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COMPARISON OF SOIL CLASSIFICATIONS BETWEEN RESIDUAL SOIL, GRANITIC AND SEDIMENTARY RESIDUAL SOILS IN NORTHERN MALAYSIA

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ABSTRACT

A total 285 disturbed soil samples in residual soil were collected from 10 stable slopes and 29 slope failures in Penang and Baling. A total of 151 disturbed soil samples were taken from the granitic residual soil in Penang while another 134 disturbed soil samples were obtained for the sedimentary residual soil in Baling. To determine the soil classifications, sieve and hydrometer tests were conducted on the disturbed soil samples. The objective of this research is to determine soil types existed in residual soil, granitic and sedimentary residual soils taken from the stable slopes and the slope failures especially in the residual soil, granitic and sedimentary residual soils in the Northern Malaysia. The aims of this research are also to check the distribution types and to determine the mean values of the percentages of gravel, sand, silt and clay of the residual soil, granitic and sedimentary residual soils in the Northern Malaysia. Normal distributions were found not to be the best fit distributions for the variations of the percentages of gravel, sand, silt and clay the three residual soils taken in the Northern Malaysia. The ranges of the percentages of gravel, sand, silt and clay for the all residual soils found in this study were very close or within the ranges that were found by the earlier researchers.

Keywords: granitic and sedimentary residual soils (rs), effective cohesion, effective friction angle, normal distribution, Northern Malaysia.

INTRODUCTION

The soil classifications were based on British Soil Classification System (BSCS) for Engineering Purposes as stated in BS 5930 (1999). Ahmad *et al.* [2] conducted a study on the characteristic of soil taken from the hilly areas in Penang Island. They concluded that there will be higher risk of a stable slope to fail when higher percentage of clay portion and thicker layer of clayey soils existed in the stable soil slope. As explained by [19], the higher the percentage of sand and silt, the higher is the risk of the stable slope to be eroded. Based on Ting and Nithiaraj [18], the ranges of the percentage of gravel, sand, silt and clay for residual soil were between 0.0 - 92.0 %, 0.0 - 94.0 %, 0.0 - 90.0 % and 0.0 - 49.0 % respectively. Maail *et al.* [14] mentioned that the range of percentage of sand, silt and clay for residual soils were between 7.0 - 49.0 %, 2.0 - 43.0 % and 5.0 - 67.0 %. The overall range of the percentage of gravel, sand, silt and clay for residual soils were 0.0 - 92.0 %, 0.0 - 94.0 %, 0.0 - 90.0 % and 0.0 - 67.0 % respectively.

In granitic residual soil, Ting and Nithiaraj [18] found that the ranges of the percentage of gravel was between 0.0 - 92.0 %, sand was between 14.0 - 83.0 %, silt was between 2.0 - 52.0 % and clay was between 2.0 - 49.0 %. Maail et al. [14] found that sand was 4.0 - 48.0 % and clay was 28.0 - 63.0 %. IKRAM CFC [9] found that silt was between 31.0 - 81.0 %. Therefore, the overall ranges of the percentage of gravel, sand, silt and clay for granitic residual soils were 0.0 - 92.0 %, 4.0 - 83.0 %, 2.0 - 81.0 % and 2.0 - 63.0 % respectively. In sedimentary residual soil, Ting and Nithiaraj [18] found that the range of the percentage of gravel was between 0.0 - 74.0%, sand was between 0.0 - 94.0%, silt was between 0.0 - 90.0 % and clay was between 0.0 - 58.0 % while Maail *et al.* [14] found that clay was between 5.0 - 67.0 %. Therefore, the overall ranges of the percentage of gravel, sand, silt and clay for sedimentary residual soils are 0.0 - 74.0 %, 0.0 - 94.0 %, 0.0 - 90.0 % and 0.0 - 67.0 % respectively.

