Investigation of engineering properties of soil in the Sajahat Formation

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ABSTRACT

In conjunction with a construction project in Singapore, the soil properties of Sajahat Formation were studied using both field and laboratory tests.. Few studies were carried out for soil in Sajahat Formation as it was rarely encountered in the past. The tests carried out were pressuremeter tests and a series of laboratory tests including physical properties, oedometer, isotropically consolidated triaxial tests under different drainage conditions and direct simple shear tests. The mechanical properties of the soil studied included consolidation history, undrained shear strength, effective cohesion and friction angle, stiffness, and stress-strain behavior of the soil in the Sajahat Formation. The geology of the Sajahat Formation was also studied using dating tests.

Keywords: Geology; Soil; Shear strength; Stiffness; Triaxial test.

1 INTRODUCTION

Sajahat Formation, is considered as one of the oldest geological formation in Singapore. As it was rarely encountered in construction in the past, the engineering properties of soil or rock in the Sajahat Formation were not properly studied. A lack of understanding of the soil properties in this unusual geological formation might lead to higher uncertainties in design parameters or higher construction risks. As Sajahat Formation is different from the other geological formation, we cannot assume that the soil and rock in this formation will behave like the other types of formations commonly encountered in Singapore, such as the residual soil. This study is to carry out further site investigation work and laboratory tests to characterize the soil or rock in the Sajahat Formation in association with a construction project and to identify the potential geological risks, if any.

2 GEOLOGICAL INFORMATION

According to the Geological Map of Singapore (Lee and Zhou, 2009), the Sajahat Formation was mapped at Punggol Point (Fig. 1). In a recent site investigation of Punggol area conducted by Land Transport Authority of Singapore, four boreholes, EN/B025/PMT, EN/B025A/PMT, EN/A182/PMT, EN/A182A/PMT were drilled at the location as shown in Fig. 1. The cross-section through the four boreholes shows that the soil and rock stratum consists of Backfill, Siltysand & Sandysilt, Sandygravel, Sandstone, Diorite and Granodiorite. Geological dating was carried out for rock samples taken from this site and the results confirmed the presence of the Sajahat Formation at this site with an age around 337±3 Ma (Early Carboniferous).

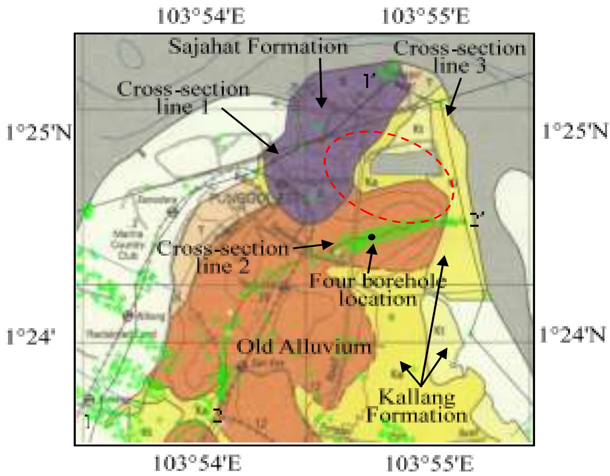

Fig. 1 Boreholes and cross-section line distribution

3 ENGINEERING PROPERTIES

In-situ pressuremeter tests and soil and rock sampling were carried out. Laboratory tests were conducted using the undisturbed samples. The soil testing included physical properties tests, oedometer tests, direct simple shear tests, isotropically consolidated undrained and drained tests. The test results are reported as follows.

3.1 Physical Properties

The range of grain size distributions of Sajahat soil is shown in Fig. 3. As seem, the main compositions of Sajahat soil are silt and sand, which is consistent with the geological information shown in Fig. 2.

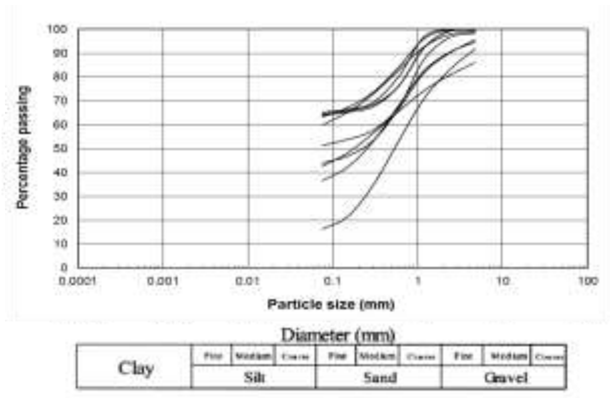

Fig. 2 Grain size distribution range of Sajahat soils

The variation of the natural water content of Sajahat soils with depth is shown in Fig. 3 along with their liquid and plastic limits. Generally, the natural water content of Sajahat soils is close to or lower than the plastic limit, which indicates the Sajahat soils are typically dry and hard. In addition, the Atterberg limits and water content exhibit a high variation that implies the complexity of Sajahat soil.

