STUDY ON CHARACTERISTICS OF SHEAR STRENGTH OF FINE CRUSHED STONE BY AUTOMATIC SHEAR TESTING

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Abstract

This paper focuses on studying the shear strength characteristics of the fine crushed stone based on automatic shear testing, which is an important parameter to evaluate the load capacity of embankment material. The fine crushed stone collected from quarries in Ha Nam province. The shear strength of the material is evaluated according to different levels of compaction, i.e. void coefficient, and cutting speed. The experimental results show that the shear strength of the fine crushed stone is relatively high and confirm that it could be used as a substitute for the river sand in land reclamation.

Keywords: *Sand; fine crushed stone; internal friction angle; shear strength; automatic shear testing.*

1. Introduction

According to statistics in Vietnam, the demand of construction sand is about 120-130 million m^3/year and the demand of leveling sand in the period of 2016-2020 is from 2.1 to 2.3 billion m^3. Whereas, the reserve of construction sand and leveling sand is predicted about only 2.1 billion m^3. In fact, the supply of natural sand from legal mining areas is predicted to meet only 40-50% of the demand [1]. By the year of 2020, we didn't have enough natural construction sand to serve the needs of localities. The scarcity of natural sand in some provinces led to the sand prices increase, which had a great negative impact on construction activities. Therefore, it is necessary to search an alternative material source to replace the natural sand. Fine crushed stone, a by-product of crushed stone production, can be considered as one of such materials. This could be effective not only in terms of economy but also in terms of environmental protection.

In some countries, where there is a great need to use fine crushed stone to replace natural sand, many studies have focused on evaluation of the mechanical properties of the fine crushed stone. Vijaya [2] observed the microstructure of the fine crushed stone by scanning electron microscopy (SEM) and showed that they have rough surfaces with many acute angles and long shapes. Whereas, the natural sand have smooth surfaces and

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spherical shapes. The such surface state and shape of the fine crushed stone allow for creation of higher friction and association (interlocking) between the particles. This improves the shear strength of the fine crushed stone mix. Moreover, with the properties metinoned above of the fine crushed stone, the arrangement of the particles is tighter, which can reduce the porosity, and thereby increase the density when filling the foundation and embankment.

a) Riverbank erosion on Highway 91 - An Giang

b) Erosion of bridge pier foundation in Ky Anh - Ha Tinh

Figure 1. The incident caused by illegal sand mining in rivers.

Kakati and Chetia [3] studied the shear resistance characteristics of two materials, the fine crushed stone and mixture of fine crushed stone and river sand (ratio 70:30). The authors conducted experiments on test samples with different dry weights and cutting speeds (0.25 mm/min, 0.625 mm/min and 1.25 mm/min). The results showed that the internal friction angle of fine crushed stone and mixture of fine crushed stone and river sand increases with cutting speed. The fact shows also that the grain composition of the fine crushed stone, and thereby its shear resistance characteristics, depends on the mining technology in each quarry.

Currently, in Vietnam research on the fine crushed stone mainly consider its potential to replace the river sand in the composition of cement concrete mix. There is still, however, a lack of studies on its shear resistance parameters. These parameters play an important role in evaluation of bearing capacity of the fine crushed stone when it is used to fill the embankment or to replace a part of soft soil under the foundation.

In this research, the authors determine the shear strength characteristics of the fine crushed stone that collected from quarries in Phu Ly - Ha Nam by using the automatic shear testing equipment SHEARMATIC with different void coefficients and cutting speeds of the test samples in dry or saturated condition.

2. Materials and Methodology

2.1. Physical characteristics of fine crushed stone

The mixture of fine crushed stone is collected from quarries in Phu Ly (Ha Nam province) with particle sizes less than 5 mm. The fine crushed stone and experiment tools are shown in Figure 2 while the physical properties of the fine crushed stone are given in Table 1.

