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FULL LENGTH ARTICLE

Correlation between PMT and SPT results for calcareous soil

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Abstract The simplicity and low cost of the standard penetration test (SPT) have always been the major advantages of this test over other field tests. Despite that other field tests (e.g. PMT, CPT, DMT, ...) are supposed to provide more reliable results, yet they are still costly and not feasible in every project. Considering that SPT is available in all site investigation programs for all sizes of project, it was tempting to provide correlations between SPT results and other field test results. Through these correlations it will be feasible to estimate the soil parameters and deformation properties from the SPT number of blows. However, it is believed that correlations will differ, if the tested soil is calcareous. Furthermore, adopting local correlations is more favorable as it caters for the geological formation of the site. In this research it is aimed to obtain correlation between the PMT results and the SPT results for calcareous soil. A site investigation comprising boreholes with SPT and PMT was carried out near to the Red sea coast in Jeddah. The study was carried out to develop a local correlation between the results of SPT and PMT considering the effects of soil gradation and carbonate content. Comparison between the obtained correlation and other available correlations is also considered.

Introduction

Pressuremeter test (PMT) was developed by Menard, in 1955 to measure the in situ soil deformation properties, Briaud [1]. The pressuremeter consists mainly of a long cylindrical probe that is expanded radially into the surrounding ground. By tracking the amount of volume of fluid and pressure used in inflating the probe, the data can be interpreted to give a complete stress–strain–strength curve. The insertion of the pressuremeter in ground depends on its type, either self-boring or pre-boring. PMT is considered theoretically sound in determining soil parameters and can test larger zone of soil mass than other in situ tests. Yet, PMT requires high level of skill

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and can easily be damaged, and above all it is relatively expensive, Mayne et al. [2]. Actually this test is not carried out in conventional geotechnical site investigation for typical projects, Charif and ShadiNajjar [3]. On the other hand, there is the Standard Penetration Test (SPT), which is performed during the advance of the boreholes and is already carried out in all site investigation programs in nearly all boreholes due to its simplicity and low cost. Due to the availability of the SPT in every site investigation program, it was tempting to obtain correlations between SPT results (number of blows) and soil properties, namely shear strength parameters and soil deformation characteristic presented by the elastic modulus. Furthermore, correlations were also obtained to relate the results of the SPT to the results of other field tests (e.g. CPT, PMT, DMT). Nevertheless, despite the many available correlations between the SPT and the CPT, there are still limited number of correlations between the SPT and the PMT. The PMT provides a direct measurement of the horizontal modulus of soil. This modulus (E_{PMT}) often is presumed to be roughly equivalent to the Young's modulus (E), Phoon and Kulhawy [4]. Furthermore, both E_H and E_V are involved in the response of the vertical loading. Several investigations found that it was at most 5% difference between E_H and E_V, Briaud [1]. Nevertheless, soil elastic modulus is the most difficult parameter to obtain as it depends on many factors such as stress level, strain level, soil density and stress history, Briaud [5] and Charif and ShadiNajjar [3].

Attempts have been made to correlate the E_{PMT} with the N_{SPT}. Ohya et al. [6] proposed correlations for both clay soil and cohesionless soil in Japan, Fig. 1. The correlations are well known, yet they are fairly weak, Phoon and Kulhawy [4].

Briaud et al. [7] presented a database of preboring pressuremeter test data and other field tests data (i.e. CPT and SPT). The sites were located in USA, 36 of them were sand formation sites and 44 were clay formation sites. Best fit regressions were performed for the entire database. Eq. (1) presents the correlation proposed for the E_{PMT} with N_{SPT} in sand. However, the scatter in the correlations was found very large. This drastic scatter made these correlations useless in design, Briaud [1], Fig. 2a.

$$E_o\ (\mathrm{kPa}) = 383N\left(\frac{\text{blows}}{30\ \text{cm}}\right);\ E_o(\mathrm{tsf}) = 4N\left(\frac{\text{blows}}{ft}\right) \tag{1}$$

