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# Stratiform Compound Mudstone Mass under Uniaxial Compression

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## Abstract

In order to study the influence of weak layer on mechanical properties of stratiform compound mudstone mass, and improve the reliability of the mechanical parameters of stratiform compound mudstone effectively, the regular layered mudstone was made by pressing, and the uniaxial compression tests were carried out in order to analyze the strength and deformation of samples, considering the samples are not easy to be obtained by coring in field. The test results show that the strength, deformation and elastic modulus of stratiform compound mudstone mass change regular with variable thickness ratios of the weak layer. And the loss strength rate is presented to analyse the influence of weak layer on the strength of stratiform compound mudstones. The conclusions are as follows, (1) The uniaxial compression strength and elastic modulus of soft and hard interbedding mudstone decline nonlinearly with thickening of weak layer. (2) The weak interlayer thickness has great influence on the mechanical properties of layered rock mass. The uniaxial compression strength and elastic modulus of layered mudstone with weak interlayer decrease with the thickening of weak interlayer. (3) The analysis of the loss strength rate shows that the soft layer weakens the strength of the hard mudstone significantly. When the hard mudstone changes to be layered mudstone with weak interlayer, the strength of layered mudstone will decline, and the loss strength rate is maximalt. The results can demonstrate a method and guids more significance for the design and construction.

## Key words

Rock mechanics, Layered mudstone, Weak interlayer, Deformation, Strength.

## 1. Introduction

The Nanning basin mudstone forms a mudstone mass interbedding mudstone and siltstone due to the changes of sedimentary environment, both of which differ a lot in mechanical parameters. The interim part from mudstone to sandstone often gets silty mudstone [1]. Weak mudstone is in a malleable ~ soft plastic state, and the hard mudstone in the hard plastic ~ solid state. The siltstone or sandstone is hard in texture. In practices, when this kind of subsoil is exploited, it is permitted to decrease the parameters or deeply bury the foundation until hard bearing stratum is discovered. The practical significance of this lays, however, is not ignorable.

Scholars at home and abroad have done much investigations on the mechanics and deformation characteristics of stratified rock. Amadei [2-5] et al. have conducted an array of tests on the mechanical properties of stratiform joint rock, and stated the inapplicability of the integral rock strength criterion. They proposed the Failure Criteria for transverse isotropy rocks. Mühlhaus et al. [6] derived a theoretical model of the stratified rock mass based on the theory of Cosserat medium, and analyzed its mechanics and deformation characteristics. Chinese scholars have extensively studied the mechanical properties, deformation characteristics, failure characteristics of interlayer salt rock and the constitutive models [7-12], but rarely on the layered mudstone subsoil with weak mudstone. Zhang Dingli et al. [13] built a mechanical model of interlayer rock mass by analyzing the construction and mechanical properties of stratified rock mass, and explored the failure and instability mechanisms of interlayer rock mass. Zhou Huoming et al. [14] made a study on the mechanical parameters of layered argillaceous limestone compound rock mass, and explored the test size effect on the deformation parameters. Jia Shanpo et al. [15], by a uniaxial compression test on stratified rock mass with similar material, analyzed the effect law of inclination, sandwich changes on the failure of rock mass. Zuo Shuangying [16] et al. by the uniaxial and triaxial compression test, explained the effect law of the layer dip angle and confining pressure on the strength and deformation characteristics of the stratified rock mass. They thought that the layer level suppressed the surrounding rock failure mode and extension direction of the plastic zone.

The above studies mainly focus on the hard rock with weak interlay and the laminated salt rock, less involved in the compound mudstone mass with weak mudstone interlayers. In particular, there is a lack of research on the mechanical behavior, the deformation characteristics and the failure mode of the subsoil of the compound mudstone mass with weak mudstone interlayers. To demonstrate the mechanical properties of layered mudstone, the sample is obtained usually by a drill hole sampling method. However, it is infeasible to free choose the sandwich thickness, interlayer lithology and distribution characteristics, and the sampling process disturbance is clear. Therefore, the test results have a great discreteness, which fails to reflect the effect law the mechanical properties of layered mudstone is subjected to change with layer characteristics. To explore the effect of weak interlayer on the mechanical properties of stratiform compound mudstone mass, this paper adopts the remoulded sample, i.e. a layered mudstone sample similar to that in the site, and regular changeable, which can be available by preparation and compression molding of powder mudstone and silty mudstone. Then a uniaxial compression test is conducted to reveal the effect law the mechanical properties of deformation characteristics of layered mudstone is subjected to change with thickness ratio of weak layer.

