

## Simulation Tests on Load Bearing Features of Mudstone Foundation in Project Lifecycle

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### ABSTRACT

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*mudstone, load bearing features, project lifecycle, soft rock*

This paper attempts to identify the load bearing features of the homogeneous hard mudstone foundation, which has been softened into a soft and hard interbedded foundation under external factors, throughout the project lifecycle. For this purpose, a homogeneous hard mudstone foundation was prepared indoor through compaction, and soaked in water to simulate the mudstone foundation in construction site. Then, the homogeneous hard mudstone foundation and the soft and hard interbedded foundation were separately subject to shallow plate static load tests. During the tests, it was observed that the mudstone foundation was greatly affected by environmental changes during project lifecycle, and the load bearing capacity of the mudstone foundation dropped by over 60% after being soaked in water. This means water action has a prominent impact on mudstone foundation in the project lifecycle; the loading bearing capacity of mudstone foundation could be greatly weakened by soaking in construction water or rainwater. Therefore, the load bearing capacity of mudstone foundation must be tested and evaluated timely in the construction period.

## 1. INTRODUCTION

Mudstone is different from ordinary rocks, and its physical and mechanical properties are significantly different from ordinary rocks [1]. Due to the special properties of mudstone in Nanning Basin, such as short diagenesis time, poor cementation, semi-consolidated diagenesis state, rock-like but it's not rock, soil-like but it's not soil, soft and hard layers deposited alternately, easy to weather, poor water stability, shrinks when loses water, swells when contacts water, and then softens and disintegrates; moreover, the natural uniaxial compressive strength is low, generally between 0.2-9.4MPa [2]. In the construction process of engineering projects, research on the properties of mudstone is a necessity. Project lifecycle refers to the construction period and the operation period. The engineering problems of mudstone within the project lifecycle mainly include the softening of the mudstone stratum after being soaked by construction water, or exposed to rainwater for a long-time during construction in rainy seasons, or the lowering in the bearing capacity of the bearing stratum caused by infiltrated surface water and soaked foundation, which would result in excessive or uneven settlement of the structure, etc. Within the project lifecycle, if the mudstone layer is softened and the foundation is weakened, it will directly affect the safety of the engineering project and increase the construction cost, the built structure might crack or even collapse in severer cases.

For the engineering problems of mudstone in project lifecycle, scholars have conducted various relevant research. In terms of the interaction between mudstone and water, Yoshida et al. [3] studied the unloading and softening of tertiary mudstone, which deteriorated and its strength decreased over time. Dehnavi and Sadeghi [4] conducted

research on the mechanical properties of claystone, and pointed out that claystone is easily eroded by water, which significantly affects its physical and mechanical properties, and changes its engineering properties to a certain extent. Zeng, et al. [5] studied the physical and mechanical properties of strongly weathered mudstone after it's subject to three cycles of drying-and-wetting, freezing-and-thawing, and drying-and-wetting, and believed that the cyclic environment has a great impact on the microstructure, stress-strain behavior, and shear strength of the samples. In terms of the mechanical properties, and failure and deformation characteristics of the interbedded mudstone, Wang et al. [6] applied the failure theory of the stratified rock mass to study the strength and failure characteristics of sandstone interbedded with mudstone interlayers through uniaxial tests, revealing that the mechanical properties and failure mechanism of sandstone interbedded with mudstone. Taheri and Tani [7] used a down-hole triaxial test method to study the shear strength and deformation ability of the mudstone interbedded with sandstone, and the results showed that the sandstone interlayers caused the shear strength and deformation characteristics of the mudstone to decrease to varying degrees. Pham et al. [8] conducted uniaxial compression tests on mudstone samples with different water contents to analyze the impact of unsaturated and re-saturated states on the mechanical properties of mudstone. Taheri and Tani [9] proposed a small hole in-situ triaxial test method to measure the shear strength and deformation ability of soft sedimentary rocks. To study the impact of soft and weak layers on the mechanical properties of interbedded mudstone and effectively improve the reliability of its mechanical parameters, considering that it's hard to obtain complete samples of soft and weak layer interbedded mudstone, Ma et al. [2] adopted

