Stability Assessment of Pinousuk Gravel Slopes from Mesilou, Kundasang, Sabah

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Abstract. The matrix of four slopes of Pinousuk Gravel from Mesilou, Kundasang, Sabah namely S1, S2, S3 and S4 were collected for physical and engineering analysis. The slope stability analysis is conducted by using Fellenius slicing method. Pinousuk gravels which originated from the glacial deposits of Mount Kinabalu during Pleistocene age consist of mixture of various sizes and types of rocks such as ultrabasic rocks and granodiorite. Engineering properties of slope’s matrixes show high to very high plasticity with the appearance of smectite and illite as clay minerals. Based on direct shear test, value of cohesion (c), friction angles (°) and shear strength (τ) of the slopes can be obtained. The results show the value of shear strength range from 7.5 kPa (S3) to 13 kPa (S2), while friction angles range from 11° (S3) to 22° (S2) and the cohesion values range from 2.1 kN (S2) to 3.1 kN (S1). Slope is considered stable if the value of factor of safety (FoS) is ≥ 1 and indicates unstable if it is less. S1, S2 and S4 are considered as stable slopes with FoS value ranges from 1.09 to 1.45. S2 is the most stable slope due to its highest friction angle and shear strength of the matrixes among bigger size of ultrabasic fragments which increase the interlocking between particles. While S3 which is dominated by smaller ultrabasic fragments is considered as unstable with FoS value of 0.97 due to the lowest shear strength and friction angle which encourage the collision between particles for slope failure to occur.

1. Introduction
Failures of natural slopes (landslides) or man-made slopes have resulted in many losses and damage either in fatalities, infrastructure destruction and economic losses. Slope stability assessment is conducted to analyse the safety of human made or natural slope design. Slope stability is the resistance forces (from the material’s shear strength) of inclined surface to failure due to the gravity by colliding or sliding between materials and failure planes. It primarily is controlled by material properties, water content and foundation strength. Slope assessment requires several information such as the properties of the materials (soil/rock mass), slope geometry, groundwater condition, existence of discontinuities, occurrences of earthquake activities and appearance of vegetation [1-2] as these will influenced to the occurrence of slope failures. Few types of slope failure that commonly occur in soils such as flow, translational slide, block/wedge slide and rotational slide. Rotational failure refers to material sliding along a curved surface and divided into circular and non-circular failures.

Circular failures are commonly associated with homogenous soil condition or very small particles compared to the size of the slope which generally observed in soil slope, weak rocks and highly
jointed rock mass. These parameters are required for the assessment of the slope stability against circular failure [3] which are the location, orientation and shape of a potential or existing failure, the distribution of the materials within and beneath the slope, types of material, drainage conditions, the distribution of piezometric level along the potential failure surface and slope geometry to its full height. Depends on the slope’s steepness, failure plane is deep with range of maximum thickness and maximum length of slide along the slope.

There are many methods used for slope stability analysis including kinematic analysis, limit equilibrium analysis and rock fall simulators [4-5]. Limit equilibrium method is conducted to study the equilibrium of tendency of soil mass to slide the slope under the influence of gravity. Most conventional slope stability analysis is using the arc of a circle as the curve of potential sliding where the soil mass above the surface of sliding is considered as a whole (assumed the slope is homogenous) or been divided into a number of vertical parallel slices where the stability of each slice is calculated separately.

1.1. Research Area Background

The study area consists of Trusmadi Formation aged of Paleocene to Middle Eocene which is overlain with unconformity by Crocker Formation of Late Eocene to Middle Miocene [6]. The youngest rock unit is Pinousuk Gravel which transported during Pleistocene age due the glacial event from Mount Kinabalu [7] before widely deposited at Pinousuk Plateau. Quaternary alluvium comprises of sediments with bad to good sorting, soft, incompressible and tend to deposit on lowlands area [8-9] (Figure 1).

