RESEARCH ARTICLE

European Journal of Environment and Earth Sciences
www.ej-geo.org

Soil Characterization Based on Physical and Mechanical Properties of Pliocene-Pleistocene Geology in Bukidnon Philippines

Cheryl F. Daleon

ABSTRACT

Soil characterization is important since it gives an idea of the state of soil in the field. Moreover, Philippine geology map shows a vast area of Pliocene-Pleistocene classification, where until now no up to limited study presented the soil characteristics of this type of geology. These soil characteristics are essential for engineering purposes like design, land development, slope stability, disaster risk mitigation, stabilization, and other relevant utilization. In addition, it identifies if the soil in the site is problematic like being expansive or collapsible. In this study, the soil from thirty sampling locations in the two barangays of Kibawe, Bukidnon with Pliocene-Pleistocene geology is characterized based on their physical and mechanical properties. The results showed that the soil in this geology is classified as fine-grained soil with other locations as gap-graded. The plasticity index (PI) varies from 14.11-71.28%, which indicates medium to very high plasticity. The liquidity index (LI) of the soil varies from 0.12 to 0.96 which means that the soils at their in-situ water content are in the plastic state of intermediate strength and can be deformed like a plastic material. Based on USCS, there are four soil types CH, MH, CL and ML while based on AASHTO soil classification system it belongs to A-7-5 and A-7-6 groups with moderate and high plasticity, respectively. Majority of the soils under this geology are highly expansive and have a high tendency to swell. On the other hand, it has 25 locations that are non-collapsible soil and only 5 are collapsible. In terms of cohesion-PI relationship, it shows that the cohesion value increases with the increasing value of PI. However, the friction angle for CL and ML decreases with increasing PI; while the friction angle for CH and MH increases with increasing PI. While some laboratory tests are expensive, these results may help estimate the soil properties and shear strength from other locations with the same geology.

Keywords: engineering properties, geology, Pliocene-Pleistocene, soil characterization.

Published Online: April 15, 2022

ISSN: 2684-446X

DOI :10.24018/ejgeo.2022.3.2.272

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I. Introduction

Soil characterization is essential as it gives geotechnical engineers, land developers, and other end-users an idea of the actual condition of the site. Hence, one can establish a technique for dealing with the field conditions for engineering purposes. Moreover, problems on soil such as expansiveness and collapsibility potential which are one of the contributing factors to construction issues can be determined from its physical and index properties. The shear strength parameters which are the cohesion and friction angle are also important
factors in slope stability, landslide susceptibility assessment, and disaster risk mitigation which are currently of government concern.

On the other hand, Philippine geology map shows a vast area of Pliocene-Pleistocene class. However, up to now, there is no limited literature on the engineering properties of soil in this type of geology. Data from this study would mean no guarantee as to the exact similarity of soil properties of the same geology but may give a good estimate of its characteristics which can be necessary in the preliminary phase of engineering projects.

II. Review of Related Literature

A. *Study Site*

The study area covers the two barangays namely Kiorao and New Kidapawan in the municipality of Kibawe, which is located in the province of Bukidnon in Region X Northern Mindanao, Philippines. The municipality of Kibawe is situated about 63 km south-south-west of the provincial capital which is the City of Malaybalay and about 894 km south-south-east of Philippine main capital Manila. Moreover, its type of geology is a Pliocene-Pleistocene class as shown in Fig. 1.

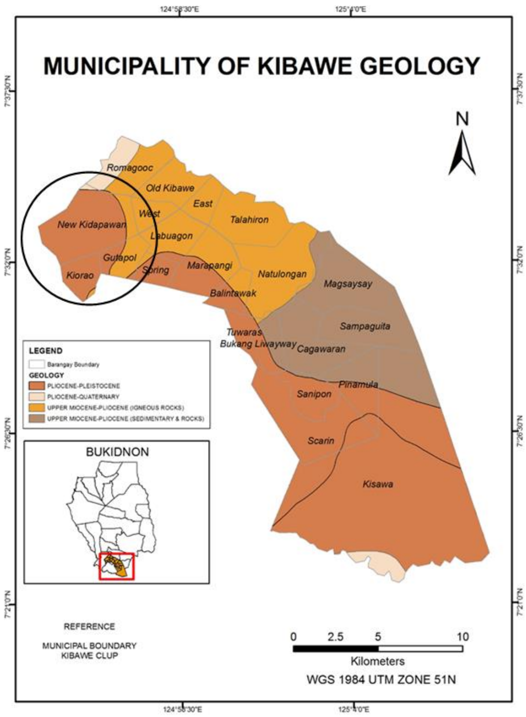

Fig. 1. Kiorao and New Kidapawan, Kibawe, Bukidnon in the Geology Map.

