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Correlation between PMT and SPT results for Kenny Hill Formation

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Abstract: The utilization and simplicity of standard penetration test (SPT) gives major advantages in site investigation over other methods. SPT is widely practised for all sizes of project and feasible to be used in low-cost construction. However, SPT does not comprehensively capture the real soil behaviour and inevitably generate disturbance to soil samples. Considering that SPT is available for every site investigation works, it was tempting to develop correlation between the pressuremeter test (PMT) results and the SPT results, particularly for local practise. PMT is normally adopted to determine the in-situ stress-strain characteristic, horizontal pressure and lateral failure load of soil. This method is considered as undisturbed soil test due to its mechanism that directly tested the soil. Kenny Hill Formation has thick layer of residual soil due to intense weathering process in the tropical climate region. Thus, adopting the local correlations is more efficient to represent the geological formation of the site. In this research study, the approach is to develop correlation between SPT and PMT. The standard penetration test (SPT) value was obtained from a soil exploration study conducted in Kenny Hills Formation, Malaysia which was conducted at selected depths of borehole. Correlation of SPT value (N_{SPT}) and PMT initial modulus (E_i) is $E_i = 0.22\ (N_{SPT}) + 10.01$ with coefficient of determination (R^2) 0.642.

Keywords: Correlation, Pressuremeter Test (PMT), Standard Penetration Test (SPT), Kenny Hill Formation

INTRODUCTION

Prior to the construction of engineering structures, site investigation is required to assess the suitability of the site for the construction planning. The results of the investigation furnish information on the aspects of engineering properties related to earth materials of the site. During the field exploration phase, in situ engineering field tests are necessary to be conducted. These include standard penetration tests (SPT) and pressure meter tests (PMT). These tests give results that are used to characterize the strength and deformation properties of earth materials (Wazoh & Mallo, 2014).

The Standard Penetration Test procedure is the activity of driving the standard split barrel sampler for a distance of 460 mm into the soil at the bottom of the boring and counting the number of blows to drive the sampler the last two 150 mm distances in order to obtain the N number by using a 63.5 kg driving hammer falling free from a height of 760 mm (Bowles, 1997). SPT is one of the simplest, cheapest and most widely used tests in many geotechnical projects worldwide. The SPT has various advantages, such as the easiness of the test procedure and the simplicity of the equipment employed. Representative but disturbed samples can be taken, which is used for classification of different layers. The test is carried out in various types of soils ranging from soft clay and loose sand to very stiff clay and dense sand (Sivrikaya & To, 2006). Standard penetration test (SPT) is the most common method of investigating properties of various types of soil including silt, clay and coarse sand, but it is not effective for coarser materials such as coarse gravels, cobbles or boulders, due to it reaching such a barrier that can result in excessive blow count (Yagiz *et al*., 2008). Sampling from SPT is normally considered as disturbed sample and will undergo laboratory process for soil physical characteristics determination and soil properties such as strength and stiffness parameters. However, results from laboratory tests is potentially in error for a number of reasons, including sample disturbance, poor operator techniques (particularly during preparation), improper drainage conditions, selection of incorrect strain rates or loadings, or by miscalculation. It is often possible to test a more representative volume of soil in situ than in the laboratory.

Truly ‘undisturbed’ samples cannot be retrieved from boreholes, and in practice there are differentiate by levels of ‘disturbed’ sample. Material secured in open-tube samplers is often disturbed, and such samplers are unsuitable for clays except if firm or of stiff consistency. Simple laboratory tests may not be reliable in most cases while more sophisticated laboratory testing can be time consuming and costly (Mair & Wood, 1987). Therefore, SPT that is normally available in every site investigation program was tempting for practitioner to obtain correlations between SPT results (based on number of blows) and soil deformation characteristic, presented by the elastic modulus. Soil physical characteristic may be correlated with one or other parameters of it. This relationship is very useful for the practitioner especially the complex and expensive testing method can be correlated with the simple test that is commonly practiced in any site. Recently, soil deformation can be evaluated in-situ using pressuremeter test. Pressuremeter test is a relatively expensive and can generate useful information about the strength and deformation properties of any soil and weak rock, which is carried out in some projects. On the other hand, the SPT test is a rather inexpensive, simple and typical in situ test used to determine the engineering properties of silt, clay, sand, and fine gravel which is utilised in almost all projects (Cheshomi & Ghodrati, 2015).