GEOLOGY AND LABORATORY TESTS

Geology of study areas

Residual soil is formed from the weathering of its parent rock and it remains at the place where it is formed as stated by McGown [15]. The rock formations in Peninsular Malaysia can be broadly classified into three major groups, namely alluvial soil, sedimentary and igneous rocks as explained by [11]. The alluvial soil mainly consists of marine clay, inter-bedded clayey and sandy materials and river deposits, generally loose to dense, or soft to very stiff soils. The most common sedimentary rocks are shale, sandstone, limestone and some meta-sedimentary rock. Granitic rock which is part of igneous rock is abundantly found in Malaysia.

Due to tropical climate, these sedimentary and granitic rocks experience extensive weathering where the rocks are completely weathered into granitic and sedimentary residual soils. Komoo [11] managed to produce a simplified geological map for Peninsular Malaysia as shown in Figure-1. Based on the simplified surface geology, the rock distributions which eventually weathered into residual soil are shown in Figure-1. The map also shows the locations of the coastal alluvial soil in Peninsular Malaysia. Figure-1 also shows the study areas of slope failures and stable slopes in Penang and Baling. Figures-2 and 3 show the locations of slope failures and

stable slopes selected in residual soil Penang and baling respectively. Figure-4 shows the selected slope failures and stable slopes within the granitic residual soil in Penang while Figure-5 show the locations of the selected slopes within the sedimentary residual soil in Baling.

Collection of soil samples and laboratory tests

A total of disturbed 285 soil samples were tested from 29 slope failures and 10 stable slopes in residual soil in Penang and Baling. Disturbed soil samples were collected at the stable slopes and slope failures are shown in Figures 4, 5 and 6. Disturbed soil samples were collected at about 100 mm depth for all stable slopes and at all slope failures except at 2 slope failures, where disturbed soil samples were also taken at varying depths of 100, 400, 700 and 1000 mm in vertical and perpendicular directions to the slope surface as in Figure-6. Figures 7 and 8 show the locations of soil samples collected in granitic residual soil in Penang and in sedimentary residual soil in Baling respectively. A total of 151 soil samples were collected from granitic residual soil while another 134 data were obtained for the sedimentary residual soil. The soil was later placed in the two-layer plastic bags to prevent moisture loss before taken to the laboratory. To determine the soil classification, sieve and hydrometer tests were carried out based on BS 1377 part 2 [3] and soils are classified in accordance with BS 5930 [4].

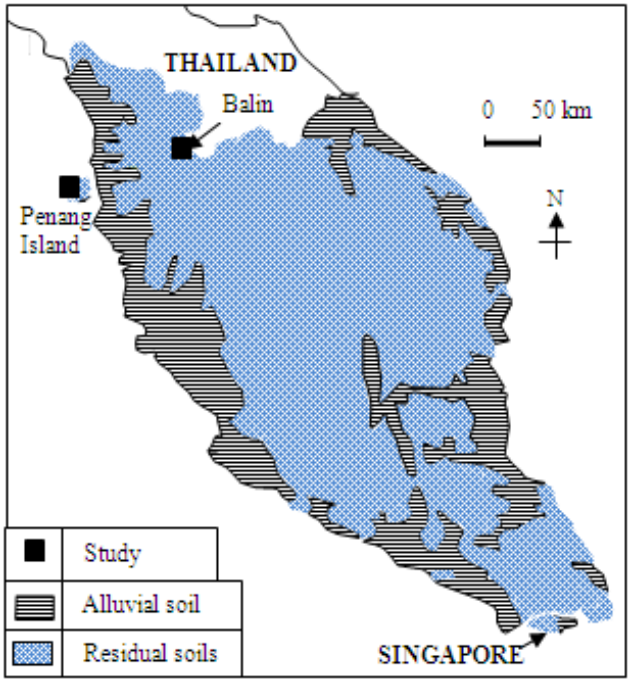


Figure-1. Study areas within the simplified geological map of Peninsular Malaysia including Singapore. (Map of Malaysia after Komoo [11] and map of Singapore after Leong and Rahardjo, [12].

