EFFECTS OF THE STRUCTURAL COMPOSITION ON THE PERFORMANCE OF WEATHERED STONE GRAVEL

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ABSTRACT

The objective of this research was to evaluate the applicability of weathered stone gravels for use in rural roads and the factors influencing the structural strength of granular materials. The effects of the gradation, coarse size content, maximum size and fines content of gravel on its CBR value and shear strength were studied by using the CBR test and large-scale direct shearing test for two kinds of weathered stone gravels. The results showed that the CBR value of weathered stone gravel is influenced greatly by the fines (<0.0 75mm) content and the maximum size. The bigger the maximum size, the higher the CBR value. It was also concluded that the shear strength (φ value) of weathered stone gravel is influenced greatly by the coarse size content, with a maximum value of the percentage retained on the 4.75 mm sieve. Weathered stone gravels with high strength have higher shear strength and their C values correlate well with the content of aggregates below 0.6 mm. Finally, target values for the key influencing factors are recommended.

1. INTRODUCTION

As China implements its "develop-the-west" strategy, the need to accommodate traffic in the western region increases continuously. Highways need to be built not only in the hinterland, but also in the rural areas of vast grasslands in the west; this will support sustainable development of the economy of the rural areas of the western region and the grasslands. The reality in the rural areas is that there is a lack of high-quality material for building roads. This means that material that meets the requirements has to be located and transported from remote places, but the economic conditions in the rural areas do not allow it to be done in this way. Weathered gravels are found in abundance in the rural areas and rural roads in fact carry a small volume of traffic. Moreover, the vehicles using these roads are mainly light-duty vehicles, so the strength of the base does not need to be very high. Therefore a bold attempt to use the weathered gravels to build the gravel base of rural roads may well prove worth it.

In order to determine the correct compaction method for weathered stone gravels, various compaction methods were studied by Han Sen, et al. (2004b). At the same time, the material properties of gravel bases for rural roads were studied by Xu Ou-ming et al. (2004). Various researchers (Li Zhen et al., 2002; Han Sen et al., 2004a) have also investigated the variable law of shear strength on the basis of the direct shearing test.

2. OBJECTIVES

The objective of this research was to evaluate the suitability of weathered stone gravels, which had been used in the rural areas, and the factors influencing the structural strength of granular materials. The structural strength considered here included the deformation properties and strength properties of gravels. This study took the CBR value as the criterion of deformation and the shear strength as the strength criterion. In particular, two kinds of mechanical property experiments were done on the gravel (CBR test and large-scale direct shear test). The relationships between the maximum size, the coarse aggregate content, the fines content and the content of aggregates below 0.6 mm and the structural performance of granular materials were evaluated. Finally, recommendations on how to use weathered stones to build gravel bases are proposed.

3. MATERIALS AND GRADATIONS

The two kinds of weathered stones used for this research were taken from the gravel pits along the reserves of completed roads in the rural areas of the Inner Mongolia Autonomous Region. They were named A and B respectively. The degree of weathering of the former was slightly less than that of the latter and their strengths differed.

Ten different gradations were chosen for the experimental study, as shown in Table 1.

Table 1. Gradations of granular material.

Size of sieve pore (mm)	37.5	31.5	19	9.5	4.75	2.36	0.6	0.075
Gradation criterion	100	90~100	73~88	49~69	29~54	17~37	8~20	0~7
Upper limit	100	100	88	69	54	37	20	7
Median	100	95	80.5	59	41.5	27	14	3.5
Lower limit	100	90	73	49	29	17	8	0
FNS	100	90	73	69	54	37	8	0
FXW1	100	87	70	46	26	14	5	0
FXW2	100	85	65	43	20	12	3	0
FSW1	100	100	90	72	57	40	23	10
FSW2	100	100	95	75	60	45	25	15
D9.5	100	100	100	0	−	−	−	−
D19	100	100	0	−	−	−	−	−

4. RESEARCH APPROACH

4.1 Vibrating Test

On the basis of the above gradations, the authors studied the relation of the maximum dry density and the moisture content by means of the vibrating test. Based on the results, we then carried out the CBR test and the shearing test.

