RESEARCH ON APPLICABILITY NATURAL RED SAND FOR THE SUBGRADE OF HIGHWAY CONSTRUCTION BY EXPERIMENT IN THE LABORATORY

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Abstract

This article presents some typical physical and mechanical characteristics of natural red sand collected in Thien Nghiep commune, Phan Thiet city, Binh Thuan province through static experiments in the laboratory. From the obtained results, it is shown that this sand belongs to group A-2 according to the AASHTO M145 standard on grain composition. The sand has a relatively high cohesion with an average value of about 29 kPa and the internal friction angle with an average value of about 35º which characterize the shear resistance of material. The CBR value of sand at a relative compaction of 0.95 is 20.67% which meets the requirements of subgrade materials for highway traffic construction according to current standards. Thus, through a series of static experiments, it is confirmed that this type of sand is potentially suitable as a subgrade material for traffic construction in Vietnam.

Keywords: *Natural red sand; relative compaction; subgrade; traffic construction; static experiments.*

1. Introduction

The road-bed and subgrade layers for highway are usually made of natural construction materials. These are diverse such as soils, rocks, and sands, etc. In particular, some types of sand are often applied by many traffic works because of characteristics such as good water permeability and being relatively homogeneous, so they have stability, high durability, ease of execution, etc. However, from statistical data, good quality natural materials used in traffic construction are increasingly scarce. Most of the construction sand is extracted from the river, leading to many consequences such as coastal subsidence, environmental pollution, floods, etc. Even many areas of the world no longer have good quality sand to serve the primary construction fields. In Vietnam, according to the Ministry of Construction survey data, the demand for sand from 2016 to 2020 needs 2.1 to 2.3 billion m^3 of sand, leading to the depletion of this material source. Currently, ministries, departments, and sectors along with experts have been actively researching

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materials that can replace natural river sand as subgrade materials. In particular, the possibility of using sea sand has been researched for roadbed construction in Vietnam [1].

Around the areas of Ninh Thuan, Binh Thuan, and Vung Tau provinces, red sand dunes are typical of the region. This type of sand has a large reserve with an area of thousands of square kilometers and a great thickness, sometimes forming dunes [2]. Realizing that this type of sand has abundant reserves, it can be used as the subgrade for traffic construction. This will be the solution to the problem of scarcity of subgrade materials, and the natural river sand is almost exhausted currently.

Fig. 1. Natural red sand dunes at Binh Thuan Province [2].

There are many criteria to determine natural sand for the subgrade of traffic construction such as: ratio of organic impurities, salt ratio, swelling degree, particle size, bearing capacity, shear resistance, etc. However, within the scope of this article, the authors present experiments to determine some typical physical and mechanical characteristics of natural red sand to evaluate the feasibility of using this type of sand as a subgrade for traffic construction.

2. Research material and experimental method

2.1. Research material

The studied sand has been collected in Thien Nghiep commune, Phan Thiet city, Binh Thuan province (Fig. 2). In the sand hill area with a hill top elevation of approximately 106 m (above sea level) after being dug away, the specimen location was taken at the elevation of approximately 95 m (above sea level). The sand in this area is red, dyed by ancient mineral deposits over millions of years of tectonics [2].

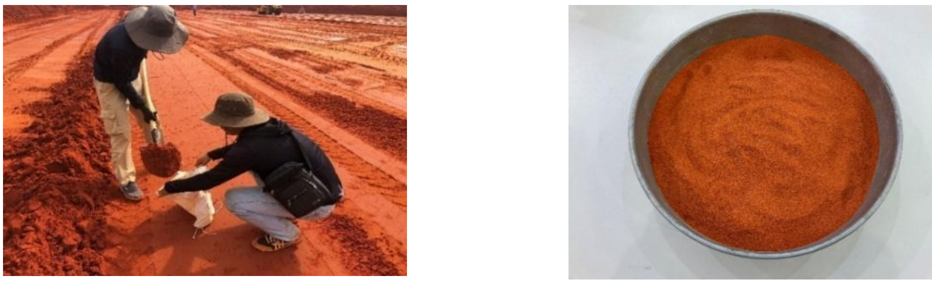

Fig. 2. Sand taken from the field and brought to the laboratory.