B. *Pliocene-Pleistocene Geology*

Geology is important for successful geotechnical engineering practice. One of the primary tasks of a geotechnical engineer is to understand the character of the soil at a site. Soils, derived from the weathering of rocks, are very complex materials and vary widely. There is no certainty that soil in one location will have the same properties as the soil just a few centimeters away. Unrealized geological formations and groundwater conditions have been responsible for the failures of many geotechnical systems and increased construction costs [1].

The generally low temperatures experienced during the past 2 to 2.5 million years represent the Pliocene - Pleistocene glaciation. During the Pliocene-Pleistocene there have been 5 distinct glacial periods, each lasting around one hundred thousand years, and 5 inter-glacial periods. Actually, it is 6 if you count the present warm stretch as an “interglacial” and take the view that there is likely to be more ice to come [2].

Most of the deposits associated with the Pliocene-Pleistocene glaciation are only 10,000 to 15,000 years old (largely because most of the earlier Pliocene-Pleistocene deposits were eroded by subsequent ice advances), and they are generally unconsolidated. Most were deposited in areas that were under ice or underwater but are now exposed on dry land because the ice and its associated water bodies are gone. Because glacial deposits are exposed on land (as steep cliffs in some cases) and because they are unconsolidated, they are especially prone to failure as slumps and slides [2].

III. Methodology

A. *Soil Sampling*

Soil sampling was equally important as soil testing since these samples represent the characteristics of the soil found in the area or in the field. A total of 30 sampling points were distributed throughout the study area. A GPS was used to identify the location (latitude, longitude – elevation included) of the sampling points.

Fig. 2 shows the location of the study with the specific sampling points. The locations were predetermined by pinning points through the GIS, where the working map was produced. Changes of some sampling points were made during the actual sampling since it was found out that some points were not accessible.

B. *Laboratory Tests*

Comprehensive laboratory tests were conducted to determine the physical and mechanical properties of soil. The testing program was composed of physical property tests, which include the index property tests, and direct shear test. The physical properties were moisture content (ω), unit weight (γ) and grain size distribution. The index properties were liquid limit (LL), plastic limit (PL), liquidity index (LI), plasticity index (PI). The test procedures were all based on the ASTM standards.

1) *Physical Property Tests*

The physical properties of soil are considered the most important preliminary phase for every type of civil engineering work. These are essential in understanding the behavior of soil which are needed in the analysis of earth structures such as structural foundations, dams, and retaining walls.

The moisture (water) content of the soil was determined in accordance with ASTM D 2216 - Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures.

A soil sample was obtained through a thin-walled Shelby tube to determine the soil density and unit weight.

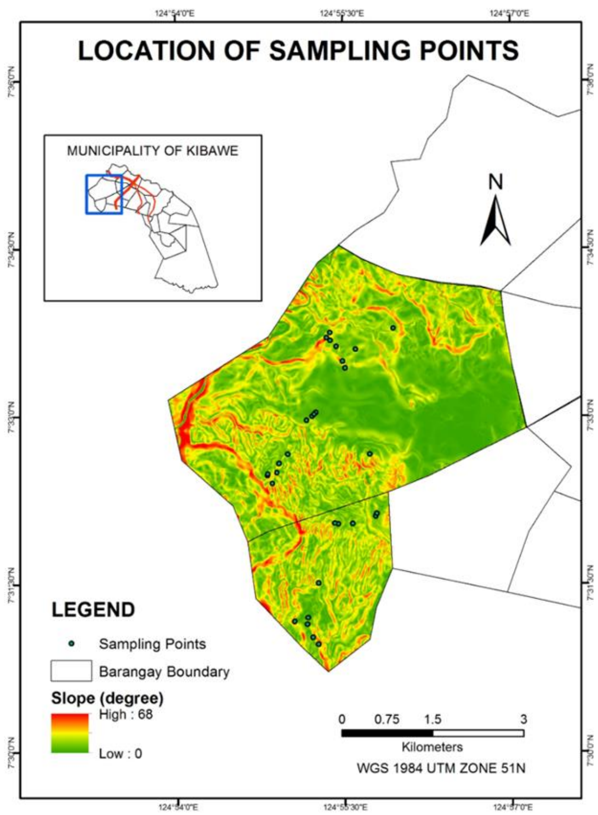

Fig. 2. Sampling locations in the study area.

