrogeological parameters of rock-soil mass, etc.

3.2. Selected test methods and contents

Physical property tests, deformation tests and strength tests were carried out on karst breccia at the dam.

The physical property tests mainly include in-situ density test, moisture content test and particle analysis test. Irrigation method was used for in situ large density test. The specimens were taken in three test pits to determine density and moisture content, and the size of test pit is about 0.5m × 0.5m × 0.5m. After the completion of in-situ density test and moisture content test, the representative specimens were screened and the grading curves were plotted.

The deformation test of rock mass is conducted by the rigid bearing plate method, with the area of 2000cm$^2$; the maximum test pressure is 1.2MPa ~ 1.6 MPa, pressurized by the step-by-step one-cycle method.

The straight shear test of the rock mass is conducted by the plain push method, and the direction of shear stress is consistent with the direction of stress on rock mass. According to the principle of not less than 1.2 times of the maximum pressure of the project and ensuring the safety of the test adit, the normal stress is reasonably distributed to each test specimens in equal difference series.

The triaxial compression test specimen of rock mass is a rectangular column, 50cm in length, 50cm in width and 100cm in height, with the bottom surface connected to the original rock and in natural water bearing state. The test specimen is manually excavated on the wall of the test adit, and then cut and shaped by the cutting machine.
3.3. Location of test points
The test points are arranged in two sections, 15-25m and 90-97m, in the PD1 adit on the left bank of the dam site. The lithology of 15-25m depth is mainly Gray Karst Breccia, and the lithology of 90-97m depth is mainly Yellow Karst Breccia. In these two main sections, small test adits are excavated at appropriate locations with the gravel particle size more uniform and reflecting its characteristics.

Three test adits with the size of 1.5m × 1.0m × 1.0m were excavated at the depth of 15-25m respectively. The Gray Karst Breccia was tested for physical properties, straight shear tests and deformation tests. The other three test adits with the size of 2.0m × 1.5m × 2.0m were excavated at the depth of 15-25m. The Yellow Karst Breccia was tested for physical properties, deformation tests and triaxial compression tests.

4. Analysis of physical property test results
Results of field physical property test of karst breccia are shown in Table 1, and grading curves of particle analysis are shown in Figure 1.

| Lithologic                  | Moisture state | Test point number | Density /g cm⁻³ | Moisture content /% |
|-----------------------------|----------------|-------------------|-----------------|--------------------|
| Natural Gray Karst Breccia  | Natural        | W1-1              | 2.58            | 7.56               |
|                             |                | W1-2              | 2.34            | 5.97               |
|                             |                | W1-3              | 2.40            | 4.77               |
|                             | Average        |                   | 2.44            | 6.10               |
| Saturated                   | W2-1           | 2.39              | 12.26           |
|                             | W2-2           | 2.46              | 8.66            |
|                             | W2-3           | 2.58              | 9.51            |
|                             | Average        |                   | 2.48            | 10.14              |
| Natural Yellow Karst Breccia| W3-1           | 2.25              | 5.97            |
|                             | W3-2           | 2.34              | 4.94            |
|                             | W3-3           | 2.22              | 5.58            |
|                             | Average        |                   | 2.27            | 5.50               |
| Saturated                   | W4-1           | 2.38              | 8.84            |
|                             | W4-2           | 2.23              | 7.34            |
|                             | W4-3           | 2.41              | 9.21            |
|                             | Average        |                   | 2.34            | 8.46               |

Figure 1. Grading curve of karst breccia
The results of particle analysis show that the nonuniformity coefficient of Gray Karst Breccia is 10.0-65.2, and the curvature coefficient is 1.7-4.6. The nonuniformity coefficient of Yellow Karst Breccia is 6.5-8.9, and the curvature coefficient is 1.0-1.1. The range of variation of the former is greater than of the latter, indicating an inconsistent distribution of grey karst breccia grains. Two kinds of karst breccia are named coarse-grained soil according to particle analysis.⁴¹
In terms of physical characteristics, the density of the Gray Karst Breccia is greater than that of the Yellow Karst Breccia, but uniformity of the latter is better than that of the former.