4.2 CBR Test

The CBR (California Bearing Ratio) is a laboratory testing method that is used to determine the relative strength of soil foundations and granular materials. A standard CBR mould of 152 mm diameter and 127 mm high was used. The CBR value is the ratio of the unit pressure that produces a penetration of 2.5 mm to the standard pressure when a standard broken stone is subjected to the same penetration. It is an index of the projected property of a material used to assess soils and granular materials.

Samples with different dry densities were placed on the vibrating platform for varying periods of time. The vibrating times for each layer were 120 s, 160 s and 200 s respectively. To take into account conditions in the most unfavourable season, the samples were soaked in water for 96 hours before the CBR test.

4.3 Direct Shearing Test

In order to study the shear resistance of weathered stone gravel, we designed a set of laboratory equipment for a full-size direct shearing test. The shearing box was rigid and was composed of an upper box, a middle box and a lower box; the total size was 400 mm × 400 mm × 500 mm. Two slots of 10 mm were made in the top and bottom of the middle box. During the test, the middle box moved while the other two were fixed and exerted force on the middle one until the sample had sheared. The shearing test equipment is shown in Figure 1.

4.3.1 Experimental steps

- According to the given gradations, the necessary sample quality is calculated and weighted on the basis of 100% vibrating maximum dry density and the volume of the shearing box.
- After being mixed evenly, the sample is divided into 8 on average.
- Pack the gravel into the shearing box after water has been added to each subsample and mix evenly.
- Weigh the armour plate being used, and place it on the sample to make the sample consolidate.

Figure 1. Shearing test equipment.

- When the vertical deformation of the sample is less than 0.03 mm per hour, the sample is thought to have already consolidated steadily and the next step can be carried out.
- Move the shearing box to the centre of the experimental platform.
- Make the armour plate level with sand.
- Adjust the experimental platform so that the horizontal pressure sensor lies in the centre of the shearing box.
- Fix the vertical pressure sensor and the electromechanical dial gauges and adjust the vertical pressure sensor so that it lies in the centre of the armour plate.
- Unclamp the fixed pins on the side of the shearing box and take the locking device out.
- Turn on the vertical oil pump to exert vertical pressure to the preset value, and then stop pressurising.

- Turn on the horizontal oil pump immediately to keep the horizontal pressure sensor in touch with the shearing box.
- Now exert pressure slowly, controlling the shearing speed at 0.05 mm per second. Turn on the automatic data monitor and type the scanned results at the same time.
- Stop the experiment when the horizontal load no longer increases or when the shearing deformation increases sharply or reaches 25 – 30mm. The time for shearing should be kept at 5 to 10 min.

5. RESULTS AND ANALYSIS

5.1 Vibrating Test

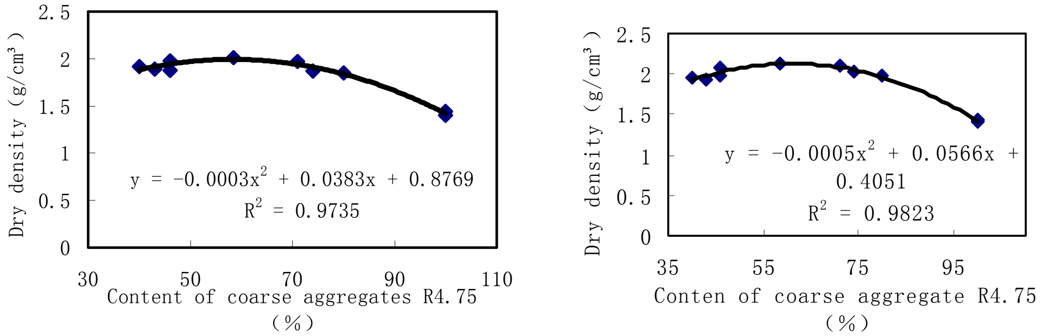
The results of the vibrating test are presented in Table 2.