an indoor compaction method to fabricate mudstone samples with regular layered structures, and conducted uniaxial tests on it to compare and analyze the strength and deformation characteristics of the samples. Zheng et al. [10] used physical model tests and discrete element method to study the failure mechanism of sandstone-mudstone interbedded slopes, and believed that the wetting and softening of mudstone is one of the main factors causing landslides. In terms of the swelling characteristics of mudstone when contacts water, R. Doostmohammadi et al. [11] studied the effect of wet-and-dry cycles on the swelling strain and swelling pressure of mudstone, and believed that increasing the number of wet-and-dry cycles can shorten the time required for the final expansion of mudstone. Zeng et al. [12] adopted bearing plate tests to study the impact of water content and wet-and-dry cycles on the swelling characteristics of carbonaceous mudstone. Mohajerani et al. [13] also studied the swelling properties of claystone. In addition, Mondol et al. [14] studied the changes in the physical properties of mudstone during the burial process. Wan et al. [15] studied the engineering properties, durability and weathering speed of silty mudstone with different degrees of weathering.

The above-mentioned research mainly focused on aspects such as the physical mechanics of mudstone, water-rock interaction, and swelling characteristics, etc., and rarely involved the bearing characteristics of hard mudstone softened into hard and soft layers under the influence of the external environment. Since mudstone has the characteristics of swelling and softening when contacts water, and shrinking when it loses water, it is often disturbed during the construction process, resulting in reduction in the bearing capacity. Therefore, studies on the impact of external environmental factors on the transformation of homogeneous hard mudstone foundation into soft-hard interbedded mudstone foundation in the project lifecycle, and the bearing characteristics of softened homogeneous hard mudstone foundation are conducive to instructing design and construction. At present, the research on the engineering properties of mudstone mainly focuses on the characteristics and properties before construction, while there's few studies concerning the properties of mudstone within the project lifecycle. In order to clarify the changes in the properties of mudstone within the project lifecycle, this study adopted physical model to conduct shallow plate static load tests, used compaction method to fabricate homogeneous hard mudstone foundation, and conducted static load tests on it. At the same time, the prefabricated hard mudstone samples were soaked in water to soften the mudstone, forming soft and hard interbedded mudstone foundation, which was then subject to the static load test to compare the bearing characteristics of the mudstone foundation under the two conditions, and study the changes in the bearing capacity of the mudstone foundation at the initial stage of soaking (24h).

## 2. TEST PLAN

### 2.1 Test design

Fabrication of hard mudstone foundation: a high-strength PE pipe with an inner diameter of 20.5cm and a height of 50cm was taken as the container to compact the mudstone layer to a thickness of 40cm, and remaining 10cm in the PE pipe was filled with water. According to the test code of the shallow

plate static load tests, the width of the test pit was 3 times the diameter or width of the bearing plate. Therefore, this test adopted steel plate with a diameter of 7cm and a thickness of 2cm as the bearing plate.

This test mainly compared the changes in the bearing characteristics of mudstone foundation before and after it's soaked in water, the shallow plate static load tests were conducted mainly from the following two aspects:

(1) Reference test: it's the physical model test on the bearing capacity of homogeneous hard mudstone foundation. The samples of homogeneous hard mudstone layer were fabricated in a test barrel, and then the static load test was performed on the surface of the hard mudstone foundation.

(2) Comparison test: it's the physical model test on the bearing capacity of the soft and hard interbedded mudstone foundation after being soaked and softened in water. This test simulated the foundation soaked in construction water, which can result in foundation softening. According to previous studies, the water soaking time for the complete disintegration of Nanning Basin mudstone is 24 hours [16]. Based on this result, 10cm water was injected into the sample barrel, and the sample was soaked for 24h to form a soft and hard interbedded mudstone foundation. When the soaking time was reached, excess water in the sample barrel was drained, and the static load test was performed.

The test model is shown in Figure 1. In order to reduce the impact of the inhomogeneity of manual sample preparation on the test results, 6 samples were fabricated for the reference and comparison tests.

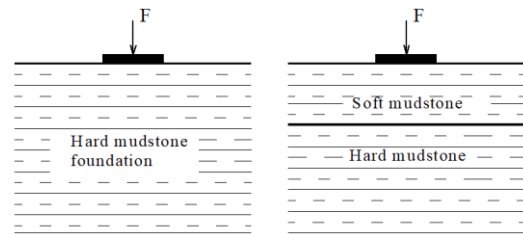


Figure 1. Foundation model of shallow plate load test

### 2.2 Measurement system and loading/unloading regulations

The loading system of this test was modified by arranging double-linked consolidation apparatus in series, the leverage ratio was 12:1, as shown in Figure 2.