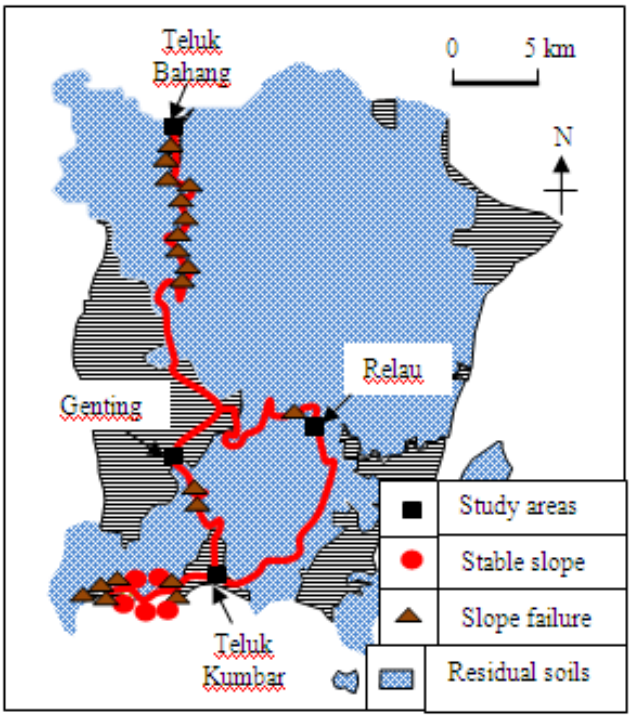


Figure-2. The stable slopes and slope failures in Penang within residual soils zone.

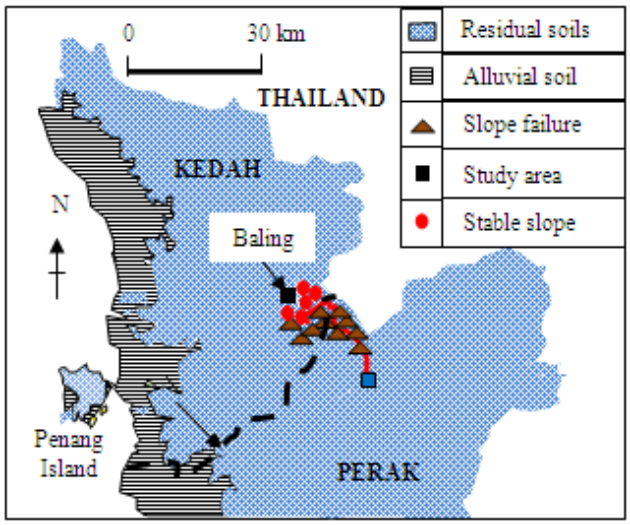


Figure-3. The stable slopes and slope failures in Baling within residual soil zone.

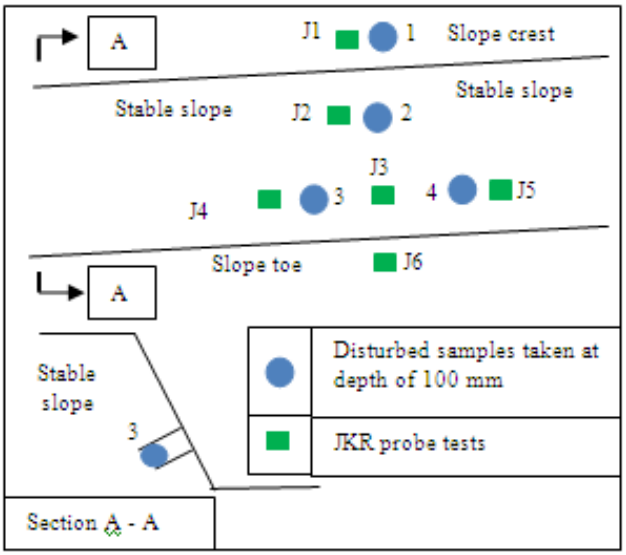


Figure-4. Locations of disturbed soil samples and JKR probe tests done at stable slope. Disturbed soil samples were collected at 100 mm depth.