Table 2. Relation between maximum dry density and moisture content.

Item / Gradation	Weathered stone A		Weathered stone B		$R_{4.75}$ (%)
	Maximum dry density (g/cm³)	Optimum moisture content (%)	Maximum dry density (g/cm³)	Optimum moisture content (%)	
Upper limit	1.98	7.0	2.09	7.1	46
Median	2.01	6.4	2.12	6.9	58.5
Lower limit	1.97	5.8	2.10	6.0	71
FSW1	1.89	6.0	1.93	7.3	43
FSW2	1.92	7.2	1.95	7.7	40
FXW1	1.87	7.4	2.02	5.5	74
FXW2	1.85	5.4	1.98	5.4	80
FNS	1.88	5.3	1.99	5.8	46
D19	1.40	2.0	1.40	2.4	100
D9.5	1.44	2.4	1.44	4.0	100

Note: ①$R_{4.75}$ denotes the content of coarse aggregate (>4.75 mm) in the gradation.

Figure 2 shows the relationship curve of $R_{4.75}$ and vibrating dry density. The curve takes the form of a parabola and the density first increases and then decreases with an increase in $R_{4.75}$. When $R_{4.75}$ is 40 - 60%, the density shows an increasing trend. When $R_{4.75}$ is 60 - 70%, the density reaches a maximum value. The density then decreases gradually while $R_{4.75}$ increases continually and exceeds the optimum content. The reason is that the quality of the same volume of fine aggregate is lower than that of the coarse aggregate. The increase in $R_{4.75}$ may cause the dry density of the granular material to increase. When $R_{4.75}$ is 40 – 60%, the coarse aggregates are not in close contact with each other and the structure is looser, so some fine aggregate fills the interstices. The coarse aggregates are then brought into closer contact with each other, so the density increases as $R_{4.75}$ increases. When $R_{4.75}$ reaches 60 – 70%, the density has a maximum value and $R_{4.75}$ is at its optimum content. When $R_{4.75}$ increases sequentially, the fine aggregates are unable to fill up all the interstices. While the coarse aggregates are well aligned, the fine aggregates lying in the voids cannot be properly compacted and therefore the density decreases slowly.



(a) Weathered stone A **(b) Weathered stone B**

Figure 2. Relation between $R_{4.75}$ and dry density.

5.2 CBR Test

The results of the CBR test are presented in Table 3.

Table 3. Results of CBR test.

Item / Gradation	Maximum size (mm)	<0.075 mm content	CBR average value(%)	
			A	B
Upper limit	31.5	7	95	65
Median	37.5	3.5	101	90
Lower limit	37.5	0	92	70
FSW1	31.5	10	53	50
FSW2	31.5	15	30	25
FXW1	37.5	0	57	58
FXW2	37.5	0	74	63
FNS	37.5	0	79	77
D19	31.5	0	33	30
D9.5	19	0	25	22

Fig. 3 shows the relation between the fines content (<0.075 mm) of two kinds of weathered stone and the CBR value. It can be seen that the CBR value is at its greatest when the optimum fines content is 3 – 5%.

Fig. 4 shows the relation between different D_{max} values and the CBR value. The bigger the maximum size of the aggregate, the more strongly the granular material resists external forces, so its CBR value will be greater. However, if the maximum size of the aggregate is too big, the stones tend to become isolated, which affects the structural strength. Bearing in mind the on site construction situation, we suggest that the maximum size of the aggregate should not exceed 40 mm. Although the Chinese standard allows a maximum particle size of 25 mm for the CBR test, values up to 37.5 mm were used in this experiment to evaluate the effect of maximum size.

