INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 16 No. 4 (2024) 23-30
https://publisher.uthm.edu.my/ojs/index.php/ijie

Investigation of Particle Gradation Effect on Soil-Rock Mixture Using Direct Shear Test

Norsyafiqah Salimun[1]*, Hisham Mohamad[1]

[1] *Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS, Seri Iskandar 32610 Perak, MALAYSIA*

*Corresponding Author: norsyafiqahsalimun@gmail.com
DOI: https://doi.org/10.30880/ijie.2024.16.04.004

Article Info

Received: 8 December 2023
Accepted: 9 July 2024
Available online: 12 August 2024

Keywords

Soil-rock mixture, particle gradation, direct shear

Abstract

Soil-rock mixture (SRM) is a special geomaterial that is composed of soil and a certain percentage of rock blocks with various sizes and strengths. It has high structural strength and renewable resources that are used as filler in subgrade, construction material and embankment dams. However, the mechanical properties of the soil-rock mixture are sophisticated owing to the complicated interaction between soil and rock particles. Previously, many experimental investigations were conducted to focus on shear behaviours and the influencing factors of SRM. Yet, limited w ork has been done to underline the effect of particle size distribution towards SRM shear strength parameters. Thus, this study conducted an SRM shear test with three different kinds of gradation and rock block percentages. Various soil densities, porosities and different framework structures have resulted from different rock particle concentrations. From the results, the well-graded SRM shows a non-linear trend of cohesion value while uniformly graded and gap-graded SRMs shows contradicting trend respectively. The result and analysis in this study are especially useful in analysing its influence on the shear strength parameters of SRM with different rock block percentages.

1. Introduction

Recent studies have shown that soil-rock mixture (SRM) landslides have become among the main geological hazards in the world [1]. The soil-rock mixture slopes and tunnels are often treated as homogeneous materials in engineering characterization and analysis which could have led to errors in design [2]. The term "soil-rock mixture," or SRM, was first used to refer to a geotechnical material that differs greatly from those of general "soil" and "rock" mechanics because of its complexity and heterogeneity [3]. The variation and non-linear properties of SRM occur from their different formation origin, lithology, and mechanical parameters.

It is necessary to define the range of rock content value, which is usually expressed as a percentage, as it determines the method of treatment and analysis of the existing geomaterial, which means SRM versus pure soil or rock. In general, it is accepted that the rock block content of the soil-rock mixture is between 25% and 75% [4]. The limit of soil-rock ratio indicates when the influence of fine grains and coarse grains occurs simultaneously, as emphasized in SRM work. Therefore, previous research often focuses on the influence of rock block ratio or percentage on the cohesion and friction angle of SRM. Some others considered other factors such as moisture content [5],[6] and rock block size [2],[7]. However, the influence of particle size distribution (PSD) on the shear parameters of SRM is still unclear due to limited research conducted.

The PSD of SRM is closely related to its mechanical properties [8]. According to [9] variations of physical properties such as soil density, porosity and different soil-rock framework structures have resulted from a soil-rock composition of different rock particle concentrations. Consequently, their stress-strain behaviour is varied.

[10] stated that particle size distribution can influence the packing density of the granular skeleton, which can determine the volume of voids to be filled with fine material. In addition, [11] studied the effect of the soil particle size distribution on soil hydraulic properties, which influence the effective soil stress and soil shear strength. Moreover, [10], [11] researched the effect medium value of PSD (D50) and determined that when D50 increases, the effect of particle sizes and shapes on the shear strength and friction angle of soils becomes more apparent. To conclude, the change in PSD can affect the structural characteristics of SRM and then lead to a change in mechanical properties. Thus, this study aims to determine the effect of different rock block content by emphasizing the variation in their particle distribution towards the shear strength parameters of SRM.

