EFFECT OF MOISTURE CONTENT AND ROCK CONTENT ON THE RESILIENT MODULUS OF WEATHERED PHYLLITE FILLERS

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ABSTRACT

Weathered phyllite fillers are easily crushed under water and load, resulting in the rock content change. Therefore, resilient modulus of weathered phyllite fillers is affected not only by moisture content, but also by rock content. With the aim of investigating the effects of moisture content and rock content on the resilient modulus of weathered phyllite fillers, a small-scale indoor resilient modulus testing apparatus was developed, and the resilient moduli of seven groups of rock content with six different moisture content were tested using the indoor test apparatus. In addition, the influence of the moisture content and the rock content on the resilient modulus of weathered phyllite filler were analyzed. Furthermore, fractal dimension was introduced to further explore the relationship between rock content and resilient modulus of weathered phyllite fillers. Results show that the resilient modulus of weathered phyllite fillers increased first and then decreased with the increase of moisture content and rock content, among which the resilient modulus reached maximum at the moisture content of 5% and rock content of 55%. Moreover, the fractal dimension of weathered phyllite fillers after compaction first increased and then decreased with the increase of rock content, while the resilient modulus increased with the increase of fractal dimension of weathered phyllite fillers after compaction. The findings in this paper could provide guidance for the construction of weathered phyllite filling subgrade.

Keywords: weathered phyllite fillers, resilient modulus, moisture content, rock content, fractal dimension

1. INTRODUCTION

Resilient modulus of subgrade soil, which describes the relationship between load and deformation based on elastic theory, is one of the parameter indexes to characterize the bearing capacity of highway subgrade. And the main factors that affect resilient modulus are natural soil moisture content, soil texture, and degree of compaction of the soil (Farrar and Turner, 1991; Khoury and Zaman, 2004; Ceratti et al., 2004; Khoury et al., 2009; Li and Lan, 2013; Rahman and Tarefder, 2015; Han and Vanapalli, 2016). As a kind of special soil, weathered phyllite belongs to soft rock and its properties are extremely different from those of ordinary soil. With low strength, poor stability, weathered phyllite is prone to collapse and soften. Thus, its resilient modulus is not only affected by moisture content, but also by rock content and degree of crushing. Fractal dimension is one of the important parameters to characterize the degree of crushing of weathered phyllite. Therefore, it is meaningful to adopt fractal dimension to analyze the influence of moisture content and rock content on resilient modulus of weathered phyllite filling subgrade.

Ling et al (2007) and Dong et al (2013) pointed out that resilient modulus of subgrade decreased with the increase of moisture content. Shi (2011), Hu et al (2012), Kim et al (2013), Zhang et al (2013), Salour and Erlingsson (2015) investigated the resilient modulus variation of clay, silt and sand with the change of moisture content and found that soil type greatly affected the resilient modulus variation. In addition, researches have shown that the higher the degree compaction, the greater the resilient modulus (Wu et al., 2005; Wu et al., 2015; Zhao and Yang, 2011; Razouki and Ibrahim, 2017). Furthermore, Simonsen et al (2002), Wang et al (2005), and Liang et al (2008) pointed out that resilient modulus of subgrade in frozen area was also influenced by the freeze-thaw cycle times.

Although scholars have carried out a great deal of research on the influencing factors on subgrade resilient modulus, the existing research is only aimed at fine - grained soil. And the gradation curve of the fine-grained soil hardly change before and after loading, which is quite different from coarse - grained soil, especially weathered phyllite. Weathered phyllite will further brake down after loading, and its gradation curve will greatly change. Therefore, it is necessary to investigate the influencing factors on resilient modulus of weathered phyllite.

With the aim of investigating the influencing factors on resilient modulus of weathered phyllite, this paper studied the influence of moisture content and rock content on resilient modulus of weathered phyllite through indoor test apparatus. Furthermore, this paper adopted the fractal dimension to analyze the relationship between degree of crushing and resilient modulus of weathered phyllite.