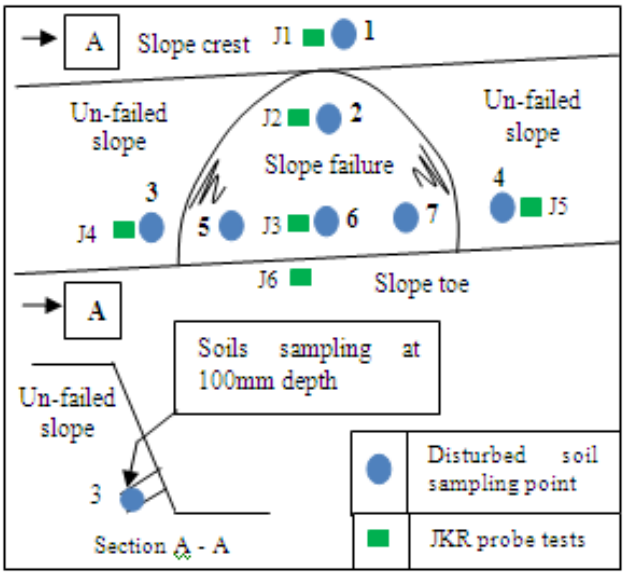


Figure-5. Soil sampling locations and JKR probe tests done at slope failure. Disturbed soil samples were collected at 100 mm depth.

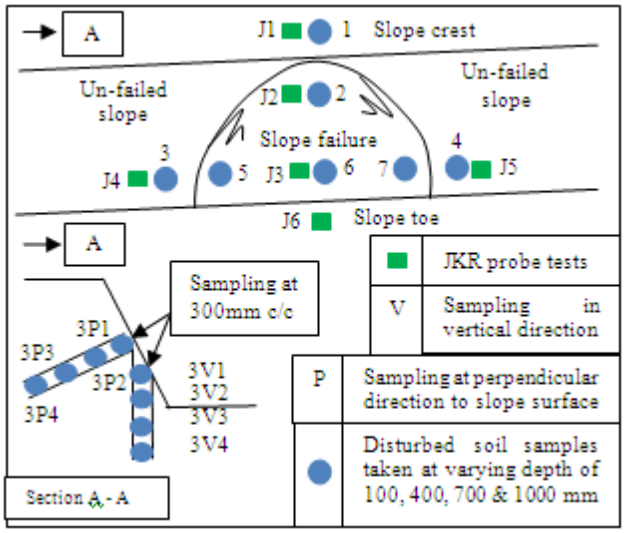


Figure-6. Locations of disturbed soil samples and JKR probe tests done at slope failure. Soil samples were taken at varying depths of 100, 400, 700 & 1000 mm.

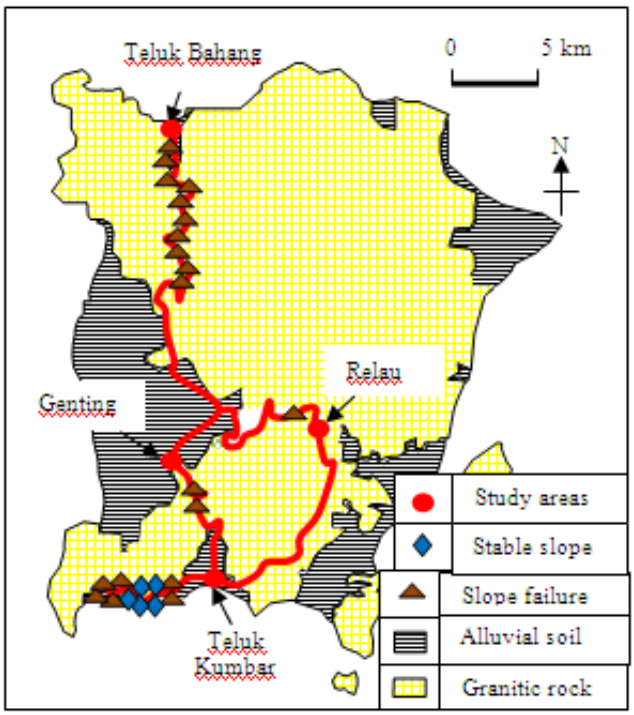


Figure-7. Slope failures and stable slopes in Penang within the simplified geological map (Jamalludin [11]).