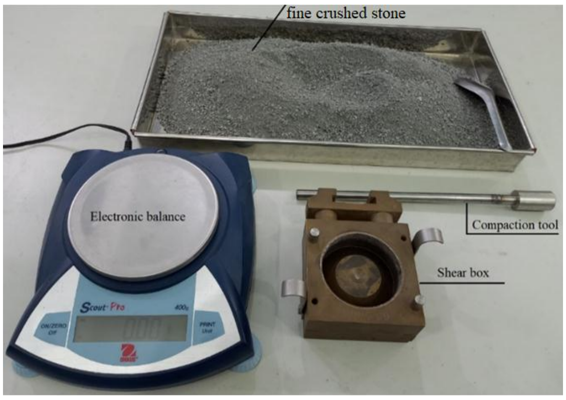


Figure 2. Fine crushed stone at the quarry in Phu Ly - Ha Nam and experiment tools.

Table 1. Physical properties of the fine crushed stone

Properties	Value
Specific gravity, G	2.698
Void ratio in the loosest state, e_{max}	0.90
Void ratio in the densest state, e_{min}	0.55

From the particle-size distribution curve, the uniformity coefficient C_u = 8.5 and the coefficient of gradation C_c = 1.7 can be determined. Based on the standard TCVN 5747:1993 [4], this fine crushed stone belongs to well-graded sand (SW).

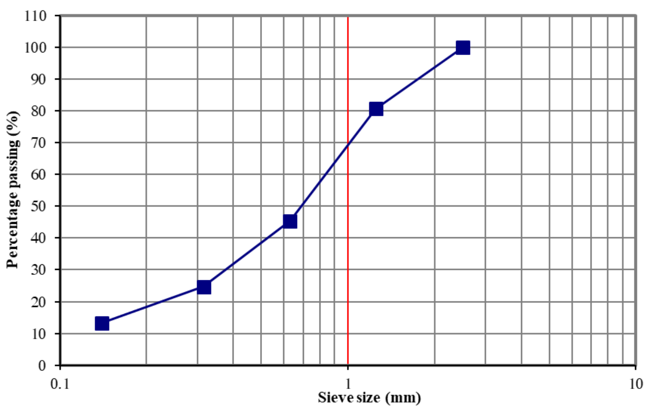


Figure 3. The grain-size distribution curve of the fine crushed stone.

2.2. Experiment on the determination of shear strength parameters of the fine crushed stone

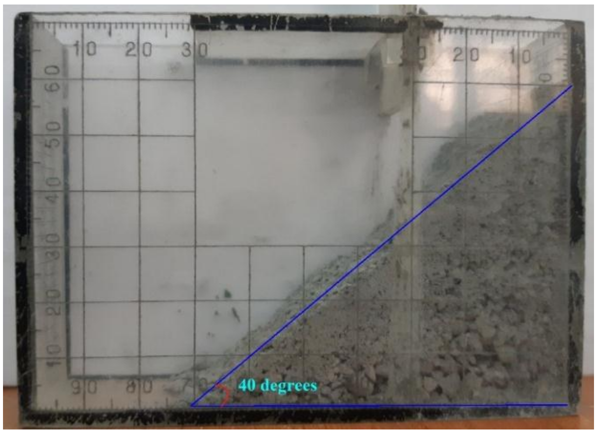
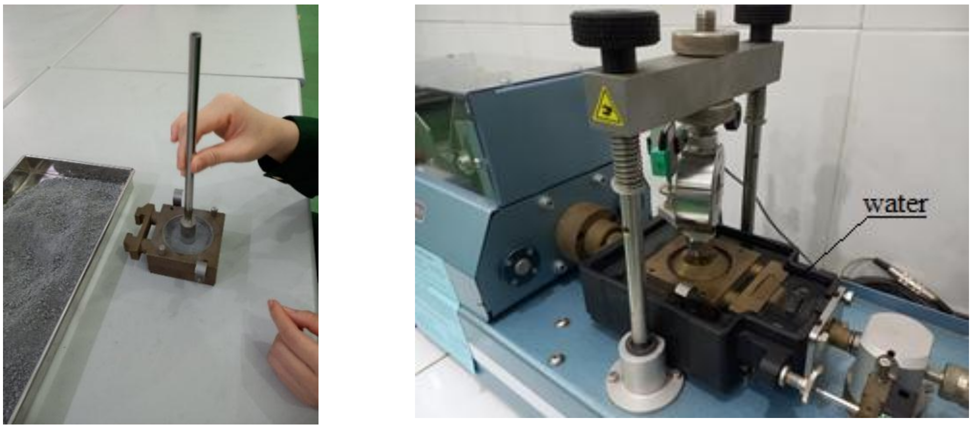


Figure 4. Determining the angle of repose of the fine crushed stone.

