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Compressibility characteristics of Sabak Bernam Marine Clay

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Abstract. This study is carried out to determine the geotechnical properties and compressibility characteristics of marine clay collected at Sabak Bernam. The compressibility characteristics of this soil are determined from 1-D consolidation test and verified by existing correlations by other researchers. No literature has been found on the compressibility characteristics of Sabak Bernam Marine Clay. It is important to carry out this study since this type of marine clay covers large coastal area of west coast Malaysia. This type of marine clay was found on the main road connecting Klang to Perak and the road keeps experiencing undulation and uneven settlement which jeopardise the safety of the road users. The soil is indicated in the Generalised Soil Map of Peninsular Malaysia as a CLAY with alluvial soil on recent marine and riverine alluvium. Based on the British Standard Soil Classification and Plasticity Chart, the soil is classified as a CLAY with very high plasticity (CV). Results from laboratory test on physical properties and compressibility parameters show that Sabak Bernam Marine Clay (SBMC) is highly compressible, has low permeability and poor drainage characteristics. The compressibility parameters obtained for SBMC is in a good agreement with other researchers in the same field.

1. Introduction

Due to the rapid urbanization of Malaysia's city centre and around the world, there has been an increase in demand for developing areas nearby coastal plain. The development of housing and infrastructure has led to the discovery of new land and existing land reclamation. In conjunctions with rapid housing development, roads to connect remote areas with cities concurrently increase in demands. Major concern for construction nearby coastal plain is the problem with soft ground. Soft ground has caused many disasters due to high compressibility, low shear strength and poor drainage characteristics of the soft soil [1,2]. There are always two main problems regarding soft soil, namely stability and settlement. However, many practicing engineers have always forgotten the importance of solving settlement problems. Since 2010, statistics of geotechnical forensic investigation on problematic projects carried out by JKR summarized that 182 cases out of 252 forensic cases (approximately 72%) are related to the issue of ground settlement, while the remaining 28% are caused by other factors such as vibration, erosion, foundation failures and so forth [3]. Problems of compressibility occurred when a change in volume is induced in all soils when the external loads increase in soft soil which produce serious settlement problem. Therefore, pre-consolidation works are necessary to be carried out to accelerate the consolidation settlement thus to prevent future excessive post construction settlement and differential settlement that will lead to failure and instability of structure. Ground improvement must be performed before any construction is carried out to ensure that the soil has enough strength and bearing capacity to resist the load from structure. Various methods of ground improvement have been implemented nowadays such as preloading with surcharge [4], prefabricated vertical drain (PVD) coal bottom ash from power plants, bottom ash column [5] and lime and silica fume [6,7,8].

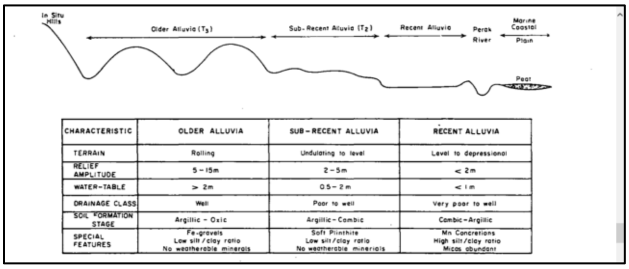
To have an efficient method of ground improvement, determination and interpretation of geotechnical properties of the soil are very crucial. Sufficient subsurface investigation with thorough monitoring by consultant engineer is crucial to ensure the SI carried out is convincing for further design of ground improvement [9]. The challenges in predicting settlements in highway embankments and reclamation works in marine, deltaic and estuarine type of deposits have been previously discussed [10]. The emphasis is on practical aspects and the difficulties experienced in confidently estimating settlements even after a century of developments and contributions. Interpreting soil parameters from laboratory and field test is important for settlement analysis. Some of the compressibility parameters are natural void ratio (e_o), preconsolidation pressure (P′c), overconsolidation ratio (OCR), compression ratio (CR) and recompression ratio (RR). All the abovementioned parameters always play major role in the settlement analyses. Many researches have been carried out in order to have more understanding in these parameters. However, the reported literature is different for all types of clay around the world [11,12]. To overcome the problem encountered in soft clay, knowledge and deep understanding about the engineering characteristics of soft clay are very important. The data will hopefully become a part of soft clay database in Malaysia. The result from this study can be referred by engineers as a useful guidance for construction on soft clay soil. The correlations produced could be used as a preliminary design for structure on soft clay soil.