2. Methodology

2.1 Material and SRM Preparation

The source of soil-rock mixture (SRM) used in this study is from a heterogenous zone of a weathered granite hill from the Segari-Lumut area as shown in Fig. 1. The site is selected based on the accessibility and suitability of the geomaterial. The granite hill in Segari, Perak was chosen as the study area because it is accessible to the soil-rock transition zone where the weathered SRM is collected. The area was previously used for granite quarrying and is currently used for oil palm plantation. The excavation and slope cutting in the study area allowed ease of access for field sampling. The soil and rock blocks were collected from a soil-rock transition zone. The sample is classified as a natural SRM sample. The material is loose, highly weathered with decomposed minerals and can be easily crumpled by hand [10]. The sample was collected by using excavation methods from the exposed cliff at depth of 8 meters from surface. This method allows visual inspection of the sample collected and is useful for collecting heterogenous sample such as SRM. The sample obtained from the field is crushed, dried, and sieved to separate the soil and rock block composition as shown in Table 1. The physical properties of the soil matrix are presented in Table 2.

The particle size distribution (PSD) chart is used as a guideline to prepare the SRM samples with different gradation types namely well-graded (WG), and two types of poorly graded type of gradation which are uniformly graded (UG) and gap-graded (GG). Fig. 2 shows the particle size distribution of the SRM sample tested with different rock block percentages. The uniformity coefficient (Cu) and coefficient of curvature (Cc) obtained for each PSD chart are tabulated in Table 3. From this, it is recognizable that the SRM sample could have similar percentages of rock block but different types of particle gradation.

Fig. 1 *Location of SRM sampling area at Segari-Lumut Perak*

Table 1 *Materials used to prepare SRM sample*

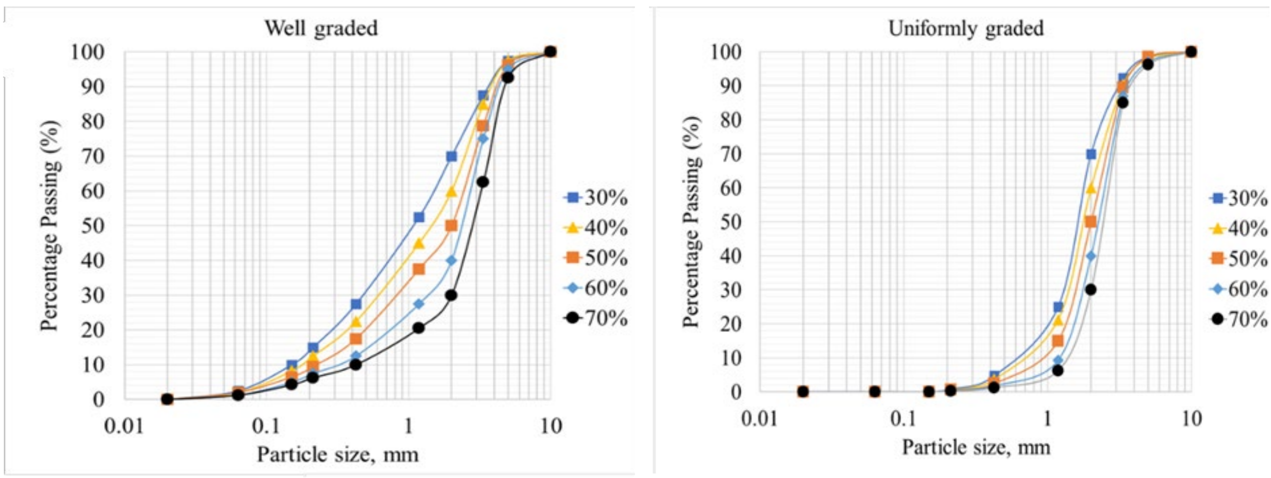
Materials	Description
Soil 	• Granitic residual soil • Particle size is less than 2mm.
Rock Block 	• Weathered granite • Angular • Particle size is bigger than 2mm, less than 5mm