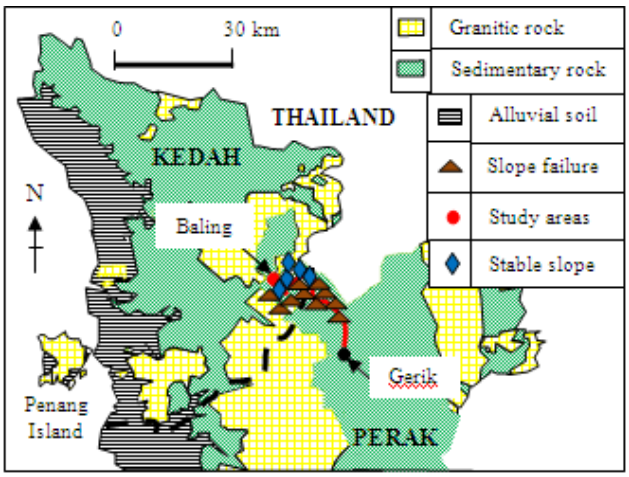
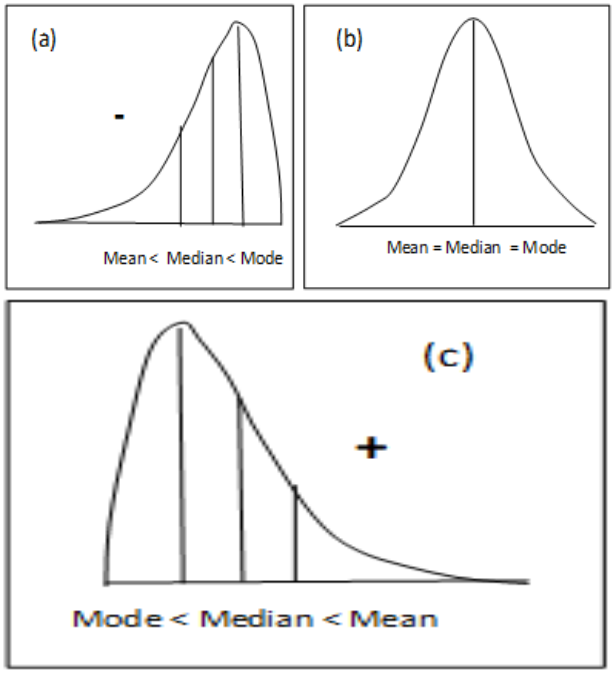


Figure-8. Slope failures and stable slopes in Baling within simplified geological map (Jamalludin [11]).

ANALYSIS OF RESULTS AND DISCUSSIONS

Skewness and Kurtosis

Skewness measures the asymmetry of a distribution. There are two types of skewness namely the negative and positive skewed as shown in Figure-9 (a) and 9 (c) while normal distribution is shown in Figures 9 (b). A distribution is known to be positive skewed if it has a longer tail on the right where the mean is greater than the median. A symmetrical distribution has a skewness of zero. If the skewness is between - 1 and + 1, the distribution is approximately symmetrical and is almost having the shape of normal distribution as explained by the Lindner (2013). The equation to determine the skewness in SPSS software is shown in equation 1 as based on El Nabris [7].



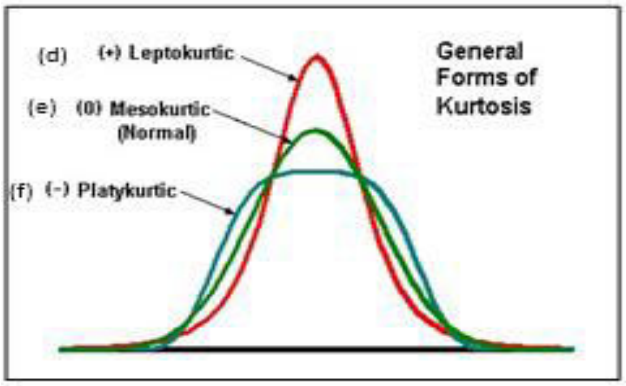


Figure-9. Skewness (a) negative skewed distribution (b) normal distribution and (c) positive skewed distribution (Figures after Doane *et al*., 2011), Kurtosis (d) positive kurtosis distribution (e) normal kurtosis distribution and (f) negative kurtosis distribution (Figure after MVPstats - Help, 2008)

$$S = \frac{n}{(n-1)(n-2)} \frac{\sum_{i=1}^{n}(x_i-\bar{x})^3}{s^3} \quad (1)$$

$$K = \left(\frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum_{i=1}^{n}\left(\frac{x_i-\bar{x}}{s}\right)^4\right) - \frac{3(n-1)^2}{(n-2)(n-3)} \quad (2)$$

