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Study on the effect of sand-clay ratio and water content to factor of safety of slope and effectiveness of Geogrid in slope reinforcement

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Abstract: *This paper focuses on studying the effect of the ratio of grain composition (sand and clay) and water content to factor of safety of artificial soil slope, and simultaneously analyzing the effectiveness of geogrid applying in slope reinforcement consisting of various grain compositions and water contents. Limit equilibrium method – LEM and Bishop's Simplified calculation method are used to analyze slope stability. Factor of safety (FS) is calculated by hand calculation method (using AutoCAD and Excel) and computed by SLOPE/W software. The analyzing result shows that with soil having sand-clay ratio of 90-10, water content influences insignificantly to FS of slope; with soil having sand-clay ratio of 80-20, water content influences significantly to FS of slope; and with soil having sand-clay ratio of 70-30, water content influences significantly to FS of slope. Besides, a stability analysis of geogrid in slope reinforcement with varying soil water content shows that the effectiveness with soil having sand-clay ratios of 90-10, 80-20 and 70-30 is not significant, good and much better, respectively.*

Keywords: *grain composition; sand-clay ratio; factor of safety (FS); geogrid.*

1. Introduction

Shear strength of soil is an important parameter in geotechnical engineering, which represents the ability of soil to resist sliding or deformation when subjected to external forces. It is essential for the stability analysis of structures such as foundations, retaining walls and slopes. Understanding shear strength parameters is important for assessing the stability of earth structures, predicting failure mechanisms, and designing safe and effective engineering solutions. By assessing the shear strength of soil, engineers can make informed decisions about construction methods, materials, and site safety.

Shear strength is influenced by several factors, including soil composition, moisture content, density and effective stress. Previous studies have shown that shear strength of soil was affected by many factors such as relative density, shape characteristics [1], particle size [2-8], and moisture content [9-14]. In addition, other studies have also shown that slope stability was affected by shear strength parameters of soil [15-17].

In this study, the authors conducted direct shear tests on three types of soil with different sand-bentonite ratios under conditions of water content from dry to saturated to determine the changes in soil shear strength parameters. Then, the results from the tests were used as input parameters to calculate the safety factor of a slope under natural conditions, conditions with traffic construction loads, and conditions reinforced with geogrid.

2. Effect of sand-Bentonite ratio to shear strength of soil

2.1 Sample preparation process and soil properties

The process for sample preparation in this study follows these steps:

a) First, sand and Bentonite were dried in the air under laboratory conditions. Hygroscopic water amount of them was determined through moisture content test.
b) Second, sand was shaken through a sieve that has an opening size of 2mm, and particles above this sieve were removed.
c) Third, soil mixtures were mixed with various sand-bentonite ratios. There are three types of artificial soil with a sand-bentonite ratio of 90%-10%, 80%-20% and 70%-30% noted by soil A, B, C respectively and the moisture contents varying from air dry to saturated (Table 1).
d) Fourth, soil samples were cured for 24 hours to ensure the moisture content inside the soil is homogeneous.

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e) Fifth, the soil sample was compressed into steel O-ring by a compression device (Model 2LF25N-4_Linear head) to obtain a sample with dry unit weight of 1.7g/cm^3.
f) Sixth, samples were put into a shear box. Then, direct shear tests were conducted.

The tested grain size distribution of the artificial soils is given in Figure 1. The percentage of particle groups was calculated based on the grain size distribution curve. Artificial soil samples become finer and finer as Bentonite content increases as shown in Table 1 and Figure 1. All the experiments to determine physical properties and mechanical properties of artificial soils complied with Vietnamese standards and their results have been shown in Table 2. The artificial soils were classified according to Vietnamese standards. Soil with 10% Bentonite was classified as silty clayey sand soil (SC-SM) because it has a plasticity index between 4% and 7%. However, soils with 20% and 30% Bentonite were classified as clayey sand soil (SC) because their plasticity indexes were greater than 7%.

2.2 Direct shear test results and discussion

The direct shear test results of artificial soils have been shown in Table 3. Shear strength parameters resulted from an average of 6 times of tests with every soil sample. In the case of air-dry conditions A-1, B-1 and C-1 soils, as fine-grained content increases, the friction angle increases slightly, approximately 8%. The reason can be explained is an increase of fine-grained content resulting in an increase of interaction between soil particles. This causes a smaller void ratio when under the same normal stress level, as shown in Figures 2 to 4. Therefore, the friction force between particles is greater. The results of direct shear test in the case of A soils with 5 different moisture contents show that the moisture content affects to friction angle. It is clear that with a small content of Bentonite, the coverage degree of Bentonite to sand particles is not large enough to influence the friction between sand particles.

In contrast to A soils, B soils and C soils tend to decrease the friction angle as well as shear stress. It can be explained that as the content of Bentonite increases sufficiently, it leads to an increase in adsorbed water in Bentonite. This water is more viscous than free water.

3. Slope stability analysis

3.1 Methodology

The limit equilibrium method (LEM) has been known as a simple hand calculation method. GeoStudio (SLOPE/W) was a modern limit equilibrium software that has made it possible to handle complexity within an analysis [18]. It was possible to deal with complex stratigraphy, highly irregular pore water pressure conditions, various linear and nonlinear shear strength models, almost any kind of slip surface shape, concentrated loads, structural reinforcement, and full three-dimensional (3D) analysis. In this paper, Bishop's simplified method was used to evaluate slope stability by using SLOPE/W software and Excel software in the cases of natural slopes and designed slopes.

A case study in this study was a project in Tam Phuoc ward, Bien Hoa City, Dong Nai Province, Viet Nam. An embankment with slope angle equal to 33 degrees was designed to construct a road above it and was surveyed geology to serve slope stability analysis. A geotechnical profile includes 5 soil layers. The artificial soils described in Article 2 are used as an embankment. The illustrative stratigraphy is given in Figure 5. In the embankment, shear strength parameter and unit weight were changed to investigate the variation of factor of safety (FS) of the slope. Meanwhile, the other layers did not change as shown in Table 4. In actual conditions, rainfall could increase soil's moisture content; therefore, the application of shear strength parameters in various soil states is meaningful.

The Mohr-Coulomb model was used for all soil layers. The soil behavior was considered in total stress state. Investigations of slope stability were considered in immediate behavior. Besides calculating FS by SLOPE/W software, FS was also checked through hand-calculation by using Excel software. All of them were calculated through Bishop's simplified method.

The slope was assumed to be constructed as a road for the transportation of goods by heavy vehicles. It was designed with 2 traffic lanes and the maximum load for each lane was 30 tons. Traffic load was converted into static surcharge load acting on embankment, traffic load was calculated equal to 21kN/m^2. The structure of the road includes 4 layers from top to bottom including asphalt, compacted soil K98, compacted soil K95 and sub-base, respectively. The embankment was under the surcharge load of the entire road structure which was detailed in Table 5. In summary, total surcharge load exerted by traffic and road structures on embankment was 80kN/m^2. This total surcharge load was used for slope stability analysis in the case of a designed slope. The required FS for slope stability was 1.25 according to Vietnamese standard (TCVN:13346-2021) [19].