Determination of the grain size distribution of the soil samples was based on ASTMD422 – Test Method for Particle-Size Analysis of Soils. The grain size analysis of the soil samples was conducted by sieve analysis.

Index tests were conducted by means of Atterberg limits test. The index properties of the soil in terms of liquid limit (LL), plastic limit (PL), plasticity index (PI), and liquidity index (LI). The method used to determine the Atterberg limits is the Fall Cone Method. It is usually considered to be a more scientific approach because it is baseless upon human judgment.

2) Soil Classification

The soils were classified according to ASTM D2487 - 11 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) and AASHTO soil classification. Classification was conducted by using Fig. 3 for USCS and a standard AASHTO table.

The soil was classified based on the results of sieve analysis, PI, and LL which resulted in groups and subgroups. Fig. 3 is the plasticity A chart for use in USCS, where the PI values were plotted against the LL values. The A-Line separated the clay soils (like CH and CL) from silts (like MH and ML). Fig. 4 was also used to determine the AASHTO soil classification where PI values were plotted against LL values.

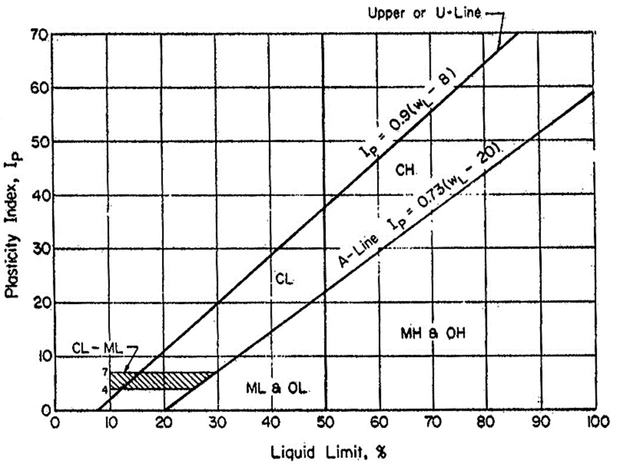

Fig. 3. Plasticity or A Chart used in Unified Soil Classification System.

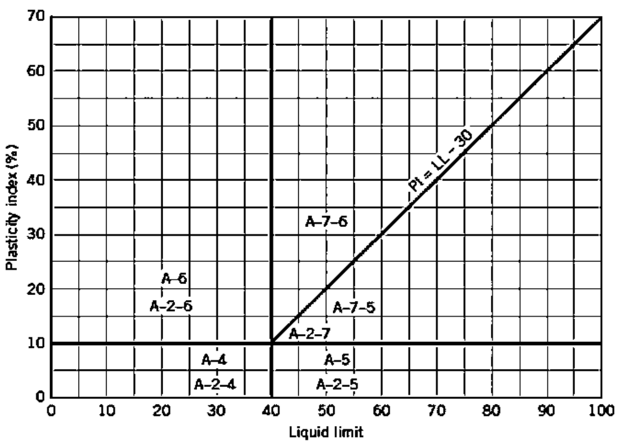

Fig. 4. Plasticity Chart used in AASHTO soil classification system.

3) Mechanical Property Test

The determination of cohesion and friction angle was conducted randomly based on the classification of soil. Out of the 30 soil samples, 20 are CH, 4 are MH, 3 are ML, and 3 are CL. Due to the expensive laboratory test in the determination of these parameters, only ten (10) were tested randomly selected from the samples.

4) Direct Shear Test

Determination of the shear strength of the soil sample was based on ASTM D 3080 - Standard Test Method for Direct Shear Test of Soils under Consolidated Drained Conditions. In this laboratory test, a direct shear device was used to determine the shear strength specifically the cohesion (c) and the friction angle (ϕ) of the soil. From the plot of the shear stress versus the horizontal displacement, the maximum shear stress was obtained for a specific vertical confining stress. After the experiment was run several times for various vertical-confining stresses, a plot of the maximum shear stresses versus the vertical (normal) confining stresses for each of the tests was produced.

IV. Results and Discussion

A. Physical Properties of Soil

The physical properties of soil in terms of water content, total unit weight, dry unit weight, and grain size distribution at different sampling locations are shown in Tables I and II.

1) Water Content, Density, and Unit Weight

It is important to determine the moisture content (ω) of soil since it will give an idea of the state of soil in the field. Changes in water content can directly impact slope stability since it influences the increase or decrease of the shear strength of the soil.