Firstly, the authors conducted experiments to determine the angle of repose of the fine crushed stone in a dry state according to the standard TCVN 8724:2012 [5] (Figure 4). The results show that the natural resting angle of the fine crushed stone in the dry state is relatively high, i.e., $\varphi = 40^o$.

Secondly, the authors conducted experiments to determine the shear strength parameters of the fine crushed stone samples with different densities, moisture contents and cutting speeds based on the standard TCVN 4199:1995 [6]. The experiments were conducted with three levels of compaction corresponding to the void coefficients $e = 0.6$, 0.7 and 0.8. For each degree of compaction, we carry out three shear tests for 3 samples corresponding to the compression load levels set as σ_v = 100 kPa, 150 kPa and 200 kPa.



(a) *(b)*

Figure 5. The samples are compacted and then saturated (a) before the shear test (b).

The sequence of testing 1 sample in the dry state with the degree of compaction e = 0.6 and compressive load σ_v = 100 kPa is as follows:

- Step 1: Take a quantity of fine crushed stone (dry state) and put it into the sample cutting box with a predetermined volume according to the void factor (m = 128.2 g);

- Step 2: Create a prototype in the cutting box. The sample was generated in a cutting box with a cylindrical shape of constant dimensions (diameter D = 6.35 cm; sample height h = 2.4 cm). The initial amount of fine crushed stone (m = 128.2 g) is poured into the cutting box. The initial sample height is more than 2.4 cm. Then, the compaction is performed until the sample reaches a predetermined height h = 2.4 cm, then it is considered that the compaction work ensures the predetermined compaction;

- Step 3: Insert the cutting box (including the prepared sample) into the Sheramatic automatic digital flat cutter;

- Step 4: Set initial parameters before experimenting such as sample size, input parameters for the consolidation stage (sample compression load σ_v = 100 kPa, consolidation speed, speed of data logging) and direct cutting stage input parameters (sample shear rate, maximum horizontal displacement, metric write speed);

- Step 5: Conduct the sample consolidation phase test;

- Step 6: Conduct the direct cutting phase experiment;

- Step 7: Take measurement data and end the experiment for the first sample.

With respect to remaining samples, the sequence was also carried out in the same order as above.

Particularly, note that, for the saturated samples, it is necessary to soak the samples in water for 3 hours before performing Step 4.

3. Result and discussion

The experimental results are shown in detail in Table 2 and Figures 6, 7, 8.

Table 2. Test results on the determination of shear strength parameters of fine crushed stone

Sample No.	**Void ratio, e**	**Experimental sample state**	**Shearing rate**	**Normal stress, σ**	**Ultimate shear strength, τ**	**Internal friction angle**
			mm/min	kPa	kPa	φ (degrees)
M1	0.60	Dry	2.00	100	160.60	56.90
				150	242.74	
				200	293.04	
M2	0.60	Dry	0.25	100	156.29	56.30
				150	231.81	
				200	291.95	

Sample No.	Void ratio, e	Experimental sample state	Shearing rate	Normal stress, σ	Ultimate shear strength, τ	Internal friction angle
			mm/min	kPa	kPa	φ (degrees)
M3	0.70	Dry	2.00	100	147.00	53.87
				150	225.04	
				200	254.29	
M4	0.70	Dry	0.25	100	139.55	51.99
				150	183.63	
				200	256.41	
M5	0.70	Saturated	2.00	100	129.91	50.88
				150	179.87	
				200	245.89	
M6	0.70	Saturated	0.25	100	131.76	50.02
				150	180.55	
				200	231.06	
M7	0.80	Dry	2.00	100	145.70	52.92
				150	210.08	
				200	249.17	
M8	0.80	Dry	0.25	100	145.56	52.65
				150	192.31	
				200	257.98	

