Reliability of Using Standard Penetration Test (SPT) in Predicting Properties of Soil

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Abstract. The properties of soil play important role in many practices of geotechnical engineering. The soil classification tests such as Atterberg limits are quick and easy to perform and also cheaper compared to the test required to determine the soil parameter such as shear strength. It may take long time to get the result and difficult to perform. So, the prediction of these properties with the Standard Penetration Test (SPT) gives a chance to obtain these parameters without using of more laboratory test. Standard penetration test is used widespread due its simplicity and not expensive. The test is performed to measure the strength of the soil. In this study, the reliability of using standard penetration test (SPT) in predicting some properties such as Atterberg limits and shears strength parameters. The soil samples collected from 14 boreholes to depths between 1.5 to 19.5 m. The site of this study is at Ulu Jelai which is located in the State of Pahang; in the district of the Cameron Highlands have been investigated. Simple correlations between Standard Penetration Test and Atterberg limit is performed by using simple regression method. The results of the research show that the shear strength of the soil affects the standard penetration test number.

1. Introduction

Estimation of engineering characteristics of soil are important parts in geotechnical works. As part of design stage, an engineer needs to determine the average value and variability of soil properties. The importance of in-situ testing in geotechnical engineering is undeniable increasing because most of laboratory test are laborious, time consuming and costly [1]. However, sometimes the outcomes are not accurate due the poor laboratory condition [2]. Another long discussion is that the result of strength values determined from laboratory testing is not applicable to the in-situ soil mass due the scale effect.

Standard Penetration Test (SPT) is the one of the most common in-situ tests to identify soil type and stratigraphy along with being a relative measure of strength during site investigation. The standard penetration test consists of driving split barrel sampler with a distance 460 mm into the soil at the bottom of the boring. The number of blows is counting to drive the sampler the last two of 150 mm distances to obtain the SPT number. A 63.5 kg driving hammer is used to drive the sampler by falling free from a height of 760 mm [3].

The SPT number could provide useful in-situ test data [4]. The number of SPT might correlated with the consistency and density the soils encountered [5]. Many studies have been developed to investigate the correlations between the number of blows, N with different soil properties including the relative density of sands, consistency and unconfined compressive strength of clays and allowable bearing
pressure on sands and clays. According to Kulhawy and Mayne [6], SPT data have been used to correlate the shear strength parameter such as cohesion and angle of friction angle of soil but Bowles and Aggour [7], [8] recommend that the measured N value is standardised by multiplying it by the ratio between the measured energy transferred to the rod and 60 % of the theoretical free fall energy of the hammer. In this study, the relationships between SPT number and soil parameters such as Atterberg limit and shear strength parameter have been discussed to ensure that which of these parameters affect the SPT number.

2. Experimental study

The study area is located in the State of Pahang, in the district of Cameron Highlands about 140 km north of Kuala Lumpur and 80 km east of west coast of mainland Malaysia. Field work consisted of drilling and samplings of 14 boreholes to depths between 13.95 m to 50 m below ground surface were carried out. A standard penetration test (SPT) was carried out by Test Sdn Bhd using standard equipment in accordance with British Standard BS EN ISO 22476-3. An indication of the in-situ density of sands is given by driving of a standard 50 mm OD diameter split barrel sampler into the bottom of a drill hole using a 63.5 kg weight falling 0.76 m. The test also provides a rough indication of in-situ strength of cohesive materials (sилts and clays).

The test involves the measurement of the number of blows for three successive penetration of 150 mm. The total blow count for the lower (final) 300 mm is recorded as the SPT number (N) values. The values that greater than 50 are commonly regarded as effective refusal. Some of the specimens with different SPT number have been take out in order to carry out for laboratory testing. The specimens were carefully transported according to standard classifications and techniques. Atterberg limits including liquid limit (LL), plastic limits (PL) and plasticity index (PI) were determined according BS 1377 Test 2B and 3 while to determine the shear strength parameters such as cohesion (c) and angle of friction (ϕ, triaxial compression (consolidated, undrained) is used according to BS 1377. These tests were performed by Test Sdn Bhd at their laboratories.

3. Results and discussion

The SPT results gave N values over the full range to 50 blows per 300 mm or until refusal but until a depth of more than 24 m that there was an absence of N values below 10. This is to indicate a significant variability in the residual soils and completely weathered (CW) to highly weathered (HW) rock. The weathering of granitic rock under tropical conditions produced zoned of very weak material where aggressive chemical alteration of the biotite and feldspar minerals results in a fabric that readily breaks down under dynamic loading.

The result from Atterberg limits show that the site is made of a typical of weathered granitic materials. The samples tested are classed according to the Unified Soil Classification System (USCS) as silts of low to high liquid limit (ML to MH). The results obtained from field and laboratory tests are presented in Table 1 and discussed in detail under this section.