2.2. Experimental method

2.2.1. Experiment to determine the particle size of sand

The authors determine the number of residual particles on the sieve sizes using a standard sieve set [3]. After determining the number of particles passing through the sieve sizes, we can build the particle size curve of the sand.

Fig. 3. Determination of particle size using standard sieves.

2.2.2. Experiment to determine the specific gravity of sand

The authors use the density meter method for determining the specific gravity of sand [4, 5]. The specific gravity (dimensionless) is the density of the object divided by the density of water.

Fig. 4. Determine the specific gravity of sand using a density meter.

2.2.3. Experiment to determine the maximum dry volumetric mass and optimum moisture of sand

The authors use standard compaction mortar to determine the maximum dry unit weight and optimum moisture content of sand in the laboratory [6]. The experiment is conducted with five different humidification times. From there, the relationship curve between dry density and moisture content can be built. From the obtained function, the maximum dry unit weight and optimum moisture content can be calculated.

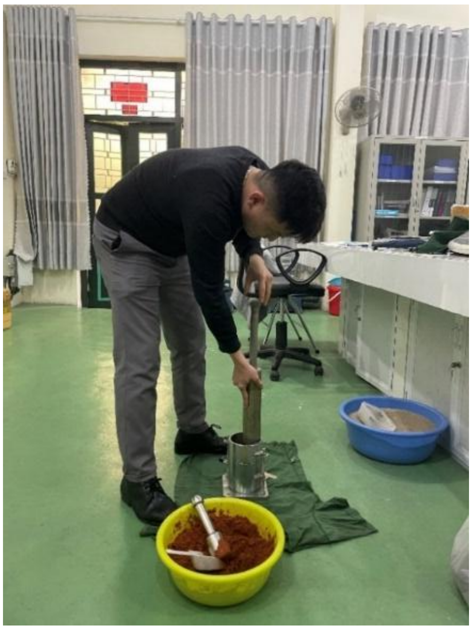

Fig. 5. Standard compaction test in the laboratory.

2.2.4. Experiment to determine the cohesion and internal friction angle of sand

The authors use the shear box apparatus test to determine the cohesion and internal friction angle of sand with a relative compaction of 0.95 at optimum moisture [7].

The relative compaction is determined by the formula [8, 9]:

$$K = \frac{\gamma_k}{\gamma_k^{\max}}, \quad (1)$$

where K is the required relative compaction (dimensionless); γ_k is the compacted dry density of soil, g/cm^3; $\gamma_k^{\max}$ is the maximum dry unit weight of soil in the laboratory (identified above), g/cm^3.

From formula (1), we can determine the mass of dry sand to be tested with the required relative compaction as follows:

$$g_k = \gamma_k \cdot V = K \cdot \gamma_k^{\max} \cdot V, \quad (2)$$

where g_k is the mass of dry sand, g; V is the volume of the mold for making a compaction specimen (corresponding to each experiment that has a different specimen mold), cm^3.

The amount of water required to prepare the sample is determined by the formula:

$$g_n = w_0 \cdot g_k, \quad (3)$$

where g_n is the mass of water required for making specimen, g; w_0 is the optimum moisture content of sand, %.

In the shear box apparatus test, the prototyping mold has a circular shape with a diameter of 6.35 cm and a height of 2.2 cm. Some experimental parameters were performed: shear speed of 0.5 mm/min and maximum shear displacement of 10 mm.

From the experimental results, we can build a relationship curve between the shear force and the shear displacement of the specimen, thereby determining the maximum shear force. Then, the maximum shear stress of the specimen is determined by the formula [8]:

$$\tau_{\max} = \frac{T_{\max}}{A}, \tag{4}$$

where $\tau_{\max}$ is the maximum shear stress, MPa; $T_{\max}$ is the maximum shear force, N; A is the specimen area, m^2.

From there, we can build a relationship curve between the maximum shear stress and the applied pressure. Thereby finding the value of the cohesion and the internal friction angle of the sand.

Fig. 6. Shear box apparatus test in the laboratory.

2.2.5. Experiment to determine the California bearing ratio in the laboratory

California bearing ratio (CBR) is the ratio (in percent) between the compressive pressure on the test specimen and the compression pressure on the standard specimen for the same specified settlement depth [10].

