Physico-chemical Properties and Mineralogical Identification of Soils from Mélange in Beluran-Sandakan, Sabah, Malaysia

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Abstract. The study area located in the main road of Beluran-Sandakan, Sabah, Malaysia which mostly consists of mélange. Melange material consists of mixed rocks with different sizes and originated from old rock formation. These materials commonly embedded in shale matrix and highly sheared. A total of twelve soil samples were collected along the main road in order to analyse the physico-chemical properties and mineral identification. The result of analysis shows the moisture content was in the range from 7.0% to 23.38% with the plasticity indexes were in the range from 6.32% to 34.18%. The plotted in plasticity chart shows that the soil can be classified as intermediate plasticity to high plasticity. The texture of soil best classified as clayey sand, silt with sandy clay, sand with silty clay and clay soil. The mineral content of the soil mainly contains of quartz, kaolinite and illite. Other minerals also were observed such as maghemite, hematite, chlorite and calcite. The various minerals composition shows many types of parent rocks. Whereas the high clay minerals will affect the stability of soil slope due to high moisture-adsorption minerals and high plasticity index.

1. Introduction
The study area is located in Sandakan Sabah, which often occurrence of mass movements that cause road damage along the main road (Figure 1). The clayey soil in Sandakan mostly originated from weathered mélange materials. The mélange consists of mixed rocks including blocks of different ages, various lithology, and commonly embedded in shale matrix [1]. The admixture of rocks with varies sizes and varied with matrix of sandstone, mudstone and shale in Sandakan area was reported as Garinono Formation [2, 3]. The appearance of ultramafic rocks such as serpentinite indicated an active plate boundary had occurred due to the tectonic activity [4]. Historical geology of Garinono Formation referred as ‘slump breccia’, formed from the sliding activities of the sea floor and actives sedimentation process after deposition of mud-rich sediments [2]. Most part of Garinono Formation consists of sandstone, mudstone and shale. The clay matrix types are illite, mica, chlorite and kaolinite [3].

Different soil has different strength, depending on its parent rocks material and mineral content. Friction strength of soil influenced by its mineral contents, shape of soil particles, pore ratio, organic materials content and soil grades [5]. Whereas the matrix in mélange dominated by clay mineral. According to [6], mélange has lack of internal continuity of rock layer and contact, therefore this...
structure contributed to the damage of rock structure. Oxide-hydroxide minerals became low plasticity and slurry when mixed with high percentages of water due to the formation of limonite minerals, therefore will trigger the landslide [7, 8]. Low plasticity makes it susceptible to failure due to reduced soil shear strength. Most landslides are triggered by hydro climatic events such as prolonged or intensive rain [9, 10]. Understanding the physico-chemical properties of soil and main type of minerals is vital in order to understand the relationship between clay minerals with the occurrences of landslide in this area.

Figure 1. Geological map of the study area in Sandakan, Sabah [1]

2. Methodology
Field investigations involved the study of mélange distribution, characteristics of mélange materials, and sample collection for laboratory analysis. The field observation also included the damage occurrences on roads, and currents slopes mitigation measurement on the study areas. Twelve (12) soil samples from the weathered mélange materials were collected from the slopes along the main road in the study area. The laboratory analysis involved the physico-chemical analysis, and mineral
identification in soil samples. The parameters in physico-chemical analysis are natural moisture content, organic content, pH value, particle size distributions and specific gravity of soil. The physico-chemical analysis followed BS1377:1990 methods [11]. The Atterberg’s limits were analyzed to identify the type of soil plasticity. Mineralogical identification were measured using X-ray diffraction (XRD) and Scanning Electron Microscope instruments.

3. Results and Discussion

3.1 Outcrop Observations of Mélange
The field observation on the road cuts shows the mélange outcrops can be described base on the degree of weathering, structure, texture and origin of parent rocks. Base on the observation it was found that all rock outcrops shows the high degree of weathering and produced thick soil profiles (Figure 2). The appearance of various parents rocks with varies sizes of fragmented and mixes blocks can be observed in the soil profiles (Figure 3). The rock blocks still exist in the soil profile due the high resistant of rocks with the weathering process. The main structure of the mélange is admixtures of varies size of rocks with shale matrix which is spreading through the soil profiles. The nature of the rock blocks is very heterogeneous which is consists of metamorphic rock, serpentinite, basalt, limestone, chert and sandstone from older formations. Almost all the classified rock units under these assemblages contain the same rock associations with varying percentage amount the units. The major matrix component is composed of pervasively sheared shale and the slicken side of hard rock material can be observed for most of the outcrops (Figure 4). The highly sheared rocks and slicken side structures indicated that the intense tectonic deformation has occurred in this area.

Figure 2. Thick soil profile outcrops from weathered mélange materials.
Figure 3. The admixtures of rocks with shale matrix spreading through the soil.

Figure 4. The major matrix component is composed of (a) pervasively sheared shale and (b) sheared hard rock as indicated by the slicken side structure.

3.2 Slope failure of mélange

The field observations of outcrops in study area mainly along the main road from Miles 32 to Sandakan Town, Sabah, shows the occurrences of mass movements that cause the road damage (Figure 5). This is might be due to the weak condition of soil structure and less hard rock unit of continuity of rock in the melange. Lack of internal bedding or continuity of rock layer contacts
because of high strata disruption is interpreted as units ‘chaotic’ [6]. Several instability history can be found in most of the outcrops shown by the deposits of talus and blocks on the toe of the slope (Figure 5a and 5b). Landslides occurrences can be observed through damage on retaining walls and road (Figure 5c and Figure 5d) and tilted of electrical power poles (Figure 5e) as among of the main geotechnical problem in the study area.