2. Objective of Study

Objectives of this study are to determine the geotechnical properties and compressibility parameters of Sabak Bernam Marine Clay and carry out verifications of the compressibility parameters obtained for SBMC with existing correlation by other researchers.

3. Alluvial Soil Formation in Malaysia

A large acreage of soils in Peninsular Malaysia is derived from riverine alluvial deposits. The subrecent alluvial deposits of peninsular Malaysia consist of kaolinite, gibbsite, goethice, anatase, mica, chlorite and mixed layer. The most important mineral is kaolinite which contains more than 50% of the clay friction [13]. In the lowlands where alluvial soils dominate, the geomorphic surface and the groundwater table determine the soil type. The alluvial soil can be found along the east and west coast of Peninsular Malaysia. It is divided into two broad categories which are riverine deposits and marine, estuarine and brackish deposits [14]. The riverine deposits including colluvial and hill wash sediments are further divided into three categories, which are older, sub-recent and recent alluvia depending on the morphological and ages of the formation as shown in Figure 1.



CHARACTERISTIC	OLDER ALLUVIA	SUB-RECENT ALLUVIA	RECENT ALLUVIA
TERRAIN	Rolling	Undulating to level	Level to depressional
RELIEF AMPLITUDE	5 - 15m	2 - 5m	< 2m
WATER-TABLE	> 2m	0.5 - 2 m	< 1 m
DRAINAGE CLASS	Well	Poor to well	Very poor to well
SOIL FORMATION STAGE	Argillic - Oxic	Argillic - Cambic	Cambic - Argillic
SPECIAL FEATURES	Fe-gravels Low silt/clay ratio No weatherable minerals	Soft Plinthite Low silt/clay ratio No weatherable minerals	Mn Concretions High silt/clay ratio Micas abundant

Figure 1. Typical soil landscape of riverine soil deposits [14].

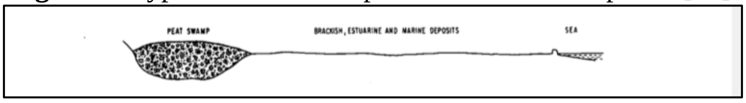


Figure 2. Typical soil landscape of Marine, Estuarine and Brackish deposits along coastal plain of west coast of Peninsular Malaysia [14].

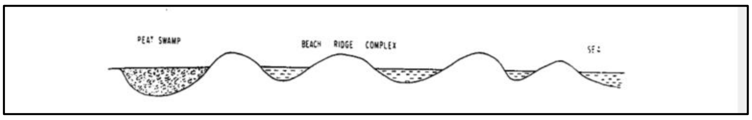


Figure 3. Typical soil landscape of Marine, Estuarine and Brackish deposits along coastal plain of east coast of Peninsular Malaysia [14].

Marine, estuarine and brackish deposits occur along the coastal plain of Peninsular Malaysia. At the west coast of Malaysia, due to present of Sumatera, calm seas condition causes the clayey soil to deposit along the coastal plain as shown in Figure 2. On the other hand, at the east coast of Peninsular Malaysia, due to strong waves of the open sea, the soil forms a series of beach ridges along the coastal plain as shown in Figure 3. Study by [15] on humus forms in alluvial soils, considered as young and heterogeneous environments. The soil structure formation is determined by both the nature of the recent alluvial deposits and the soil fauna. Paleosols formed from weathering of alluvial mudstones in the Late Cretaceous (Maastrichtian) Prince Creek Formation, North Slope Alaska, are dominated by detrital smectite, discrete illite, kaolinite, chlorite, quartz, and pedogenicillite–smectite mixed-layer clays [16].