The test to determine CBR is carried out on a specimen group (three specimens) that is compacted at the optimum moisture content corresponding to the specified compaction method. CBR of the test material is determined corresponding to the specified relative compaction K.

CBR is calculated according to the following formula [9]:

$$CBR_1 = \frac{p_1}{6.9} \cdot 100, \tag{5}$$

$$CBR_2 = \frac{p_2}{10.3} \cdot 100, \tag{6}$$

where CBR_1 is the ratio calculated with the settlement depth of 2.54 mm, %; CBR_2 is the ratio calculated with the settlement depth of 5.08 mm, %; p_1 is the compressive pressure on the corrected test specimen with a settlement depth of 2.54 mm, MPa; p_2 is the compressive pressure on the corrected test specimen with a settlement depth of 5.08 mm, MPa.

Fig. 7. CBR testing equipment in the laboratory.

3. Results and discussion

3.1. Results

3.1.1. The particle size of sand

Table 1. The particle size of sand using a standard sieve set

Sieve size (mm)	Mass of sieve (g)	Mass of sieve and residual sand (g)	Mass of residual sand per sieve size (g)	Total mass of experimental sand (g)	Particle rate per sieve (%)	Pass-through sieve rate (%)
> 5	1105	1105	0	1000	0	100
2.5 - 5	1110.1	1110.2	0.1		0.01	99.99
1 - 2.5	1036.5	1039.1	2.6		0.26	99.73
0.5 - 1	945.5	1000.8	55.3		5.53	94.2
0.25 - 0.5	932.9	1557.1	624.2		62.42	31.78
0.1 - 0.25	849.6	1139.1	289.5		28.95	2.83
< 0.1	-	-	28.3		2.83	-

From the data in Table 1, we can construct the particle size curve of the studied sand, as shown in Fig. 8.

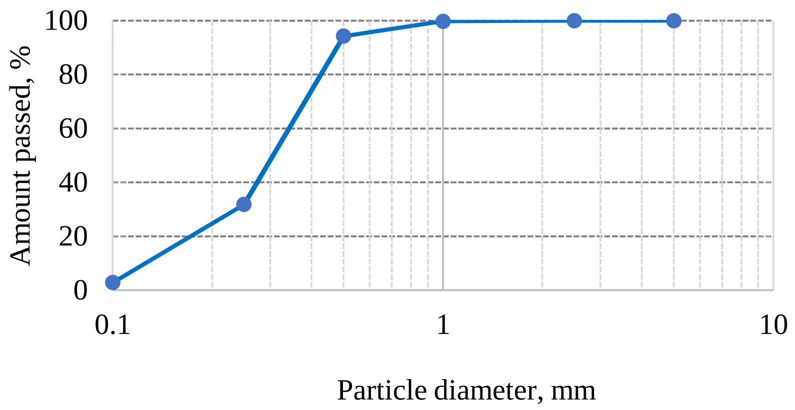

Fig. 8. The particle size curve.

3.1.2. The specific gravity of sand

Table 2. Determine the specific gravity of sand

Mass of jar (g)	Mass of jar and sand (g)	Mass of dry sand in each jar (g)	Mass of jar, sand, and water after boiling (g)	Mass of jar and water (g)	Mass of water displaced (g)	Volume of water displaced (cm^3)	Specific gravity of specimens	Specific gravity of sand
27.13	80.25	53.12	160.57	127.35	19.90	19.90	2.67	2.63
25.23	74.55	49.32	154.46	123.97	18.83	18.83	2.62	
29.29	85.69	56.40	164.68	130.07	21.79	21.79	2.59	

3.1.3. The maximum dry unit weight and optimum moisture content of sand

Table 3. Determine the relationship between dry density of sand and moisture content (*)

Mass of mortar and sand after compaction (g)	Mass of sand after compaction (g)	Mass of moisture determination jar (g)	Mass of jar and sand with moisture (g)	Mass of jar and dry sand (g)	Sand moisture content in each jar (%)	Average moisture content of the specimen (%)	Mass of dry sand in mortar (g)	Dry density of sand (g/cm^3)
3538	1794.50	10.73	43.75	41.63	5.09	4.90	1710.79	1.8417
		14.58	48.81	46.61	4.72			
		14.06	50.42	48.08	4.87			
3553	1809.50	14.72	40.24	38.27	5.15	5.30	1718.49	1.8500
		13.73	44.59	42.31	5.39			
		14.21	40.95	38.87	5.35			

