Effect of bedding of different dip angles on the strength of argillaceous dolomite

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Abstract: In order to study the influence of different dip angles on the strength characteristics of layered argillaceous dolomite, the compressive strength and elastic modulus of argillaceous dolomite are obtained by uniaxial compression test. The research shows that the compressive strength and elastic modulus of argillaceous dolomite have a certain degree of dispersion; the argillaceous dolomite has strong elastic brittleness; the compressive strength of the specimen increases with the bedding angle. Generally, the trend of decreasing first and then increasing is observed. When the bedding angle is 90°, the compressive strength of the argillaceous dolomite specimen is the largest. When the bedding angle is 30°, the argillaceous dolomite specimen has the smallest compressive strength.

1. Introduction
In the bedding rock, the existence of the bedding plane has a significant impact on the mechanical properties, strength characteristics and fracture mode of the rock. If it is still assumed to be a continuous medium, it will deviate greatly from the actual situation. Different types of bedding rocks have different orientations of layers, and the degree of influence of bedding on their properties is different. Some studies have shown that in the study of uniaxial compression strength of bedding rock, the inclination angle increases with the bedding angle, and the strength curve is improved. "U-shaped", "wavy", "shoulder" and other shapes. The extensive distribution of bedding rocks makes underground projects such as tunnel engineering, mining engineering, and oil and gas development often associated with them.

In order to ensure the quality and safety of the project, the large and medium-sized geotechnical engineering generally conducts a series of tests to study the rock mechanics properties within the scope of the project. With the construction of Guiyang Rail Transit Project, understand the variation law and failure characteristics of argillaceous dolomite mechanical properties under different bedding angles, and clarify the influence of layering dip angle on the strength of natural rock mass, and choose the construction method of underground structure. Provide reference materials. In this chapter, the uniaxial compression test of argillaceous dolomite specimens collected from fire-sand tunnels is carried out to analyze the influence of bedding angle on the tensile performance of argillaceous dolomite. The research results show that the surrounding rock is a muddy dolomite tunnel. It has certain reference in fine design and construction[1-6].

2. Laboratory test
In the field of rock mechanics research, mechanical testing of core samples taken from rocks is one of the most direct methods for obtaining rock-related mechanical parameters (such as rock compressive strength, elastic modulus, Poisson's ratio, etc.)[7-10].
2.1 Sampling background
Guiyang Rail Transit Line 1 Railway Station ~ Sha Chong Road Station Tunnel (hereinafter referred to as Huo-Sha tunnel) is a double-hole single-line structure with a total length of 925.411m. The survey data shows that the ZDK26+143.2 ~ +300 section is composed of a block layer and a red clay layer, and the underlying bedrock is a argillaceous dolomite of the second member of Songzikan. The rock mass is relatively broken, and the joint fissures are relatively shallow. Gray, grayish white, medium thick layered. The cores drilled on site are mostly columnar, short columnar and blocky. The surface of some cores is distributed with honeycomb dissolved pores, crystal cavities and joints. The RQD value is 30%~75%, and the closed joints are distributed. There are many, only a few joints are open, and the open joints are mostly calcite fine vein cementation, the degree of cementation is good, and the surrounding rock grade belongs to Grade IV surrounding rock.

2.2 Test preparation
The rock samples used in the test are taken from the muddy dolomite in the same construction step of the fire-sand tunnel. Drilling and sampling method is adopted, and the coring machine is taken out from the surrounding rock of the construction tunnel, and the sample is immediately wax-sealed to ensure the originality, and the post-packing is brought into the core engineering laboratory of Guizhou University. Samples taken from the field are of different lengths. For the next indoor experiment, the sample needs to be reworked, cut and polished. The finished test piece shall meet the requirements of the "Code for Engineering Rock Mass Test Methods" (GB/T 50266-2013). The specific parameters of the test piece are as follows:

1. The uniaxial compression test uses a cylindrical test piece with a diameter \(d\) × height \(h = 50\) mm × 100 mm. During the core drilling, cutting and grinding process, the diameter and height of the test piece are strictly controlled.
2. The processing of the test piece is completed, the maximum error of the height and diameter of the test piece is 3.78%; the deviation of the two ends of the test piece perpendicular to the axis is 0.25°; the maximum error of the non-parallelism of the end faces is 0.02 mm.
3. After the processing is completed, the test piece is wax-sealed and opened when the test is to be carried out.