## 2 Test Procedure

### 2.1 Test Design

The test includes two stages, the first is based on the statistical data about basic mechanical properties of Nanning basin mudstone and test data about undisturbed soil sample to trail-produce mudstone with full hard layer and full weak layer, and determine the compressive strength of sample by a uniaxial compression test and physical and mechanics parameters based on the statistical data. The second stage is to carry out a uniaxial compression test on the thickness ratio gradient of weak layer. The test procedure is given as follows:

(1) A test is conducted for the physical and mechanics properties of undisturbed mudstone sample.

(2) The layered mudstone is compacted using a self-made depressor, a volume-controlled type, which allows to produce a stratiform sample with density as required by sample volume restriction.

(3) Uniaxial compression test is performed on hard mudstone, soft mudstone, and layered mudstone samples with variable thicknesses.

### 2.2 Test Equipment and Specimen Preparation

#### 2.2.1 Basic Characteristics of Nanning Basin Mudstone

We learn from the literatures [17] that the natural moisture content of the basin mudstone is 8% ~ 28.9%; in general, the uniaxial compression strength in the native status is 0.12 ~ 9.4MPa; the deformation modulus is 8 ~ 275MPa; the limits of bearing capacity on the pile base usually takes the value of about 1000 ~ 3500kPa; the bearing capacity of shallow foundation takes the eigenvalue value of 180 ~ 800kPa.

### 2.2.2 Test Equipment

A depressor, which, as a volume-controlled type, is self-made based on intactness of specimen volume, consists of base, barrel, compact column, control loop and hoop, as shown in Figure 1. The mass of the soil samples required in a certain volume is calculated based on required density before compacting the specimen. This is possible to compact it layer by layer, or once molded. Such depressor avoids overpressure and underpressure, and ensures a uniform pressure applied on the prepared sample.

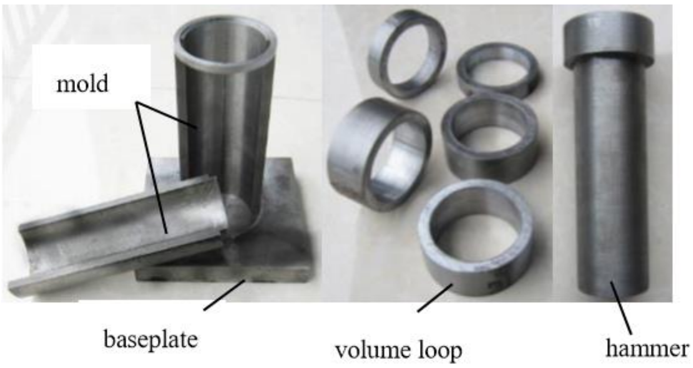

Fig.1. Apparatus for Sample Preparation with Capacity Control

The TSZ-2 full-automatic triaxial apparatus is used to carry out the uniaxial compression test on the layered mudstone at the testing stage of mechanical properties. The test equipment enables to implement a stress, strain-type test without lateral confinement, and a compression shear test like UU, CU, CD, etc. It allows to determine the sample porewater pressure as required. The maximum diameter of the specimen reaches 101mm, and the maximum confining pressure is 2MPa; the maximum axial force of the triaxial cell gets to 60kN.