According to ASTM D4719-07 (2007), the procedure involved in pre-bored pressuremeter test is classified as three major steps. The pressuremeter test commenced by inserting pressuremeter probe into the existing borehole and applying regular increment of pressure. The pressure is allowed to increase either by regular interval of pressure or regular interval of radial displacement. The corresponding radial strain is recorded. The increment of pressure will discontinue if the borehole reached double size or soil yielding increase disproportionally. The pressuremeter modulus (E_M) is calculated from the elastic range of stress-strain curve. In general, the configuration of pressuremeter test basically involved lateral loading at specific depth in cylindrical borehole. The instrument required in pressuremeter test are pressuremeter probe, tubing, control and measuring unit and compressed air unit to supply pressure as shown in Figure 1.

The pressuremeter test was established as having well-defined boundary conditions and delivered more rigorous theoretical analysis than any other in-situ test. The fundamental of pressuremeter test is cavity expansion theory. Main assumption is that soil mass known as homogeneous, isotropic and continuous medium, at least used in the analysis. An ideal pressuremeter test as illustrated in Figure 2 which the initial cavity pressure (p_i) would be equal to the in-situ total horizontal stress ($\sigma_{ho} = p_0$). Then, the initial volume (V_0), of the cylindrical cavity can be calculated from the initial cavity radius (a_0) and the height of the pressuremeter cavity (h). Hooke's law was assumed at the initial part of loading with soil behaves elastically until the onset of yielding. Using a small strain theory in cylindrical coordinates, the change of volume.

($\Delta V = V - V_0$) can be related to the cavity strain (ε_c) by

$$\Delta V / V = 1 - 1 / (1 + \varepsilon_c)^2 \quad (1)$$

The boundary conditions around the cavity are well-defined at the cavity wall in which r = a and σ_r = p. From the equilibrium equation, the horizontal stress around the cavity can be expressed as

$$p - \sigma_h = 2G\varepsilon \quad (2)$$

where G is the shear modulus of soil. The in-situ shear modulus of the soil can be determined by measuring displacement of the cavity wall as the cavity pressure increase above σ_{h0}

$$G = 1/2 \; dp/d\varepsilon_c \quad (3)$$

The soil modulus can be also expressed in terms of volumetric strains as

$$G = V_0 \; dp/dV \quad (4)$$

As discussed by Mair & Wood (1987), the description of the cavity, which appears to be a compression process and will turn out to be an entirely shearing process. Thus, properties determined from this basis of analysis will concern on the shearing and not the compression of the surrounding soil (Schnaid, 2009).

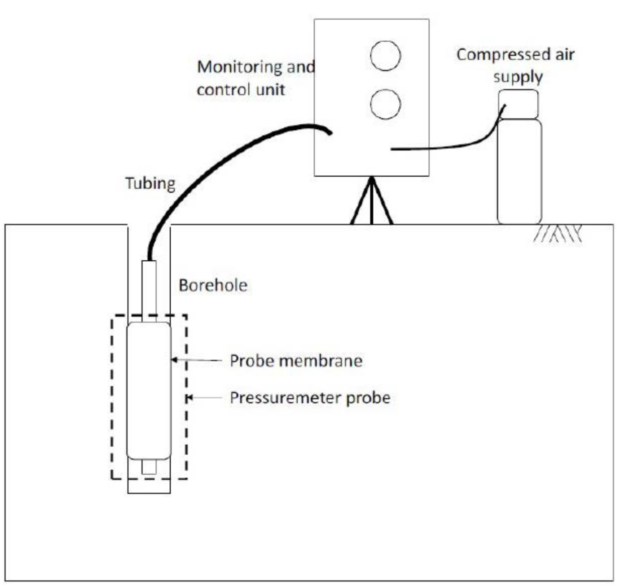

Figure 1: Instrument of pressuremeter test.