3.1 Geological Formation of Study Area

The soil sample was obtained at Sungai Besar, Sabak Bernam, Selangor where the area is about 2 km from coastal plain of Malacca Straits as indicated in the Generalised Soil Map of Peninsular Malaysia, 1970 [17] in Figure 4. Based on the map, the area whereby the soil sample was obtained is classified as a clay soil with alluvial soil on recent marine and riverine alluvium as shown in Figure 5 [17,18]. The verification of the sampling location has been indicated in the map as shown in Figure 5. The physical appearance of the marine clay sample is as shown in Figure 6 which is greyish in colour. Study conducted by [19] revealed that Sabak Bernam Marine clay (SBMC) soils have high pH, high cation exchange capacity (CEC) – specific surface area (SSA) values, and high clay content with the presence of montmorillonite. SBMC soils contain montmorillonite, which is an active clay mineral that increases the CEC and SSA values. These values have contributed to maximum sorption capacity for SBMC soils.

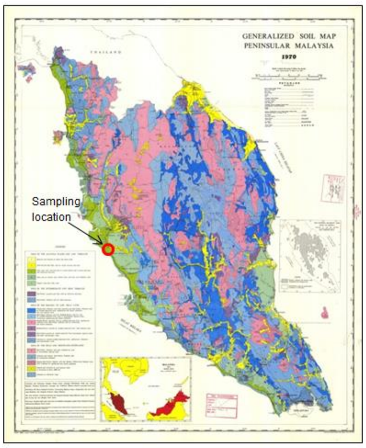


Figure 4. Generalised Soil Map of Peninsular Malaysia, 1970 [17].

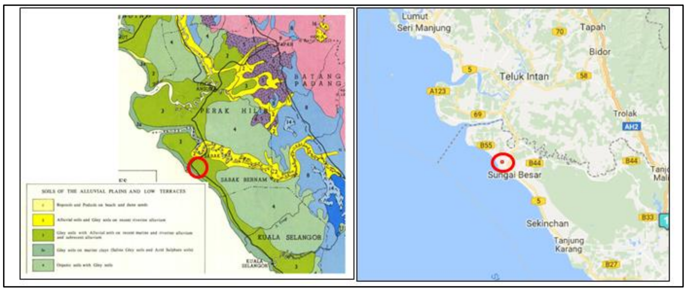


Figure 5. Location of Soil Sampling [17, 18].

4. Geotechnical Properties and Laboratory Compressibility Test

Determination of geotechnical properties of the SBMC is undertaken in this study. Laboratory test were carried out to determine the physical and compressibility properties of the SBMC as shown in Figures 7 to 9. Standard test method BS 1377:1990 is referred. Moisture content test was carried out to determine the natural moisture content of the soil taken from the site location. To prevent the loss of moisture, the soil was kept in a sealed container to the laboratory test for moisture content test. Sieving test was carried out to determine the particle size of soil passes the 0.063mm sieve size which is classified as a fine soil. Hydrometer test was performed on the soil particle passing 0.063mm sieve size to determine particle size distribution of fine-grained soil. Atterberg limit test was performed to determine the plasticity index and liquid limit of the soil. Two methods have been executed for determination of liquid limit of the soil namely cone penetrometer test and Casagrande test. Particle density test has been performed to determine the specific gravity of soil by using Pycnometer apparatus. On the other hand, for compression characterization of the soft soil, 1-D consolidation test was performed using Oedometer apparatus as shown in Figure 10.

Figure 6. Marine clay soil taken at Sabak Bernam Selangor.

Figure 7. Some of physical properties test setup.

Figure 8. Atterberg limit test.

Figure 9. Oedometer test.

5. Results and Discussion

5.1 Physical and Chemical Properties of Sabak Bernam Marine Clay

Particle size distribution of fine soil and plasticity chart as shown in Figure 10 indicated that the soil is classified as CLAY with Very High Plasticity, CV. From the plasticity chart, the test results are recorded to be above the A-Line. The summary of soil parameters from physical properties tests are shown in Table 1. Moisture content and liquid limit of the soil is high which are 80% and 79% respectively indicated that the soil is highly compressible. The plasticity index is 48%. Results obtained were compared with other marine clay properties in South East Asia [20] as shown in Figure 11. It is shown that the physical properties of SBMC sample in this study is in the range of other marine clays in South East Asia.