### 2.2.3 Specimen Preparation

This test simple comes from a flyover foundation pit, Baisha Avenue in Nanning. The undisturbed sample is captured by artificial excavation, and its physical and mechanical indexes are shown in Table 1. In the re-molding sample preparation phase, the mudstone and silty mudstone are air-dried and crushed separately, and the initial moisture content is measured. To make sure that the strength of the hard mudstone as molded by compaction is consistent with that of undisturbed sample, the cement is selected as the cementing material to prepare the hard mudstone. On the one hand, this can improve the strength of the hard mudstone. On the other hand, there is a better bonding among soil particles. After trial-preparation and test, it is better that the cement content is 12% of the mass of air-dried samples. A sample, φ39.1 mm × 80 mm, is made by using a self-made depressor. A level between hard layer and weak layer of mudstone is shaped. The physical and mechanical indexes of repressive remodeling sample are shown in Table 2. A part of the specimen used in the test is shown in Fig. 2.

Tab.1. The Physical and Mechanical Parameters of Undisturbed Samples

| Soil sample | Natural moisture content $\omega$/(%) | Unit weight $\gamma$/(kN·m$^{-3}$) | Cohesion c/kPa | Angle of internal friction $\varphi$ /(°) | Compressive on modulus $E_{s1-2}$ /MPa | Uniaxial compressive strength R/ MPa |
|---|---|---|---|---|---|---|
| Hard layer | 14.3 | 2.18 | 125.5 | 27.6 | 20.6 | 1.64 |
| Weak layer | 25.8 | 1.88 | 24.5 | 9.5 | 6.5 | 0.12 |

Tab.2. The Physical and Mechanical Parameters of Disturbed Samples

| Soil sample | Moisture content $\omega$/(%) | Unit weight $\gamma$/(kN·m$^{-3}$) | Cohesion c/kPa | Angle of internal friction $\varphi$ /(°) | Compressive on modulus $E_{s1-2}$ /MPa | Uniaxial compressive strength R/ MPa |
|---|---|---|---|---|---|---|
| Hard layer | 13.8 | 2.20 | 130.3 | 26.5 | 19.8 | 1.57 |
| Weak layer | 24.4 | 1.89 | 23.6 | 9.0 | 6.3 | 0.11 |

Hard layer sample and weak layer sample

soft-hard interbedding mudstone samples

Layered mudstone with weak interlayer

Fig.2. Part of Layered Mudstone Samples

## 3. Mechanical Test on Stratiform Compound Mudstone Mass with Soft-Hard Interbedding

The uniaxial compression test is conducted to probe in the mechanical properties of the stratiform compound mudstone mass with soft-hard interbedding's from variation in thickness of weak layer. Then we analyze the influence that the mechanical properties of compound mudstone is subjected to change with thickness of weak layer.

## 3.1 Uniaxial Compression Test on Solf-Hard Interbedding Mudstone as A Function of Thickness of Weak Layer

Uniaxial compression test is carried out respectively for three soft-hard interbedding mudstone samples upper-soft and lower-hard. A stress-strain curve of the three samples as a function of thickness of weak layer is shown in Fig. 3.

The results from the uniaxial compression test on the soft-hard interbedding mudstone with thickness variables of weak layer are shown in Table 3. By incorporating Fig. 3 and Table 3, we know that the strength and the characteristics are demonstrated as follows:

(1) Under the uniaxial compression conditions, the stress-strain curve of soft-hard interbedding mudstone as a function of thickness ratio (in relation to the total elevation of specimen) of weak interlayer turns from strain hardening to strain-softening patterns as the weak interlayer thickens.

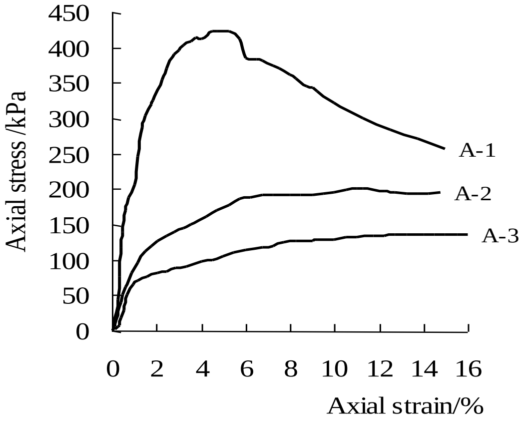

Fig.3. Stress-strain of layered Mudstone Samples as a Function of Soft Thickness Under Uniaxial Compression