2. MATERIALS AND METHODS

2.1 Testing equipment

The testing equipment (as shown in Fig. 1) used in this paper consisted of three parts: Plexiglas tube, loading device and deformation acquisition device. The Plexiglas tube with inside dimension of 50 cm×65 cm, was used to hold weathered phyllite fillers. The rigid plate was located below the Plexiglas guard and was used to support the Plexiglas tube. The loading device was composed of reaction beam, jack, TJH-4A load sensor and TY5D/A digital display instrument. In order to ensure that the filler was evenly loaded, a rigid bearing plate with diameter of 20 cm was placed between the filler and the loading device. The quantitative deformation acquisition device consisted of two dial indicators and fixed dial indicator devices. The dial indicators with the maximum mileage of 1 cm and the precision of 0.001 cm, were adopted to monitor the deformation of the tested filler.

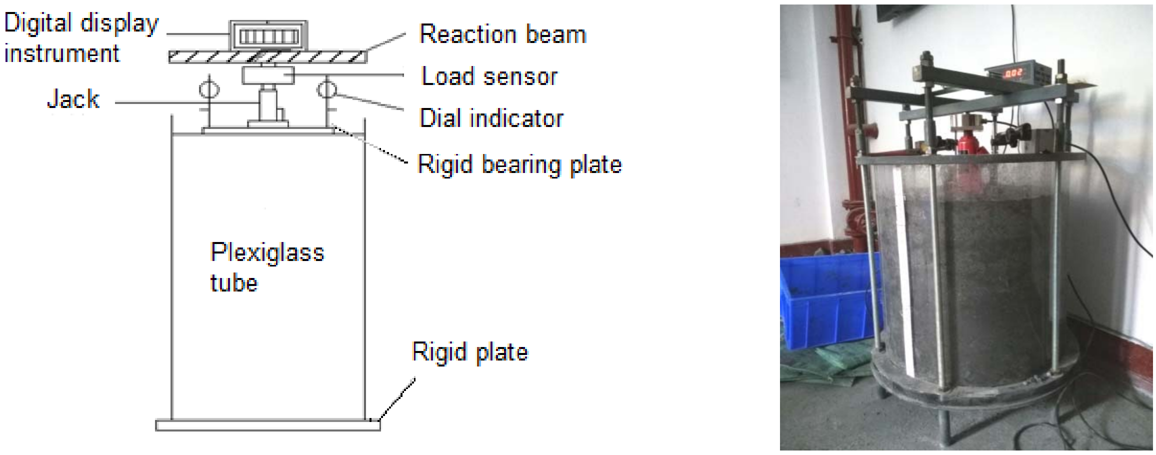


Figure. 1 Testing apparatus

2.2 Materials

The weathered phyllite fillers used in the test were extracted from excavated discards in the eastern section of Ankang, Shitian highway (as shown in Fig. 2), and its main mineral components are chlorite, sericite, muscovite, quartz, plagioclase and metal mineral. Atterberg Limits of weathered phyllite fillers are shown in Table 1. According to the unconfined compression strength test, the maximum compression strength of the weathered phyllite in the natural state was 29.5 MPa, while the maximum compression strength in the saturated state after immersion for 48 h was 14.3 MPa. According to Table 2, the weathered phyllite fillers used in the experiment belonged to the soft rock.

Figure. 2 Weathered phyllite from eastern Ankang of Shitian highway.

Table 1 Atterberg limits of weathered phyllite fillers

Liquid Limit	Plastic Limit	Plasticity Index
19.8%	16%	3.8%

Table 2 Rock hardness classification table

Hardness degree	Hardest rock	Hard rock	Soft rock	Softer rock	Softest rock
Saturated uniaxial compression strength / R_W（MPa）	$R_W>60$	$60\geq R_W>30$	$30\geq R_W>15$	$15\geq R_W>5$	$R_W\leq 5$

2.3 Filling and loading method

The weathered phyllite fillers were filled in four layers into the Plexiglas tube by volume control method. The quantity of weathered phyllite filler filling into each layer was calculated according to Eq. (1). After calculation, the detailed filling parameters for each layer are shown in Table 3.

$$M=\rho_{\mathrm{dmax}}\mathrm{v}\gamma \tag{1}$$

where M is the quantity of weathered phyllite fillers filling into each layer (g), $\rho_{d\max}$ is the maximum dry density of the weathered phyllite fillers (g/cm^3), V is the volume of weathered phyllite filler filling into each layer, $V=\pi\times25^2\times15$ (cm^3), γ is compaction degree, and in this test γ is 94%.