Figure 5: Occurrences of mass movements of clayey soil originated from mélange in the study area (a) Slope failure of oil palm plantation; (b) Blocks of sandstones and chert found in the study area; (c) Major landslide that caused serious damage to the retaining wall and road; (d) The displacement of road due to the instability of land; (e) Tilted electricity poles indicates mass movement.

3.3 Soil Physico-Chemical Properties
Table 1 shows the results of analysis for moisture content, organic matter content, specific gravity, pH, sorting characteristics and soil classification for twelve soil samples collected from mélange
materials in the study area. Based on the result, the soil moisture content was at the range of 7.00% to 23.38%; the soil organic content range from 1.10% to 3.08%; the soil specific gravity at the range of 2.09 to 2.61, and the average pH value was from pH 4.80 to pH 9.58. Most of the samples show the acidity to neutral soil, whereas S7, S9 and S10 were basic soils due to the existence of carbonate rocks as one of the parent rocks in the particular outcrops. Sample S6 shows the highest moisture content and soil organic content which was 23.38% and 3.08% respectively, while S4 shows the highest specific gravity (2.61). The specific gravity tests were conducted to determine the density of each soil sample by calculating the ratio between the mass of dry soil and distilled water. Based on [12] classification, the soil samples classified as clay soil except S6 (clayey sand), S8 and S11 (silt with sandy clay) and S10 (sand with silty clay). Most of the soil has poorly sorting textures indicated of various sizes of soil particles.

Table 1. Physico-chemical properties of soil samples

| Sample | Moisture content, Wo (%) | Soil organic matter content, OM (%) | pH | Specific Gravity, SG | Sorting | Soil classification |
|--------|--------------------------|----------------------------------|-----|----------------------|---------|---------------------|
| S1     | 16.05                    | 1.11                             | 7.45| 2.60                 | Well    | Clay                |
| S2     | 20.75                    | 1.32                             | 7.60| 2.58                 | Poorly  | Clay                |
| S3     | 22.10                    | 2.12                             | 5.25| 2.57                 | Poorly  | Clay                |
| S4     | 16.00                    | 2.32                             | 4.80| 2.61                 | Poorly  | Clay                |
| S5     | 15.26                    | 1.10                             | 7.51| 2.58                 | Poorly  | Clay                |
| S6     | 23.38                    | 3.08                             | 5.97| 2.09                 | Poorly  | Clayey Sand         |
| S7     | 19.17                    | 1.30                             | 8.48| 2.17                 | Poorly  | Clay                |
| S8     | 16.02                    | 2.71                             | 7.20| 2.15                 | Well    | Silt with Sandy Clay|
| S9     | 7.00                     | 1.99                             | 8.88| 2.29                 | Poorly  | Clay                |
| S10    | 10.16                    | 1.70                             | 9.58| 2.22                 | Poorly  | Sand with Silty Clay|
| S11    | 13.73                    | 1.59                             | 7.09| 2.21                 | Well    | Silt with Sandy Clay|
| S12    | 21.93                    | 1.78                             | 7.64| 2.12                 | Poorly  | Clay                |

3.4 Atterberg’s Limit of Soil Samples

The result of Atterberg’s limits tests for twelve soil samples are given in Figure 6. Atterberg’s limits consist of plastic limit test, liquid limit test and soil plasticity index. Soil conditions can be divided into four phases, namely solid, semi-solid, plastic and liquid [12]. Based on the analysis, average liquid limit of clayey soil sample various from 45.1% to 59.8%. Average plastic limit ranges from 21.48% to 33.49%, while the plasticity indexes were in the range of 23.25% to 33.91%. The plasticity chart of soil shows that S9 was classified as low plasticity soil, while S1, S5, S10 and S11 were classified as intermediate plasticity; whereas the others samples were classified as high plasticity (Figure 6). Based on the clay activity analysis it was found that all soil samples are classified as inactive clay except for S2 soil which classified as normal clay.
3.5 Mineralogical Identification

The result of XRD analysis shows that the main mineral content in soil consists of quartz, kaolinite and illite as shown in S1 and S5 (Figure 7). Other minerals also were observed such as ferum oxide minerals (maghemite and hematite) and calcite were found in carbonate rocks as in S9 and S10 (Figure 8). The existence of the minerals was due to the origin of parent rocks in mélange. The field observation shows the appearance of block with different size as ultramafic, basalt, chert, sandstone and carbonate rock. The micro morphology and microstructure of soil from SEM images showed the presence of layered kaolinite and finer needle-like illite as dominant secondary minerals. The quartz mineral also can be observed the SEM images.

Figure 6. Plasticity chart of soil samples

Figure 7. The X-Ray Diffractograms analysis and Scanning Electron Microscope images showed the appearance of quartz, kaolinit and illite as main minerals in S1 and S5
Figure 8. The X-Ray Diffractograms analysis showed the appearance of ferum oxide minerals and calcite in S9 and S10.

4. Conclusion

The field observations show the study area mostly covered by melange deposit which in consists of fragmented mixed rocks with different sizes and originated from serpentinite, basalt, chert, carbonate and sandstone. These materials commonly embedded in shale matrix and highly sheared.

The physico-chemical analysis shows the moisture content was in the range from 7.0% to 23.38%, and plasticity indexes between 6.32% to 34.18%. The soil can be classified as intermediate plasticity to high plasticity, whereas the texture of soil classified as clayey sand, silt sandy clay, sand silty clay and clay soil.

The mineralogy of the soil mainly contains of quartz, kaolinite and illite. Other minerals also were observed such as maghemite, hematite, chlorite and calcite. These various minerals composition shows many types of parent rocks.

The physico-chemical properties and mineral content of soil originated from mélangé material indicated that the slope failure in the study area mainly controlled by loose particle material in the mélangé and high moisture-adsorption clay minerals with high plasticity index.

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