Tab.3. Results of Layered Mudstone Samples as a Function of Soft Thickness Under Uniaxial Compression

| Soil samples | Thickness ration of weak layer /% | Uniaxial compressive strength /kPa | Secant modulus $E_{50}$/MPa |
|---|---|---|---|
| Hard layer | 100 | 113.1 | 5.6 |
| Weak layer | 0 | 1568.1 | 88.6 |
| A-1 | 25 | 423.2 | 20.8 |
| A-2 | 50 | 200.2 | 8.1 |
| A-3 | 75 | 135.9 | 6.2 |

(2) When the thickness ratio of the weak layer is 25%, and the uniaxial compression strength of interbedding mudstone is 423.2 kPa; when it increases to 75%, the uniaxial compression strength

drops to 135.9 kPa. A regression analysis is performed for the uniaxial compression strength and the thickness ratio of weak layer, both of which take on a high correlation, see Fig. 4 for its variation trend. The uniaxial compression strength impairs nonlinearly with the addition of weak layer. The loss rates of strength is used to characterize the influence of variable thicknesses of weak layer on the strength of soft-hard interbedding mudstone, i.e. $P_r=(P_n- P_{n+1})/ P_n$ ($P_n$ is the compression strength that corresponds to the thickness ratio $n$) . When the axial strain is 1%, the thickness ratio of weak layer changes from 0 to 25%, the loss rate of strength is 73.0% at maximum; when the mudstone changes from75% thickness ratio to full-soft layer, the loss rate of strength is 16.8% at minimum. It is further explained that the weak layer reduces the carrying capacity of the soft and hard interlayer layered mudstone body, and the thickness of the soft layer is the key factor to control the mechanical properties of the stratified rock. This test, therefore, further demonstrated that it is the weak layer that impairs the carrying capacity of soft-hard interbedding mudstone. The thickness value of weak layer is a key factor to contain how the stratified rock exerts its mechanical properties.

(3) When it hits peak stress, the axial strain increases as the weak layer thickens, and tends to be equal when its thickness reaches 50% and above, that is to say, the plastic strain of interbedding mudstone gets stronger with thickening of weak layer, thus impairing its carrying capacity.

(4) The elasticity modulus of soft-hard interbedding mudstone reduces with thickening of weak layer.

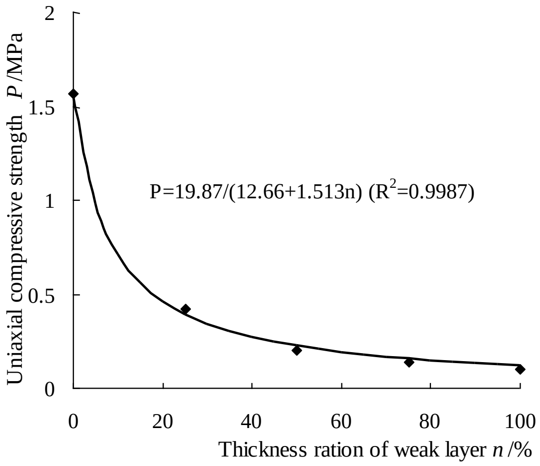

Fig.4. Relation Between Uniaxial Compressive Strength and Soft Thickness

## 3.2 Uniaxial Compression Test on Layered Mudstone with Different Weak Interlayer

To capture the law of mechanical properties and deformation characteristics of layered mudstone where the thickness ratios of weak interlayer differ, the uniaxial compression test is conducted, and the stress-strain curve of this type of layered mudstone is shown in Fig.5. We can know from Fig. 5, the stress-strain curve of layered mudstone as a function of thickness ratio of weak interlayer changes from strain softening to strain-hardening patterns as the weak interlayer gets thick. The curve of 50% weak interlayer has a similar shape to that of 75%.