First, the bearing capacity of the mudstone foundation was estimated with the loading effect taking into consideration, and the loads of the reference and the comparison tests were estimated as well. For the reference tests, the loading weight of each level was 3kg, according to the leverage ratio and the diameter of the load plate, the converted load of each level acting on the mudstone layer was 187kPa. For the comparison tests, the loading weight of each level was 1.5kg, again according to the leverage ratio and the diameter of the load plate, the converted load of each level acting on the mudstone layer was 94kPa.

The load was applied slowly to maintain the loading weight as steady as possible, under the action of the load of each level, dial indicator readings were recorded at 10min, 10min, 10min, 15min, and 15min intervals, and then measured and recorded every 30min afterwards. Within two consecutive hours, when the settlement per hour was less than 0.1mm, the load of the next level was applied. When under the load of a certain level,

the settlement rate within 24h could not reach the stable standard, or the ratio of the settlement amount to the width or diameter of the bearing plate was greater than or equal to 0.06, the loading was terminated.

The test equipment and instruments are shown in Figure 3.

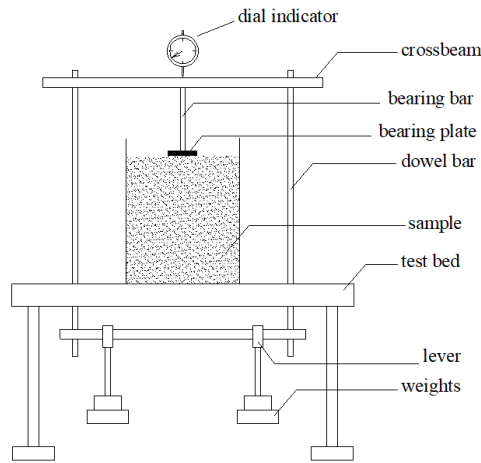


Figure 2. Load measurement system

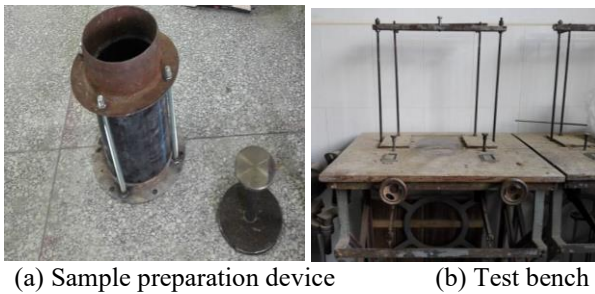


Figure 3. Test equipment

### 2.3 Sample production

By airing, crushing and sieving the collected samples, the samples with a water content of 15% were prepared and stood airtightly for one day and one night for later use. After that, the fabricated samples were subject to the tests and the parameters are shown in Table 1 below.

Table 1. Physical and mechanical parameters of the mudstone

Category	Water content $\omega$ (%)	Density $\rho$ ( $\text{g}\cdot\text{cm}^{-3}$ )	Porosity ratio $e$
Mudstone	15.07	2.185	0.4325
liquidity index $I_L$	Internal friction angle $\varphi$ ( $^\circ$ )	cohesion force $c$ (kPa)	Permeability coefficient ( $\times 10^{-8}$ cm/s)
-0.12	18	85	1.74

Table 2. Test results of homogeneous hard mudstone foundation under static load

Samples	Sample 1#	Sample 2#	Sample 3#	Sample 4#	Sample 5#	Sample 6#	Representative value
Limit bearing capacity/kPa	1122	1122	1122	1122	935	1122	1122
Total settlement/mm	9.71	10.10	9.21	10.99	12.18	11.97	10.46

The prepared samples were separated into three layers and compacted, the surface between layers were roughened with a scraper, the fabrication process is shown in Figure 4.



Figure 4. Sample preparation

## 3. SIMULATION TESTS ON THE BEARING CHARACTERISTICS OF HOMOGENEOUS HARD MUDSTONE FOUNDATION

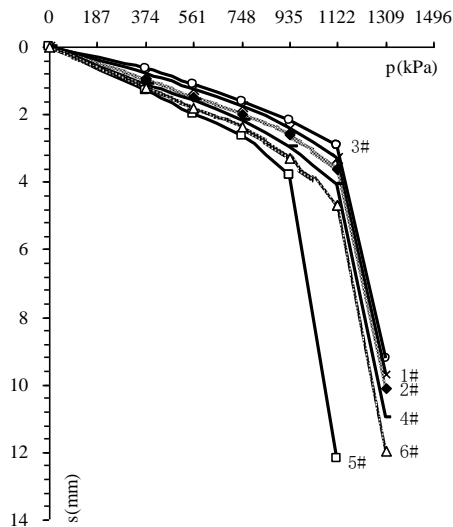
### 3.1 Test steps

First, the processed sample barrel was place on the test bench, and leveled with medium sand, then the bearing plate and force transfer column were installed, and the force transfer rod was connected; after that, a dial indicator was installed on the beam, the loading lever was adjusted, and a 1kPa weight was applied to make all parts in close contact, and the dial indicator was adjusted to zero. Finally, the loads were applied level by level according to loading requirements, and the settlement amount was recorded.