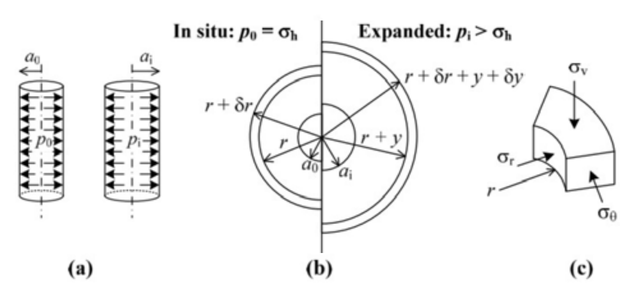

Figure 2: Definitions used in cavity expansion analysis: (a) expansion of cylindrical cavity; (b) expansion of an element at radius r; and (c) stress action on an element at radius r (Likitlersuang *et al*., 2013).

PREVIOUS SPT-N – PMT CORRELATIONS

According to Briaud (1992), a database of preboring pressuremeter test data and other field tests data (i.e. CPT and SPT) was presented. The sites were located in USA, 36 of them were sand formation sites and 44 were clay formation sites. In this study, best fit regressions were determined for the entire database. Equation 1 presents the correlation established for the E_{PMT} with N_{SPT} in sand. However, the scatter in the correlations was found very large. This unreliable scatter made these correlations useless in design.

$$E_0\ (kPa) = 383N\ (blows/30\ cm) \quad (5)$$

Yagiz *et al*. (2008) proposed correlations between N_{SPT} and E_{PMT} analysis for sandy silty clayey soil obtained from 15 boreholes in Turkey. The borehole depths were varying from 5-8 m, and the tests were performed at depths 1.5-2 m only. Regression analysis was considered and best fit regression between the parameters in a linear combination with 95% confidence level. The correlation is presented by Equation 6. The correlation was developed based on only 15 results.

$$E_m = 388N_{cor} + 4554 \quad (6)$$

Bozbey & Togrol (2010) proposed a correlation from case study of 182 tests in Turkey, as given in Equation 7 and 8.

For sandy soil : $E_{PMT}(MPa) = 1.33(N_{60})^{0.77}\ \ (r^2 = 0.82)$ (7)
For clayey soil : $E_{PMT}(MPa) = 1.61(N_{60})^{0.71}\ \ (r^2 = 0.72)$ (8)

Another correlation also provided by Kenmogne *et al*. (2011) with the data obtained from site investigation in Cameroon. The correlation was linear and is given in Equation 9.

$$E_m = b \times N \quad (9)$$

where b = 2-8 for gravely sand
= 2-20 for clayey sand

Cheshomi & Ghodrati (2015) presented correlations for silty sand and silty clay soil from the case study in Iran (38 tests for silty clay soil and 16 tests for silty sand soil), given by Equation 10 and 11. These correlations are valid only for the range of NSPT measured in site (i.e. 9-50 number of blows).

For silty sand : $E_{PMT}/P_a = 9.8N_{60} - 94.3\ \ (r^2 = 0.62)$ (10)
For silty clay : $E_{PMT}/P_a = 10N_{60} - 26.7\ \ (r^2 = 0.72)$ (11)

Anwar (2016) also proposed empirical correlations for E_{PMT} with N_{SPT} in Equation 12 below

$$E_{PMT}/P_a = 33.92(N_{SPT})^{0.803}\ (r^2 = 0.71) \quad (12)$$

As shown in the correlation above, r-square (r^2) is higher in most cases. However, Ohya *et al*. (1982) proposed correlation in Equation 13 with $r^2 = 0.39$ for clayey soil

$$E_m/P_a = 19.3(N_{60})^{0.63}\ (r^2 = 0.39) \quad (13)$$

According to Özvan *et al*. (2017), correlation for E_{PMT} and N_{SPT} for clayey soil is as shown in equation 14 below