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3.2 Results of slope stability analysis and discussion

The factor of safety in case of initial slope was calculated by SLOPE/W software (Fs_{1*}). Its reliability was assessed through comparison with the factor of safety, which was calculated through Excel software (Fs_1). The trial slip surface and center of slip surface were assumed in calculations. Parameters of n^{th} slice (width b, average height H, and angle α) were measured through AutoCAD software. As a result, a trial-and-error method was conducted by Excel software to determine the value of FS. Figure 6 shows FS calculation of an embankment through Excel software and SLOPE/W software. In SLOPE/W software, the number of slices was chosen to be 30 to optimize the effectiveness of analysis and increase the reliability for decisions in the future. In addition, selection of the number of slices also depends on the performance of the computer. Meanwhile, for hand-calculation of FS through Excel software, the number of slices was 10. The purpose of this was to help the calculation make it simpler and more convenient.

The FS from two programs was greater than 1, which shows that initial slope seems safe. However, results calculated by these software have a little difference, as shown in Table 6. The max difference between FS in SLOPE/W and FS in Excel was 3.5%. This can be explained through the number of slices selected for calculations and rounding of measurements in the dimensions of slices. But in general, the calculated results were still acceptable. Therefore, the model in SLOPE/W software was suitable for this study, and it was used for the following analysis programs. Stability analysis programs for designed slopes under surcharge load and slope reinforcement cases were performed by SLOPE/W software and the Bishop's simplified method was used.

In general, FS of initial slope with 10% Bentonite content was little affected by moisture content. In addition, for an initial slope with 20% Bentonite content, FS has large variation, but the minimum value of FS was still greater than 1. The variations of FS were greatest for initial slope with 30% Bentonite content. Specifically, this case has both the largest FS, and the smallest FS compared to all cases in this study. Through that, the safety factor of slope was more and more affected by moisture content as Bentonite content increased more and more in artificial soil.

When designing slopes under surcharge load of $80kN/m^2$ caused by a road structure, the changing trend of factor of safety (Fs_2) compared with changing trend of Fs_{1*} was similar. However, Fs_2 values decrease depending on Bentonite content in soil of slope, as shown in Figure 7 and Table 7. Specifically, Fs_2 was decreased by an average of 11% for soils with 10% Bentonite, an average decrease of 17% for soils with 20% Bentonite, and an average decrease of 24% for soils with 30% Bentonite. Notably, almost Fs_2 were greater than 1.25 except for two cases C-5, C-6 soils. The factor of safety less than 1.25 was not approved for the safety condition of this study. When the factor of safety was not satisfied, embankments can be in danger of slipping and damaging slope and road structure. For those cases, slopes must be reinforced by geogrids to ensure safety of slope and road structure.

Soil replacement and reinforced geogrid were selected as a measure for slope reinforcement. It was designed according to "Mechanically Stabilized Earth Walls and Reinforced Slopes - Design and Construction Guidelines". Figure 8 shows the design of geogrids for slope reinforcement. Uniaxial geogrids were chosen for design because they were made of high-density polyethylene materials and were thoroughly tested to maintain a high tensile modulus, strong junction, and improved durability against construction failure. In addition, they were specifically created for soil retaining walls and slope applications. Their properties were shown in Tables 8 and 9. The overall slope height (H) was divided into 2 zones, as shown in Figure 8. The number of geogrid layers in top and bottom zones was 5 layers of *T045* and 7 layers of *T090*, respectively. The lengths of geogrid in top and bottom zones were 11m and 14m, respectively.

In the case of A-5 soil was applied as properties of backfill soil. The overall failure analysis indicated a critical factor of safety of 1.717 for failure surfaces extending outside the reinforced section, as shown in Figure 9. The FS meets safety requirements because it was larger than 1.25. Through checking, the designed measure seems affordable in this case.

The results of FS analyzed from SLOPE/W software were shown in Table 10. FS significantly increased by reinforcement with geogrids. However, backfill soil with 10% Bentonite content, geogrids were not necessary because FS of reinforced slope increased a little bit, to an average of 0.7% and slope was still safe to slide. Meanwhile, backfill soil with 20% Bentonite content, FS of reinforced slope was significantly increased by an average of 10.3% when moisture content was in a range of 17.5% to saturated moisture content 21.4%. In addition, backfill soil with 30% Bentonite content, effect of reinforcement was strongly shown through FS increase when moisture content was more than 10%. Specifically, it increased by an average of 18%. Especially, FS of two dangerous cases C-5 and C-6 soils were improved by an average of 28% and FS of those slopes was approved for a safe requirement, as shown in Figure 10.

For artificial backfill soils, the most suitable soil for replacement was soil with 10% Bentonite content. Reinforced geogrids do not need to be required for this soil. If backfill soils with 20% and 30% Bentonite contents were used, the most hazardous case should be considered (saturated soil). The reason for this conclusion was a decrease in shear strength of cohesive soils due to moisture increase. In addition, decrease in shear strength causes unsafety for slope and danger to construction. The effect of geogrid reinforcement was shown by an increase of FS. However, in this study, geogrid reinforcement was only considered through the strength satisfaction and slope stability satisfaction. Tests with various types of geogrids having different strengths were not conducted because of time limits. Therefore, this could be a reason that caused differences in effect of geogrid reinforcement.

4. Conclusions

The case study in this paper was used for the investigation of slope stability through variation of FS when the shear strength parameters of soil change. In the case of the initial slope, all FS were greater than 1 which shows that slope seems safe. The reliability of SLOPE/W software was proven by comparison of FS results in SLOPE/W software with FS results in hand-calculation (Excel software). Their maximum variation was less than 5%.

In the case of slopes under surcharge load, most of FS were greater than 1.25, except for two dangerous cases. Embankment was unstable for slopes with 30% Bentonite content with moisture content from 20% to saturated moisture content. Therefore, reinforced geogrids were chosen as a method to reinforce slopes. A factor of safety was checked after the design, which shows that the slope seems safe. All slope stability analyses were conducted through the Bishop's simplified method. Design calculations for the soils that were used as the backfill were conducted. Through that, the most suitable soil for backfill was soil with 10% Bentonite content. Considering soil with 20% and 30% Bentonite content, the shear strength of saturated soil needs to be considered when the slope stability was analyzed.

The shear strength of soil was affected by gradation and moisture content. It has different behavior which depends on Bentonite content and moisture content in soil. Experimental investigation showed that shear stress decreased when Bentonite content and moisture content were increased. In this project, with Bentonite content in the range of 20% to 30% and an increase in moisture content, the shear stress significantly decreased.