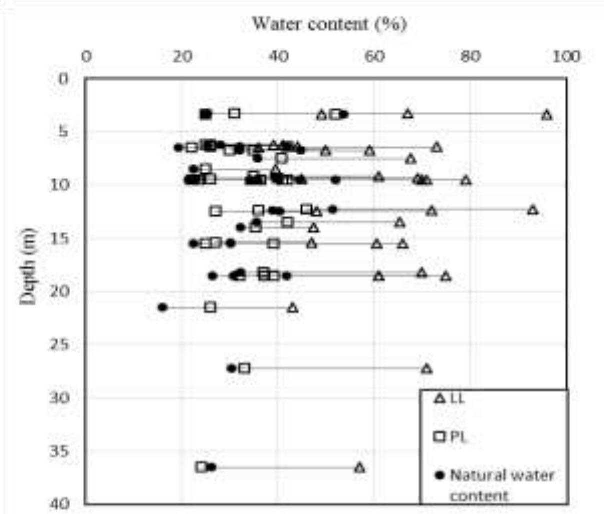

Fig. 3 Variation of Atterberg limits and natural water content with depth

3.2 Compressibility and permeability parameters

Oedometer tests were carried out to determine the compressibility and permeability parameters. As shown in Fig. 4, the permeability coefficient k of Sajahat soils varies from 10^{-8} to 10^{-10} m/s, which is comparable to the typical permeability values for residual soils (Sharma et al. 1999). However, there is a major difference between the Sajahat soils and residual soils - the composites of Sajahat soil is more erratic and more joints or fissures are observed on Sajahat soil during sampling.

From e-log σ_v' curves, the compression index C_c and recompression index C_r as well as moisture content ω are correlated with the initial void ratio e_0 in Fig. 5. It can be seen that C_c and C_r increase with increasing in the initial void ratio of the soil.

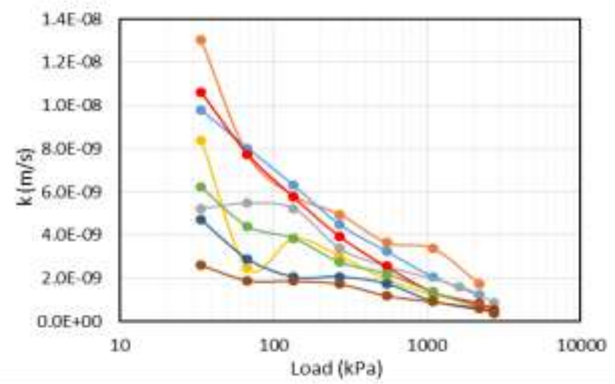

Fig. 4 Permeability coefficient of Sajahat soils derived from Oedometer tests

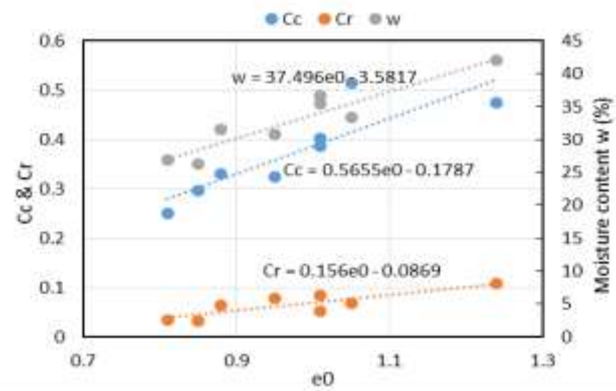

Fig. 5 Relationship of Compressibility parameters C_c, C_r, natural water content and initial void ratio e_0

3.3 Undrained shear strength

Three types of tests, in-situ pressuremeter, undrained triaxial (CIU) and direct simple shear (DSS) tests, were adopted to determine the undrained shear strength c_u of Sajahat soils. The DSS tests were carried out using a procedure detailed in Chu et al. (2003). The test results are presented in Fig. 6. The undrained shear strength c_u measured by the DSS tests is smaller than that by the CIU tests, while the c_u by the pressuremeter tests are in between. As it is well known that the c_u obtained by CIU tests may be overestimated, the c_u determined by the pressuremeter appears to be reasonable.