![Figure 1. Geological map of the study area](image)

Trusmadi Formation has been divided into two parts and named as Slate Formation and Phyllite Trusmadi Formation [10] where it comprises of turbidite deposits, arenite flow with volcanic and argillite rocks; grey to dark greyish of shale or mudstones; which has metamorphosed by low green schist facies [11-13]. It consists of fine schist grains with quartz veins due to tectonic process [14] which formed fractures and later filled by quartz crystals. Crocker Formation was formed from sediments of Crocker Range which is submarine fan (deep marine) deposition comprises of
sandstones, shale and interbedded of sandstone and shale [15-16]. Crocker Formation usually comprises of fine to coarse grains of jointed sandstones and layers of sheared red or grey shale [8-9]. Pinousuk Gravel is known as tilloid deposits which comprises of materials transported by glacier from Mount Kinabalu and its surroundings such as granite blocks embedded in mud and sand matrixes [14]. It is divided into two units namely Lower Unit and Upper Unit based on its size, roundness and sphericity of the materials [6]. Angular sandstones and ultrabasic rocks which deposited due to the glacial transportation is classified as Lower Unit while Upper Unit is characterized with rounded granodiorite due to the deposition of mudflow during meltdown glacial activity [12].

The study area is prone to landslide occurrences. Kundasang consists of Mensaban fault zone with 12 km width and 110 m length in radar image [17]. The fault has cut across Pinousuk Gravel during Quaternary age thus accelerates the mass movement at the intersection of Crocker and Mensaban faults. Landslides in Kg. Mesilou, Kundasang were influenced by geological factors such as high topography, active fault zone and unconsolidated Pinousuk Gravel unit which underlie the area. Loose, porous, highly weathered and vulnerable Pinousuk Gravel is considered weak materials which caused landslides in the study area [18-19]. Therefore, the objective of this research is to assess the Pinousuk Gravel slopes by study the physico-chemical and engineering properties of the matrixes and its slope stability.

2. Materials and Methodology

Four (4) slopes from Pinousuk Gravel unit were collected from different types of soil lithology where S1 is dominated soil from various types of rocks such as ultrabasic, sandstones and chert with 1 meter rock diameter; S2 consists of mixture of fragments-matrix originated of ultrabasic rocks with size of fragment up to 1 meter while S3 is dominated of less than 30 cm smaller fragments of ultrabasic rocks; S4 consists of soil from granodiorite with size of blocks up to 1-2 meters long (Figure 2). Previous research is been conducted in the early study to understand the study area and related methodology to be used for this study. Base map and geological maps are produced before fieldworks started. Base map contains geographical information such as stream, topography and transportation system while the geological map shows the distribution and boundary of rock units in the study area. Field investigations including slope observations which is to record the slope orientation, angle, length, height, fragments size, occurrences of seepage and the extent of vegetation of the slope area.

Soil samples (matrixes) were collected from each slope to undergo laboratory analysis. The laboratory analysis includes physico-chemical properties (moisture content, organic content, pH value, particle size distribution, specific gravity and Atterberg Limits) and direct shear test for engineering properties purpose. Both physico-chemical and engineering properties were followed British Standard 1377:1990 methods [20]. Direct shear test is conducted to determine the shear strength parameters which are the friction angle (ϕ) and soil cohesion (c). Soil samples were initially compacted before being compressed with 1 kg, 5 kg and 10 kg of weights. The graph of shear stress over normal load is produced where cohesion value is obtained on the intersection of straight line with shear stress axis; while friction angle is acquired by measuring the angle between the best intersection line with load axis.

For slope stability analysis, limit equilibrium analysis namely Fellenius slicing method [21] is used to calculate the factor of safety (FoS) of the slopes. Each slope is been sliced to several slices (Figure 3A) where the FoS is calculated by using this formula = Σ (CL + (W cos α - μL) (tan ϕ)) / Σ W sin α; where: c = soil cohesion, ϕ = friction angle, W = weight of slice, α = slope angle of slice’s base, μ = water force and L = length of slice’s base (Figure 3B). If the FoS value is more than 1, the slope is classified as stable; whereas less than 1 of FoS value is classified as unstable slopes.
Figure 2. Slopes in the study area: (A) ultrabasic soil dominated; (B) large fragmented up to 1 metre size; (C) smaller fragments no less than 30 cm; (D) granodiorite-originated soil slopes

Figure 3. (A) Slicing method used to analyse the stability of soil slope; (B) Forces act on each slice

3. Results and Discussions

3.1 Physico-chemical Properties
Table 1 below shows the physico-chemical properties of soil samples from four (4) Pinousuk Gravel slopes in the study area. Based on the result, it is found that the moisture content was at the range of 42.93% to 81.15%, organic content was in between of 1.53% and 6.63% and pH value was 4.53 to 7.93. Soil S1 shows the highest content of moisture and organic matter (81.15% and 6.63% respectively) which contributed to most acidic value (pH 4.53) where Ca, Mg and K cations leached
out during weathering process and left more stable materials such as Fe and iron oxide [22]. Specific gravity test is conducted to determine the density of each soil sample by calculating the ratio between the mass of dry soil and distilled water. The value of specific gravity of the soil samples at the range of 2.43 to 2.56 where lower specific gravity is influenced by the existence of organic matter [23-24]. The triangular chart classification indicates that soil S1 and S3 are best classified as silty & sandy clay, S2 is sandy clay while S4 is a clay texture soil [25] (Figure 4).