Mass of mortar and sand after compaction (g)	Mass of sand after compaction (g)	Mass of moisture determination jar (g)	Mass of jar and sand with moisture (g)	Mass of jar and dry sand (g)	Sand moisture content in each jar (%)	Average moisture content of the specimen (%)	Mass of dry sand in mortar (g)	Dry density of sand (g/cm^3)
3623	1879.50	13.92	44.58	41.6	7.16	7.23	1752.74	1.8869
		10.61	44.89	41.83	7.32			
		15.91	50.36	46.97	7.22			
3630	1886.50	10.31	43.35	40.07	8.19	8.15	1744.25	1.8778
		18.23	45.33	41.91	8.16			
		11.28	37.55	34.73	8.12			
3631	1887.50	14.72	45.95	41.72	10.14	10.25	1712.02	1.8431
		13.73	48.69	44.12	10.36			
		14.21	47.32	42.92	10.25			

Note: (*) The mortar used is 10.1 cm in diameter and 11.6 cm in height. The mass of the mortar is 1743.50 g.

From Table 3, we can build a relationship curve between dry density and moisture content of studied sand, as shown in Fig. 9.

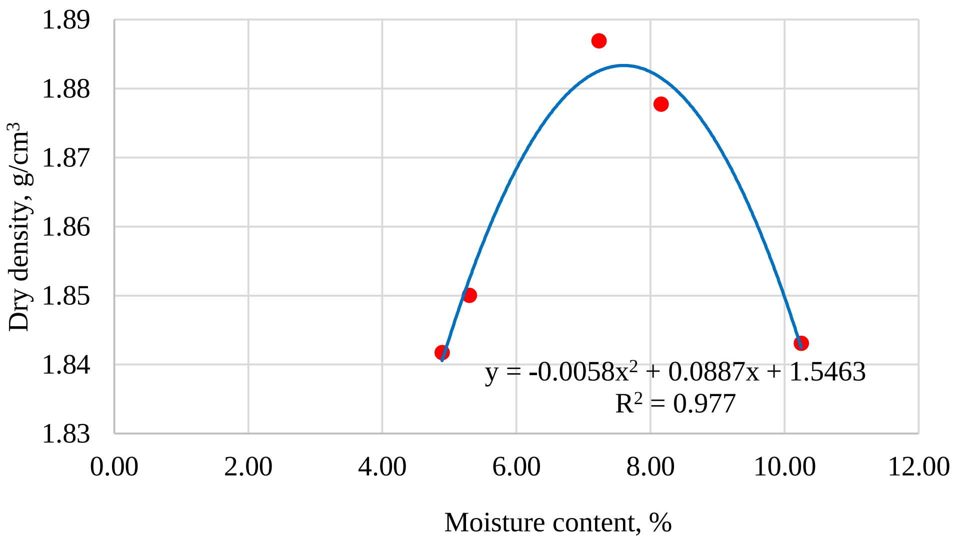

Fig. 9. Relationship between dry density and moisture content.

From the function shown in Fig. 9, the maximum dry unit weight γ_k^{max} is 1.8854 g/cm^3 with an optimum moisture content w_0 of 7.65%.

3.1.4. Cohesion and internal friction angle of sand with a relative compaction of 0.95

Table 4. Maximum value of shear force and shear stress by shear box apparatus test

Applied pressure (kPa)	First time		Second time		Third time	
	Maximum shear force (N)	Maximum shear stress (kPa)	Maximum shear force (N)	Maximum shear stress (kPa)	Maximum shear force (N)	Maximum shear stress (kPa)
50	206.912	65.369	178.119	56.272	190.2	60.089
100	306.893	96.955	347.581	109.810	341.954	108.032
150	430.04	135.861	393.68	124.374	413.936	130.773

From the data collected in Table 4, we can build a relationship curve between the maximum shear stress and the applied pressure causing that shear stress, as shown in Figs. 10, 11, and 12.