The undrained shear strength is generally affected by consolidation history and initial confining stress. Therefore, c_u should be evaluated using the c_u versus initial effective vertical stress σ_{10}' ratio, c_u/σ_{v0}', which is correlated with OCR. The well-known c_u/σ_{v0}' versus OCR relationship is shown in Eq. (1):

$$\left(\frac{c_u}{\sigma_{v0}'}\right)_{OC} = \left(\frac{c_u}{\sigma_{v0}'}\right)_{NC} OCR^{\Lambda} \tag{1}$$

where $(c_u/\sigma_{v0}')_{OC}$ and $(c_u/\sigma_{v0}')_{NC}$ are the undrained shear strength ratio for OC and NC soil specimens respectively, and ʌ is a constant coefficient. The ʌ value is different for different tests or stress conditions and can be correlated with effective friction angle as shown in Fig. 7. For CIU and DSS tests, the relationships are:

For CIU:

$$\left(\frac{c_u}{\sigma_{v0}'}\right)_{OC} = \left(\frac{c_u}{\sigma_{v0}'}\right)_{NC} OCR^{1.39\sin\varphi' + 0.15} \tag{2}$$

For DSS:

$$\left(\frac{c_u}{\sigma_{v0}'}\right)_{OC} = \left(\frac{c_u}{\sigma_{v0}'}\right)_{NC} OCR^{2.27\sin\varphi' - 0.33} \tag{3}$$

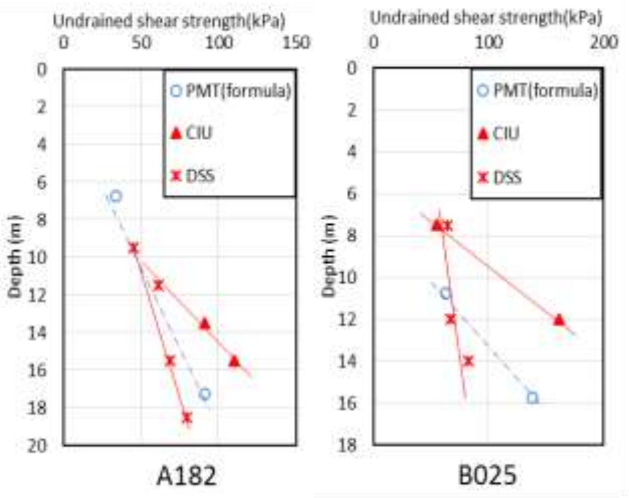

Fig. 6 Correlation between constant coefficient α and friction angle φ' for Sajahat soil

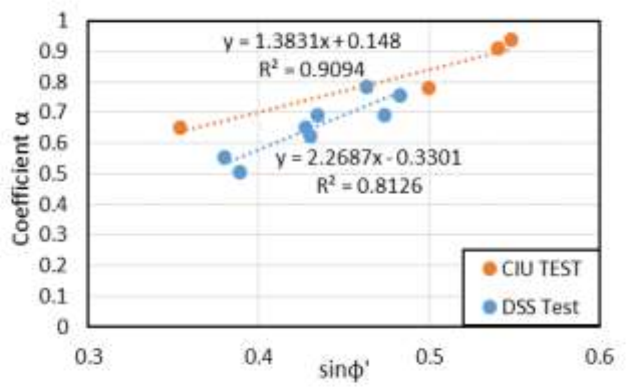

Fig. 7 Undrained shear strength of Sajahat soils derived from CIU, DSS and in-situ pressuremeter tests

3.4 Effective strength parameters

The effective strength parameters, cohesion c′ and internal friction angle φ′, were measured by drained, undrained triaxial or direct simples shear tests. The range of effective strength parameters derived from the three types of test approaches is shown in Fig. 8. Generally, the effective cohesion c′ of Sajahat soil varies from 0 to 30 kPa and the internal friction angle φ′ from 20 - 35°. The c′ value appears to increase with depth as shown in Fig. 8a, reflecting the fact the cementation increases with depth due to different degree of weathering. The φ′ value obtained from CID appears to be comparable with that from DSS whereas the φ' measured by CIU appears to be higher. Overall, the variation in the φ' is large probably due to the effect of fissures on the failure mode or failure state.