When Bentonite content increased from 20% to 30%, shear stress decreased an average of 18% for soil with 15% moisture content and decreased an average of 28% for soil with 20% moisture content. In addition, when moisture content was more than 15%, shear stress significantly decreased for soil with 20% Bentonite content. However, it was more than 10% for soil with 30% Bentonite content to significantly decrease shear stress. The effect of Bentonite content on friction angle and cohesion of soil depends on moisture content. In general, increases in Bentonite content cause a decrease of friction angle and an increase of cohesion. The effect of moisture content on friction angle and cohesion of soil depends on Bentonite content. However, differences in friction angle values or cohesion values were small for soil with 10% Bentonite content. In addition, the differences in friction angle values or cohesion values increase as the Bentonite content increases.

The factor of safety calculated by using SLOPE/W and Excel was compared. It shows that the numerical model is more efficient. In addition, slope stability was affected by the shear strength parameters, but its level depends on Bentonite content and moisture content. Changing shear strength parameters for analyzing slope stability helps engineers find the appropriate soil gradation and moisture content for safe slope design. The results have shown that the most suitable soil for backfill was soil with 10% Bentonite content, without reinforcement of geogrids. In the case of soils with 20% and 30% Bentonite content used for backfilling, the shear strength of saturated soil needs to be considered when the slope stability was analyzed.

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Tables and figures (with descriptions)