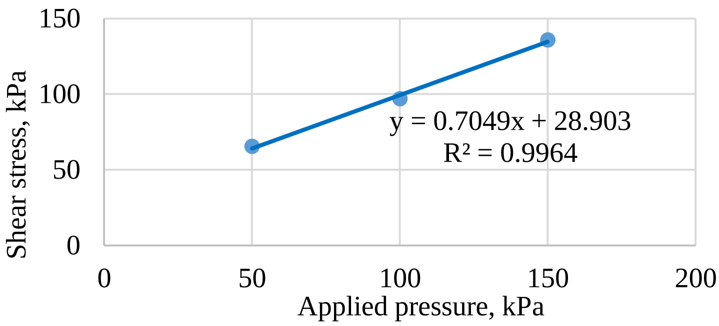

Fig. 10. Relationship curve between maximum shear stress and applied pressure (first time).

From the function obtained in Fig. 10, we find that the value of the cohesion of sand is 28.9 kPa, and the internal friction angle of the sand is 35.1°.

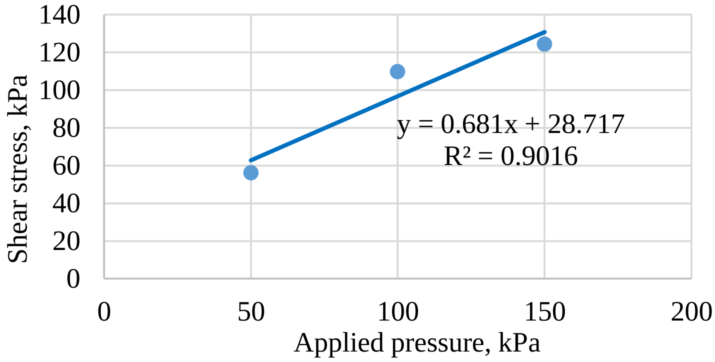

Fig. 11. Relationship curve between maximum shear stress and applied pressure (second time).

From the function obtained in Fig. 11, we find that the value of the cohesion of sand is 28.7 kPa, and the internal friction angle of the sand is 34.2°.

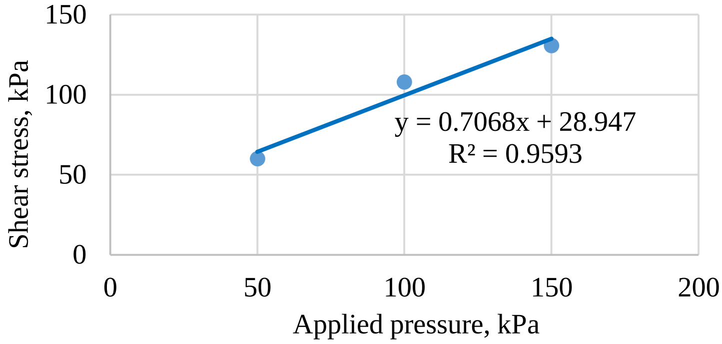

Fig. 12. Relationship curve between maximum shear stress and applied pressure (third time).

From the function obtained in Fig. 12, we find that the value of the cohesion of sand is 28.95 kPa, and the internal friction angle of the sand is 35.2°.

Taking the average of the measurements, determine the cohesion of the sand is 28.85 kPa, and the internal friction angle of the sand is 34.8°.

3.1.5. CBR of sand with a relative compaction of 0.95

Table 5. CBR test parameters with three specimens

Specimen name	1	2	3
Number of layers	5	5	5
Number of pestles /layer	10	30	65
Mold mass (g)	7215	7325	7236
Mold and specimen mass (g)	11430	11736	11540
Mold volume (cm^3)	2318.30	2305.60	2113.70
Wet density (g/cm^3)	1.818	1.913	2.036

Table 6. CBR value of sand with three test specimens

Settlement depth (mm)	No. 1			No. 2			No. 3		
	10 times of pestle			30 times of pestle			65 times of pestle		
	Compressive force (N)	Pressure (MPa)	CBR (%)	Compressive force (N)	Pressure (MPa)	CBR (%)	Compressive force (N)	Pressure (MPa)	CBR (%)
0	0	0.00		0	0.00		0	0.00	
0.64	153	0.079		257	0.132		386	0.199	
1.27	325	0.167		472	0.243		784	0.404	
1.91	510	0.263		862	0.444		1516	0.781	
2.54	713	0.367	5.3	1245	0.641	9.3	2342	1.206	17.5
3.18	915	0.471		1811	0.933		2925	1.506	