Moreover, unit weight (γ) is another significant factor that affects soil slope stability. Based on soil type classification by [3], Table I shows that the average value of dry unit weight (γ_d) for the entire geology is 10.77 kN/m^3 which was not clearly classified since this value falls between the range values of soft organic clay (6 - 8 kN/m^3) to soft clay (11.5 – 14.5 kN/m^3). However, considering the moisture content which is 43.83%, its soil type is classified as soft clay, where according to [3] that soil with in-situ moisture content of 30 – 50% is a soft clay.

2) Grain Size Distribution

The data on grain size analysis of soil is summarized in Table II. It shows that 27 out of 30 or 90% of soil samples have high fine content ranging from 54.81- 99.28%. They are classified as fine-grained soils since based on USCS if over 50% of weight passing the 0.075 mm or No. 200 sieve it is classified as fine-grained, otherwise it is coarse-grained soils. The coarse-grained soils from BH17, BH18 and BH26 soil samples with fine content of 41.45, 30.51 and 41.65%, respectively. Fine-grained soils have poor load-bearing capacities and poor drainage qualities, and their strength and volume-change characteristics are significantly affected by changes in moisture conditions.

The uniformity coefficient Cu varies from 8.68-72.32 except those soils from BH17, BH18 and BH26 with Cu of 98.76, 1,753.64 and 1,210.71, respectively. The coefficient of curvature Cc varies from 0.05 – 0.65. Cu must be >4 and Cc must between 1 to 3 to be considered as well graded soil. Cu values are all greater than 4, however Cc values are <1. Since it does not satisfy one of two criteria, it is instead termed as gap-graded. It means that soil has an excess or deficiency of certain particle sizes or a soil that has at least one particle size missing.

TABLE I: MOISTURE CONTENT, DENSITY AND UNIT WEIGHT

Sampling Code	Moisture Content (%)	Density (kg/m^3)	Total Unit Weight (kN/m^3)	Dry Unit Weight (kN/m^3)
BH1	49.71	1,533.96	15.05	10.05
BH2	46.51	1,728.45	16.96	11.57
BH3	43.68	1,709.91	16.77	11.67
BH4	43.89	1,572.59	15.43	10.72
BH5	43.13	1,721.80	16.89	11.80
BH6	46.19	1,656.20	16.25	11.11
BH7	62.97	1,575.44	15.46	9.48
BH8	48.63	1,616.81	15.86	10.67
BH9	48.24	1,550.66	15.21	10.26
BH10	44.21	1,640.98	16.10	11.16
BH11	44.68	1,586.37	15.56	10.76
BH12	49.75	1,632.65	16.02	10.70
BH13	42.33	1,654.61	16.23	11.40
BH14	43.25	1,416.61	13.90	9.70
BH15	37.28	1,559.47	15.30	11.14
BH16	56.63	1,660.00	16.28	10.40
BH17	32.03	1,645.74	16.14	12.23
BH18	29.72	1,522.67	14.94	11.52
BH19	52.53	1,455.18	14.28	9.36
BH20	37.62	1,584.89	15.55	11.30
BH21	48.75	1,583.94	15.54	10.45
BH22	44.39	1,428.91	14.02	9.71
BH23	53.91	1,462.17	14.34	9.32
BH24	29.83	1,613.02	15.82	12.19
BH25	54.88	1,553.83	15.24	9.84
BH26	18.61	1,426.60	13.99	11.80
BH27	40.00	1,591.62	15.61	11.15
BH28	43.20	1,509.45	14.81	10.34
BH29	36.74	1,511.82	14.83	10.85
BH30	41.52	1,522.44	14.94	10.55
Average	43.83	1,574.29	15.44	10.77