Table 3 Filling parameters for different groups

Rock content	0	25%	35%	45%	55%	65%	75%
Maximum dry density (g/cm^3)	2.091	2.100	2.112	2.215	2.358	2.227	2.218
Optimum moisture content (%)	9.014	8.924	8.717	8.036	7.305	6.741	6.382
Quantity of fillers for each layer (g)	69823	70124	70524	73296	78739	74364	74064
Total quantity of fillers (g)	279290	280490	282100	296080	314960	297460	296260

The weathered phyllite fillers was pre- loaded with 0.05 MPa using the jack, to make the rigid bearing plate touch the fillers. Then the specimen was unloaded and the dial indicators were adjusted to a position close to the full range. The predetermined maximum unit pressure (0.4 MPa) was divided into 4-6 parts as the loading pressure for each stage. When the loading time of each stage reached 1 min, the dial indicators readings were recorded, and at the same time, the specimen was unloaded to recover the deformation. When the unloading time reached 1 min, the dial indicators readings were recorded again, and the next stage load was applied at the same time. The loading and unloading were carried out gradually, and the dial indicator readings were recorded until the last stage of the load.

2.4 Calculation and correction of resilient modulus of weathered phyllite

Based on the elastic half-space theory and the field test method, resilient modulus of the weathered phyllite was calculated according to Eq. (2).

$$E_0 = \frac{\pi D}{4} \cdot \frac{\sum p_i}{\sum l_i}\left(1 - u_0^2\right) \tag{2}$$

where E_0 is the resilient modulus (kPa), u_0 is the Poisson ratio, and u_0= 0.35 in this test, P_i is the pressure value at each level (cm), l_i is the resilient deformation corresponding to P_i (kPa)), D is the diameter of bearing plate (cm), and D = 20 cm in this test.

However, the test in this paper was indoor test and the Plexiglas tube had restraining effect on the weathered phyllite fillers. According to Specifications for Design of Highway Asphalt Pavement (JTG D 50-2006), it is necessary to correct the resilient modulus according to Eq. (3)

$$E_{os} = \lambda E_0 \tag{3}$$

where E_{os} is the corrected resilient modulus (MPa), λ is the correction factor, and according to Eq. (4), $\lambda = 0.4$ in this study.

$$\lambda = 1.2381 \times 10^{-5} D^2 - 5.5838 \times 10^{-3} D + 1.0283 \tag{4}$$

where D is the diameter of the rigid bearing plate, and D is 200mm in this paper.

2.5 Test program

According to ASTM D2488, particles that will be retained on a No. 4 (4.75-mm) U.S. standard sieve include gravel, clay, boulders and cobbles. Liu et al (2017) defined particles with diameter larger than 5mm (round-hole mesh) as rock. Hence, weathered phyllite fillers with diameter larger than 4.75 mm (squre hole mesh) were defined as rock in this paper. In order to study the effect of rock content on the resilient modulus of weathered phyllite, seven groups of weathered phyllite fillers with different gradations, which were fine grain content, 25%, 35%, 45%, 55%, 65% and 75% rock content separately, were prepared in this test (gradation curves are shown in Fig. 3). And each gradation group was prepared with six moisture contents levels, as shown in Table 4. The weathered phyllite fillers were loaded using jack to induce deformation. It is worth noting that if the filler becomes too soft to detect its deformation, test of the group is considered invalid.