Settlement depth (mm)	No. 1			No. 2			No. 3		
	10 times of pestle			30 times of pestle			65 times of pestle		
	Compressive force (N)	Pressure (MPa)	CBR (%)	Compressive force (N)	Pressure (MPa)	CBR (%)	Compressive force (N)	Pressure (MPa)	CBR (%)
3.75	1118	0.576		2435	1.254		3236	1.666	
4.45	1370	0.705		3034	1.562		3903	2.010	
5.08	2121	1.092	10.6	3424	1.763	17.1	4931	2.539	24.7
7.62	2925	1.506		4245	2.186		6009	3.094	
Dry density (g/cm^3)	1.648			1.733			1.846		

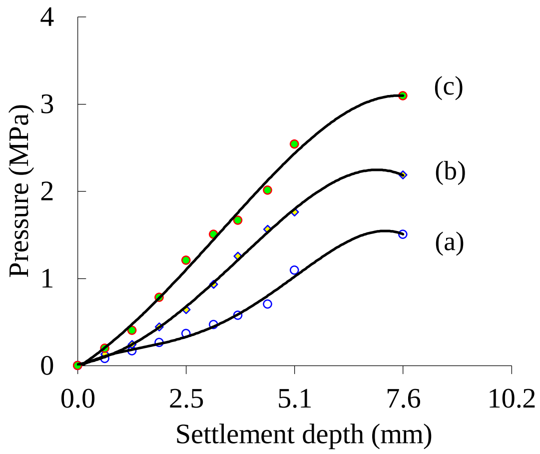

Fig. 13. Relationship curve between applied pressure and settlement depth (a) No. 1; (b) No. 2; (c) No. 3.

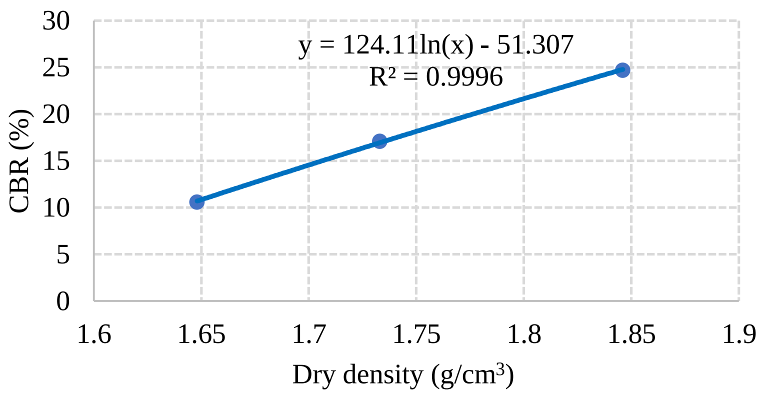

Fig. 14. Relationship curve between CBR and dry density of specimens.

From formula (1), at the relative compaction of 0.95, the compacted dry density of sand is 1.786 g/cm^3. So, from the equation in Fig. 14, CBR value at the relative compaction of 0.95 is 20.67%.

3.2. Discussion

Through the static experiment data, it is found that:

When analyzing the grain composition, it was found that the sand is a granular material with a grain content, as shown in Table 1. This sand has particle size which belongs to group A-2 [11]. In addition, the specific gravity of sand has a value of 2.63 g/cm^3 within the required value range according to [9].

By the shear box apparatus test, the studied red sand has a relatively high cohesion of about 29 kPa, and analysis of the particle size, along with previous studies on the geology of these red sand strata [2], shows that this cohesion accurately reflects the hook insertion, adhesion between particles. However, in the current design calculations for sand materials in Vietnam, the value of cohesion is often ignored, so this type of sand will be much better in calculation and ensure safety in design, execution, and operation.

From the results of determining the CBR value of sand at the relative compaction of 0.95 in the laboratory is 20.67%. According to [12], the required CBR value of the subgrade layer of highway traffic contruction is greater than 8%. Comparing the experimental results, we see that this type of sand is completely suitable as a subgrade material for traffic contruction.