Where

x_i = actual monitoring data, $\bar{x}$ = the mean, s = standard deviation n = number of data, S = skewness, K = kurtosis

Kurtosis is a measure of how flat the top portion of a distribution when compared with a normal distribution of the same variance as shown in Figures 9 (d) to 9 (f). A kurtosis value nearing to zero indicates a shape close to normal distribution. A positive value indicates a distribution which is more peaked than normal, and a negative kurtosis indicates a shape flatter than normal as shown in Figure-9 (d) to 9 (f). A kurtosis value of ± 1is considered within the acceptable limit as described by the Lindner [13]. The equation to determine Kurtosis in the SPSS software is as in equation 2 as explained by El Nabris [7].

Coefficient of Variation (CV)

As reported by Spiegel [17], when comparing the distributions of different means and standard deviations, a useful measurement is by using the coefficient of variation (CV). The CV is the ratio of the standard deviation to the mean as shown below:

$$CV = \frac{\sigma}{\bar{x}} \quad (3)$$

where,

σ = standard deviation, $\bar{x}$ = mean

CV is independent of units used and it is useful when comparing distributions of variations where the units may be different. When the value of CV < 1, then the

distributions are considered to have smaller relative variations. This indicates that the data are more consistent as explained by Spiegel [17].

Table-1. Distribution poperties of the percentage of gravel, sand, silt and clay in residul soils.

Distribution property	Residual soil			
	% Gravel	% Sand	% Silt	% Clay
No of data	285	285	285	285
Min value (%)	0.10	7.45	15.50	0.00
Max value (%)	76.93	67.79	90.08	8.78
Mean (%)	14.55	31.22	53.67	0.59
Std. deviation	13.93	15.00	21.92	0.99
Skewness	1.32	0.88	-0.22	4.36
Kurtois	1.62	0.27	-1.25	26.45
CV	0.96	0.48	0.41	1.67
p = Asymp. Sig. (2-tailed)	0.00	0.00	0.00	0.00
Range in this study (%)	0.10 - 76.93	7.46 - 67.79	15.50 - 90.08	0. 00 - 8.78
Range from publications (%)	0.00 - 92.00	0.00 - 94.00	0.00 - 90.00	0.00 - 67.00

Table-2a. Distribution properties of percentages of gravel, sand, silt and clay in granitic residual soil.

Distribution property	Granitic residual soil			
	% Gravel	% Sand	% Silt	% Clay
No of data	151	151	151	151
Min value (%)	0.10	7.45	15.50	0.00
Max value (%)	76.93	67.79	81.93	1.75
Mean (%)	21.44	37.64	40.60	0.37
Std. deviation	15.19	15.48	19.17	0.46
Skewness	0.70	0.69	0.53	1.36
Kurtois	0.39	-0.52	-0.96	0.66
CV	0.71	0.41	0.47	1.26
p = Asymp. Sig. (2-tailed)	0.00	0.00	0.00	0.00
Range in this study (%)	0.10 - 76.93	7.45 - 67.79	15.50 - 81.93	0.0 - 1.75
Range from publications (%)	0.00 - 92.00	4.00 - 83.00	2.00 - 81.00	2.00 - 63.00

Table-2b. Distribution properties of percentages of gravel, sand, silt and clay in sedimentary residual soil