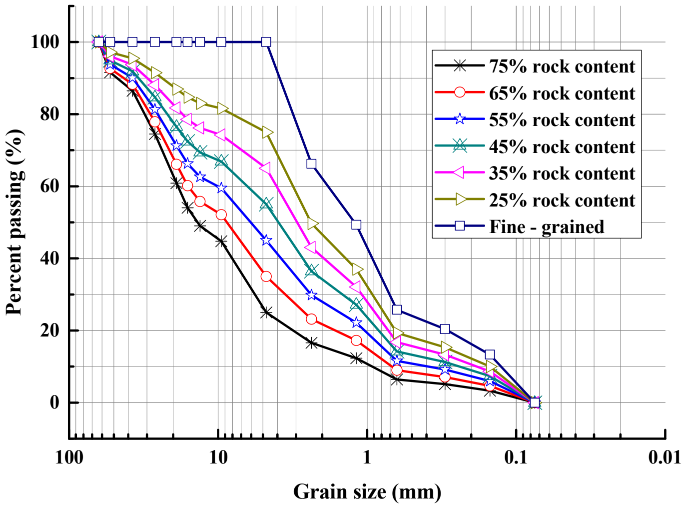


Figure. 3 Grain size distributions for weathered phyllite fillers

Table 4 Test scheme design

Moisture content / Rock content	3%	5%	7%	9%	11%	13%
0	✓	✓	✓	✓	✓	✓
25%	✓	✓	✓	✓	✓	✓
35%	✓	✓	✓	✓	✓	✓
45%	✓	✓	✓	✓	✓	✓
55%	✓	✓	✓	✓	✓	✓
65%	✓	✓	✓	✓	✓	✓
75%	✓	✓	✓	✓	✓	✓

3. RESULTS AND DISCUSSION

3.1 Resilient modulus of weathered phyllite fillers

When the moisture content was greater than 9%, weathered phyllite fillers with rock content of 65% and 75% were difficult to compact due to the excessive pore water pressure, and their deformations could not be measured. Therefore, the two groups were eliminated. Similarly, when the moisture content was 13%, deformations of weathered phyllite fillers could not be detected except fine grain content weathered phyllite fillers. Resilient modulus curves of weathered phyllite for each group are shown in Fig. 4.

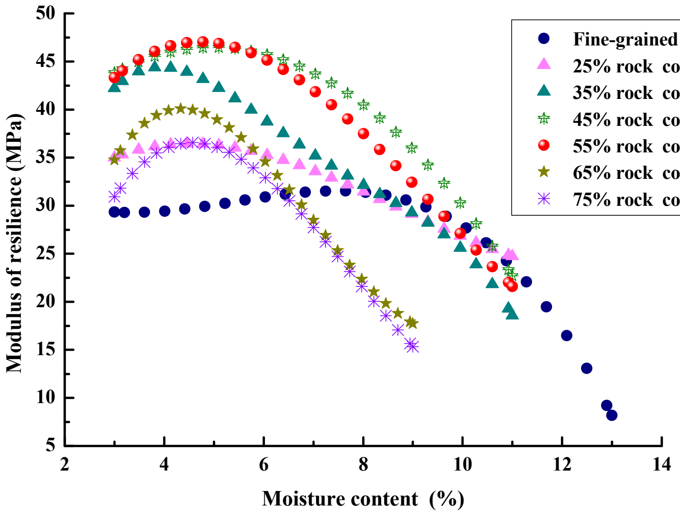


Figure. 4 Resilient modulus curves of weathered phyllite

As can be seen from Fig. 4, resilient modulus of weathered phyllite fillers varies with the change of moisture content and rock content. However, the shape of resilient modulus curves of weathered phyllite fillers with different rock content is similar, showing a trend of first increasing and then decreasing, and the moisture content corresponding to the peak resilient modulus of each group is slightly smaller than the optimum moisture content of weathered phyllite. That is because water acts as a lubricant between the weathered phyllite particles when the moisture content of the weathered phyllite is less than the optimum moisture content. Water is conducive to the compaction of weathered phyllite fillers. Hence, the strength of weathered phyllite increases with the increase of moisture content, resulting in the increase of resilient modulus. Nevertheless, when the moisture content of the weathered phyllite is larger than the optimum moisture content, the water film on the surface of weathered phyllite particles becomes thicker with the increase of moisture content. Water hinders weathered phyllite particles from further moving closer to each other, resulting in the decrease of soil strength and resilient modulus. Especially when the moisture content reaches a certain extent, the weathered phyllite fillers will soak, and the strength of the weathered phyllite will decrease sharply, making the rapid decline of resilient modulus.