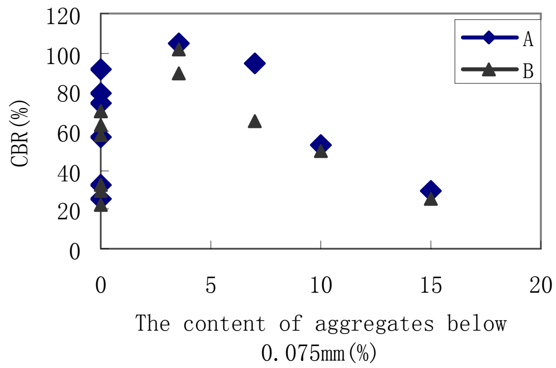


Figure 3. Relation of fines content of weathered gravels and CBR value.

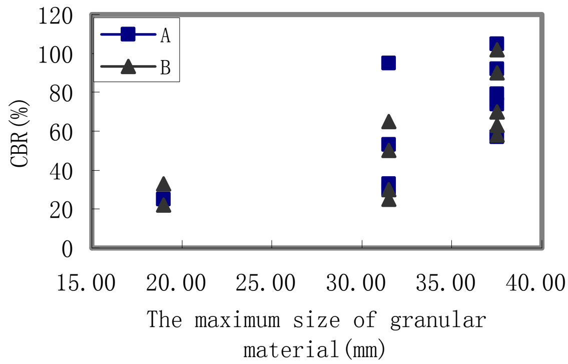


Figure 4. Relation of the maximum size of granular material and CBR value.

Fig. 5 shows the relation between $R_{4.75}$ and CBR value. The CBR value increases with the $R_{4.75}$, reaching a maximum value when $R_{4.75}$ is 55 – 65%. If the $R_{4.75}$ continues increasing, the CBR value will gradually reduce. The authors think that the $R_{4.75}$ has an optimum content for CBR value. Coarse aggregates act mainly as a framework for granular material. At the beginning, coarse aggregates cannot provide a framework because the $R_{4.75}$ is low. So the coarse aggregates are in fact in suspension in the fine aggregates; the granular material only needs a small load for the same degree of penetration and the CBR value is low. As the $R_{4.75}$ increases, there is more and more contact between the coarse aggregates, which then begin to form a framework with the fine aggregates filling the spaces and giving the closely-knit structure of a good framework. The granular material therefore needs a larger load for the same degree of penetration and the CBR value gradually increases. As the $R_{4.75}$ continues increasing, there is more and more contact between the coarse aggregates, but there are not enough fine aggregates to pack into the spaces and the interference between the coarse aggregates becomes worse and worse. The granular material may need only a small load for the same degree of penetration and the CBR value is again low. It is believed that the $R_{4.75}$ should have a suitable content (55 – 65%) from a point of view of favourable to the CBR value.

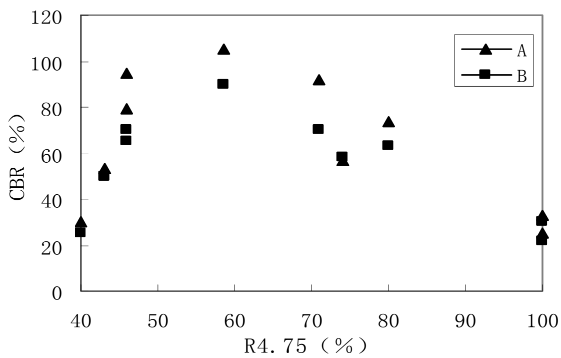


Figure 5. Relation between CBR and coarse aggregate fraction.

<u>5.3 Shearing Test</u>
The results of the shearing test are shown in Table 4.

Table 4. Results of shearing test.