Based on plasticity chart classification, the soil plasticity can be classified as high (S1, S4) and very high (S2, S3) with non-active to active clay activities [26] (Table 2) (Figure 5). The existence of expansive minerals even in small quantities, it could expand and increase the plasticity of soil particles [27].

### Table 1. Physico-chemical properties of soil samples

|                | S1       | S2       | S3       | S4       |
|----------------|----------|----------|----------|----------|
| Moisture Content (%) | 81.15    | 42.93    | 77.51    | 43.51    |
| Organic Content (%)    | 6.63     | 1.53     | 5.30     | 2.84     |
| pH Value                | 4.53     | 7.98     | 6.37     | 5.43     |
| Specific Gravity       | 2.43     | 2.56     | 2.48     | 2.46     |
| % Sand                  | 28.91    | 60.34    | 34.39    | 48.56    |
| % Silt                  | 44.99    | 7.83     | 36.45    | 21.09    |
| % Clay                  | 26.10    | 31.83    | 29.16    | 30.35    |
| Soil Texture Classification | Silty & Sandy Clay | Sandy Clay | Silty & Sandy Clay | Clay |

![Figure 4. Triangular chart shows soil samples texture classification](image)

### Table 2. Result of the Atterberg’s Limit of soil samples

|                | S1       | S2       | S3       | S4       |
|----------------|----------|----------|----------|----------|
| Plastic Limit  | 33.52    | 56.78    | 55.71    | 50.89    |
| Liquid Limit   | 64.00    | 82.00    | 71.90    | 64.20    |
| Plasticity Index | 30.48    | 25.22    | 16.19    | 13.31    |
| Soil Plasticity Classification | High | Very High | Very High | High |
| Clay Activity  | 1.65 (Active) | 0.79 (Normal) | 0.44 (Non-active) | 0.59 (Non-active) |
3.2 Direct Shear Test

Soil samples are compacted before being tested with different weight of 1 kg, 5 kg, and 10 kg. Soil failure is determined by the failure axis which consists of normal pressure of vertical forces and shear pressure of horizontal forces. This test is conducted to obtain soil friction angle and cohesion value which are the crucial parameter of soil strength where it controls the soil stability on certain pressures onto [28]. Cohesion value is obtained from the forces which hold among particles while friction angle depends on the contact angle between particles [29]. Based on the analysis, soil cohesion shows the value ranges from 2.1 kN to 3.5 kN and range of friction angle is from 11° to 22° (Figure 6) (Table 3).

![Figure 5. Plasticity chart of soil samples](image)

![Figure 6. Graphs show the shear stress (kN) versus normal load (kPa) to indicate the cohesion value and friction angle for all soil samples](image)
Table 3. Result of direct shear test for soil samples from each slope

| Soil Cohesion, C (kN) | S1 | S2 | S3 | S4 |
|-----------------------|----|----|----|----|
| Friction Angle (ϕ)    |    |    |    |    |
| Soil Strength, τ (kPa)|    |    |    |    |

Soil from S2 shows the highest friction angle with 22° due to the high percentage of sand particles (60.34%) which increase the interlocking bond between particles from its angularity [30]. It has lowest cohesion with 2.1 kN due to lowest moisture content (42.93%) and fine particles (39.66%). This increase the matrix suction between soil particles with moisture film which enhance the bonding between particle [31] and increase the soil strength (13 kPa). While soil from S3 has high moisture content (77.51%) which reduce the matrix suction among particles thus reduce the cohesion and friction angle (11°), therefore provides S3 with the lowest strength with 7.5 kPa.

Differences in the size of fragments also contributed to the friction axis and interlocking angle between particles. S2 consists of much bigger fragments up to 1 meter in length (Figure 7A) compared to smaller size of fragments in S3 (Figure 7B) which reduce the friction angle and encourage the collision to occur among particles.

Figure 7. (a) Fragments size up to 1 meter in S2 contributed to higher angularity and frictional axis compared to (b) smaller size of fragments in S3 which encourage the particles collision.