The results from uniaxial compression test on the layered mudstone with different thickness ratios of weak interlayer are listed in Table 4. See Fig. 5 and Table 5 as below for strength and deformation characteristics:

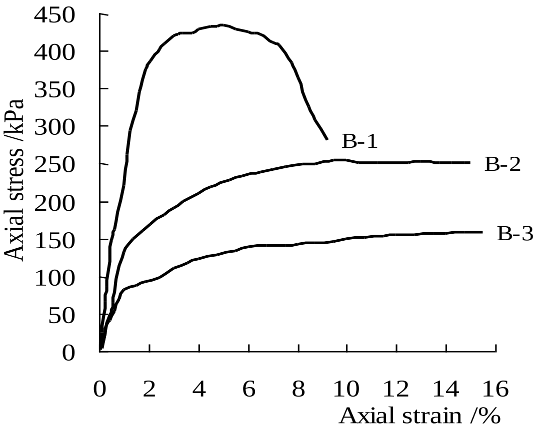

Fig.5. Stress-strain of Layered Mudstone Samples as a Function of Soft Interlayer Thickness Under Uniaxial Compression

Tab.4. Results of Layered Mudstone Samples as a Function of Soft Interlayer Thickness under Uniaxial Compression

| Soil samples | Thickness ration of weak layer /% | Uniaxial compressive strength /kPa | Secant modulus $E_{50}$/MPa |
|---|---|---|---|
| B-1 | 25 | 433.8 | 22.4 |
| B-2 | 50 | 253.8 | 13.3 |
| B-3 | 75 | 158.5 | 8.1 |

(1) When the weak interlayer is 25% in thickness, the uniaxial compression strength of layered mudstone goes up to 433.8kPa; and 75% for the least of 158.5, decreased by 63.5%. The test results show that the uniaxial compression strength goes down significantly with the increase of the thickness of weak interlayer. Compare uniaxial compression strengths against different thickness ratios of weak interlayer at the same strain, it is found that, when the axial strain is 1%, and it changes from the full-hard mudstone to interlayer mudstone with weak interlayer of 25%, the loss rate of its strength is 74.7% at maximum; when it changes from 75% to full-weak layer, the loss

rate is 28.6% at minimum. Compared with soft-hard interbedding mudstone, it is known that the uniaxial compression strength of layered mudstone with weak interlayers is higher. It is demonstrated that the hardened layer in layered mudstone plays a closure effect, and produces an overlying crust enclosure effect [18]. It is hereby concluded that at the equal thickness ratio, the strength of layered mudstone with weak interlayer is higher than that of soft-hard interbedding mudstone.

(2) The variation trend that the elastic modulus is subjected to change with thickness ratios of weak interlayer resembles to that of uniaxial compression strength, i.e. it decreases with increasing of interlayer thickness. When the thickness ratio is 25%, the elastic modulus gets to 22.4MPa; when it reaches 75%, the elastic modulus drops to 8.1MPa, decreased by 63.8%. The resistance to damage deformation debates as the interlayer thickness ratio increases.

## Conclusion

Given that it is difficult to take a complete layered mudstone specimen with weak interlayer on the spot, a self-made volume controlled depressor is used indoor to compact the mudstone specimen with regular layered features, based on which to study the effect of weak mudstone interlayer on the mechanical properties of stratiform compound mudstone mass. The reliability of mechanical parameters of the stratiform compound mudstone mass is improved greatly. The following conclusions are derived from this indoor test:

(1) The uniaxial compression strength and elastic modulus of the soft-hard interbedding mudstone specimen show a nonlinear sink as the thickness of the weak layer increases. The loss rate of strength is used to characterize the influence of thickness ratio of weak layer on the strength of soft-hard interbedding mudstone. The test shows that the weak layer worsens the carrying capacity of soft-hard interbedding mudstone. The thickness of weak layer is a key factor to control the mechanical strength of stratified rock mass.

(2) Under conditions of the uniaxial compression test, the thickness of weak interlayer has a great influence on the mechanical properties of layered mudstone with weak interlayer. Weak interlayer worsens the capacity of the layered mudstone, and exaggerates its deformation. The uniaxial compression strength and elastic modulus of layered mudstone with weak interlayer are subjected to decrease in different extent with the increase of thickness of weak interlayer. The hardened layer in the layered mudstone that contains the weak interlayer produces an overlying crust effect. At the same thickness ratio as weak interlayer is, the strength of layered mudstone with weak interlayer is higher than that of the hard and soft interbedding mudstone.