Table 2 *Physical properties of the soil matrix*

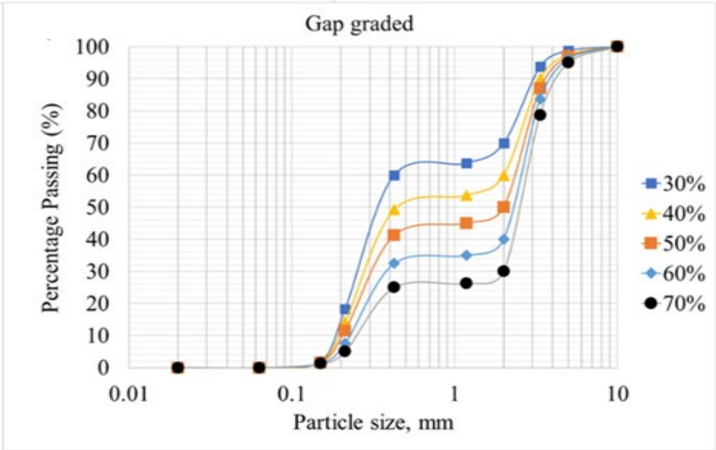
Maximum Dry Density (g/cm^3)	Moisture Content (%)	Specific Gravity	Liquid Limit (%)	Plastic Limit (%)
1.79	17.6	2.51	46.7	38

2.2 Direct Shear Box Test

Direct shear box tests were performed on 45 reconstituted samples of SRM with different rock block percentages and gradation types in the laboratory. To run the test, the 'soils' and 'rock blocks' components are fully mixed to ensure the distribution on the SRM sample are uniform. Then, the SRM sample is poured into the shear box and tamped in three layers. The instrument used and the sample preparation example is displayed in Fig. 3. The load applied is set to 100, 200 and 300 kPa respectively for each SRM sample by stages. The horizontal displacement rate is 0.25mm/min following ASTM D3080-04.

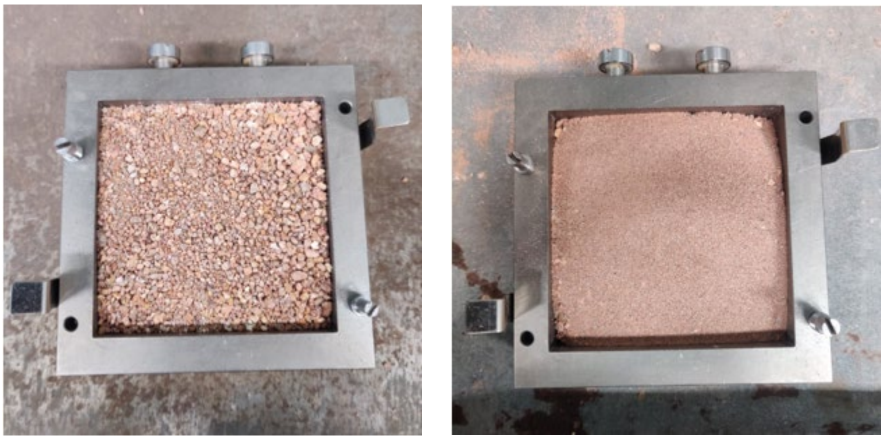


(a) (b)



(c)

Fig. 2 *Three types of particle size distribution of the SRM samples (a) well graded; (b) uniformly graded; (c) gap graded*



(a) **(b)**

Fig. 3 *Soil-rock mixture sample with different rock block percentages (a) 30% rock block; and (b) 70% rock block compacted into shear box mound*

3. Result and Discussion

3.1 Physical Properties of SRM

The geotechnical laboratory test is conducted on all samples prepared and the results are tabulated in Table 3. According to factor analysis of the physical properties, there are two main components with Eigenvalue more than 1. This represents two factors that are most significant among the properties measured that are influenced by the variation of PSD which is specific gravity and void ratio. It is known that the distribution of fine and coarse particles determines the packing and grain interaction [8]. It can be observed from the result that the well-graded and gap-graded SRM have the highest porosity when the rock block percentage is 50%. This shows that the PSD at this percentage has a stable soil-rock skeleton and has more void space compared to other curves.