3.3 Slope Stability Analysis

The slope stability method used for this study is limit equilibrium technique which is the Fellenius slicing method [21]. Slope failure occurs when moment of resistance force is lower than moment of moving force. The sliding mass above the failure surface is divided into a number of slices (Figure 8) where the forces acting on each slice are determined by considering the force and moment for each slices including the friction angle and the cohesion. By using this method, only soil weight, along with shear and normal stresses along the failure axis are considered. The output for this analysis is the factor of safety which is the ratio of the shear strength to the shear stress; where if it is less than 1.0, then the slope is considered unstable (Table 4).

Table 4. Result of slope analysis for each slope in the study area based on its factor of safety

|                | S1  | S2  | S3  | S4  |
|----------------|-----|-----|-----|-----|
| Factor of Safety (FoS) | 1.09| 1.45| 0.97| 1.41|
| Classification    | Stable| Stable| Unstable| Stable|
Figure 8. Slicing model analysis for each slope in the study area

From Table 4, slope S1, S2 and S4 are classified as stable slopes based on the value of factor of safety which is 1.09, 1.45 and 1.41 respectively, whereas slope S3 is considered as unstable due to the value of FoS is less than 1.0 (FoS 0.97).

Slope S2 shows the highest factor of safety with 1.45. The slope face is covered with surface vegetation with clear water passage due to the dominance of sand particles of 60.34% which prevent the absorption for water accumulation. This has reduced the cohesion among soil particles though the appearance of smectite increased the plasticity of S2 (Figure 9A). The bigger fragments of ultrabasic rocks in S2 show strong interlocking which binds the materials even for a steep 70° slope angle; where it contributed to high friction angle among particles in slope S2.

Slope S3 is considered unstable due to the FoS is less than 1.00. Matrixes in S3 are dominated with finer particles (65.61%) which possess the ability to absorb water. This decrease the friction angle among particles as the smaller size of rock fragments of slope S3 are easy to collide on the failure axis due to the existence of microfractures (Figure 9B), connected pores and clays.

Slope S1 and S4 were divided into 6 and 5 slices with 3 and 4 meters width respectively, for each slice. The factor of safety shows value of 1.09 for S1 and 1.41 for S4 which both are classified as stable. High cohesion of 3.5 kN with high plasticity in S1 contributed to strong cohesiveness among particles due to the appearance of ferum oxide minerals [32] such as antigorite (Figure 9C). However, the high content of moisture with existence of active clay activities may increase the water absorption thus accelerates the potential of slope failure in S1. Slope S4 is considered safe due to the slope height is less than 4 meters with low moisture content and good grading among particle sizes. Friction angle
and cohesiveness among particles in S4 makes the slope stable when the collision ability is reduced. However, the existence of pores (Figure 9D) may lessen the strength as failure plane is provided [33].

![Figure 9] SEM microphotographs show (A) the appearance of smectite which increase the soil plasticity in S2, (B) the microfractures in S3, (C) the appearance of ferum oxide which increase the water absorption in S1 and (D) the existence of pores as failure plane in S4.

4. Conclusions
The study area consists of Trusmadi Formation, Crocker Formation, Pinousuk Gravel and Alluvium Quaternary which focused on Pleistocene aged, tilloid deposits Pinousuk Gravel. Four slopes have been chosen where S1 have the highest moisture content (81.15%) and organic content (6.63%); and the lowest specific gravity (2.43) and most acidic (pH 4.53). S1 and S3 are classified as sandy and silty clay while S3 is sandy clay and S4 is clay soil. All samples show high to very high plasticity due to the existence of finer particles and expansive clays such as smectite and illite.

Based on direct shear test, the value of shear strength range from 7.5 kPa (S3) to 13 kPa (S2), while friction angles range from 11° (S3) to 22° (S2) and the cohesion values range from 2.1 kN (S2) to 3.1 kN (S1). Slope S1, S2 and S4 are considered as stable slopes with FoS value ranges from 1.09 to 1.45 where S2 is the most stable slope due to its highest friction angle and shear strength of the matrixes among bigger size of ultrabasic fragments which increase the interlocking between particles. S3 is considered as unstable with FoS value of 0.97 due to the lowest shear strength and friction angle which is dominated by smaller ultrabasic fragments which encourage the collision between particles for slope failure to occur. However, slope S1, S2 and S4 has potential to fail due to the existence of microfractures, pores and expansive clay minerals which acted as failure plane for particles collision.
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