Distribution property	Sedimenatry residual soil			
	% Gravel	% Sand	% Silt	% Clay
No of data	134	134	134	134
Min value (%)	0.28	8.04	24.67	0.01
Max value (%)	36.12	53.15	90.08	8.78
Mean (%)	6.78	23.99	68.39	0.85
Std. deviation	6.25	10.53	14.11	1.31
Skewness	1.86	0.68	-0.80	3.43
Kurtois	4.43	-0.07	0.44	14.72
CV	0.92	0.44	0.21	1.55
p = Asymp. Sig. (2-tailed)	0.00	0.03	0.04	0.00
Range in this study (%)	0.28 - 36.12	8.04 - 53.15	24.67- 90.08	0.01 - 8.78
Range from publications (%)	0.00 - 74.00	0.00 - 94.00	0.00 - 90.00	0.00 - 67.00

Tables-1 and 2 illustrate the distribution properties of the percentages of gravel, sand, silt and clay in residual soil, granitic and sedimenatry residual soils in this study. All the values of CV < 1 indicating that the data are consistent except for the variations of the clay portions in the 3 residual soils where the values of CV > 1. These may due to the existence of few outliers data which has affected the values of the mean.

Goodness-of-Fit Test Using Kolmogorov - Smirnov Tests Method

The percentages of gravel, sand, silt and clay in residual soil, granitic and sedimenatry residual soils were tested based on Kolmogorov-Smirnov method using SPSS software, to check the normality of the data distributions. Coaker and Steed [5] expressed that, if the significant level p > 0.05, normality is assumed where normal distribution is the best fit distribution. However, from Tables 1 and 2, normal distributions are not attained for all percentages of gravel, sand, silt and clay in residual soil, granitic and sedimenatry residual soils since p < 0.05. More than a quarter of the values of skewness and kurtosis are outside the range of - 1 and + 1, indicating that distributions are not normally distributed and are in the forms of skewed distributions. Furthermore, more than a quarter of the values of skewness and kurtosis are outside the range of - 1 and + 1, indicating that distributions are not in the shapes of normal distributions. From the study conducted by Lumb (1966) on four typical residual soil formations commonly found in Hong Kong, he found that most of the distributions of the soil properties are approximately normally distributed. However, in the 3 cases in this study they are not normally distributed.

Soil Types

Soil classification systems

Figures 10, 11 and 12 are the pie charts showing the types of soils found in residual soil, granitic and sedimenatry residual soils in this study. The soil types found in this research are mainly sandy SILT, slightly sandy SILT, slightly gravelly SILT, SAND, very silty SAND, very gravelly SAND very silty GRAVEL and very sandy GRAVEL. Figures 10, 11 and 12 are the pie charts depicting the types of soils in residual soil, granitic and sedimenatry residual soils in this study respectively where slightly sandy SILT is the most common and abundantly soil type found the 3 types of residual soils.

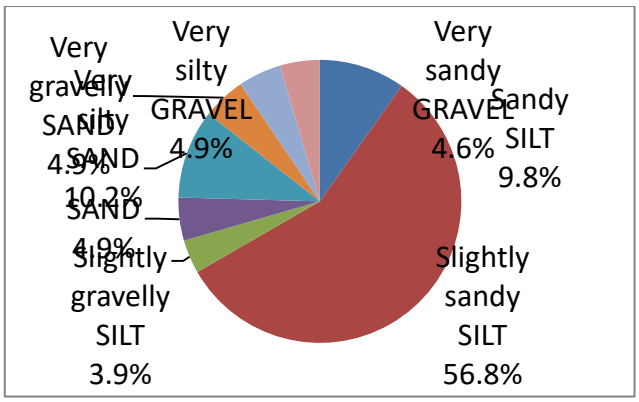


Figure-10. Distributions of soil types in residual soil.

Formation of granitic and sedimentary residual soils

The results in the pie charts in Figures 10, 11 and 12 are reorganised into high % of fine-grained soils and coarse-grained soil as in Table-3. High % of fine-grained soils existed in both the granitic and sedimenatry residual soils although a higher % of fine-grained soils existed in sedimentary residual soil than granitic residual soil. From Table-3, atlmost the same % of fine-grained soils and coarse-grained soil existed in granitic reisidual soil. Both the sedimentary and granite rocks produce clay, silt and sand once they are weathered as explained by Ahmad *et al.*, [1].