$$E_m = 2.611(N_{60}) - 26.03\ (r^2 = 0.914) \quad (14)$$

GEOLOGY OF THE STUDY AREA

Kuala Lumpur is situated on the west coast central region of Peninsular Malaysia. It is the capital of the country, the largest city and the fastest growing metropolitan in Malaysia. Klang Valley is an area comprising Kuala Lumpur and adjoining towns and cities in Selangor state. Underneath Klang Valley, it is well-known of the existence of Kenny Hill Formation and Kuala Lumpur Limestone. Both formations possess distinctive characteristics (Figure 3). The Kenny Hill Formation contains homogeneous residual soil and weathered sedimentary rocks while the Kuala Lumpur Limestone is well-known for its karstic limestone. According to Hutchison & Tan (2009), Tan & Komoo (1990) and Tan (2006), Kenny Hill Formation is a meta-sedimentary rock formation. It majorly consists of interbedded sandstone, mudstone and shale. It lies unconformably over Kuala Lumpur Limestone (Mohamed *et al*., 2007; Huei *et al*., 2011). Certain parts of these

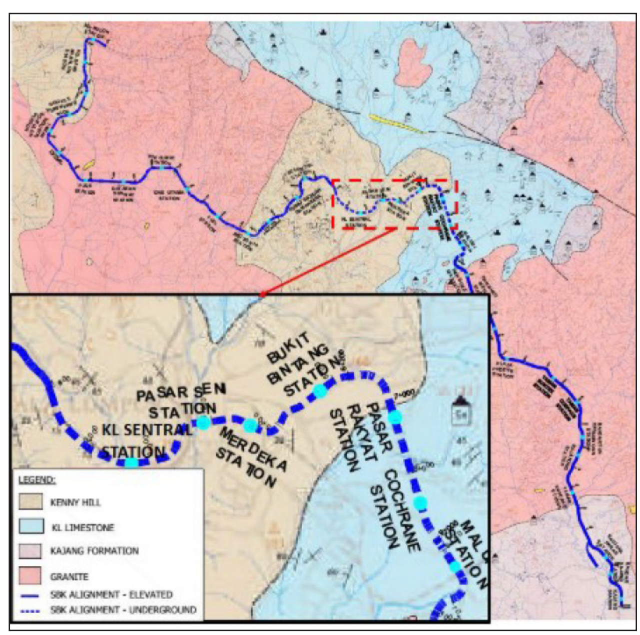

Figure 3: The Geological Map of Kuala Lumpur consisting of Kenny Hill Formation and Kuala Lumpur Limestone with KVMRT Twin Tunnels Alignment and Station Location (from Geological Map of Selangor, Sheet 94).

sedimentary rocks were metamorphosed into quartzite and phyllite. The near-surface layer of the Kenny Hill Formation has undergone weathering process and the resulting residual soil is found in this layer.

Kenny Hill Formation consists of rock which had undergone sedimentation process and followed by metamorphism process. Malaysia is widely known as a tropical climate country and this has accelerated the process of weathering in that particular formation. Products from this process include cohesionless soil and cohesive soil. Sandy silt which is categorized as cohesive soil consist primarily of silt. This fine-grained soil was predominantly observed in the study area. Table 1 presents the consistency of cohesive soil with correlation with SPT-N. It can be classified into 6 stages of consistency. This table is used as a guideline to identify the consistency of soil during the development of correlation between N_{SPT} and E_{PMT}. For this study, approximately 92 data were utilized as dataset. Most of the results from SPT-N values are ranging from firm to hard consistency. These data were selected based on similar lithology identified at specific depths and was taken between the upper layer and bottom layer of the conducted point pressuremeter test. Several points which cannot be categorized as cohesive soil or exist as a mixture between cohesive and cohesionless for the upper layer and bottom layer were not considered for analysis. The intention is to correctly measure cohesive soil (majorly sandy silt) in the project area to ensure the data is more reliable for prediction and comparison with previous researches.

Table 1: SPT-N correlation to soil consistency for cohesive soil (Karol, 1960).