In 2008, Yagiz et al. [8] proposed correlations between N_{SPT} and E_{PMT} results for sandy silty clayey soil based on 15 boreholes in Turkey. The borehole depths were 5–8 m, and the tests were carried out at depth 1.5–2 m only. Regression analysis was undertaken and best fit regression between the parameters in a linear combination with 95% confidence level. The correlation is presented by Eq. (2). Fig. 2b presents the correlation, based on only 15 results.

$$E_m = 388\ N_{\mathrm{cor}} + 4554 \tag{2}$$

In 2010, Bozbey and Togrol [9], proposed a correlation based on case study of 182 tests in Turkey as given in Eqs. (3.a) and (3.b):

$$\text{For Sandy soil}:\ E_{\mathrm{PMT}}\ (\mathrm{MPa}) = 1.33(N_{60})^{0.77}\quad (r^2 = 0.82) \tag{3.a}$$

$$\text{For Clayey soil}:\ E_{\mathrm{PMT}}\ (\mathrm{MPa}) = 1.61(N_{60})^{0.71}\quad (r^2 = 0.72) \tag{3.b}$$

Another correlation was given by Kenmogne et al. [10] based on site investigation data in Cameroon. The correlation was linear and is given in Eq. (4).

$$E_m = b \times N \tag{4}$$

where
b = 2–8 for gravely sand.
= 2–20 for clayey sand.

Cheshomi and Ghodrati [11] presented correlations for silty sand and silty clay soil based on case study in Iran (38 tests for silty clay soil and 16 tests for silty sand soil) given by Eqs. (5.a) and (5.b). These correlations are valid only for the range of N_{SPT} measured in site (i.e. 9–50 number of blows).

$$\text{For silty sand}:\ E_{\mathrm{PMT}}/P_a = 9.8N_{60} - 94.3\quad (r = 0.79) \tag{5.a}$$

$$\text{For silty clay}:\ E_{\mathrm{PMT}}/P_a = 10N_{60} - 26.7\quad (r = 0.85) \tag{5.b}$$

As presented above, the available correlations between the E_{PMT} and the N_{SPT} are either highly scattered (i.e. small correlation factor) or based on limited number of results. Yet they are representing local correlations that are developed within specific geologic setting. Reference to Phoon and Kulhawy [4] local correlations is preferable to generalized global correlations, but they need to be accurate, which leads to the need of more studies and data to develop these correlations into more mature state. However, all cases using empirical correlations should be with caution as it is linking two items together that are not directly related, Kulhawy [12]. Another factor needs to be considered when adopting those correlations. This factor is that these correlations are based on tests carried out in siliceous soil. Many references such as SPT, ElKateb and Ali [13], Kulhawy and Mayne [14], Ahmed et al. [15], Vafeian et al. [16], Schneider and Lehane [17] are discussing the difference in behavior between calcareous or carbonate soil and siliceous soil under field tests especially destructive tests. It is very likely that destructive testing as SPT can possibly break cementation of calcareous sand and may crush the actual sand particles resulting in change in the physical properties of the soil matrix, Charif and ShadiNajjar [3], which implies the need for specific correlations for this type of soil. The aim of this research was to provide correlation between the PMT and SPT results to be able to obtain the soil moduli taking into consideration the soil gradation and its calcareous nature.

Site characterization

The soil under study is located in Jeddah area, relatively near to the Red Sea coast. The soil formation comprised of interbedded layers of silty/clayey sand with silty/clayey gravel and sandy gravel, which is known as Wadi deposits. Cementation was observed at some depths. Such layers continued from ground surface down to 20 m depth. The in-situ compactness of these layers was found generally to be medium dense to very dense. Layers of the cohesive soil were encountered at shallow depths of 1.5 m in some boreholes and as deep as 18 m in others. The thickness of the sandy lean clay layer ranged from 1.5 to 3 m or more. The carried out site investigation comprised of many boreholes with depths ranging from 20 to 50 m. PMT was carried out in 17 BHs and SPT was also carried out at depth interval of 1.5 m. Groundwater was