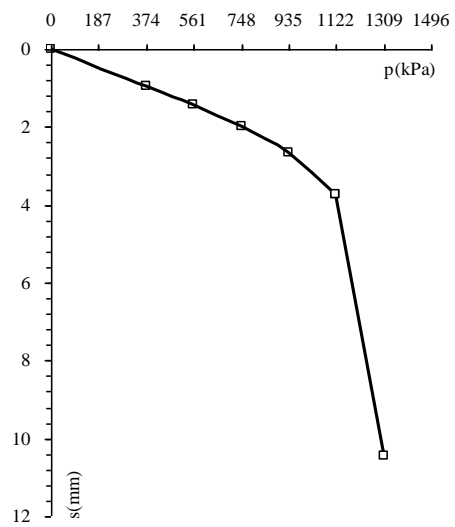
### 3.2 Test results and analysis

The static load tests of the homogeneous hard mudstone foundation gave 6 load and displacement curves, as shown in Figure 5. The test results of each sample are shown in Table 2. It can be seen from Table 2 that the results of sample 5# were smaller than those of other samples, indicating that there's a problem with the preparation of the sample, the data was abnormal and should be eliminated. After that, the average values of samples 1#, 2#, 3#, 4#, and 6# were taken as the representative value of the homogeneous hard mudstone foundation, and the representative p-s curve for static load test of the homogeneous hard mudstone foundation is shown in Figure 6.

It can be seen from Figure 6 that the p-s curve dropped sharply when the load was applied to 1122kPa. When the load was applied to 1309kPa, the settlement rate cannot reach the stable standard within 24h, so the limit bearing capacity of the homogeneous hard mudstone foundation was 1122kPa.



**Figure 5.** P-S curves of static load test of homogeneous hard mudstone foundation



**Figure 6.** Representative p-s curve of static load test of homogeneous hard mudstone foundation

#### 4. SIMULATION TEST ON THE BEARING CHARACTERISTICS OF SOFTENED HARD MUDSTONE FOUNDATION

The model test mainly studied the load-bearing characteristics of the homogeneous hard foundation softened into soft-and-hard interbedded foundation caused by construction water or external environment.

##### 4.1 Test steps

After the hard mudstone was compacted, water was poured into the sample barrel, the height of the water was 10cm, the mudstone was soaked for 24h under normal water level, after that, the water in the sample barrel was drained, and samples were taken from the section of the mudstone to measure the water content. After that, the sample barrel was placed on the loading platform, and the end surface was leveled with medium, then the bearing plate and force transfer column were installed, the force transfer rod was connected, a dial indicator was installed on the beam, and the loading lever was adjusted. Finally, the static load test was performed.

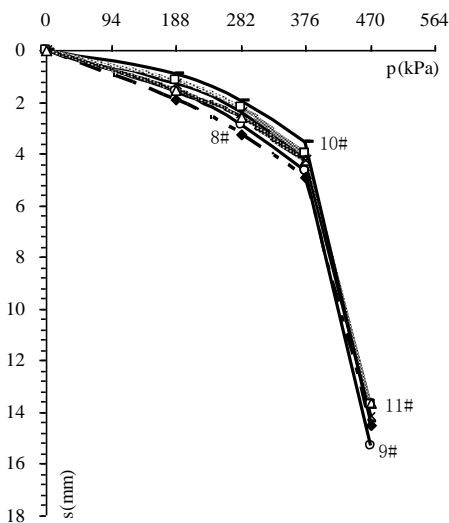
##### 4.2 Test results and analysis

For the six tests, soaking and softening process was performed to build soft-and-hard interbedded mudstone foundation, and test curves of the static load tests of the soft-and-hard interbedded mudstone foundation were obtained as shown in Figure 7. The bearing capacity and total settlement of each sample are shown in Table 3. It can be seen from Figure 7 that the uniformity of the sample was good, and the average value of 6 test results was taken as the representative value of the static load test of the softened hard foundation. The representative p-s curve of static load test of soft and hard interbedded mudstone foundation is shown in Figure 8. At the same time, after water soaking, 6 samples were prepared for water content test. The average water content of the 6 samples was 17.31%, which had increased by 2.24% compared with the initial water content.