Table 3 *Physical properties of SRM samples*

Gradation Type	Rock Block %	Cu	Cc	Specific Gravity	Dry Density, g/m^3	Optimum Moisture Content, %	Void Ratio, e	Porosity, %
Well Graded	30	10.21	2.18	2.538	1.777	15.86	0.233	18.89
	40	11.39	1.93	2.536	1.778	15.56	0.234	18.99
	50	11.11	1.63	2.518	1.780	15.28	0.267	21.07

	60	8.70	1.48	2.491	1.783	16.38	0.200	16.69
	70	7.64	1.35	2.434	1.798	14.29	0.185	15.60
Uniformly Graded	30	2.9	1.13	2.615	1.753	16.79	0.277	21.70
	40	2.93	0.98	2.522	1.7805	15.18	0.230	18.68
	50	2.88	0.74	2.538	1.7781	16.13	0.229	18.63
	60	2.67	0.74	2.376	1.7704	14.93	0.168	14.36
	70	2.05	0.54	1.861	1.7404	16.16	0.130	11.54
Gap Graded	30	2.35	3.54	2.478	1.7734	15.48	0.210	17.36
	40	4.56	0.56	2.430	1.7240	16.90	0.206	17.10
	50	11.67	0.72	2.489	1.6858	16.47	0.267	21.10
	60	16.76	0.99	2.491	1.7820	15.03	0.215	17.70
	70	10.67	0.27	2.488	1.7698	16.90	0.203	16.85

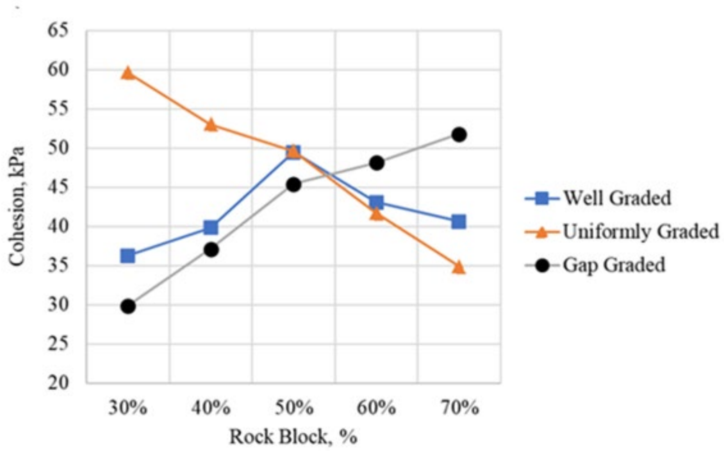
3.2 Shear Strength Parameters of SRM

In this section, the effect of rock block content and gradation type based on PSD towards the shear strength parameters of SRMs was discussed based on the results obtained in this study and those reported in the literature. The peak shear strength obtained for all tests is tabulated in Table 4. As can be seen, the peak shear stress for all gradation types increases as the rock block increases.

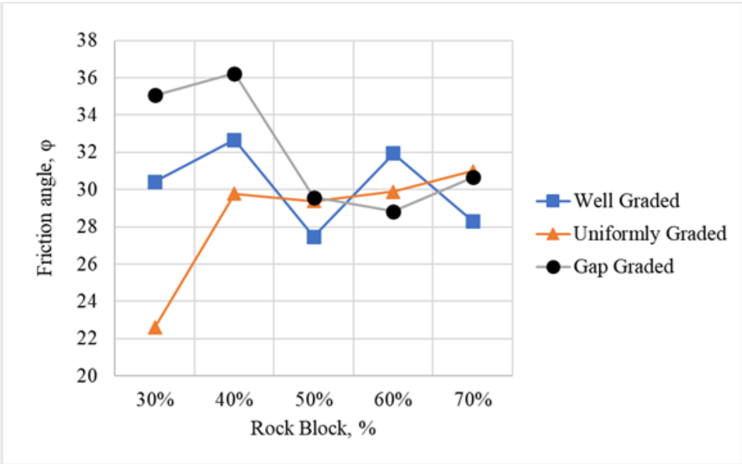
Table 4 *Peak shear strength measured from the direct shear test*