Moisture content corresponding to the peak resilient modulus varied with rock content of the weathered phyllite fillers. According to Fig. 4, the greater the rock content of the weathered phyllite, the smaller the moisture content corresponding to the peak resilient modulus. Similarly, it can be seen from Table 3, the optimum moisture content of weathered phyllite also decreased with the increase of rock content, indicating that the water holding capacity of weathered phyllite decreases with the increase of the rock content.

Furthermore, Fig. 4 also shows that resilient modulus of weathered phyllite fillers firstly increased and then decreased with the increase of rock content. Resilient modulus of weathered phyllite fillers with 55% rock content were obviously larger than that of other gradation groups, and under 5% moisture content, resilient modulus of weathered phyllite fillers with 55% rock content reached the maximum value of 47.37 MPa. That may be attribute to that the weathered phyllite fillers with 55% rock content had the maximum dry density (shown in Table 3).

3.2 Relationship between resilient modulus and fractal dimension

Due to the breakability of weathered phyllite, it will further brake down under load, resulting the rock content change of weathered phyllite. Fractal dimension is one of the important indicators to characterize the disintegration and fragmentation of weathered phyllite. Therefore, fractal dimension of weathered phyllite has a certain relationship with the resilient modulus.

Tyler and Wheatcraft (1992) assumed that different soil particles had the same density, and on this basis, they established a fractal model of particle mass-particle distribution, as shown in Eq. (5).

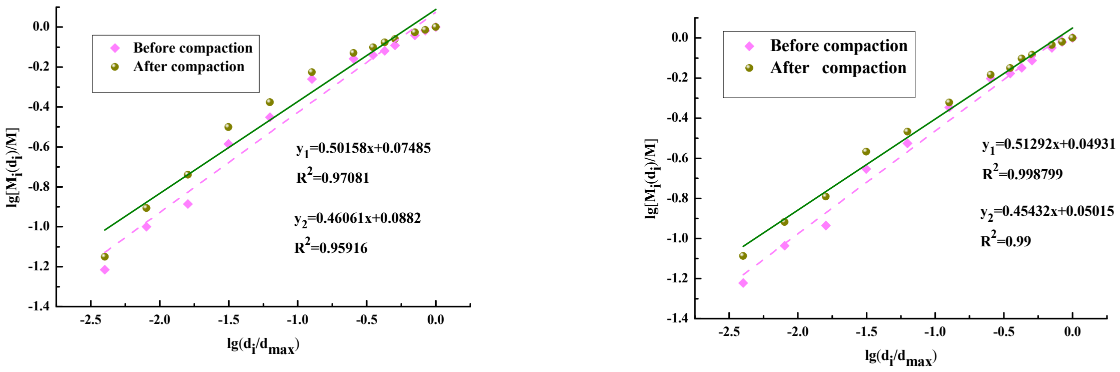
$$\frac{M_1(\mathrm{d_i})}{M_t}=1-\frac{M_2(\mathrm{d_i})}{M_t}=\left(\frac{\mathrm{d_i}}{\mathrm{d_{max}}}\right)^{3-D} \tag{5}$$

where $\mathrm{d_i}$ is the sieve size, $\mathrm{d_{max}}$ is the maximum particle size of the weathered phyllite fillers, $M_1(\mathrm{d_i})$ is the mass of weathered phyllite fillers with particle sizes of less than $\mathrm{d_i}$, $M_2(\mathrm{d_i})$ is the mass of weathered phyllite fillers with particle sizes of larger than $\mathrm{d_i}$, M_t is the total mass of the weathered phyllite fillers, and $M_t = M_1(\mathrm{di}) + M_2(\mathrm{di})$, D is the fractal dimension of the weathered phyllite fillers.