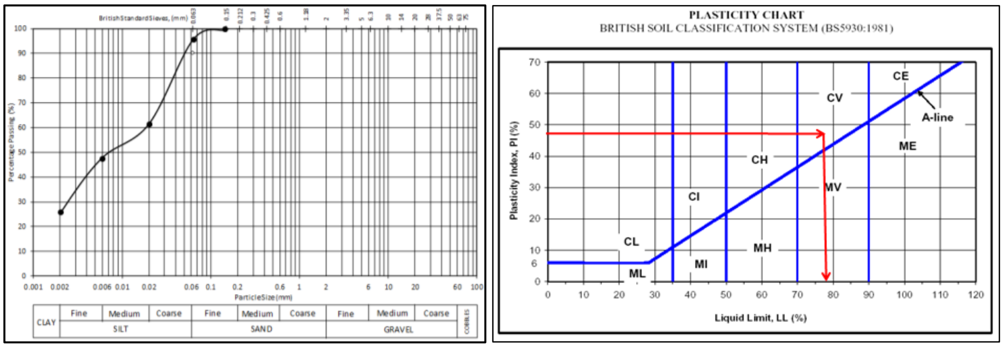


Figure 10. Particle size distribution and plasticity chart of fine soil.

Table 1. Physical and Chemical Properties of Sabak Bernam Marine Clay

Soil Parameters	**Value**
Moisture content, Mc (%)	80
Bulk density (Mg/mm^3)	1.474
Dry density (Mg/mm^3)	0.819
Liquid limit, LL (%)	79
Plastic limit, PL (%)	31
Plasticity index, PI	48
Linear shrinkage (%)	17
Specific gravity	2.352
pH value	5
Chloride content, CL(%)	0.01
Sulphate content (SO^3) (mg/L)	<200

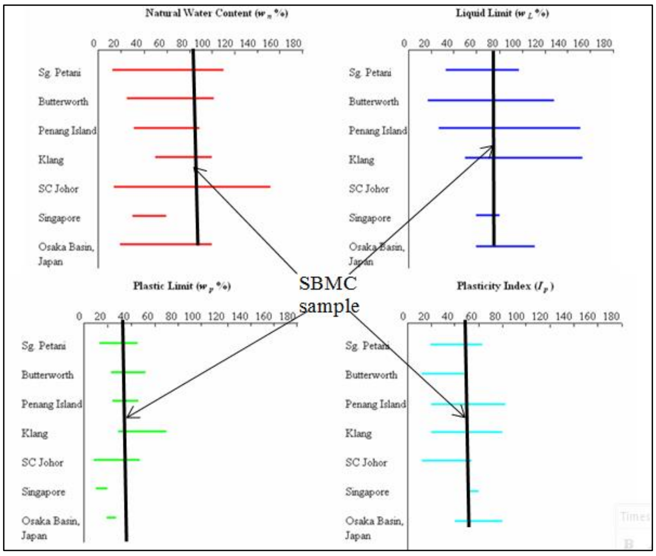


Figure 11. Atterberg Limits of SBMC in comparison with other Marine Clay in South East Asia [20].

5.2 Compression Characteristics of Sabak Bernam Marine Clay

Compression index, C_c is the slope of the linear portion of the e – log σ′ plot and is dimensionless. The recompression index, C_r is also an important parameter for soft compressible ground settlement analysis. C_r is defined in the same way as C_c except that it applies to the unloading reloading phase of the oedometer test. Figures 12 to 14 show void ratio and log effective stress relationship curve (e log σ') for undisturbed and remoulded sample of Sabak Bernam Clay soil from oedometer laboratory test. From the e log σ' curve, the average compression index is 0.614 whereas the average recompression ratio is 0.169. The compression parameters for the tested soil are tabulated in Table 2. The results of compression ratio are compared with the existing correlations from established researchers. Values of C_c by the researchers as shown in Table 3 is in a good agreement with C_c value obtained in this study.