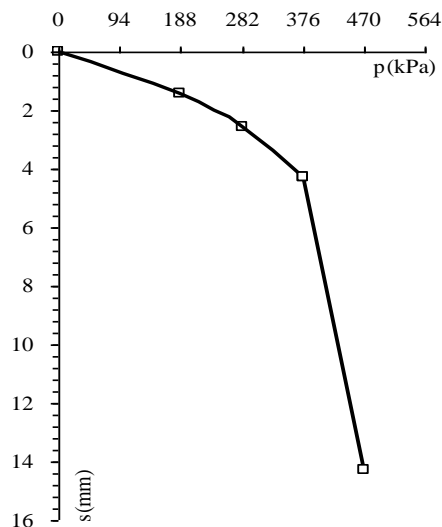
It can be seen from Figure 8 that the p-s curve dropped sharply when the load was applied to 376kPa. When the load

was applied to 470kPa, the settlement rate cannot reach the stable standard within 24h, so the limit bearing capacity of the soft and hard interbedded mudstone foundation was 376kPa.

Through static load tests on homogeneous mudstone foundations and soft and hard interbedded mudstone foundations softened by water, the softening phenomenon of hard mudstone layers in project lifecycle was simulated, their bearing characteristics were studied, and the changes in the bearing capacity of softened mudstone foundation in the initial soaking stage were analyzed. The simulation test showed that the limit bearing capacity of homogeneous hard mudstone foundation was 1122kPa, the maximum cumulative settlement was 10.46mm; the limit bearing capacity of the hard layer softened into soft and hard mudstone foundation was 376 kPa, and its maximum cumulative settlement was 14.28mm. The comparison showed that the limit bearing capacity of the water-soaked mudstone foundation was 746 kPa smaller than that of the un-soaked mudstone foundation, decreased by 66.5%, and the maximum cumulative settlement increased by 26.8%. This test showed that the bearing capacity of mudstone foundation at the initial stage of water-soaking had decreased sharply by more than 60%, this is because the samples in this simulation test were remodeled samples, which were different from the original mudstone. The original structure of the mudstone was destroyed, so the water stability was worse, and the action of water and rock was more significant, resulting in a sharp decrease in the bearing capacity of mudstone foundation after water-soaking. The test results showed that under the condition that mudstone had interacted with water for 24h, the bearing capacity suddenly decreased by more than 60%. At the same time, the test results also showed that, after soaked in construction water or rainwater, the soaked parts of the samples should be processed before the next procedure, so as to ensure that the bearing capacity of the mudstone foundation can meet the requirements and safety could be ensured. It can be seen that the external environment has a great impact on the mudstone stratum in the project lifecycle, especially the construction water and rainwater have a great impact on the bearing capacity of the mudstone foundation, which would greatly weaken the bearing capacity of the structure, therefore, it should be noted to process the soft and weak layers first during construction.



**Figure 7.** P-s curves of static load test of softened hard mudstone foundation



**Figure 8.** Representative p-s curve of static load test of softened hard mudstone foundation

**Table 3.** Test results of softened hard mudstone foundation under static load

Samples	Sample 7#	Sample 8#	Sample 9#	Sample 10#	Sample 11#	Sample 12#	Representative value
Limit bearing capacity/kPa	376	376	376	376	376	376	376
Total settlement/mm	14.13	14.51	15.27	14.38	13.73	13.65	14.28

## 5. CONCLUSION

Within the project lifecycle, the impact of environmental changes on mudstone stratum is prominent, especially the action of water has a great impact on it, therefore the effect of construction water on the force bearing layer should not be ignored during project lifecycle, and safety measures for ensuring the strength of the foundation should be adopted. Within the project lifecycle, the softening of the hard mudstone layer weakened the bearing capacity of the stratum, and the decrease can exceed 60% at the initial stage of water-soaking (24h), therefore, protection of mudstone foundation during construction should be strengthened, and soft and weak layers caused by construction water or rainwater should be removed completely; at the same time, test and evaluation on the bearing capacity of force bearing layers should be carried out; to ensure engineering safety, the next procedure should be carried out only after all requirements are met.

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