Rock block (%)	Normal Stress (kPa)	Peak Shear Stress (kPa/mm^2)		
		Well graded	Poorly Graded	Gap graded
30	100	98.5	97.8	97.1
	200	156.3	146.5	171
	300	211.7	179.5	234.8
40	100	96.5	100.5	109.2
	200	175.0	182.8	180.6
	300	200.5	212.8	253
50	100	89.8	105.5	109.2
	200	149.5	159.0	141.7
	300	226.6	216.0	221.1
60	100	86.2	93.6	93.8
	200	181.55	163.5	172.8
	300	218.5	206.4	201.8
70	100	105.0	92.7	109.2
	200	138.8	155/o	167.7
	300	204.2	210.5	226.5

Fig. 4 shows the shear strength parameters measured for different rock block percentages. Generally, for each gradation type, the cohesion and friction angle obtained shows different trends against the rock block percentage respectively. Nonlinear patterns can be observed for well-graded samples. Both uniformly and gap graded sample which has poor gradation have contradicting trend.



(a)



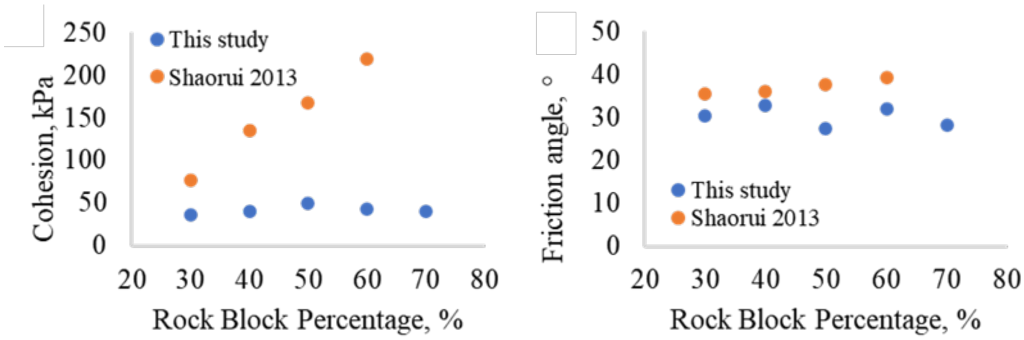
(b)

Fig. 4 *Shear strength parameters measured from direct shear box test for each type of gradation:(a) cohesion vs rock block percentage; and (b) friction angle vs rock block percentage*

Generally, the cohesion shows a non-linear trend for the well-graded type of SRM. The cohesion increased when the rock block was 50% and decreased forward. Its friction angle shows no significant trend. The lowest friction angle is at 40% rock block percentage which is 27.9°. In contrast, the cohesion values decrease for uniformly graded but increase for gap-graded type of gradation. The friction angle value for both these gradations does not vary significantly. The range of friction angle is between 22° to 30° for uniformly graded SRM and 28° to 35°for the gap graded SRM.

Maximum soil-rock particle contacts at 50% form a stable rock skeleton and its interlocking structure led to higher cohesion well graded SRM. Contradicting trends in two types of poorly graded SRM make PSD influence evident. Uniformly graded SRM had a smaller range or particle size, increasing coarser particles reducing cohesion and increasing friction angle. Meanwhile, the gap-graded sample becomes more stable when the rock block percentage increases causing particle uniformity increases the stability and shows an increment of cohesion value.