TABLE II: PARTICLE SIZE DISTRIBUTION OF SOIL

Sampling Code	Coefficient of Uniformity Cu	Coefficient of Concavity Cc	Textural Composition (%)		
			Gravel	Sand	Clay and Silt
BH1	11.00	0.62	0.00	10.25	89.75
BH2	8.74	0.65	0.00	0.72	99.28
BH3	9.61	0.64	2.28	2.62	95.10
BH4	8.89	0.65	0.07	1.44	98.49
BH5	9.74	0.63	0.00	5.48	94.52
BH6	8.68	0.65	0.00	0.42	99.58
BH7	13.07	0.60	0.00	16.27	83.73
BH8	14.80	0.58	1.49	18.65	79.86
BH9	10.60	0.62	0.43	8.41	91.16
BH10	11.34	0.62	7.61	3.76	88.62
BH11	10.25	0.63	3.32	4.19	92.49
BH12	22.85	0.53	5.60	25.62	68.78
BH13	11.37	0.62	0.21	11.25	88.54
BH14	9.47	0.64	0.82	3.44	95.75
BH15	9.13	0.64	0.66	2.05	97.29
BH16	10.55	0.62	0.00	8.67	91.33
BH17	98.76	0.64	0.03	58.52	41.45
BH18	1,753.64	0.16	49.17	20.32	30.51
BH19	9.89	0.63	0.57	5.52	93.91
BH20	9.99	0.63	1.08	5.43	93.49
BH21	11.45	0.61	3.64	8.10	88.26
BH22	9.93	0.63	1.38	4.88	93.74
BH23	9.25	0.64	1.63	1.63	96.74
BH24	72.32	0.32	16.88	28.30	54.81
BH25	12.24	0.61	0.48	13.59	85.93
BH26	1,210.71	0.05	36.31	22.04	41.65
BH27	19.50	0.55	2.36	25.19	72.45
BH28	21.82	0.54	18.55	11.65	69.81
BH29	65.58	0.32	8.99	34.51	56.50
BH30	12.93	0.60	0.00	15.92	84.08

The index properties of the soil in terms of liquid limit (LL), plastic limit (PL), plasticity index (PI), and liquidity index (LI) are shown in Table III. Fine-grained soils, mainly silts, and clays are classified according to their Atterberg limits. The plastic limit ranges from 13.15-39.88% or an average of 24.73%. It indicates that the soils are from silt to clay. The liquid limit ranges from 41.65-94.17%. These values are within the range of 40% -150% which indicates that the soil is clay. The plasticity index varies from 14.11-71.28%. These values are within the range of 10% to greater than 40% which indicates medium to very high plasticity [4]. It also means that the clay content of soil is high.

Lastly, the liquidity index can also describe qualitatively the soil strength in its natural state. In the same table, it was shown that LI of the soil varies from 0.12 to 0.96. This range is within 0 to 1.0 which means that the soils at its in-situ water content are in the plastic state of intermediate strength and can be deformed like a plastic material.

TABLE III. ATTERBERG LIMITS OF SOIL

Sampling Code	LL (%)	PL (%)	PI (%)	LI
BH1	64.9	36.29	28.61	0.47
BH2	67.7	20.9	46.80	0.55
BH3	74.99	19.67	55.32	0.43
BH4	75.98	28.02	47.96	0.33
BH5	58.79	13.15	45.64	0.66
BH6	73.87	23.16	50.71	0.45
BH7	65.02	37.52	27.50	0.93
BH8	50.57	14.56	36.01	0.95
BH9	56.36	36.75	19.61	0.59
BH10	68.14	16.77	51.37	0.53
BH11	94.17	34.09	60.08	0.18
BH12	68.27	16.59	51.68	0.64
BH13	47.38	31.10	16.28	0.69
BH14	68.27	16.59	51.68	0.52
BH15	79.08	25.93	53.15	0.21
BH16	57.93	24.78	33.15	0.96
BH17	45.06	19.94	25.12	0.48
BH18	54.98	23.12	31.86	0.21
BH19	89.74	29.86	59.88	0.38
BH20	86.33	30.55	55.78	0.13
BH21	80.09	20.87	59.22	0.47
BH22	78.27	39.88	38.39	0.12
BH23	89.12	17.84	71.28	0.51
BH24	42.21	13.43	28.78	0.57
BH25	56.81	16.02	40.79	0.95
BH26	41.65	16.99	24.66	0.07
BH27	44.57	26.73	17.84	0.74
BH28	74.87	32.43	42.44	0.25
BH29	47.15	33.04	14.11	0.26
BH30	52.53	25.29	27.24	0.60
Average	65.16	24.73	40.43	0.49

3) USCS and AASHTO Soil Classification Systems

Table IV shows the classification of soil based on USCS and AASHTO, the description based on physical features of soil as seen in the laboratory and the degree of plasticity.

Based on Table IV and Fig. 5, the Pliocene-Pleistocene geology in this study has four types of soils, namely: CH (fat clay), MH (elastic silt), CL (lean clay) and ML (silt). CH has high to very high plasticity; MH has medium to high plasticity; CL has high plasticity; and ML has medium plasticity. Among the soil samples, 13.33% have medium plasticity, 30% have high plasticity and majority or 56.67% have very high plasticity. Considering the average PI in the entire study area which is 40.83%, it indicates that Pliocene-Pleistocene geology within the study area has very high plasticity.