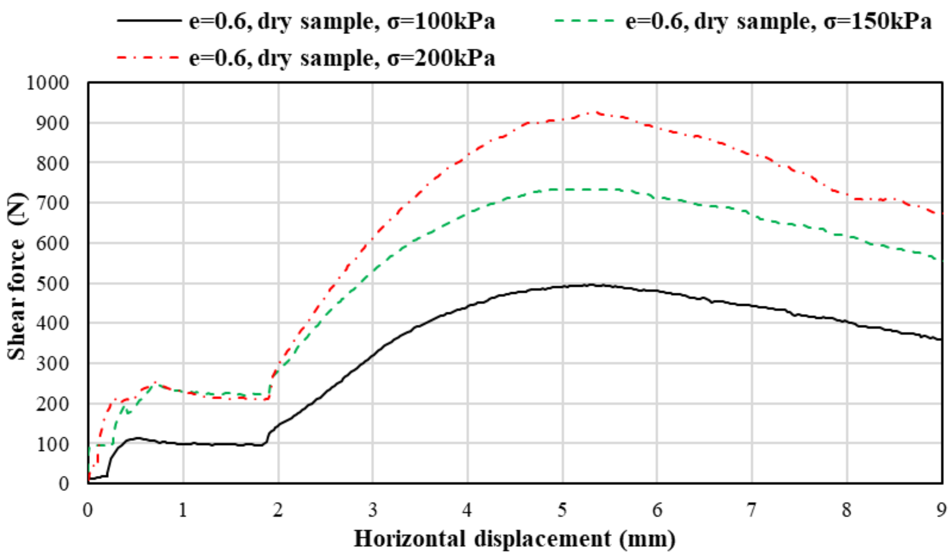


Figure 6. Relationship of shear force and horizontal displacement (dry sample, void ratio e = 0.6, shearing rate 0.25 mm/min).

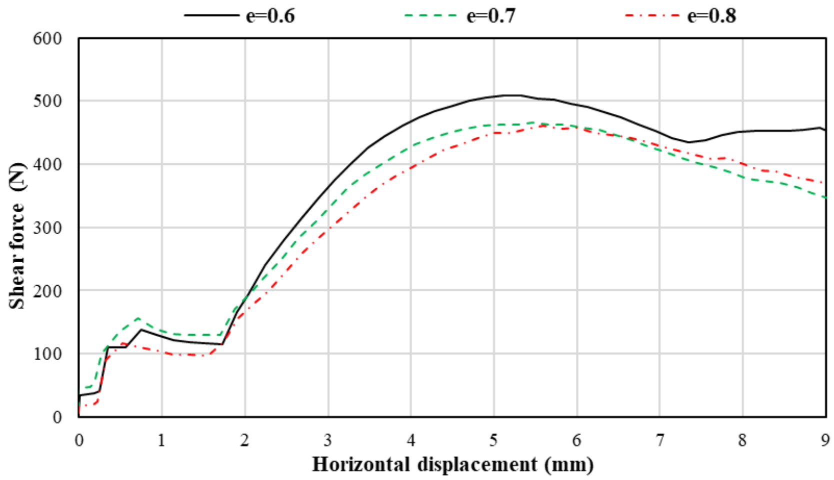


Figure 7. Relationship of shear force and horizontal displacement with different void ratio (dry sample, normal stress σ = 100 kPa, shearing rate 2.0 mm/min).