Item / Gradation	A		B		ΔΦ (degree)	Δ C (kPa)	$R_{4.75}$ (%)
	Φ (degree)	C (kPa)	Φ (degree)	C (kPa)			
Upper limit	34.14	35.1	29.10	30.63	7.12	4.47	46
Median	36.17	11.7	32.53	21.76	3.64	-10.06	58.5
Lower limit	35.29	9.98	30.75	30.93	4.54	-20.95	71
FSW1	29.64	26.62	28.51	29.45	1.13	-2.83	43
FSW2	29.16	47	28.02	26.19	1.14	20.81	40
FXW1	37.23	6.71	36.40	1.53	1.19	5.18	74
FXW2	38.06	2.43	37.17	1.12	0.89	1.31	80
FNS	35.23	8.75	35.05	3.48	0.18	5.27	46
D19	28.15	0	27.04	0	1.11	0	100
D9.5	25.13	0	23.82	0	1.31	0	100

Note: ①Δφ=φ of A -φ of B；②Δ C= C of A - C of B.

Fig. 6 shows the relation between gradation and φ value. It can be seen that the gradations of FXW1 and FXW2 have a greater φ value, and the φ value of A is bigger than that of B.

Fig. 7 shows the relation between $R_{4.75}$ and φ value. With increasing $R_{4.75}$, the φ value first increases and attains a maximum value when $R_{4.75}$ reaches a certain content. Then the φ value reduces gradually with increasing $R_{4.75}$. Again, the coarse aggregates act mainly as a framework for granular material. At the beginning, coarse aggregates cannot provide a framework because the $R_{4.75}$ is low. So the coarse aggregates are in fact in suspension in the fine aggregates; they have little contact with each other and the φ value is low. As the $R_{4.75}$ increases, there is more and more contact between the coarse aggregates, so the φ value gradually increases because the coarse aggregates need to overcome the frictional force between them in order to move. As the $R_{4.75}$ continues increasing, the area of contact between the coarse aggregates reduces gradually, so the φ value also reduces gradually. The authors conclude that the $R_{4.75}$ has an optimum content for the φ value, and the suitable content of $R_{4.75}$ may be 60 – 80%.

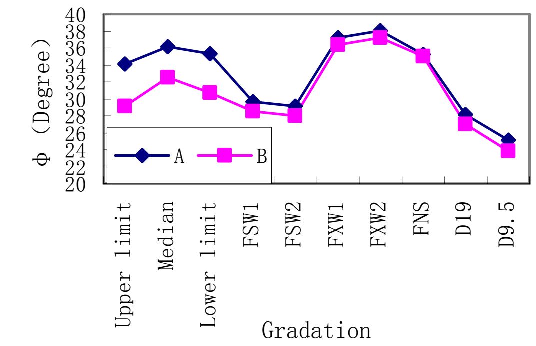


Figure 6. Relation of gradation and φ value.

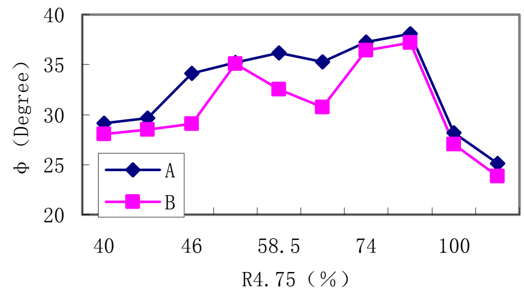
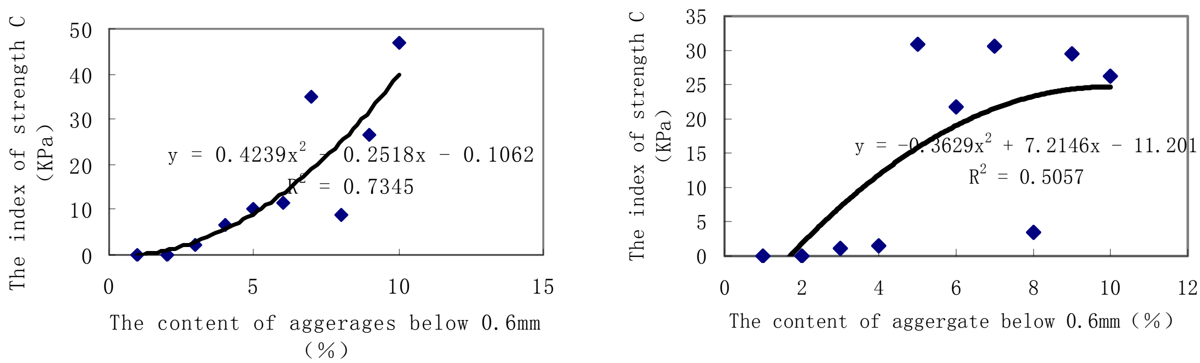


Figure 7. Relation of $R_{4.75}$ and φ value.