TABLE IV. SOIL CLASSIFICATION

Sampling Code	Soil Classification USCS	AASHTO	Degree of Plasticity
BH1	MH	A-7-5	High
BH2	CH	A-7-6	Very high
BH3	CH	A-7-6	Very high
BH4	CH	A-7-6	Very high
BH5	CH	A-7-6	Very high
BH6	CH	A-7-6	Very high
BH7	MH	A-7-5	High
BH8	CH	A-7-6	Very high
BH9	MH	A-7-5	Medium
BH10	CH	A-7-6	Very high
BH11	CH	A-7-5	Very high
BH12	CH	A-7-6	Very high
BH13	ML	A-7-5	Medium
BH14	CH	A-7-6	Very high
BH15	CH	A-7-6	Very high
BH16	CH	A-7-6	High
BH17	CL	A-7-6	High
BH18	CH	A-7-6	High
BH19	CH	A-7-6	Very high
BH20	CH	A-7-5	Very high
BH21	CH	A-7-6	Very high
BH22	MH	A-7-5	High
BH23	CH	A-7-6	Very high
BH24	CL	A-7-6	High
BH25	CH	A-7-6	Very high
BH26	CL	A-7-6	High
BH27	ML	A-7-5	Medium
BH28	CH	A-7-5	Very high
BH29	ML	A-7-5	Medium
BH30	CH	A-7-6	High

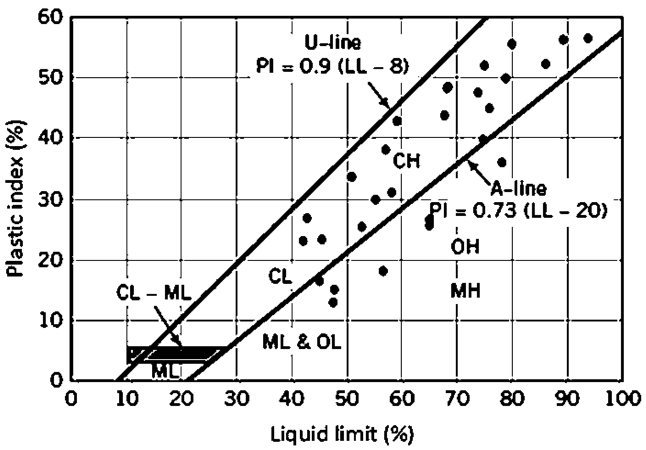

Fig. 5. Plot of PI vs LL to determine USCS soil classification.

Soil plasticity is a field indicator of slope stability. The engineering concept of soil plasticity has evolved to explain why some soils are more failure prone than others. Plastic soils exhibit clay-like behavior. Adding even modest quantities of water to such soils may cause unusually large and frequent slope failures [5]. Highly plastic inorganic soils are prone to sliding during rainfall events, due to the reduction of shear resistance [6], [7]. The same scenario plays out on the slopes of Mount Elgon, where highly plastic inorganic clays become susceptible to sliding even under moderate rainfall events [7].

Clays of high plasticity are highly expansive, more compressible and consolidate over a longer period of time under load than clays of low plasticity. Moreover, high-plasticity clays are more difficult to compact when used as fill materials.

On the other hand, based on AASHTO classification shown in Table IV and Fig. 6, the soil has A-7-5 or A-7-6 groups. For A-7-5 soil, it includes those materials which have moderate plasticity indexes in relation to liquid limit and which may be highly elastic as well as subject to considerable volume change. For A-7-6 soil, it includes those materials which have high plasticity indexes in relation to liquid limit which are subject to extremely high-volume change.

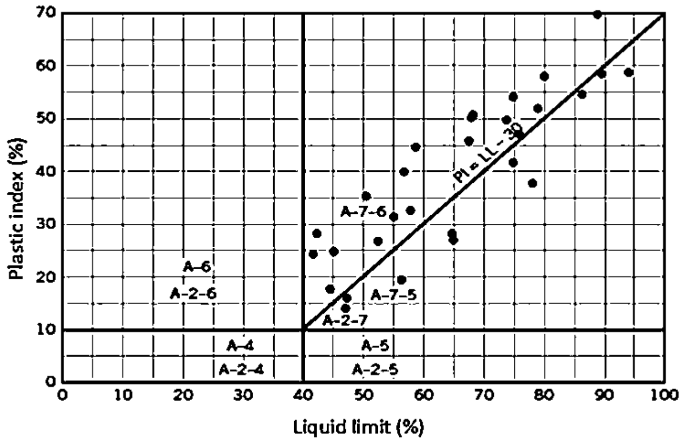

Fig. 6. Plot of PI vs LL to determine AASHTO soil classification.