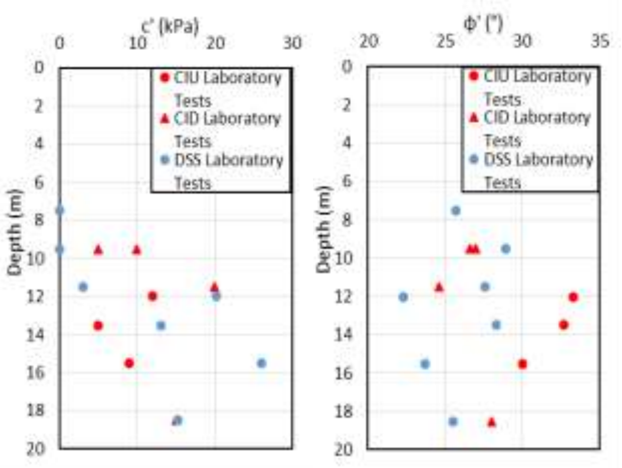

Fig. 8 Effective shear strength parameters c' and φ' of Sajahat soils

3.5 Modulus of elasticity

The undrained Young's modulus E_u of Sajahat soils was determined by means of in-situ pressuremeter tests and triaxial tests where small strain method was adopted. The local strain measuring device was used for small strain measurement. As shown in Fig. 9, the small strain measurement presents a more accurate decay curve for the variation of secant modulus with axial strain as also observed for other soils (Goh et al. 2012). From pressuremeter tests, two different moduli of elasticity, E_m and E_r, can be obtained. The modulus of elasticity E_m is determined by the pseudo-elastic phase during a pressuremeter test which underestimates the soil stiffness. E_r is obtained from the unload–reload cycle which is typically au upper bound of modulus of elasticity derived from various other interpretations. As shown in Fig. 9, the soil stiffness from the small strain method is between E_m and E_r and thus is more accurate and reliable then the modulus determined using the global strain (i.e., conventional) method.

As a comparison, the stiffness distribution with depth for the Sajahat soil determined in this study is plotted together with those measured for the Bukit Timah or Jurong Formation residual soils (Leong et al. 2003) in Fig. 10. For Sajahat soil, an increasing trend with depth can be observed from Fig. 10. This should be the case theoretically as the stress level is increasing with depth. Most of the data used in Fig. 10 for the Bukit Timah or Jurong Formation residual soil were obtained using the conventional testing method (Leong et al. 2003). Thus, the stiffness would be considerably underestimated or unreliable. This explains why the theoretical trend of modulus increasing with depth were not clearly observed for Bukit Timah or Jurong Formation residual soil. For the same reason, the undrained Young's modulus for Sajahat soils may not be necessarily higher than those for Bukit Timah or Jurong Formation residual soils as suggested in Fig. 10. However, as far as the variation of undrained modulus is concerned, the data presented in Fig. 10 presents the modulus in the range of strain that is comparable to range of strain the soil might experience in a real excavation or tunneling project (Mair, 1993).

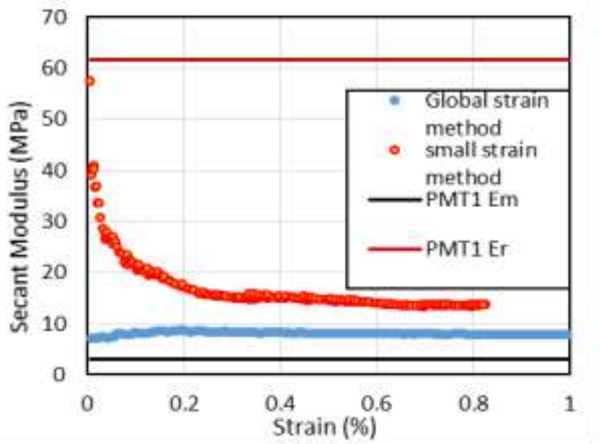

Fig. 9 Comparison of conventional global strain method and small strain method

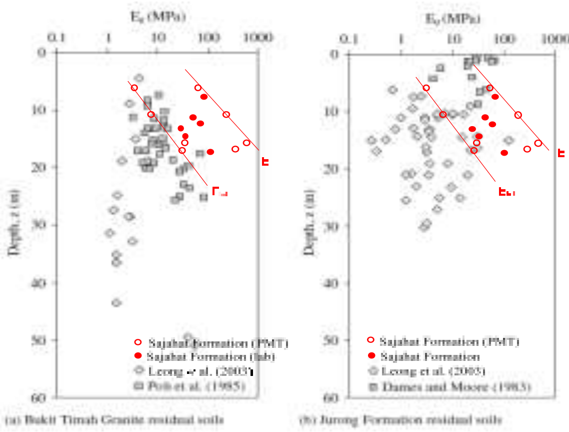

Fig. 10 Modulus of elasticity of Sajahat soils, Bukit Timah (a) and Jurong Formation (b) residual soils

4 CONCLUSION

The geological information and engineering properties of Sajahat Formation in Singapore has been investigated using both field and laboratory tests. The following conclusions may be derived:

1) The soil compositions and engineering properties of Sajahat Formation are different from those of the soil from other formations in Singapore. Sajahat soil is more heterogenic or fissured. Thus, the variation in the engineering properties of Sajahat soil is greater. The fissures in the soil can cause a greater variation in the shear strength of the soil too.
2) The range of undrained shear strength c_u of Sajahat soil is between 53 to 146 kPa. The effective shear strength parameters c' and φ' vary between 0 – 30 kPa and 20 - 35° respectively.
3) The elastic modulus of Sajahat soil appears to increase with depth. The value varies from 23 to 114 MPa as measured by triaxial undrained tests using small strain which is between the initial modulus and the unloading-reloading modulus measured by pressuremeter tests.

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