![Fig.1 Drill core sampling and core sample](image1)
![Fig.2 The test piece is processed](image2)
![Fig.3 The test piece completed by the single-axis compression test](image3)

2.3 Stratification requirements
The test rock samples are pure natural argillaceous dolomite, and the bedding development is accompanied by multiple strips. In this test, the surface layer of the test piece is marked along its direction with a signature pen, and the most obvious bedding is extracted as the main bedding to determine the bedding angle. In the uniaxial compression test, the angle between the main course and the cylinder axis is defined as the layered inclination angle, as shown in Fig.4. Finally, according to the bedding statistics, the irregular layered test piece is thrown away, and 24 specimens with layering inclinations of 0°, 15°, 30°, 45°, 60°, 75°, 90° are selected for uniaxial compression test.

![Fig.4 The bedding angle specification for the uniaxial compression test](image4)
2.4 Data Collection
When collecting test data, the selected equipments are static resistance strain gauges, resistance strain gauges and computers. When the strain gauge is selected, the length of the strain gauge barrier is greater than 10 times the diameter of the largest mineral particle of the rock, which is smaller than the radius of the test piece; the selected work piece of the same test piece is the same as the specification and sensitivity coefficient of the compensation piece, and the allowable deviation of the resistance value is 0.2 Ω.

![Fig.5 Attachment of strain gauges on one side of the test piece](image1)

![Fig.6 Preparation of data acquisition](image2)

2.5 Test piece failure form
The shale dolomite specimens with different bedding angles showed different failure modes under uniaxial compression. Some upper and lower parts of the rock specimens are conical fractured, and the middle part of the rock specimens showed strip-shaped failure morphology; The failure mode of the rock specimen is broken and the fractured piece is strip and block. The surface of some rock specimens is distributed through the surface of the specimen and the crack with a width of 1mm. The rock specimen breaks along this crack. The failure surface develops along the fracture and the failure surface is smooth. Fig.7 shows the uniaxial compression failure morphology of some specimens. During the test, it is found that under the load, the rock sample with larger compressive strength is more fully broken, the brittle damage is more obvious, and the breaking moment of the test piece also gave a crisp breaking sound. Combined with the failure modes of all the test pieces in this test, they can be classified into three categories, namely, splitting failure, compression shear slip damage and crushing damage. The processes, phenomena and forms of these three types of damage are described as follows:

1) Splitting failure, under the action of load, the bedding parallel to the loading axis is penetrated, the test piece is divided into strips, the middle is more cracked into flakes, and the individual rock samples still have shear bifurcation damage. Phenomenon, as shown in Fig.8(a);

2) Compression shear slip damage, there is obvious shear failure surface, the shear plane has a certain inclination angle with the axial direction of the rock sample, the bedding angle range is 22.5°~45°, and the debris generated by the rock sample after the failure is more Less, as shown in Fig.8(b);

3) crushing damage, the specimen is easy to burst into pieces under the load, and the debris generated by the rock sample is more. The muddy dolomite sample is dominated by various factors, and the fracture surface is more complicated. Most of the fracture surface occurs at the cement, especially in areas with severe weathering and poor cementation, because the cement particles have an induction and traction effect during crack propagation, as shown in Fig.8(c).

![Sample D3](image3)
![Sample D11](image4)
![Sample D22](image5)

Fig.7 Uniaxial compression failure of some specimens
3. Analysis of test results

3.1 Uniaxial compression test load and time curve

Through the uniaxial compression test of the layered dip test piece, the load curve of the test piece with time is obtained. Fig.9 shows the load force of a group of test pieces D12 randomly selected in the test results with time.

From the curve change in the figure, it can be divided into two stages (OA segment and AB segment) and three processes. The OA segment on the curve can be regarded as a compaction process; the AB segment on the curve can be regarded as an elastic deformation process; plastic deformation and failure process.