4) Soil Type Based on BSWM

In addition to the above classifications, based on Soil Type Map from Bureau of Soil and Water Management (BSWM), the study area has two soil types which are: Kidapawan Clay and Macolod Clay as shown in Fig. 7.

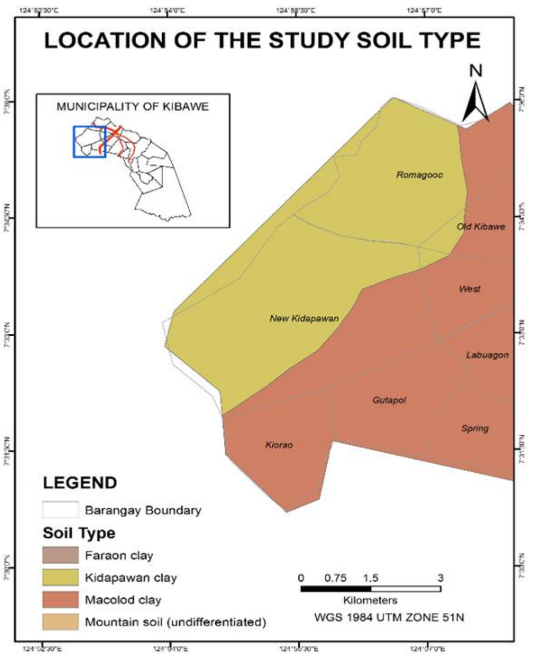

Fig. 7. Soil type of the study area from BSWM.

5) Expansiveness of Soil

According to literature, the expansive soils that may swell enough to cause pavement problems are generally clays falling into the AASHTO A-6 or A-7 groups, or classified as CH, MH, or OH by the Unified Classification System, and with a Plasticity Index greater than about 25 by ASTM D4318 [8]. It is clear from the laboratory test results that 86.67% of the soil samples have PI greater than 25 while 80% is classified under CH and MH. Hence, the majority of the soils under Pliocene-Pleistocene geology within the study area are

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highly expansive soils that have high tendency to swell.

The entire geology has an average LL of 65.16%. This value is within the range of 50-70% for a high degree of expansion IS 1498(1987), and >60% for a very high degree of expansion [9]. The average PI is 40.43% which is >35%, which indicates very high degree of expansion [9]-[11]. Expansive soils have the characteristics of loss of strength upon wetting. Its existence will eventually cause detrimental effect to structures. Accordingly, [12] stated that expansive soil slope instability occurs after heavy rains and landslide survey shows that rainfall and the rain infiltration are the main external cause of expansive soil slope instability

6) Collapsibility of Soil

Collapsibility is a characteristic of soil with an open structure formed by sharp grains, low initial density, low natural water content, low plasticity, relatively high stiffness and strength in the dry state, and often by particle size in the silt to the fine sand range [13], [14]. [14]. They added that in most cases collapsible soils contain over 60% of fines and have a porosity of 50% to 60%, a liquid limit of about 25, and a plastic limit ranging from 0 to 10.

However, the results of this study show that soils in this geology are highly plastic and with high water content. Its liquid limit ranges from 41.65% to 94.17% and plastic limit ranged from 13.15% to 39.88%. In addition, based on the results of the natural dry density and the liquid limit of the 30 soil samples as shown in Fig. 8; 25 samples are non-collapsible, and 5 samples are collapsible soil yet very close to the collapse potential curve. The collapsible soils are BH16, BH25, BH26, BH27 and BH53, respectively

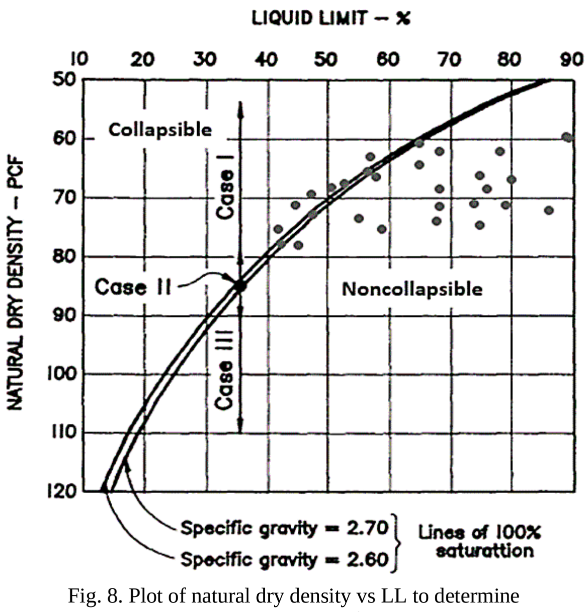

Fig. 8. Plot of natural dry density vs LL to determine collapse potential of soil.