Consistency	SPT-N values
Very soft	0-2
Soft	2-4
Firm	4-8
Stiff	8-16
Very stiff	16-32
Hard	More than 32

RESULTS AND DISCUSSION

The site investigation comprised of many boreholes with depths ranging from reduce level approximately 80 m to −40 m. PMT was conducted at 92 specific depths in the drilled borehole during preliminary stage. According to the scatter graphs in Figure 4, initial pressuremeter moduli or E_i in this fine-grained soil which predominantly observed as sandy silt in Kenny Hill Formation referred as $E_i = 0.22(N_{SPT}) + 10.01$ which correlates with N_{SPT}. This E_i was interchangeable as E_{PMT} and pressuremeter modulus. From the regression analysis undertaken, best fit regression between the parameters in a linear combination with 95% confidence level produce $R^2 = 0.642$. Regression analysis was carried out the least squares that fit given data and R-square was computed to evaluate the accuracy of the relation. This R-square is slightly lower than R-square obtained from most correlation in previous studied. However, its performed higher than $R^2 = 0.39$, proposed by Ohya *et al*. (1982).

Figure 5 presents a regression analysis of the relationship between unloading/reloading pressuremeter moduli (E_{ur}) for fine-grained soil in Kenny Hill Formation $E_{ur} = 0.25(N_{SPT}) + 32.55$ and N_{SPT}. $R^2 = 0.524$ represent a finding of 52.4% E_{ur} changes in the dependent variable is due to changes in independent variable (N_{SPT}). The coefficient of determination (R^2) between E_{PMT} and N_{SPT} was calculated as 0.524 was found having less accuracy in R^2.

According to result in Figure 6, E_{ur} versus E_i established as $E_{ur} = 1.03(E_i) + 24.86$. It was observed from regression analysis value of $R^2 = 0.675$ yield slightly increase in

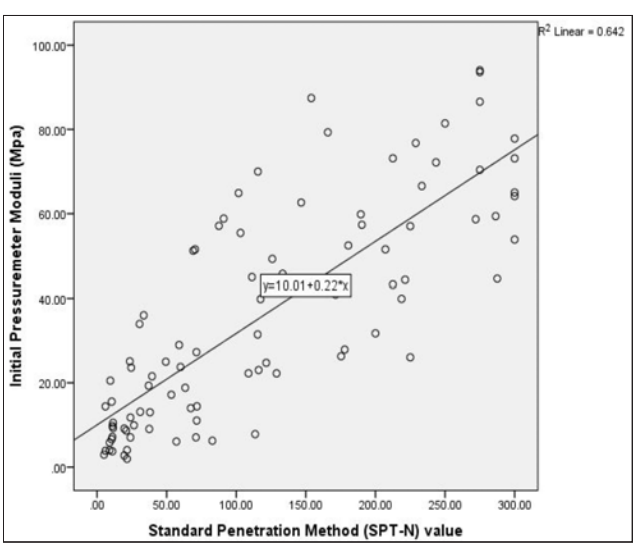

Figure 4: Initial Pressuremeter Moduli versus Standard Penetration Method.

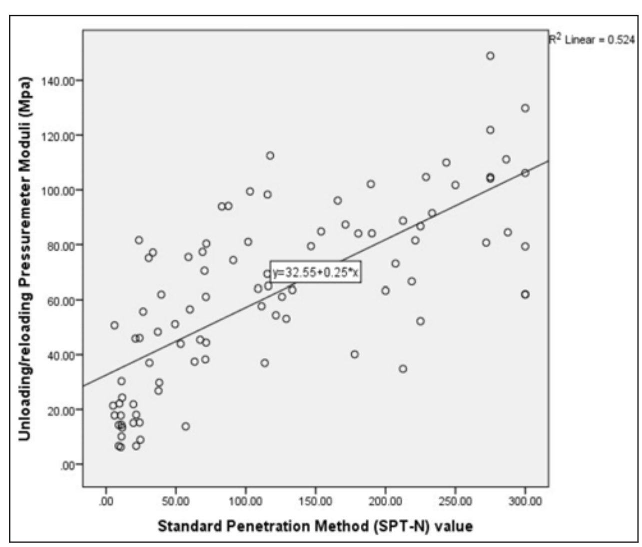

Figure 5: Unloading/reloading Pressuremeter Moduli versus Standard Penetration Method.

coefficient of determination as compared to the discussion above. This proposed equation produced regression between the parameters in a linear combination with 95% confidence level with $R^2 = 0.675$. The tendencies of both the E_{ur} and E_i show an approximate linear relationship between these parameters and will increase concurrently. In general, E_{ur} is higher than E_i.