We also observe that the upper limit gradation and the FNS gradation have the same content of coarse (>4.75 mm) aggregate (46%) at the start of the curve in Fig. 8, but they have different φ values. We believe this may have something to do with their gradations and the maximum size of the aggregate. However, as the same applies to the end of the curve, the authors conclude that the bigger the maximum size of the aggregate, the greater the φ value becomes.

Fig. 8 shows the relation between the content of aggregates below 0.6 mm and the C value.



(a) Weathered stone A **(b) Weathered stone B**

Figure 8. Relation of the content of aggregate below 0.6 mm and C value.

It can be seen that the relation between the content of aggregate below 0.6 mm and the C value with stone A correlates well with the following quadratic polynomial; the correlation coefficient is 85.7%.

$$y = 0.4239x^2 – 0.2518x – 0.1062 \tag{1}$$

where:

y = C value
x = content of aggregate below 0.6 mm.

The relation of the content of aggregate below 0.6 mm and the C value of stone B also has some relation to the following quadratic polynomial, but the correlation is worse than with stone A and the correlation coefficient is 71.7%.

$$y = -0.3629x^2 + 7.2146x - 11.201 \quad (2)$$

where:

y = C value
x = content of aggregate below 0.6 mm.

It is our opinion that this kind of difference is involved in the strength of granular materials. The strength of weathered stone B is relatively low, so the granular material may be crushed during crushing. The actual content of <0.6 mm is relatively larger than the initial content below 0.6 mm.

6. CONCLUSIONS

This research effort focused on the applicability of weathered stones and the factors influencing the structural strength of granular materials. The conclusions drawn from this study are as follows:

1. The content of coarse aggregate should be kept within a certain range in order to obtain a higher dry density, CBR value and good shear resistance (φ value).
2. The CBR value of weathered stone remains related to the strength, the content of aggregate below 0.075 mm and the maximum size of the granular material. The larger the granular material, the bigger the CBR value. When the content of aggregate below 0.075 mm is 3 – 5%, the CBR value will be high. We also found that the higher the maximum, the higher the CBR value becomes. We propose that the maximum size of granular material should not exceed 40 mm to prevent construction problems.
3. The shear resistance of weathered stone remains related to the strength and the maximum size of the granular material. When the content of coarse aggregates reaches a certain value, the φ value will increase with the maximum size or with the strength of the granular material. To obtain a good φ value, the authors suggest that the granular material should be of a dense gradation with a suitable maximum size and superior strength.
4. The experimental results show that the C values of two kinds of weathered stones are not zero, and the C values correlate well with the content of aggregate below 0.6 mm.
5. The results also show that the CBR test and shearing test obey similar laws, and that the CBR and φ values are closely related to the strength, the maximum size and the content of coarse aggregate in the granular material. When the strength of the weathered stone is high or the maximum size of granular material is reached, the CBR and φ values are high. When the content of coarse aggregate is optimum (60 – 65%), more ideal CBR and φ values are obtained.

7. RECOMMENDATIONS

The following values for the key influencing factors are recommended:

1. The content of coarse aggregate should be kept between 60 and 65%.
2. The fines content of the aggregate (–0.075 mm) should be kept between 3 and 5%.
3. When the maximum size of the gravel is 40 – 50 mm, good CBR and φ values and good compaction of gravel can be achieved, and segregation can also be avoided.

8. REFERENCES

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