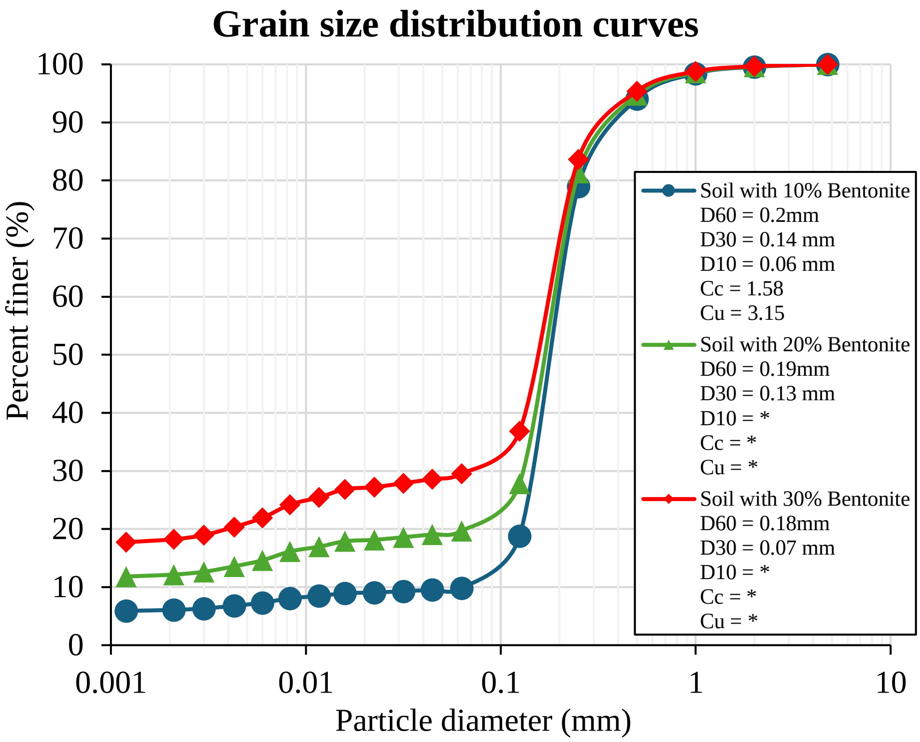

Fig. 1. Grain size distribution curve of Artificial soils

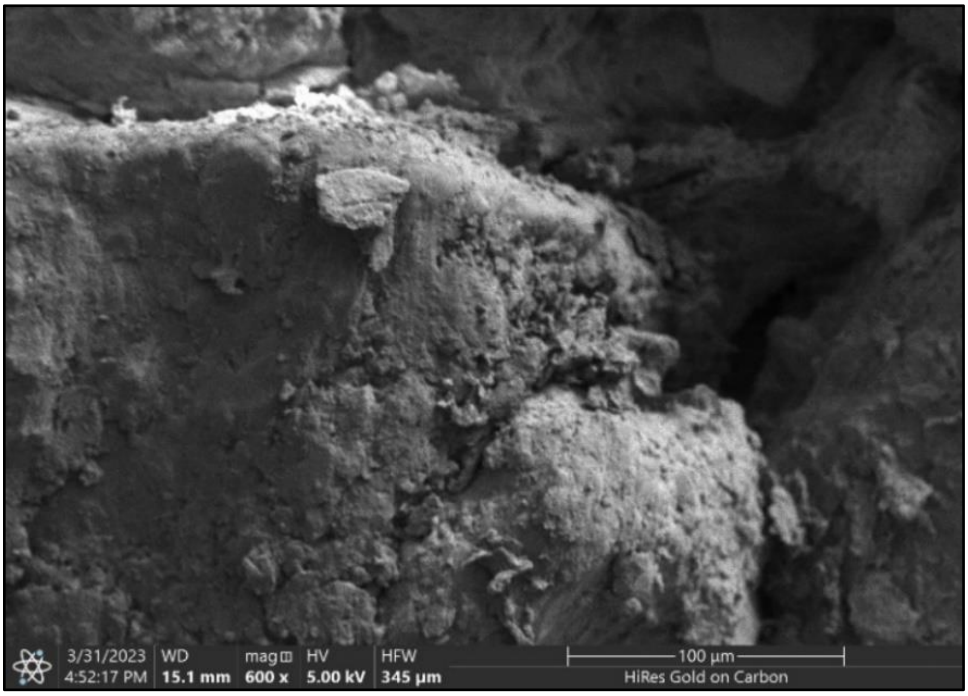

Fig. 2. Scanning electron micrograph (SEM) image of A soils

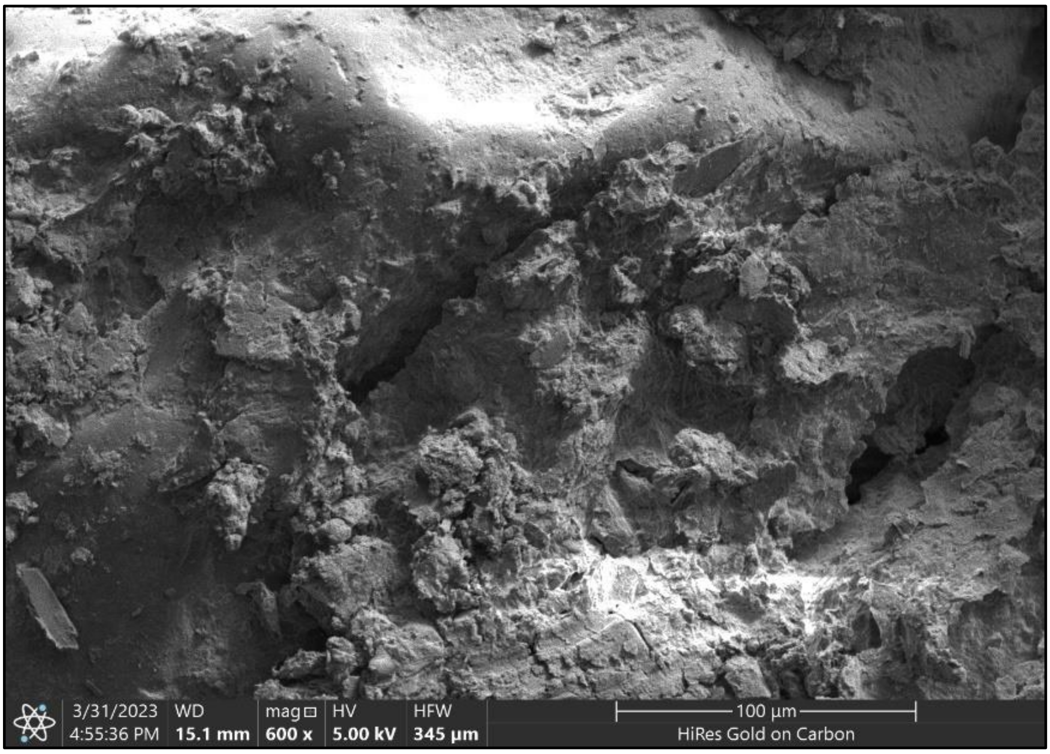