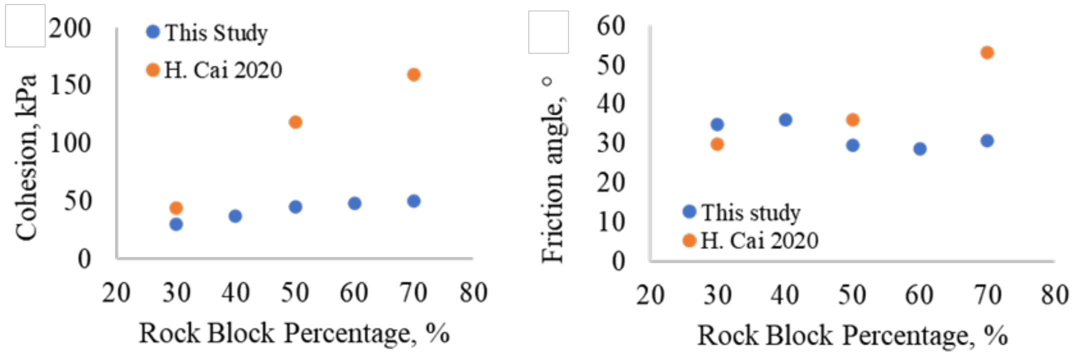
Fig. 5 and Fig. 6 display the comparison of previous work with that same SRM gradation and tested using direct shear box test [7[, [14]. Fig. 5 shows a results comparison of a well-graded type of SRM from this study and previous work [5]. It can be observed that both the cohesion and friction angle value from this study is lower. Yet, the friction angle for both investigations shows a similar increasing trend with increasing rock block percentage. It is also necessary to mention here that [5] used SRM samples from talus slopes while this study used granitic residual soil. This indicates that the difference in SRM type of source material also affects the value of shear strength parameters. Hence, future works on the effect of different materials forming SRM as an influencing factor affecting shear strength are suggested.



(a) **(b)**

Fig. 5 *Relationships between rock block content and shear strength parameters for well-graded SRM*

Meanwhile, Fig. 6 specifies the comparison between this study and previous work that implements the same laboratory test on gap-graded SRM samples. Again, the cohesion value observed from this study is lower compared to the related previous work. Moreover, a nonlinear trend is reflected in the friction angle value compared to the increasing trend observed in [12]. For a gap-graded type, at 30-40% percentage of rock block, there is a larger volume of fine particles that enclose the coarse particles. Compared to 50-60% rock, the coarse particle is no longer able to form a soil skeleton as the finer material is not enough to fill the space between them. When the rock block reaches 70%, the coarse grain is much higher, and all the fine particles fill their space. In this condition, the shear strength is controlled mainly by embedded and interlocking coarse-grain particles [12]. Hence, the gap-graded SRM in both works shows a similar increasing trend as the rock block percentages increased.



(a) **(b)**

Fig. 6 *Relationships between rock block content and shear strength parameters for gap-graded SRM*

4. Conclusion

This study helps to delineate the effects of the different particle size distributions of SRM samples on direct shear tests. The rock block content also affects the shear strength parameters of SRM. For gap-graded SRM, the higher the rock block content, the higher the shear strength is. Instead, the uniformly-graded SRM has lower shear strength as the rock block content increases. Meanwhile, the shear strength increases first and decreases when the rock block content is 50% in well-graded SRM. Thus, it is important to note that each particle size distribution chart shows a different soil gradation and is very useful in analyzing its influence on the shear strength parameters of SRM. The presented chart from particle size distribution can be used to anticipate the shear strength of the SRM sample with different rock block percentages.