3.2 Uniaxial compression test stress-strain curve

In the uniaxial compression test, by collecting the load and its corresponding strain value, it can be transformed into the stress and its corresponding strain, and the stress-strain curve of each test piece is drawn. It can be seen from the stress-strain diagram of the specimen D15 that the curve is divided into two stages, OA and AB. The OA section is concave, because there are bedding, cracks, small cavities, etc. in the dolomite specimens, and the axial direction of the loading process. The deformation is large, the strain change is faster than the stress change, and it is the compaction stage of the test piece; the AB section is loaded with the bedding, the crack, the small cavity, etc., and the stress should become linear growth, which is the linear compression stage of the test piece. Until the load breaks. On the whole, the stress-strain relationship of the uniaxial compression test specimen can be fitted by a linear relationship, and the fitting equation is \( y = 0.04x \).

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Fig.8 Uniaxial compression failure mode

(a) splitting failure  
(b) compression shear slip damage  
(c) crushing damage

Fig.9 Test piece D12 load versus time curve

Fig.10 Stress and strain diagram of specimen D15
3.3 Influence of bedding angle on compressive strength and elastic modulus

The results of statistical tests show that the compressive strength of argillaceous dolomite is relatively high, distributed between 60 and 130 MPa, and the average compressive strength is 87.25 MPa. With the increase of the bedding angle, the compressive strength of the specimen generally show a trend of decreasing first and then increasing, indicating that the bedding angle had an effect on the compressive strength of the specimen. According to Fig. 2.16, when the bedding angle is 90°, the compressive strength of the argillaceous dolomite specimen is 128.70 MPa; when the bedding angle is 30°, the minimum compressive strength of the argillaceous dolomite specimen is 61.65 MPa, the maximum value is 2.09 times the minimum value. When the specimen is subjected to axial compressive loads, the rock failure generally breaks along the bedding plane, mainly due to the low shear strength of the bonding layer composed of the muddy cement and the mineral and metamorphic minerals in the rock sample. Therefore, as the bedding angle changes, the compressive strength of argillaceous dolomite has obvious anisotropy. According to the strength grades of the rock in Table 1, it can be seen that the argillaceous dolomite is a C-class medium-strength rock.

In order to judge the anisotropy of rock materials, in 1989, Singh proposed the concept of anisotropy ratio, which is defined as the ratio of uniaxial compressive strength to minimum compressive strength at a bedding angle of 90°:

$$R_c = \frac{\sigma_{ci (90°)}}{\sigma_{ci (\min)}}$$  \hspace{1cm} (1)

In the formula (1), $\sigma_{ci (90°)}$ is a uniaxial compressive strength at a lamination angle of 90°; and $\sigma_{ci (\min)}$ is a minimum uniaxial compressive strength.

According to the results of the compression test of argillaceous dolomite, comparing the classification criteria of the anisotropy of the compressive strength of rock materials in Table 1, it can be seen that the argillaceous dolomite is a highly anisotropic rock mass.

| Grade                  | Anisotropy Rc value range |
|------------------------|---------------------------|
| Isotropic              | 1.0–1.1                   |
| Low anisotropy         | 1.1–2.0                   |
| Moderate anisotropy    | 2.0–4.0                   |
| High anisotropic       | 4.0–6.0                   |
| Extremely high anisotropy | >6.0                     |

For the reason that the minimum compressive strength occurs when the bedding angle is 30°, according to the stress analysis diagram of the test piece under the layered dip angle of Fig. 11, it can be seen that there are shear stress $\tau_{\theta}$ along the bedding direction and respectively in the bedding. Normal stress $\sigma_{\theta}$ perpendicular to the bedding direction. Take the unit body of the test piece and use the knowledge of material mechanics to obtain the maximum effective shear stress inside the test piece:

$$f_{vx} = \sigma_1 \cos \theta; \quad f_{vy} = \sigma_2 \sin \theta; \quad f_v = \sqrt{f_{vx}^2 + f_{vy}^2}$$ \hspace{1cm} (2)

$$\sigma_v = f_{vx} \cos \theta + f_{vy} \sin \theta$$ \hspace{1cm} (3)

$$\tau_v = \sqrt{f_{vx}^2 - \sigma_v^2 - \mu \sigma_v}$$ \hspace{1cm} (4)

In the formula (2)–(4), $f_{vx}$ -The direction component of the layered surface; $f_{vy}$ -The direction
component of the layered surface; $f_v$. - The force acting on the layered surface; $\sigma_v$. - The normal stress acting on the layered surface; $\tau_v$. - Effective shear stress on the bedding.