Table 1 Field and laboratory results
The relationships between field and experimental data included Standard Penetration Test number (N) at depth of sample taken from ground surface, Atterberg limits such as liquid limit (LL), plastic limit (PL) and plastic index (PI), shear strength parameters such as cohesion (c) and friction angle (ϕ) is plotted. The coefficient of correlation ($R^2$) between field and experimental data is determined. According to Taylor [9], coefficient of correlation ($R^2$) is representing the degree of linear association between two variables. The relationship between any parameters is classified as:

1. $R^2<0.3$ (no correlation)
2. $0.3<R^2<0.499$ (mild relationship)
3. $0.5<R^2<0.699$ (moderate relationship)
4. $0.7<R^2<1.0$ (strong relationship)

The relationship between these mentioned parameters have been performed as follows:

### 3.1 Effect of soil depth (D) below ground surface

Figures 1 to 4 show the relationships between depth of sample from the ground surface with different parameters such as SPT number, liquid limit (LL), plastic limit (PL) and plastic index (PI). As shown
in Figure 1, the correlation coefficient ($R^2 = 0.34$) is considered to be mild relationship. The SPT number is increase as the depth of sample from the ground increase. It means that the density of soil is increase as the depth is increase. This is because the effect of stress imposed on the layer of soil by the weight of overlaying material also called as overburden pressure.

![Figure 1. Depth of sample from the ground versus SPT number](image)

Figure 2 (a)-(c) show the relationships between depth of soil and Atterberg limits (LL, PL and PI) respectively. From these figures, it shows that there is no correlation between Atterberg limit and depth of soil since the coefficient of correlation are less than 0.3. This means that the depth of soil do no effect the plasticity of soil because the plasticity of soil is depend on the physical and mechanical properties of soil particle.

![Figure 2. Depth of soil and Atterberg limits a) liquid limit (LL), b) plastic limit (PL) and c) plastic index (PI)](image)
3.2 SPT versus Atterberg limits LL, PL and PI

The relationships between SPT number and Atterberg limit such as liquid limit (LL), plastic limit (PL) and plastic index (PI) are show in Figures 3 (a)-(c) respectively. Based on these figures, the Atterberg limits do not depend on SPT number since the values of correlation coefficient is less than 0.30. it is because the SPT number is depend on the relative density of layer as mentioned in previous section.

![Figure 3](image_url)

**Figure 3.** The relationships between SPT number and Atterberg limit a) liquid limit (LL), b) plastic limit (PL) and c) plastic index (PI)

3.3 SPT versus shear strength parameter (cohesion and friction angle)

Figures 4 (a) and (b) show the relationships between SPT number and shear strength parameters of soil (cohesion and angle of friction). The number of SPT is increases as the shear strength of the soil increase as shown in these figures. As the depth of soil increase, the relative density of soil increase due to the overburden stress effect. The density of soil increase may be due to the insertion of fine soil particles in the voids between sand particles to make the specimens are less voids. So, the friction surface is increases. As the friction surface increases, the shear strength also increases. In these figures, it show strong correlation between SPT number and shear strength parameters since the correlation coefficient is greater than 0.7. This means that the shear strength parameters have strongly affected the SPT number.
Figure 4. The relationships between SPT number and shear strength parameters of soil a) cohesion, and b) angle of friction.

4. Conclusion

Standard Penetration Test is the most popular tool for geotechnical characterisation at site due its simplicity and low cost besides it can provide useful and reliable data. Based on this study, the results are concluded as follows:

1. The depth of soil is significantly affected the SPT number.
2. The Atterberg limits have no effect on SPT number because it depends on the physical and mechanical properties of soil particles.
3. The shear strength parameter is strongly affected the SPT number.
4. Despite the fact that SPT is performed in the field on disturbed soil, it is adequate using SPT rather than using laboratory tests to determine shear strength parameter.
5. By considering standard penetration test, it is reliable to predict the shear strength parameter

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References

[1] Mair R J and Wood D M 1987 Construction Industry Research and Information Association
[2] Venkatasubramanian C and Dhinakaran G 2011 International Journal. Civil Structure. Engineeneering 2 614
[3] Bowles J E 2001 Foundation Analysis Third Edition
[4] Terzaghi K 1940 Purdue Conference on Soil Mechanics and its Applications 151
[5] Terzaghi K and Peck R B 1948 Soil Mechanics In Engineering Practice
[6] Kulhawy F H and Mayne P W 1990 Manual on estimating soil properties for foundation design
[7] Bowles J E 1997, Foundation Analysis and Design Fifth Edition 20 3
[8] Aggour M S and Radding W R 2001 Maryland State Highway Administration Rep. No. MD02-007B48
[9] Taylor R 1990 Journal of diagnostic Medical Sonography 6 35