5. Analysis of test results on deformation and strength tests of rock mass

5.1. Deformation characteristics of rock mass

The deformation test of grey karst breccia consists of two groups: E1 and E2. Group E1 is in natural water bearing state and group E2 is in saturated state. The deformation test of Yellow Karst Breccia has two groups, E3 and E4. E3 is in natural water bearing state and E4 is in saturated state. The physical properties and deformation characteristics of rock mass are shown in Table 2, and the relationship curve between deformation modulus and water content is shown in Figure 2.

From the deformation test results (Table 2), the deformation modulus of karst breccia is low, which is close to the nature of soil. In the natural water bearing state, the deformation modulus of Gray Karst Breccia and Yellow Karst Breccia is similar. In saturated state, the deformation modulus of the two kinds of color karst breccias is also close to each other, and the average value is basically the same. The water content weakens the mechanical properties of karst breccia. The same kind of lithology, the higher the water content is, the lower the deformation modulus is.

| Test point number | Moisture content /% | Deformation modulus /GPa | Elastic modulus /GPa |
|-------------------|---------------------|--------------------------|----------------------|
| E1-1              | 7.56                | 0.154                    | 0.373                |
| E1-2              | 5.97                | 0.218                    | 0.544                |
| E1-3              | 4.77                | 0.121                    | 0.515                |
| E2-1              | 12.26               | 0.037                    | 0.140                |
| E2-2              | 8.66                | 0.061                    | 0.278                |
| E2-3              | 9.51                | 0.096                    | 0.287                |
| E3-1              | 5.97                | 0.167                    | 0.410                |
| E3-2              | 4.94                | 0.272                    | 0.693                |
| E3-3              | 5.58                | 0.203                    | 0.727                |
| E4-1              | 8.84                | 0.057                    | 0.345                |
| E4-2              | 7.34                | 0.056                    | 0.344                |
| E4-3              | 9.21                | 0.064                    | 0.408                |

Figure 2. Relationship curve of deformation modulus and moisture content

The comparison of deformation modulus of the same lithologic before and after saturation is shown in Table 3. The deformation modulus in saturated state is significantly lower than that in natural state. Among them, the deformation modulus of Gray Karst Breccia is reduced by 60.36%, while that of
Yellow Karst Breccia is decreased by 72.43%, and the water content increased significantly. This is mainly due to the fact that the argillaceous cement in the rock mass softens after saturation, showing similar properties to the soil. It can be seen that the state of water content has a great influence on the deformation modulus of rock mass.

| Lithologic            | Deformation modulus/GPa | (E₀-E₁)/E₀ |
|-----------------------|-------------------------|------------|
|                       | Natural/E₀  | Saturated/E₁ |         |
| Gray Karst Breccia    | 0.164       | 0.065       | 60.36%  |
| Yellow Karst Breccia  | 0.214       | 0.059       | 72.43%  |

The deformation characteristics of karst breccia are also related to its particle size. From the deformation test curve, the natural state of deformation test of karst breccia is up-concave curve, and the saturated state is linear, which indicates that the rock mass particle size is small, easy to compress characteristics, showing a large compression deformation under low stress.

5.2. Direct shear strength characteristics of rock mass

The direct shear strength characteristics of Gray Karst Breccia rock mass (Group τ₁ and Group τ₂) are tested at 15m ~ 25m of Adit PD1. The results of direct shear tests are shown in Table 4.

| Lithologic | Test point number | normal stress σ/MPa | shear stress τ/MPa | f' c'/MPa | shear stress τ/MPa | f c/MPa |
|------------|-------------------|---------------------|-------------------|----------|-------------------|--------|
| Gray Karst Breccia | τ₁-1 | 0.79 | 0.77 | 0.56 |
|               | τ₁-2 | 0.40 | 0.51 | 0.46 |
|               | τ₁-3 | 1.20 | 1.20 | 1.12 |
|               | τ₁-4 | 0.00 | 0.19 | /      |
|               | τ₁-5 | 1.95 | 1.50 | 1.28 |
|               | τ₁-6 | 1.40 | 0.93 | 0.9    |
|               | τ₂-1 | 0.63 | 0.42 | 0.38 |
|               | τ₂-2 | 0.30 | 0.33 | 0.33 |
|               | τ₂-3 | 1.07 | 0.59 | 0.59 |
|               | τ₂-4 | 0.86 | 0.63 | 0.43 |
|               | τ₂-5 | 0.00 | 0.16 | /      |
|               | τ₂-6 | 0.47 | 0.40 | 0.31 |

The test locations of Group τ₁ and Group τ₂ are close to each other with the same lithology, which avoids the influence of factors such as stratigraphic lithology and geological structure on the strength characteristics, and the main difference lies in the different water bearing states. Among them, Group τ₁ is in natural water bearing state and Group τ₂ is in saturated state. In the two test conditions, the rock mass shows a certain degree of plastic failure with large fluctuation difference. The results show that the shear strength of Gray Karst Breccia in saturated state is lower than that in natural state, indicating that the water bearing state has obvious weakening effect on the shear strength of karst breccia.