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## References

1. X.G. Zhang, N.P. Yi, Analysis of causes to in validate bored piles on abase of shallow mudstone in Nanning basin, 2006, Rock and Soil Mechanics, vol. 27, no. s, pp. 1273-1276.
2. C.M. Gerrard, Elastic models of rock masses having one, two and three sets of joints, 1982, International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts, vol. 19, no. 1, pp. 15-23.
3. B. Amadei, Strength of a regularly jointed rock mass under biaxial and axisymmetric loading conditions, 1988, International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstr, vol. 2, no. 1, pp. 3-13.
4. Y.M. Tien, P.F. Tsao, Preparation and mechanical properties of artificial transversely isotropic rock, 2000, Intemational Joumals of Rock Mechanics & Mining Science, vol. 37, no. 6, pp. 1001-1012.
5. Y.M. Tien, M.C. Kuo, A failure criterion for transversely isotropic rocks, 2001, International Journals of Rock Mechanics & Mining Science, vol. 38, pp. 399-412.
6. H.B. Mühlhaus, P. Hornby, Energy and averages in the mechanics of granular materials, 2001, Tectonophysics, vol. 335, no. 1-2, pp. 63-80.
7. S.G. Xu, W.G. Liang, J. Mo, Influence of weak mudstone intercalated layer on mechanical properties of lam inated salt rock, 2009, Chinese Journal of Underground Space and Engineering, vol. 5, no. 5, pp. 878-883.
8. Y.P. Li, J. Liu, C.H. Yang, Influence of mudstone interlayer on deformation and fallure characteristics of salt rock, 2006, Chinese Journal of Rock Mechanics and Engineering, vol. 25, no. 12, pp. 2461-2466.
9. L.W. Cao, X.H. Peng, Z.J. Ren, Mesoscopic damage constitutive model of bedded salt rock mass under triaxial compression, 2010, Chinese Journal of Rock Mechanics and Engineering, vol. 29, no. 11, pp. 2304-2311.
10. D.Y. Jiang, T. Ren, J. Chen, Experimental study of mechanical characteristics of molded salt rock with weak interlayer, 2012, Chinese Journal of Rock Mechanics and Engineering , vol. 31, no. 9, pp. 1797-1803.
11. A.M. Wang, C.L. Yang, C. Huang, Numerical experiment study of deformation and mechanical

properties of layered salt rock, 2009, Rock and Soil Mechanics, vol. 30, no. 7, pp. 2173-2178.

12. L. Li, J. Chen, D.Y. Jiang, Analysis of surface crack growth in layered salt rock under uniaxial compression, 2011, Rock and Soil Mechanics, vol. 32, no. 5, pp. 1394-1398.
13. D.L. Zhang, Y.H. Wang, T.Z. Qu. Influence analysis of interband on stability of stratified rock mass, 2005, Chinese Journal of Rock Mechanics and Engineering, vol. 24, no. 23, pp. 4226-4232.
14. H.M. Zhou, Q. Sheng, S.W. Chen, Numerical simulation on size-effect in deformation test of layer composite rockmass, 2004, Chinese Journal oF Rock Mechanics and Engineering, vol. 23, no. 2, pp. 289-292.
15. S.P. Jia, J.Z. Luo, B. Wu, Experimental study on the behavior of concrete filled steel tubes with concrete block subjected to axial load, 2014, Journal of Zhengzhou University (Engineering Science), vol. 35, no. 5, pp. 69-73.
16. S.Y. Zuo, M.L. Ye, X.L. Tang, Numerical modle and validation of failure mode for underground caverns in layered rock mass, 2013, Rock and Soil Mechanics, vol. 34, no. s1, pp. 458-465.
17. Q.Y. Fan, Swelling rock and engineering, 2008, Beijing: Science Press Ltd., pp. 30-50.
18. X.M. Wang, Calculation of proportional limit load for soft clay foundation involving the effect of dry crust, 2002, Chinese Journal of Geotechnical Engineering, vol. 24, no. 6, pp. 720-723.