Fig. 3. Scanning electron micrograph (SEM) image of B soils

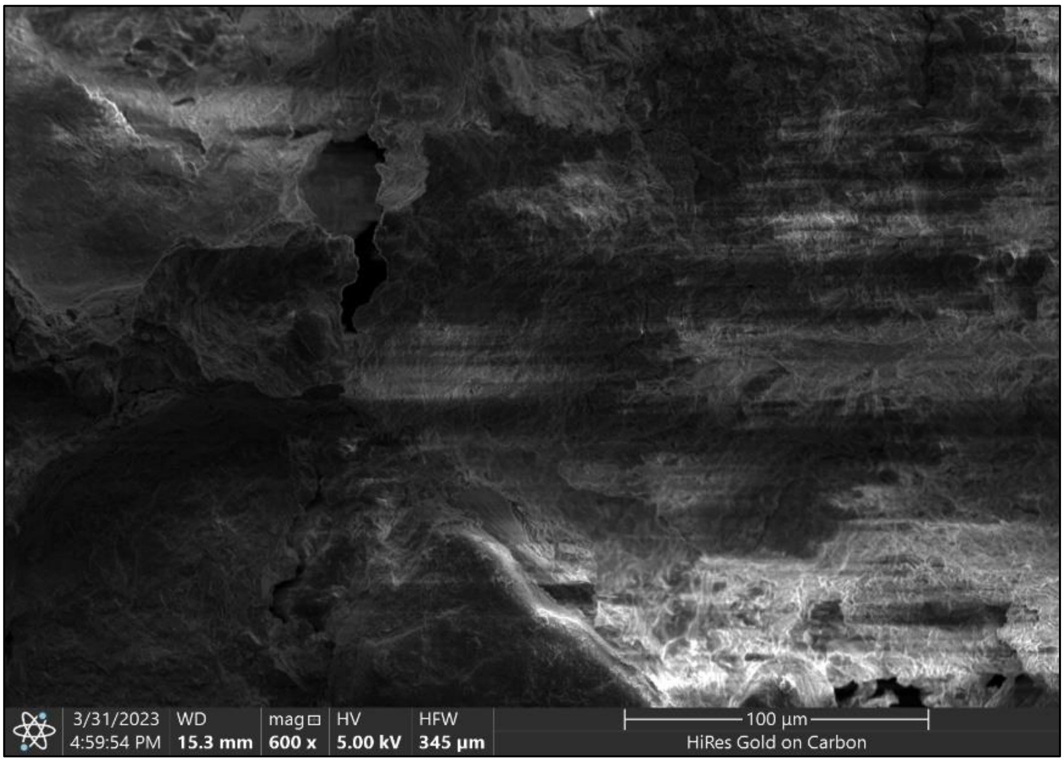

Fig. 4. Scanning electron micrograph (SEM) image of C soils

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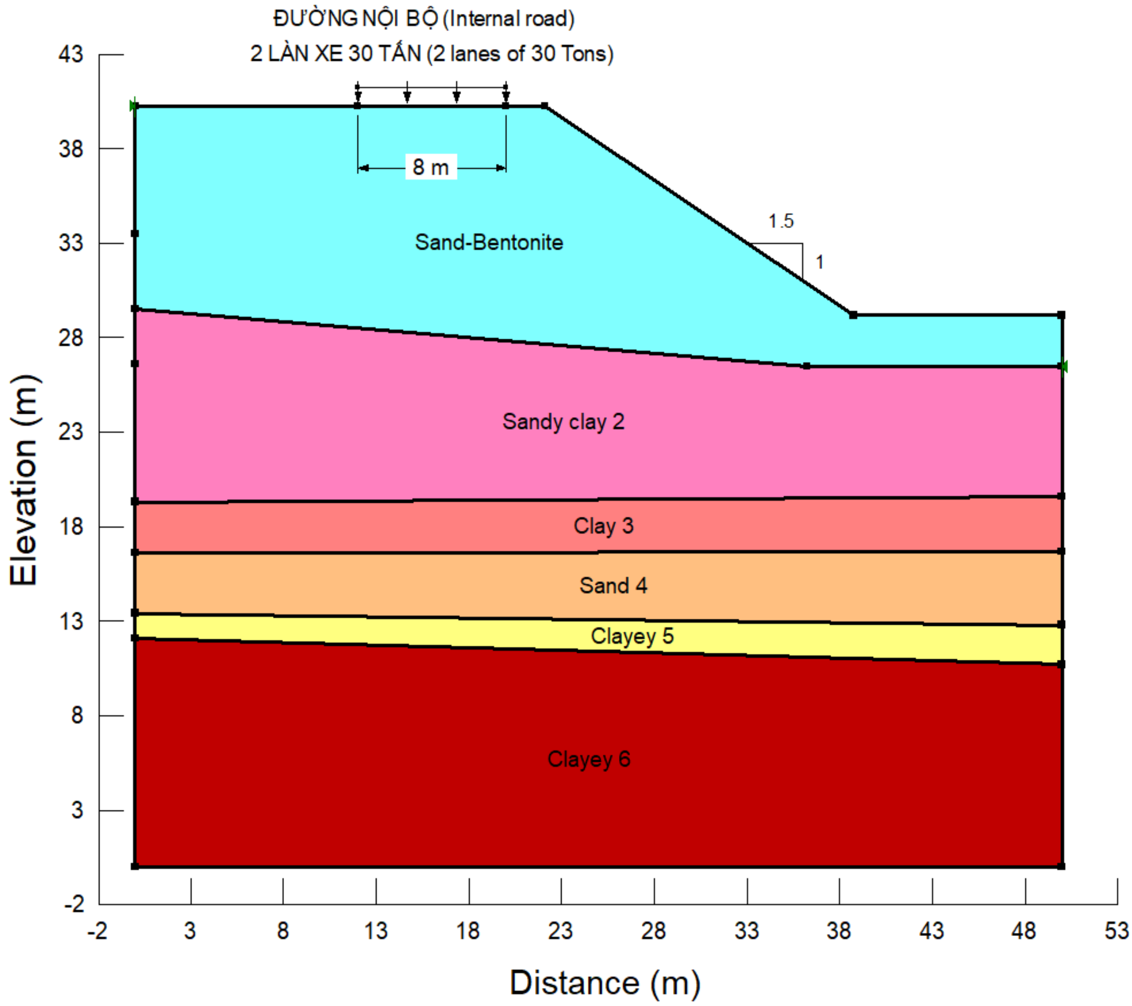