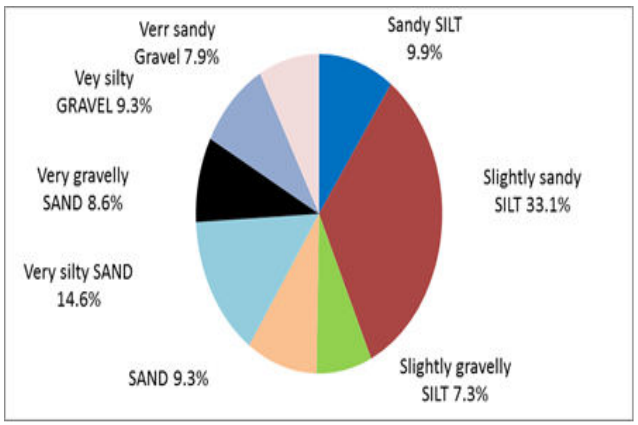


Figure-11. Distributions of soil types in granitic residual soil.

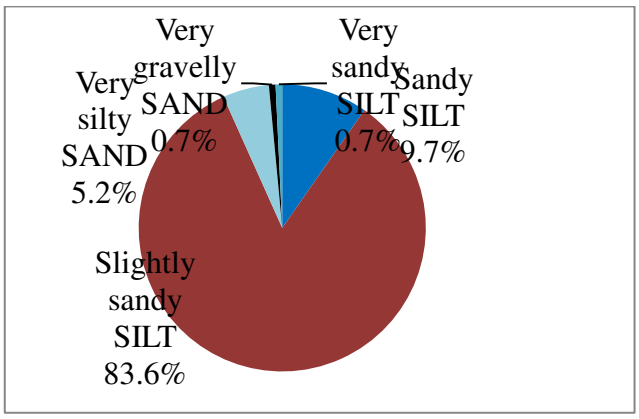


Figure-12. Distributions of soil types in sedimentary residual soil.

Table-3. Percentages of fine-grained & coarse-grained soils in Northern Malaysia (Jamalludin [10]).

Item	Soil Type	% in residual soils	% in Granitic RS	% in Sedimentary RS	Notes
1	Sandy SILT	71.8	50.3	93.3	High % of fine-grained soil
2	Slightly sandy SILT				
3	Slightly gravelly SILT				
4	SAND	28.2	49.7	6.7	High % of coarse-grained soil
5	Very silty SAND				
6	Very gravelly SAND				
7	Very silty GRAVEL				
8	Very sandy GRAVEL				
	Total (%)	100	100	100	

Table-2 and Table-3 show distribution properties of the percentages of gravel, sand, silt and clay in residual, granitic and sedimenatry residual soils. The values of skewness and kurtosis were obtained using SPSS software. More than a quarter of the values of skewness and kurtosis are outside the range of - 1 and + 1, indicating that distributions are not normally distributed as explained by Lindner [13].

It was found all the ranges of the percentage of gravel, sand, silt and clay in residual soil, granitic and sedimentary residual soils in this study are very close or within the ranges found by earlier researchers as in Tables 2 and 3.

CONCLUSIONS

Although many continuous data are approximately normally distributed, some are not normally distributed. None of the distributions of the percentages of gravel, sand, silt and clay the residual soil, granitic and sedimentary residual soils was normally distributed although the data were almost consistent. The mean values of the percentages of gravel, sand, silt and clay in the residual soils, granitic and sedimentary residual soil as tabulated in Table 4. All the ranges of the percentages of gravel, sand, silt and clay in the residual soils, granitic and sedimentary residual soils in this study were very close or within the ranges that were found by the earlier researchers.

Table-4. Mean values.

Soil type	% Gravel	% Sand	% Silt	% Clay	Distribution type
Residual soils	14.55	31.22	53.67	0.59	Skewed distribution
Granitic residual soil	21.44	37.64	40.60	0.37	Skewed distribution
Sedimentary residual soil	6.78	23.99	68.39	0.85	Skewed distribution

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