Acknowledgement

This research is funded by the Fundamental Research Grant Scheme (FRGS/1/2022/TK06/UTP/02/2) awarded by the Ministry of High Education (MOHE) Malaysia which is gratefully acknowledged. The authors are also thankful for the support of lab staff in using facilities at the Department of Civil and Environmental Engineering, Universiti Teknologi PETRONAS.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Salimun N., Mohammad H.;* ***data collection:*** *Salimun N.;* ***analysis and interpretation of results:*** *Salimun N., Mohammad H.;* ***draft manuscript preparation:*** *Salimun N., Mohammad H. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Xu, W.J, Hu, R. L. & Yue, Q. (2009). Genesis and stability of the Zhoujiawan landslide, Three Gorges, China. Bulletin of Engineering Geology and the Environment, 68, 47–54. https://doi.org/10.1007/s10064-008-0154-1

[2] Zhao, Y. & Liu Z. (2018). Study of material composition effects on the mechanical properties of soil-rock mixtures. Advances in Civil Engineering, 2018, 1–10. https://doi.org/10.1155/2018/3854727

[3] Xu, W.J. & Hu, R. L. (2009). Conception, classification, and significations of soil-rock mixture. Hydrogeology Engineering Geology, 4, 50-56.

[4] Xu, W.J, Xu, Q. & Hu, R. L. (2011). Study on the shear strength of soil-rock mixture by large scale direct shear test. International Journal of Rock Mechanics and Mining Sciences. 48(8), 1235-1247. https://doi: 10.1016/j.ijrmms.2011.09.018

[5] Xue, Y., Yue, L. & Li, S. (2015). Experimental study on mechanical properties of soil-rock mixture containing water. Journal of Engineering Geology, 23(1), 21–29. https://doi:10.13544/j.cnki.jeg.2015.01.004

[6] Li, B. (2020). Study on Shear Properties of the Soil-rock Mixture. E3S Web of Conferences, 165(63), 1–6.

[7] Shaorui, S., Penglei, X., Jimin, W., Jihong, W., Wengan, F., Jin, L. & Kanungo, D. P. (2013). Strength parameter identification and application of soil–rock mixture for steep-walled talus slopes in southwestern. China Bulletin of Engineering Geology and the Environment, 73(1), 123–140. https://doi.org/10.1007/s10064-013-0524-1

[8] Fu, X., Ding, H., Sheng, Q., Zhang, Z., Yin, D. & Chen, F. (2022). Fractal analysis of particle distribution and scale effect in a soil–rock mixture. Fractal and Fractional, 6, 120. https://doi.org/10.3390/fractalfract6020120

[9] Li,u L., Zhang, S., Cheng, Y. M. & Liang, L. (2019). Advanced reliability analysis of slopes in spatially variable soils using multivariate adaptive regression splines. Geoscience Frontiers, 10(2), 671–682. https://doi.org/10.1016/j.gsf.2018.03.013

[10] Mehdipour, I. & Khayat, K. H. (2017). Effect of particle-size distribution and specific surface area of different binder systems on packing density and flow characteristics of cement paste. Cement and Concrete Composites, 78, 120–131. http://dx.doi.org/10.1016/j.cemconcomp.2017.01.005

[11] Zhang, Zhong, X., Lin, J., Zhao, D., Jiang, F., Wang, M. K., Ge, H. & Huang, Y. (2020). Effects of fractal dimension and water content on the shear strength of red soil in the hilly granitic region of southern China. Geomorphology, 351, 106956. https://doi.org/10.1016/j.geomorph.2019.106956

[12] Hamidi, A., Salimi, N., & Yazdanjou, V. (2011). Shape and size effects of gravel grains on the shear behaviour of sandy soil. Geosciences, 20(80), 189–196. https://doi.org/10.1007/s11440-022-01449-0

[13] Hamidi, A., Yazdanjou, V. & Salimi, N. (2009). Shear strength characteristics of sand-gravel mixtures. International Journal of Geotechnical Engineering, 3(1), 29–38. https://doi.org/10.3328/IJGE.2009.03.01.29-38

[14] Cai, H., Wei, R., Xiao, J. Z., Wang, Z. W., Yan, J., Wu, S. F. & Sun, L. M. (2020). Direct shear test on coarse gap-graded fill: plate opening size and its effect on measured shear strength. Advances in Civil Engineering, 2020. https://doi.org/10.1155/2020/5750438