The results of $C_c/(1+e_o)$ in this study is 0.213 and is applicable for normally consolidated soil and these results show that the soil is classified as highly compressible according to Table 4 [20]. According to Neoh [11], the normal compression ratio (Cc/ [1+e_o]) for soft clay is from 0.2 to 0.4 which is within the range of (Cc/ [1+e_o]) obtained in this study. The over consolidated soil is slightly compressible as shown by the shallow slope whilst the normal consolidated soil is highly compressible as shown by the steep slope. The volume of compressibility, m_v for SBMC soil is 0.571 as shown in Figures 15 to 17 and the coefficient of permeability is 1.68 x 10^{-10} m/s indicated that the drainage properties of this soil is very poor as shown in Figure 19. C_v value obtained in this study is 1.8mm^2/min (0.93m^2/yr) as shown in Figure 18 which is in the range of C_v for soft clay according to Neoh [12] those are 0.5 to 1.5 m^2/ year.

The response of C_v to pressure increase in clays is governed by the mechanical and physicochemical factors that govern the compressibility [23]. The comparison between in situ and laboratory C_v values show that the macrostructure of the soil layer influences the behavior of the whole layer [24].

Table 2. Compressibility Parameters of Sabak Bernam Marine Clay.

Compression Parameters	Value
Compression index, C_c	0.614
Recompression index, C_r	0.169
Preconsolidation pressure, P_c	60kPa
Coefficient of consolidation, C_v	1.8mm^2/min(0.93m^2/yr)
$C_c/(1+e_o)$	0.213
$C_r/(1+e_o)$	0.059
C_c/C_r	3.63
m_v (m^2/MN)	0.571
k (m/s)	1.68 x 10^{-10}

Table 3. Compression index, C_c for soft clay by other researchers.

Equation	C_c (with respect to LL=79%, PI= 48)
Terzaghi and Peck, 1967 For undisturbed clay: C_c= 0.009 (LL – 10) For remolded clay C_c= 0.007 (LL – 10)	0.62 0.483
Schofield and Wroth, 1968 C_c =1.35 PI	0.65
Tan et al (2000) C_c= 0.02LL – 0.87 (Klang Marine Clay)	0.71
Kulhawy and Mayne (1990) C_c=PI/74	0.65

Table 4. Classification of soil compressibility[a] [21].

$C_c/(1+e_o)$ or $C_r/(1+e_o)$	Classification
0 – 0.05	Very slightly compressible
0.05 – 0.10	Slightly compressible
0.10 - 0.20	Moderately compressible
0.20 – 0.35	Highly compressible
>0.35	Very highly compressible

[a]For soils that are normally consolidated, base the classification on $C_c/(1+e_o)$.
For soils that are overconsolidated, base the classification on $C_r/(1+e_o)$

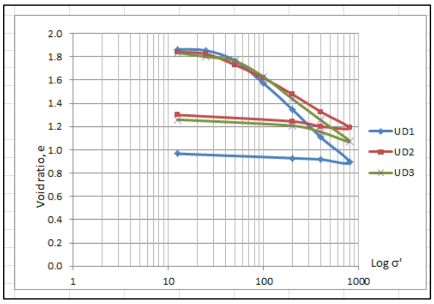


Figure 12. e log σ' curve for undisturbed soil .

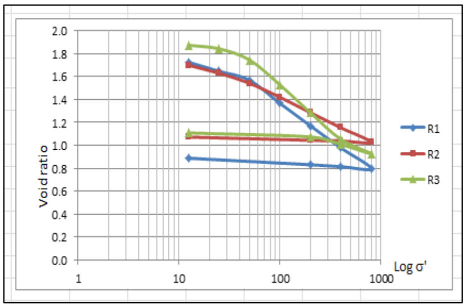


Figure 13. e log σ' curve for remoulded soil.

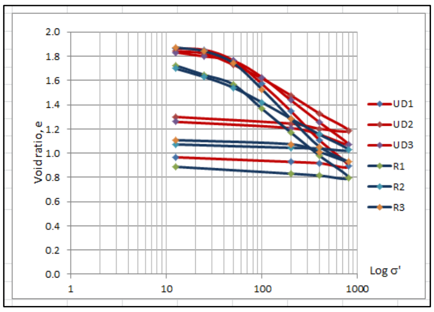


Figure 14. e log σ' curve for undisturbed and remoulded soil.