Problems from non-collapsible soils can be attributed to other factors such as soil strength and plasticity. The engineering concept of soil plasticity has evolved to explain why some soils are more failure prone than others. Plastic soils exhibit clay-like behavior. Adding even modest quantities of water to such soils may cause unusually large and frequent soil failures.

B. Shear Strength Parameters

Table V shows values of shear strength parameters particularly the cohesion and friction angle from various soil classifications. It can be seen that the cohesion of different soil types has the following range of values: 19.8-24.6 kN/m^2 for CH; 11.4-30.9 kN/m^2 for MH; 19.6-20.6 kN/m^2 for CL; and 16.1-23.1 kN/m^2 for ML. Considering the average values of each soil classification on the same table, the result shows that CH has the highest cohesion value of 21.67 kN/m^2 while ML has the lowest value of 19.60 kN/m^2. It also shows that CH has the highest plasticity index while having the highest cohesion value. On the other hand, ML has the lowest plasticity index while having the lowest cohesion value. Therefore, the cohesion value increases with the increasing value of the plasticity index. It conforms to the behavior of fine-grained soils in which high plasticity soils tend to have higher cohesion value while low plasticity soils tend to have lower cohesion value. In addition, cohesion can also be correlated with slope angles as presented in the study [15].

TABLE V: SHEAR STRENGTH PARAMETERS OF SOIL

USCS	Sampling Code	Cohesion (kN/m^2)	Average Cohesion (kN/m^2)	Friction Angle (degree)	Average Friction Angle (degree)	PI (%)
CH	BH4	19.8	21.67	10.8	14.63	48.60
	BH19	20.6		16.9		
	BH28	24.6		16.2		
MH	BH1	11.4	20.0	16.9	13.53	28.53
	BH7	17.7		14.1		
	BH22	30.9		9.6		
CL	BH17	19.6	20.1	14.1	11.10	26.19
	BH24	20.6		8.1		
ML	BH13	16.1	19.6	15.7	11.85	16.07
	BH29	23.1		8.0		

The values of friction angle are: 10.80-16.9 degrees for CH; 9.6-16.9 degrees for MH; 8.1-14.1 degrees for CL; and 8.0-15.7 degrees for ML. Based on the average values,

Generally, friction angle decreases with the increase of PI value. Table V shows that for CL and ML soils, friction angle slightly decreases from 11.85 degrees to 11.10 degrees, with increasing PI. However, it shows that for CH and MH soils, friction angle increases with increasing PI. This relationship seems unusual, but it could imply that there are other parameters that can give better correlation of friction angle especially for highly plastic clay. The friction angles and PI values of two different clays as studied by [16] showed the same results in this study in two ways: first, the red and the grey Beaumont clays, like CL and ML, have almost the same friction angles with different PI values; second, like CH and MH, they have increasing friction angles with increasing PI.

The shear strength correlations of highly plastic clay soils in the previous study [17] stated that the data suggested the difficulty that may be encountered in correlating the effective stress friction angle to the plasticity index or the liquid limit for the red and the grey Beaumont clay. Both soils exhibited almost the same friction angle but had different Plasticity Indices and Liquid Limits. They added that based on the results of the study shown by [18], it is possible for two soils to have the same friction angle but different liquid limits, provided the soils have different clay size fractions. Unfortunately, results reported in the literature usually involve clays having clay size fractions greater than 50 percent as one group of soils with no further distinction.

It is suggested that clay size fraction and mineralogy are probably the most important parameters in estimating the residual friction angle [19], [20], [16].

V. Conclusion

The soil in the study site with Pliocene-Pleistocene geology is classified as soft clay. They are classified as fine-grained soils and some are gap-graded. It has medium to very high plasticity which means that the soils at its in-situ water content are in the plastic state of intermediate strength and can be deformed like a plastic material. Based on USCS and AASHTO, there are four soil types in this geology, these are CH, MH, CL and ML and belongs to A-7-5 and A-7-6 groups, respectively. The study area has two soil types, namely: Kidapawan Clay and Macolod Clay. In addition, in terms of cohesion-PI relationship, it shows that the cohesion value increases with the increasing value of PI. However, the clay size fraction and mineralogy are suggested as the important parameters in correlating friction angle.

Acknowledgment

C. F. Daleon thanks Central Mindanao University and Department of Science and Technology-Engineering Research Development for Technology (DOST-ERDT) for the support of this study.

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