4. Conclusion

Through a series of static experiments in the laboratory, the authors draw some conclusions about the natural red sand in Thien Nghiep commune, Phan Thiet city, Binh Thuan province as follows:

The result of the partilce size of the studied sand shows that it belongs to group A-2 according to AASHTO M145, meeting the material requirements for the subgrade of traffic construction.

The CBR value in the laboratory of sand at the relative compaction of 0.95 meets requirement of a subgrade for highway traffic construction according to Vietnamese standards TCVN 9436:2012.

Thus, the data collected from the experiments show that this natural red sand has special physical and mechanical characteristics, and the strength criterion is relatively high. It is recommended to use this material which is potentially suitable for the subgrade of traffic construction in the situation of scarce material resources as well as almost exhausted river sands currently.

References

[1] Văn Viết Thiên Ân, Nguyễn Việt Phương, Bùi Phú Doanh, Hoàng Tùng, "Vật liệu đắp nền đường và khả năng sử dụng cát nhiễm mặn để đắp nền đường ô tô tại Việt Nam", *Tạp chí Khoa học Kiến trúc và Xây dựng*, Số 45, tr. 29-33, 2022.

[2] Nguyễn Quang Lộc, *"Nghiên cứu địa tầng và trầm tích của cát đỏ khu vực Phan Thiết và đánh giá tiềm năng khoáng sản liên quan*", Luận văn thạc sĩ, Trường Đại học Khoa học Tự nhiên, 2012.

[3] *Standard Test Method for Particle-Size Analysis of Soils*, ASTM D422-63, 2002.

[4] *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort*, ASTM D1557-12, 2021.

[5] *Standard Test Methods for Laboratory Determination of Density and Unit Weight of Soil Specimens*, ASTM D7263-21, 2021.

[6] *Đất xây dựng - Phương pháp xác định - Khối lượng riêng trong phòng thí nghiệm*, TCVN 4195:2012, 2012.

[7] *Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions*, ASTM D3080-11, 2021.

[8] *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort*, ASTM D698-12, 2021.

[9] Braja M. Das, Dean Emeritus, Khaled Sobhan, *Principles of Geotechnical Engineering, Eighth Edition*. SI. Publisher, Global Engineering: Christopher M. Shortt, 2013.

[10] *Vật liệu nền, móng mặt đường - Phương pháp xác định tỷ số CBR trong phòng thí nghiệm*, Tiêu chuẩn quốc gia TCVN 12792:2020, 2020.

[11] *Standard Specification for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes*, AASHTO M 145-91, 2021.

[12] *Nền đường ô tô - Thi công và nghiệm thu*, Tiêu chuẩn quốc gia TCVN 9436:2012, Bộ Khoa học và Công nghệ, 2012.

NGHIÊN CỨU KHẢ NĂNG ỨNG DỤNG CÁT ĐỎ TỰ NHIÊN LÀM NỀN CÔNG TRÌNH GIAO THÔNG BẰNG THÍ NGHIỆM TRONG PHÒNG

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Tóm tắt: Bài báo trình bày một số tính chất cơ lý đặc trưng của cát đỏ tự nhiên lấy tại khu vực xã Thiện Nghiệp, thành phố Phan Thiết, tỉnh Bình Thuận thông qua các thí nghiệm tĩnh trong phòng. Từ kết quả thu được thấy rằng loại cát này thuộc nhóm A-2 theo tiêu chuẩn AASHTO M145 về thành phần hạt. Cát có lực dính đơn vị tương đối cao với giá trị khoảng 29 kPa và góc ma sát trong khoảng 35º, đặc trưng cho khả năng kháng cắt của vật liệu. Giá trị CBR của cát tại độ chặt tương đối 0,95 là 20,67%, đáp ứng được yêu cầu của vật liệu nền công trình giao thông cấp cao theo tiêu chuẩn hiện hành. Như vậy, qua hàng loạt thí nghiệm tĩnh cho thấy loại cát này có khả năng phù hợp làm vật liệu nền cho công trình giao thông ở Việt Nam.

Từ khóa: *Cát đỏ tự nhiên; độ chặt; nền; công trình giao thông; thí nghiệm tĩnh.*

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