Figure 7 shows graph established from correlation using recent data of N_{SPT}. This research study proposed $E_i = 0.22(N_{SPT}) + 10.01$ for cohesive soil in Kenny Hill Formation. According to the scatter graph, most similar result to this equation is established by Bozbey & Togrol (2010). It also presents similar pattern with Ohya *et al*. (1982).

CONCLUSIONS

This research study focuses on the correlation between standard penetration test and pressuremeter test for Kenny Hill Formation, Kuala Lumpur, Malaysia. The correlation established is considerd applicable for similar geologic formation. The study deals with the several statistical analyses with determination of R^2 and correlation derived as $E_i = 0.22(N_{SPT}) + 10.01$ with $R^2 = 0.642$. This correlation is specifically established for cohesive soil only and it can be extended to the purposes of design and development of subsurface soil profile in this particular area having similar soil lithology and geological condition.

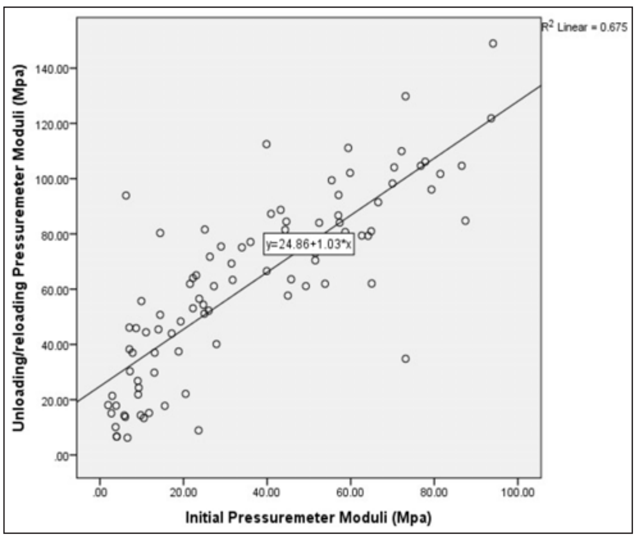

Figure 6: Unloading/reloading Pressuremeter Moduli versus Initial Pressuremeter Moduli.

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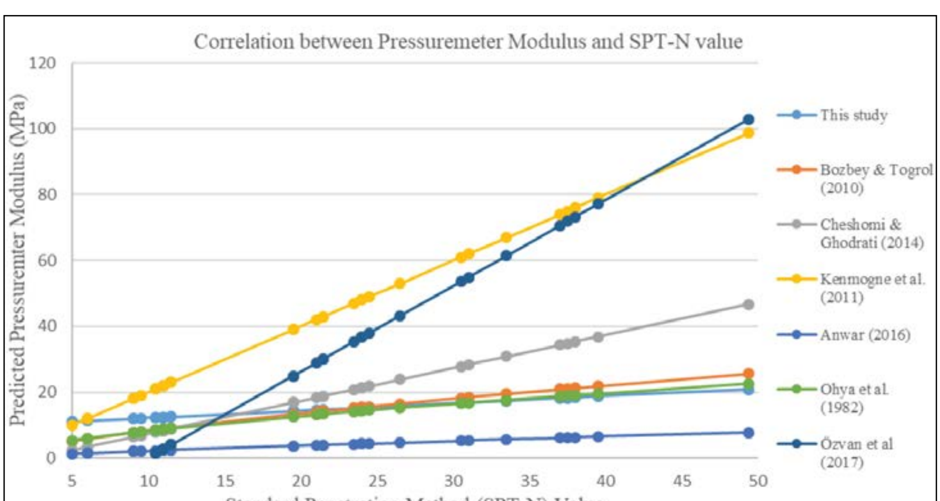

Figure 7: Results of correlation between Pressuremeter Modulus and N_{SPT} value for recent and previous studies.

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