5.3. Analysis of triaxial compression test results

The stress-strain relationship curve of karst breccia is obtained by triaxial compression test. According to the stress-strain relationship curve, the deformation modulus, elastic modulus and yield strength σₚ of the rock mass are calculated. Based on the test results, the deformation and strength characteristics of karst breccia are analyzed.

5.3.1. Analysis of deformation characteristics

A. The stress-strain relationship curve can be roughly divided into 3 segments (see Figure 3).
   a) Initial segment (AB), with a small deformation rate.
   b) Linearly deformed segment (BC), with point C as the yield limit. The axial deformation is generally linear and the rate of deformation is greater than that of the initial segment.
c) Accelerated deformation segment (CD), after the stress reaches the yield limit, the axial deformation rate increases, and the specimen expands until it is destroyed.

B. Side pressure, gravel content, and moisture content are important factors affecting deformation modulus. The relationship curve between deformation modulus and lateral pressure is shown in Figure 4.

a) The deformation modulus is higher at Specimen R5 because of the higher content of gravel (see Figure 5).

b) The deformation modulus of Specimen R3 and Specimen R6 is low, which is due to the high moisture content. Specimen R3 and Specimen R6 are located in the same test adit, with water seepage on the side wall of the test adit.

c) The deformation modulus is positively correlated with the side pressure, and the correlation formula is:

$$E_0 = 382 \sigma_3 + 124$$

Where $E_0$ is the deformation modulus (MPa); $\sigma_3$ is the side pressure (MPa).

Figure 3. Typical relation curve between axial stress and axial strain

Figure 4. Relationship curve between deformation modulus ($E_0$) and side pressure ($\sigma_3$)

C. From the stress-strain curve of loading and unloading, it can be seen that the specimen has large plastic deformation and small rebound deformation. Which indicates that the rock mass is broken, with large and loose voids between particles.
5.3.2. Strength property analysis
Destruction pattern: after the rock mass reaches the yield limit, the axial deformation increases, the specimen starts to expand, the side pressure rises, and it needs to be continuously decompressed. The axial pressure is unstable and needed to be compensated; until the axial pressure cannot be maintained, the specimen is destroyed. After failure, the specimen is damaged in tension, with non-pass-through cracks and no pass-through damage surface, and the surface rock body in the middle of the specimen flaked off.

According to the failure characteristics of the specimen, there is no fixed shear plane in the triaxial compression test, and the specimen is destroyed along the weak plane. The failure mechanism is related to the integrity of rock mass, the size and arrangement of particles. However, the direct shear test has interactive shear plane, which is basically destroyed along the designated shear plane. Its failure mechanism is related to the integrity of rock mass, the roughness of rock surface and the fluctuation difference. Due to the uneven distribution of karst breccia particles, poor cementation and looseness, it is difficult to form ideal triaxial shear failure, so the shear strength parameters determined by triaxial compression test are higher than those determined by direct shear test.

6. Conclusion
Based on the field physical property tests, deformation tests, direct shear tests and triaxial compression tests of two kinds of karst breccias with different main components in adit PD1 on the left bank of the dam site, the physical properties, deformation characteristics and strength characteristics of karst breccia are studied. The study shows that:

a) The engineering properties of the karst breccia in the dam site area are close to soil. The grey karst breccia has an inconsistent grain distribution, while the Yellow Karst Breccia has an almost identical grain distribution. The names are all coarse-grained soils according to the grain analysis.

b) Moisture content, breccia content and lateral pressure are important factors affecting deformation modulus. The water content weakens the mechanical properties of karst breccia. The higher the water content is, the lower the deformation modulus is.

c) The shear strength parameters of karst breccia determined by the triaxial compression test are higher than that of the direct shear test.

In the dam site area, field tests such as sonic measurement, dynamic penetration test and permeability test are also carried out, which can further study the engineering characteristics of karst breccia.

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