Fig. 5. Soil stratigraphy

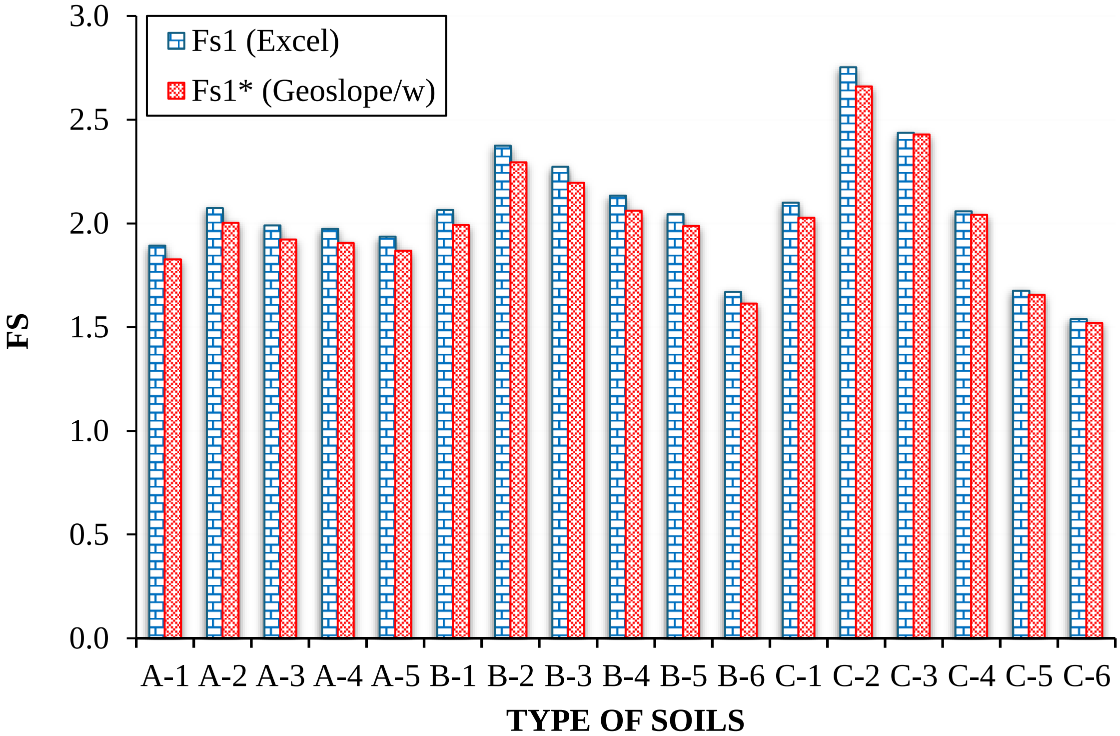

Fig. 6. FS results for the case of initial slope

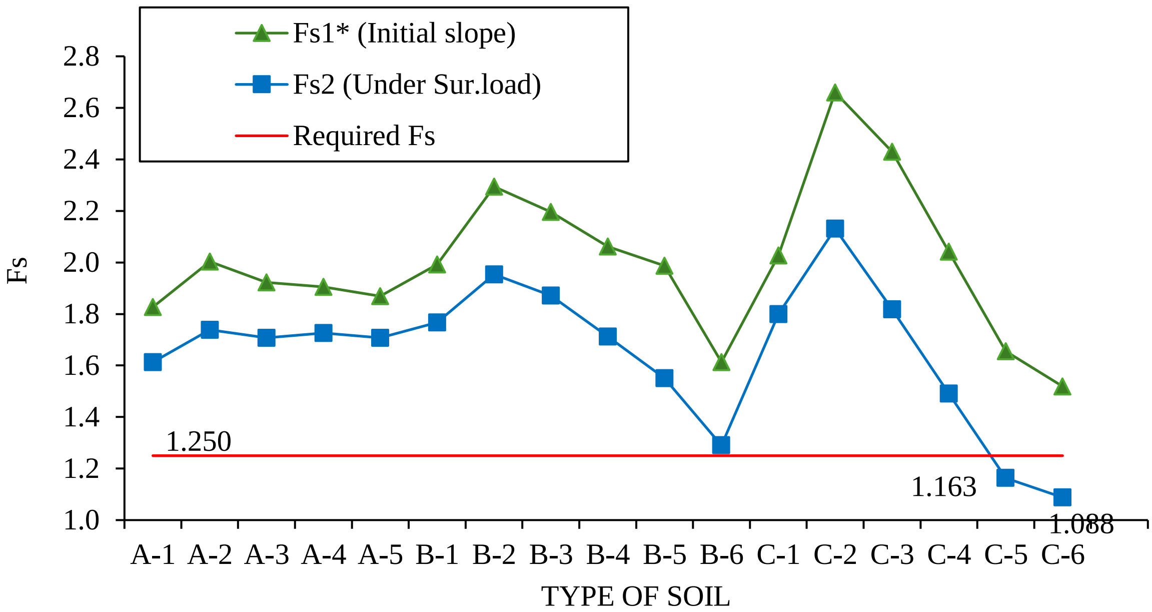

Fig. 7. FS results for the case of slope under surcharge load

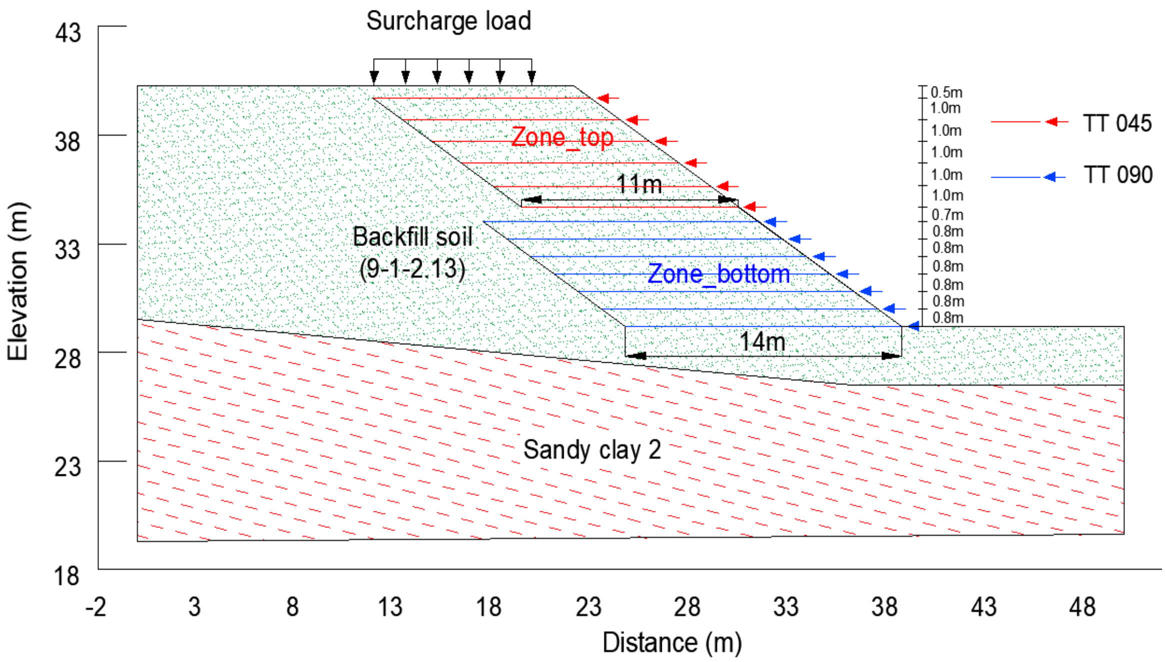

Fig. 8. The design of geogrids for slope reinforcement

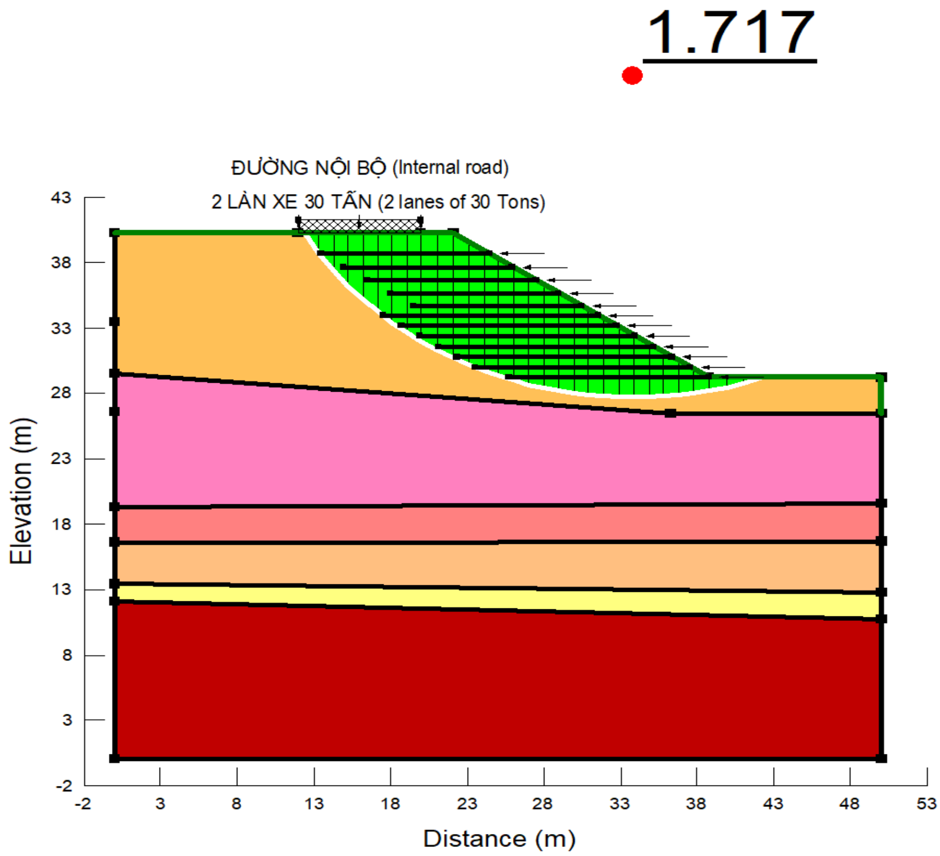

Fig. 9. Critical FS in case of A-5 soil

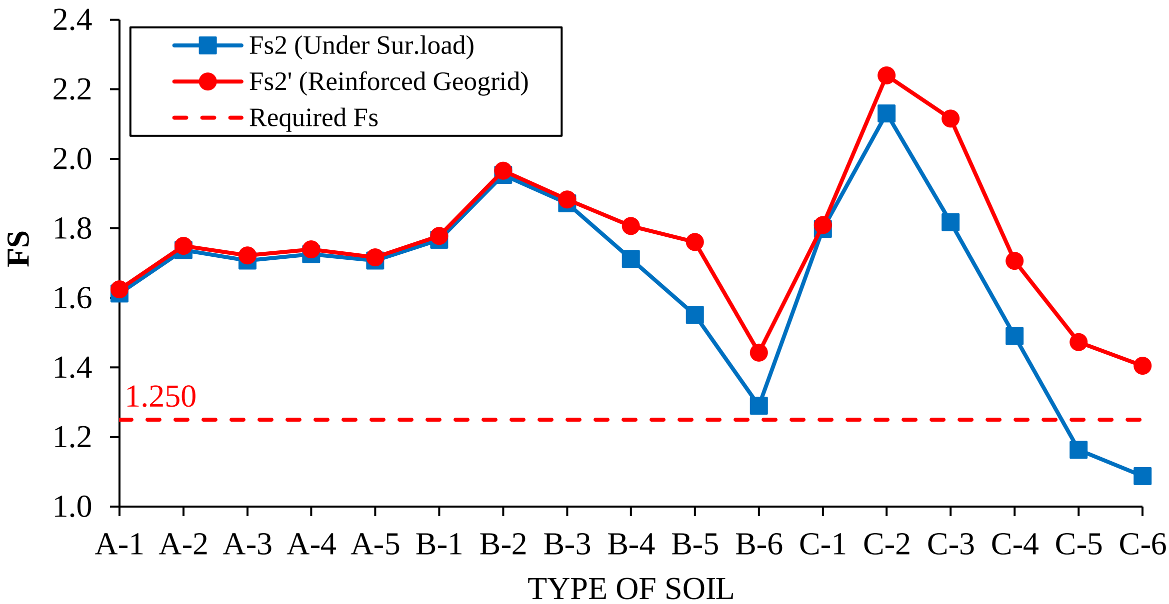

Fig. 10. FS results for the case of slope under surcharge load and geogrid

Tab. 1. Size range of particles of Artificial soils

		Remark	**Grain size distribution**

Sand – Clay Ratio	Moisture content (%)		Gravel (%) *D >2 (mm)*	Sand (%) *0.05< D <2 (mm)*	Silt (%) *0.002< D <0.05 (mm)*	Clay (%) *D <0.002 (mm)*
90%-10%	1.6	A-1	1.6	88.8	3.5	6.1
90%-10%	10	A-2				
90%-10%	15	A-3				
90%-10%	20	A-4				
90%-10%	21.3	A-5				
80%-20%	2.7	B-1	1.4	79.3	7.1	12.1
80%-20%	10	B-2				
80%-20%	15	B-3				
80%-20%	17.5	B-4				
80%-20%	20	B-5				
80%-20%	21.4	B-6				
70%-30%	3.9	C-1	1.3	69.9	10.6	18.2
70%-30%	10	C-2				
70%-30%	15	C-3				
70%-30%	17.5	C-4				
70%-30%	20	C-5				
70%-30%	21.5	C-6				

Tab. 2. Physical properties of Artificial soils

Artificial soil	Degree of Saturation S_e (%)	Dry unit weight γ_d g/cm³	Specific gravity G_s	Liquid limit L_L (%)	Plastic limit P_L (%)	Plasticity index P_I (%)	Void ratio e_0
A-1	7.5	**1.7**	2.67	22.4	16.2	6.2	0.568
A-2	46.9						
A-3	70.4						
A-4	93.8						
A-5	100.0						
B-1	12.6		2.67	26.3	17.1	9.2	0.572
B-2	46.7						
B-3	70.1						
B-4	81.8						
B-5	93.5						
B-6	100.0						
C-1	18.2		2.68	42.6	22.1	20.5	0.575

C-2	46.6						
C-3	69.8						
C-4	81.5						
C-5	93.1						
C-6	100.0						

Tab. 3. The Direct shear test results of Artificial soils

Artificial soil	Cohesion C (kPa)	Friction angle φ (degrees)	Average Shear stress (kPa)		
			τ (σ = 100 kPa)	τ (σ = 200 kPa)	τ (σ = 300 kPa)
A-1	6.7	31.9	70.3	128.8	194.8
A-2	14.4	30.8	78.3	125.3	197.5
A-3	10.9	31.7	76.5	127.3	200.3
A-4	8.2	33.0	79.8	125.0	209.8
A-5	7.5	32.9	76.0	129.0	205.3
B-1	6.8	34.5	76.8	141.3	214.0
B-2	21.3	31.8	86.8	138.5	210.8
B-3	22.7	29.9	81.5	135.0	196.5