$p$ - pressure; $\alpha$ - bedding angle; $\sigma_\theta$. - shear stress; $\sigma_\alpha$. - normal stress

Fig.11 Schematic diagram of force analysis of layered dip test piece

Let $\sigma_2 = 0$, $\cos \varphi = \sqrt{1 + \mu^2}$, $\sin \varphi = \frac{\mu}{\sqrt{1 + \mu^2}}$, you can get

$$\tau_\theta = \sigma_1 \cos \theta \sin (\theta - \varphi)$$

(5)

For the formula (5), both sides simultaneously obtain partial derivatives for $\theta$, and after finishing, they can be obtained:

$$\frac{\partial \tau_\theta}{\partial \theta} = \sigma_1 \cos (2\theta - \varphi)$$

(6)

Now $\frac{\partial \tau_\theta}{\partial \theta} = 0$, then $\theta = \frac{\pi}{4} + \frac{\arctan \mu}{2}$, and because $\mu \in (0,1)$, so $\theta \in \left(\frac{\pi}{4}, \frac{3\pi}{8}\right)$, and $\alpha + \theta = \frac{\pi}{2}$, so $\alpha \in \left(\frac{\pi}{8}, \frac{\pi}{4}\right)$ can be obtained, that is, the most easily broken layering angle in the rock mass is $22.5^\circ$~$45^\circ$. The calculation result is consistent with the test results.

It can be seen from Fig.12 that when the $15^\circ$<layering angle<$30^\circ$, the compressive elastic modulus of the argillaceous dolomite specimen decreases with the increase of the bedding angle, and the rest increases with the increase of the bedding angle. And when the bedding angle is $30^\circ$, the elastic modulus is the smallest, because the bedding angle is $30^\circ$, which is easy to rupture the lamination angle range, the compressive strength is small, the deformation is large, the strain is large, and the elastic modulus minimum is 32.10GPa; when the lamination angle is $90^\circ$, the elastic modulus is the largest, because the compressive strength of the test piece is larger when the bedding angle is $90^\circ$, the deformation is smaller, the strain is smaller, and the maximum elastic modulus is 75.64 GPa. The maximum elastic modulus of the test piece is 2.36 times the minimum value, and the average elastic modulus is 53.4 GPa. From the overall trend of the curve, the elastic modulus of the argillaceous dolomite specimens basically conforms to the function $y = 1.3558x^2 - 4.7035x + 45.1$ with the change of the bedding angle.
4. Conclusion
(1) With the help of indoor uniaxial compression test method, the compressive strength and elastic modulus values of argillaceous dolomite under the bedding angle are obtained, and show a certain dispersion;

(2) Through the analysis of the load-time curve obtained by the uniaxial compression test, the argillaceous dolomite has strong elastic brittle failure characteristics. When the load-time curve reaches the extreme value, the residual strength suddenly disappears, reflecting the obvious yielding segment;

(3) The compressive strength of argillaceous dolomite measured by uniaxial compression test is relatively high, distributed between 60 and 130 MPa, and the average compressive strength is 87.25 MPa. With the increase of the bedding angle, the compressive strength of the specimen generally decreases first and then increases. When the bedding angle is 90°, the compressive strength of the argillaceous dolomite specimen is the largest, when the bedding angle is at 30°, the compressive strength of the argillaceous dolomite specimens is minimal. Through theoretical deduction, it is concluded that the most easily fractured bedding angle in the rock mass is 22.5°~45°, which is consistent with the experimental results, and the compressive elastic modulus increases with the bedding angle.

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