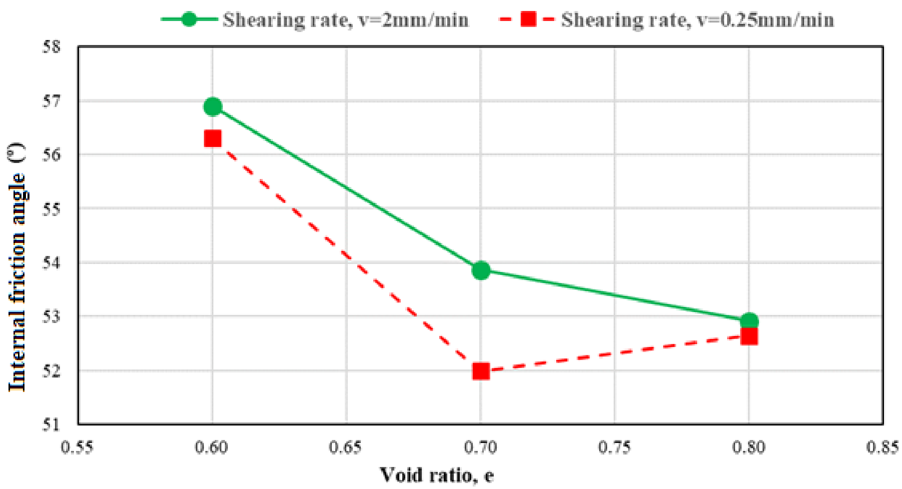


Figure 8. Effect of void ratio on internal friction angle of fine crushed stone.

The results of the study as described above show that:

- The fine crushed stone in collected from quarries in Phu Ly - Ha Nam is SW grade. It is a good grade in comparing with the standard TCVN 5747:1993.

- Figures 6 and 7 show experimental results for three levels of compaction. They show that when the fine crushed stone is in different compaction states (e = 0.6, 0.7, 0.8) relationship curve between shear force and transverse displacement shows a significant peak value, and then the fine crushed stone behaves post-peak softening.

- The dry resting angle of fine crushed stone (φ = 40^{o}) is much larger than that of the river sand that is approximately 30^{o}.

- When the degree of compaction increases from, i.e., e = 0.8 to e = 0.6, the shear strength increases as illustrated in Figure 7. The internal friction angle increases from 52.92^o to 56.90^o (at dry state, cutting speed 2 mm/min) and increases from 52.65^o to 56.30^o (at dry state, cutting speed 0.25 mm/min).

- When the cutting speed increases, the internal friction angle of the fine crushed stone also increases. This increase is high with respect to the void coefficient e = 0.7. This is not the case with the void coefficient e = 0.6 and e = 0.8.

- As expected, the fine crushed stone in the saturated state has a smaller friction angle than in the dry state, but the difference is not much. The cutting speed has little effect on the change of the internal friction angle of the fine crushed stone in the saturated state (Table 2).

4. Conclusion

The paper is devoted to study the shear strength characteristics of the fine crushed stone collected from quarry in Phu Ly - Ha Nam. The obtained results show that when the void ratio decreases and the cutting speed increases, the internal friction angle of the fine crushed stone increases. In the range of void coefficient change from 0.6 to 0.8, cutting speed from 0.25 mm/min to 2.0 mm/min, the internal friction angle of the fine crushed stone is much higher than that of the river sand in both the dry state and saturation state. This confirms that the fine crushed stone in the Phu Ly - Ha Nam quarry is a reasonable substitute for the river sand that is becoming increasingly scarce. The fine crushed stone could be used to fill the foundation or replace a part of the soft soil layer to reduce the load on the underlying soil layer. This material brings not only the economic benefit but also the benefit in protection of environment.

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NGHIÊN CỨU ĐẶC TRƯNG KHÁNG CẮT CỦA ĐÁ MẠT BẰNG MÁY CẮT PHẲNG TỰ ĐỘNG

Phạm Đức Tiệp, Trần Nam Hưng, Trần Văn Cương

Tóm tắt: *Bài báo tập trung nghiên cứu đặc trưng kháng cắt của đá mạt dựa trên thí nghiệm cắt tự động, đây là thông số quan trọng để đánh giá khả năng chịu tải của vật liệu đắp. Đá mạt được lấy từ các mỏ đá trên địa bàn tỉnh Hà Nam. Đặc trưng kháng cắt của vật liệu được đánh giá theo các mức độ đầm nén khác nhau và tốc độ cắt. Kết quả thí nghiệm cho thấy, đặc trưng kháng cắt của đá mạt tương đối cao và khẳng định rằng nó có thể được sử dụng thay thế cho cát sông trong đắp nền công trình.*

Từ khóa: Cát; đá mạt; góc nội ma sát; đặc trưng kháng cắt; thí nghiệm cắt tự động.

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