B-4	28.7	24.4	75.3	118.5	166.8
B-5	40.5	15.8	69.0	96.5	125.5
B-6	35.3	12.7	58.3	79.8	103.5
C-1	7.3	34.8	77.3	145.5	216.3
C-2	39.7	27.6	90.8	146.5	195.3
C-3	44.1	20.1	81.3	116.3	154.5
C-4	44.8	12.8	68.3	89.0	113.8
C-5	42.4	6.8	54.0	66.8	77.8
C-6	40.3	6.7	52.5	62.8	76.0

Tab. 44. Soil properties were imported into software

Layer	Name	Model	Unit weight (kN/m^3)	Cohesion (kPa)	Friction angle (°)
1	Sand-Bentonite	*Mohr-Coulomb*	17.3 ÷ 21.5	6.7 ÷ 44.8	6.7 ÷ 34.8
2	Sandy clay 2	*Mohr-Coulomb*	19.9	20.2	25.2
3	Clay 3	*Mohr-Coulomb*	19.7	47.1	15.9
4	Sand 4	*Mohr-Coulomb*	20.2	3.9	33.8

5	Clayey 5	*Mohr-Coulomb*	20.1	67.7	16.9
6	Clayey 6	*Mohr-Coulomb*	19.3	52.0	14.0

Tab. 5. Surcharge load of the road structure

Layer	Unit weight (kN/m^3)	Thickness (m)	Surcharge load (kN/m^2)
Asphalt	22.5	0.67	15.1
Compacted soil (K98)	19.3	0.50	9.7
Compacted soil (K95)	19.3	1.17	22.6
Sub-base	22.5	0.50	11.3
Total		**2.84**	**59**

Tab. 6. Fs results for case of Initial slope

No.	Artificial soil	Fs_1 (Excel)	Fs_{1*} (SLOPE/W)	$(Fs_{1*})/(Fs_1)$
1	A-1	1.892	1.827	*0.965*
2	A-2	2.074	2.003	*0.966*
3	A-3	1.991	1.922	*0.966*
4	A-4	1.973	1.905	*0.966*
5	A-5	1.936	1.869	*0.965*
6	B-1	2.064	1.992	*0.965*
7	B-2	2.375	2.294	*0.966*
8	B-3	2.273	2.196	*0.966*
9	B-4	2.134	2.062	*0.966*
10	B-5	2.045	1.987	*0.972*
11	B-6	1.669	1.613	*0.967*
12	C-1	2.100	2.027	*0.965*
13	C-2	2.752	2.660	*0.966*
14	C-3	2.437	2.429	*0.997*
15	C-4	2.058	2.042	*0.992*
16	C-5	1.676	1.655	*0.988*
17	C-6	1.537	1.519	*0.988*

Tab. 7. Comparison of Fs between Initial slope and Under surcharge load

No.	Artificial soil	Fs_{1*} (Initial slope)	Fs_2 (Under sur. Load)	Fs_2/Fs_{1*}
1	A-1	1.827	1.613	*0.883*
2	A-2	2.003	1.738	*0.868*

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3	A-3	1.922	1.708	*0.889*
4	A-4	1.905	1.726	*0.906*
5	A-5	1.869	1.708	*0.914*
6	B-1	1.992	1.767	*0.887*
7	B-2	2.294	1.954	*0.852*
8	B-3	2.196	1.872	*0.852*
9	B-4	2.062	1.712	*0.830*
10	B-5	1.987	1.551	*0.781*
11	B-6	1.613	1.290	*0.800*
12	C-1	2.027	1.799	*0.888*
13	C-2	2.660	2.131	*0.801*
14	C-3	2.429	1.818	*0.748*
15	C-4	2.042	1.491	*0.730*
16	C-5	1.655	**1.163**	*0.703*
17	C-6	1.519	**1.088**	*0.716*