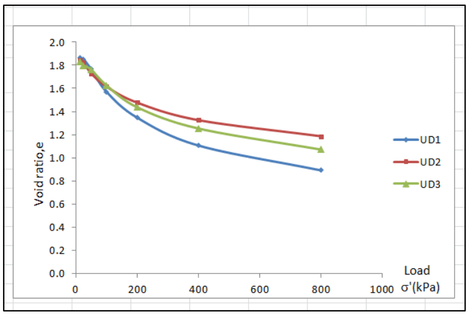


Figure 15. e vs σ' curve for undisturbed soil.

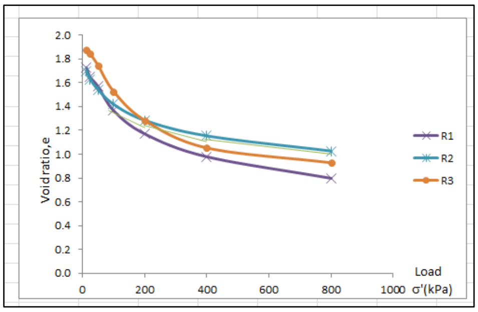


Figure 16. e vs σ' curve for remoulded soil.

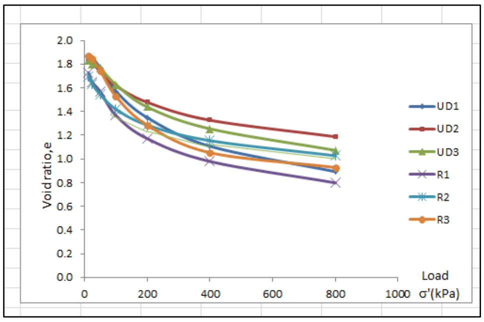


Figure 17. e vs σ' curve for undisturbed and remoulded soil.

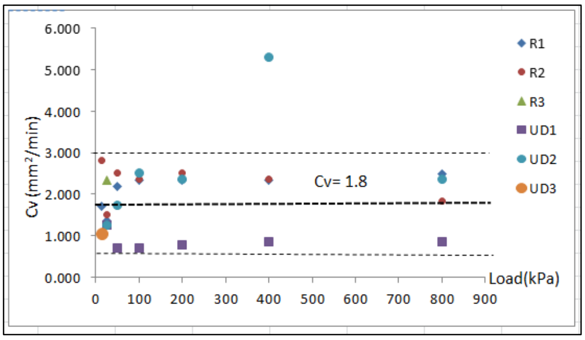


Figure 18. C_v for SBMC.

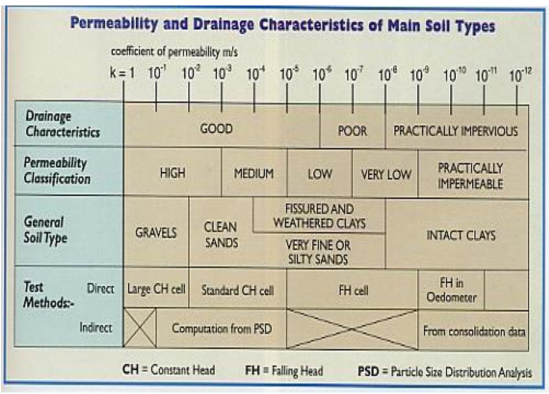


Figure 19. Permeability and drainage characteristics of main soil types.

6. Conclusion

Soil sample collected at Sabak Bernam is an alluvial deposit of marine clay. Based on British Standard Soil Classification and Plasticity Chart, the soil is classified as CLAY with very high plasticity (CV). The moisture content of SBMC is high with 80% and the coefficient of permeability is very low which denote the poor drainage characteristics of the soil. The physical properties of SBMC sample is in the range value of other marine clay in Malaysia and South East Asia. Compressibility parameters show that SBMC is highly compressible, has low permeability and poor drainage characteristics. The compressibility parameters obtained for SBMC are in good agreement with other researchers in the same field.

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