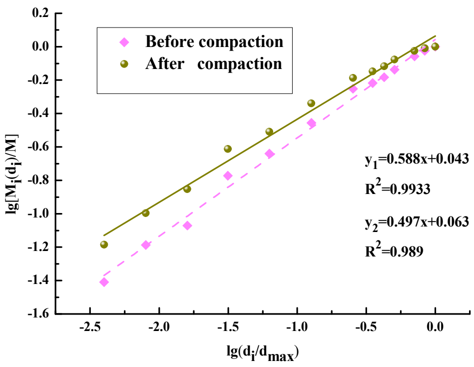
Take the logarithm on both sides of Eq. (5), we get:

$$\lg\left[M_1(\mathrm{d_i})/M\right]=\left(3-D\right)\lg\left(\mathrm{d_i}/\mathrm{d_{max}}\right) \tag{6}$$

As can be seen from Eq. (6), the fractal dimension can be obtained if the particle size and mass of the weathered phyllite are known. In this test, particle sizes and masses of weathered phyllite fillers with 45%, 55% and 65% rock content were obtained before and after compaction test. And the results are plotted in Fig. 5.



(a) 45% rock content (b) 55% rock content



(c) 65% rock content

Figure. 5 $\lg[M_1(d_i)/M]$ **vs** $\lg(d_i/d_{max})$ **before and after compaction**

It can be seen from Fig. 5 that $\lg[M_1(d_i)/M]$ has a good linear relationship with $\lg(d_i/d_{max})$ before and after compaction, and the correlation coefficients of the linear fit are both above 0.95. Therefore, the slops of these straight lines are equal to (3-*D*), and then we got fractal dimensions (*D*) of the weathered phyllite fillers, as shown in Table 5.

Table 5 Fractal dimensions of the weathered phyllite fillers

Rock content State	45%	55%	65%
Before compaction	2.4984	2.4871	2.412
After compaction	2.5394	2.5457	2.503

The fractal dimension of weathered phyllite fillers quantitatively reflects their fragmentation degree. And the larger the fractal dimension, the higher the degree of fragmentation of the fillers. It should be noticed that the greater the fractal dimension of the subgrade filler after compaction, the smaller the probability of further crushing of the fillers under load. Namely, the larger the fractal dimension after compaction, the greater the stability.

As can be seen from Table 5, the fractal dimension of fillers before compaction decreased gradually with the increase of rock content, indicating that fragmentation degree of fillers with 45% rock content was the largest among the three groups. After compaction, the fractal dimensions of all the weathered phyllite fillers increased, denoting that weathered phyllite fillers were further broken down after compaction. Furthermore, among the three groups, the fractal dimension of weathered phyllite fillers with 55% rock content was the largest after compaction. That is, the degree of crushing of weathered phyllite fillers with 55% rock content after compaction was the largest, indicating that it was less likely to further brake down under load. On the contrary, weathered phyllite with 65% rock content was most likely to further brake down under load. Therefore, weathered phyllite fillers with 55% rock content has the best stability among the three groups, resulting the smallest settlement under load and the largest resilient modulus. It can be concluded that fractal dimension of weathered phyllite fillers after compaction first increased and then decreased with the increase of the rock content. Besides, the resilient modulus increases with the increase of fractal dimension of weathered phyllite fillers after compaction.

4. CONCLUSIONS

In this paper, the influence of moisture content and rock content on the resilient modulus of weathered phyllite filler was researched using in-house built test apparatus. Besides, relationships between the rock content and the resilient modulus of weathered phyllite fillers were analyzed. The experimental finding from this study can be summarized as follows:

1. Resilient modulus of weathered phyllite was greatly affected by moisture content and rock content. And with the increase of moisture content, resilient modulus of weathered phyllite fillers first increased and then decreased. Similarly, with the increase of rock content, resilient modulus of weathered phyllite fillers first increases and then decreases. Besides, resilient modulus of weathered phyllite fillers reached maximum at the moisture content of 5% and rock content of 55%.

2. Moisture content corresponding to the peak resilient modulus of each group of weathered phyllite fillers was slightly smaller than the optimum moisture content of the fillers. And the higher the rock content of the weathered phyllite fillers is, the smaller the moisture content corresponding to the peak resilient modulus.

3. Fractal dimensions of weathered phyllite fillers with 45%, 55% and 65% before and after compaction were tested. It was found that the fractal dimension of weathered phyllite fillers after compaction first increased and then decreased with the increase of the rock content. Furthermore, stability increased with the increase of fractal dimension of weathered phyllite fillers after compaction, resulting in the increase of resilient modulus. The findings in this paper are of great significance for the construction of weathered phyllite filling subgrade.

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