Tab. 8. Geogrid properties for reinforced slope

Uniaxial Geogrid	Ultimate Tensile Strength (kN/m)	Allowable Tensile Strength (kN/m)	Design life (years)
TT 045 (TENAX)	50	21.2	120
TT 090 (TENAX)	98	42.4	120
TT 150 (TENAX)	150	61.5	120

Tab. 9. Geogrid data of the model

Zone	Uniaxial Geogrid	Number of layers	Reinforcement length (m)	Allowable Tensile Strength (kN/m)	Vertical spacing (m)
Top	*TT 045 (TENAX)*	5	11	21.2	1.0
Bottom	*TT 090 (TENAX)*	7	14	42.4	0.8

Tab. 10. Results of reinforced slope analysis

No.	Backfill soil	Fs_2 (Under Surcharge load)	Fs_2' (Reinforced Geogrid)	Fs_2'/Fs_2
1	A-1	1.613	1.625	*1.007*
2	A-2	1.738	1.750	*1.007*

3	A-3	1.708	1.720	*1.008*
4	A-4	1.726	1.736	*1.008*
5	A-5	1.708	1.717	*1.005*
6	B-1	1.767	1.778	*1.006*
7	B-2	1.954	1.966	*1.006*
8	B-3	1.872	1.883	*1.006*
9	B-4	1.712	1.807	*1.055*
10	B-5	1.551	1.761	*1.135*
11	B-6	1.290	1.443	*1.119*
12	C-1	1.799	1.810	*1.006*
13	C-2	2.131	2.267	*1.051*
14	C-3	1.818	2.116	*1.164*
15	C-4	1.491	1.707	*1.145*
16	C-5	1.163	1.473	*1.267*
17	C-6	1.088	1.405	*1.291*

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Literature – References

1. Siang J. L. M., D. C. Wijeyesekera, A. Bin Zainorabidin, I. Bin Hj Bakar, "Effect of particle grading size and shape on density, dilatancy and shear strength of sands," Malaysian J. Sci., vol. 31, no. 2, pp. 161–174, 2012, doi: 10.22452/mjs.vol31no2.12.
2. Afrazi M., M. Yazdani, "Determination of the Effect of Soil Particle Size Distribution on the Shear Behavior of Sand," J. Adv. Eng. Comput., vol. 5, no. 2, p. 125, 2021, doi: 10.25073/jaec.202152.331.
3. Alias R., "Particle Size Effect on Shear Strength of Granular Materials in Direct Shear Test Physical Properties and Morphological Characteristics of Tropical Peat Soil in Sabah View project," vol. 8, no. 11, pp. 1144–1147, 2014, [Online]. Available: https://www.researchgate.net/publication/335227730
4. Cabalar A.F., "The Effects of Fines on the Behaviour of a Sand Mixture," Geotech. Geol. Eng., vol. 29, no. 1, pp. 91–100, 2011, doi: 10.1007/s10706-010-9355-z.
5. Kim D., B. H. Nam, H. Youn, "Effect of clay content on the shear strength of clay–sand mixture," Int. J. Geo-Engineering, vol. 9, no. 1, 2018, doi: 10.1186/s40703-018-0087-x.
6. Monkul M. M., G. Ozden, "Compressional behavior of clayey sand and transition fines content," Eng. Geol., vol. 89, no. 3–4, pp. 195–205, 2007, doi: 10.1016/j.enggeo.2006.10.001.
7. Vallejo L. E., R. Mawby, "Porosity influence on the shear strength of granular material-clay mixtures," Eng. Geol., vol. 58, no. 2, pp. 125–136, 2000, doi: 10.1016/S0013-7952(00)00051-X.
8. Saravanan R., K. Poongodi, P. Murthi, E. Sudharshan, R. Gobinath, "Effect of particle grain size on its shear strength behaviour of soils," IOP Conf. Ser. Mater. Sci. Eng., vol. 981, no. 3, 2020, doi: 10.1088/1757-899X/981/3/032079.
9. Dafalla M. A., "Effects of clay and moisture content on direct shear tests for clay-sand mixtures," Adv. Mater. Sci. Eng., vol. 2013, 2013, doi: 10.1155/2013/562726.
10. Ghosh R., "Effect of soil moisture in the analysis of undrained shear strength of compacted clayey soil," J. Civ. Eng. Constr. Technol., vol. 4, no. 1, pp. 23–31, 2013, doi: 10.5897/JCECT12.070.

https://doi.org/10.29227/IM-2025-01-02-020 Received: 30 Oct 2024, Accepted: 01 May 2025, Published: 01 Sep 2025

11. Liu P., J. Lin, Y. Wang, X. Yang, "Effect of moisture content on the shear behaviour of a completely decomposed granite: An experimental study," Adv. Civ. Eng., vol. 2021, 2021, doi: 10.1155/2021/6631422.
12. Ravindran S., I. Gratchev, "Effect of Water Content on Apparent Cohesion of Soils from Landslide Sites," Geotechnics, vol. 2, no. 2, pp. 385–394, 2022, doi: 10.3390/geotechnics2020017.
13. Trauner L., B. Dolinar, M. Mišič, "Relationship between the Undrained Shear Strength, Water Content, and Mineralogical Properties of Fine-Grained Soils," Int. J. Geomech., vol. 5, no. 4, pp. 350–355, 2005, doi: 10.1061/(asce)1532-3641(2005)5:4(350).
14. Wei Y. et al., "The effect of water content on the shear strength characteristics of granitic soils in South China," Soil Tillage Res., vol. 187, no. October 2017, pp. 50–59, 2019, doi: 10.1016/j.still.2018.11.013.
15. Harabinová S., E. Panulinová, "Impact of shear strength parameters on slope stability," MATEC Web Conf., vol. 310, p. 00040, 2020, doi: 10.1051/matecconf/202031000040.
16. Khan M. I., S. Wang, "Slope stability analysis to correlate shear strength with slope angle and shear stress by considering saturated and unsaturated seismic conditions," Appl. Sci., vol. 11, no. 10, 2021, doi: 10.3390/app11104568.
17. Nalgire T., D. P. P, M. A.A, H. P.D, "Slope Stability Analysis by GeoSlope," Helix, vol. 10, no. 1, pp. 71–75, 2020, doi: 10.29042/2020-10-1-71-75.
18. Geo-Slope International Ltd. (2021). SLOPE/W Version 11.2. 2.23310, User Manual.
19. Standard: TCVN 13346:2021 - Construction to prevent landslides on highways - Survey and design requirements.