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Estimation of pressuremeter modulus and limit pressure from Cone Penetration Test for desert sands

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HIGHLIGHTS

- CPT-PMT pairs were collected from locations in the Gulf Cooperation Countries.
- Regression analysis is employed to generate formulas that can predict P_L and E_P.
- A separate data set was used to verify the developed regression formulas
- Calculated P_L and E_P were employed to estimate the settlements.
- Measured settlements from a load test were compared with the estimated ones.

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ABSTRACT

Pressuremeter Test (PMT) is comparatively expensive and takes more time to execute compared to Cone Penetration Test (CPT). Regression analysis is employed to generate formulas that can predict the limit pressure (P_L) and the pressuremeter modulus (E_P) from CPT. A total of 126 CPT-PMT pairs of desert dune sand soils were used to develop those formulas. Proposed formulas were verified using a separate data set that was not used in the analysis and were compared with previously published equations. The P_L and E_P resulting from the developed formulas show a good correlation with the measured ones. Additionally, measured settlements from a load test was compared with the estimated ones using the PMT method proposed by Menard (1975) utilizing P_L and E_P values calculated using the developed formulas. A good agreement between the predicted and measured settlements is presented in this research.

1. Introduction

Field and laboratory tests are the primary methods to determine soil parameters. Designers usually prefer in-situ tests due to disturbance of laboratory samples. Also, it is difficult to obtain undisturbed field samples of granular soil to perform laboratory tests. As a result, field tests are necessary for geotechnical exploration to define the engineering characteristics of the soil.

The Pressuremeter Test (PMT) is a robust field test to gather information about the strength and deformation of soils and weak rocks. The test is unique because it can be performed in soft clays to weak rock. The stress strain curve can be derived from PMT; not just a single value of an engineering property. PMT is comparatively expensive and takes more time to perform compared to the Cone Penetration Test (CPT). PMT results are usually used to calculate foundation settlement using the method proposed by Menard [1].

On the other hand, CPT is a simplistic, immediate, gives continuous soil profile, and inexpensive in-situ test used to define the engineering properties of the soil. However, CPT is not suitable for rocks. Foundation settlements are usually estimated based on CPT results using popular methods presented by Schmertmann's [2], Meyerhof's [3], and DeBeer's [4]. CPT is a reasonably cheap and regular part of most geotechnical exploration programs, while PMT is relatively expensive and most of the time is not performed in small size projects. Therefore, developing a correlation between CPT and PMT is useful to estimate the PMT modulus and limit pressure from CPT data. CPT-PMT correlations assist geotechnical engineers in assessing, comparing, and interpreting or cross-checking the soil parameters gathered from these two tests.

The GCC (Saudi Arabia, United Arab Emirates, Kuwait, Bahrain, Oman, and Qatar) have a tropical desert climate. The weather is remarkably hot and humid, and most days are sunny throughout the year. During the summertime, the temperature may reach

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55 °C (131°F). Practicing geotechnical engineers in the GCC Region always ask the question, Can we use CPT data to calculate footing settlements using the method proposed by Menard [1] which requires performing PMT? They always ask for a correlation between PMT and CPT that can be utilized in the GCC Region because it is not easy to implement PMT, especially during the summertime. Because of the reasons mentioned above, the researchers decided to find a correlation between PMT and CPT that can be used for desert sands, which cover most of those countries.

The goal of this research is to develop empirical formulas that can predict the PMT modulus (E_p) and limit pressure (P_L) for desert dune sands from the CPT data. The results of those formulas are also verified by comparing them with previously published equations.

The following tasks were performed to achieve the goal of this research:

- A comprehensive literature search was conducted to find previously published CPT-PMT correlations.
- CPT-PMT pairs were collected for desert dune sands from several projects in the Gulf Cooperation Countries (GCC).
- Regression analysis was used to develop empirical formulas.
- The developed empirical formulas were verified by comparing their results with previously published formulas by Briaud et al. [5] for a separate data set.
- Measured settlements from a load test were compared with the estimated ones by the PMT method proposed by Menard [1] using P_L and E_P values calculated using the developed formulas.

2. Existing correlations between CPT and PMT

Baguelin et al. [6] developed a CPT-PMT correlation for different types of soil, based on previously published testing data. They concluded that the net CPT cone resistance (q_c^*) and the net limit pressure (P_L^*) are more representative. q_c^* and P_L^* can be calculated using Eqs. (1) and (2). In their study, they proposed formulas to the predicted P_L^* function of q_c^* as shown in Table 1.

$$q_c^* = q_c - q_o \tag{1}$$

$$P_L^* = P_L - P_o \tag{2}$$

where:

q_o = the total vertical stress

P_o = total at rest horizontal earth pressure at the test level at the time of the test

Briaud et al. [5,7] collected CPT-PMT data from different locations in the United States for different soil types. The results of their study are presented in Table 2. The formulas presented in Table 2 are the most commonly used by practicing geotechnical engineers. Hamidi et al. [8] carried out CPT-PMT correlation for carbonate sand, the results of their correlation are presented in Table 2.

Table 1
CPT-PMT correlation by Baguelin et al. [6].

Soil type	Formula
Sand and Gravel	P_L^* = 0.08 q_c^* to 0.2 q_c^*
Compacted Silt	P_L^* = 0.25 q_c^* to 0.33 q_c^*
Very loose to loose Sand and compressible Silt	P_L^* = 0.67 q_c^* to q_c^*
	P_L^* = 0.25 q_c^* to 0.33 q_c^*
Very Stiff to hard Clay	P_L^* = 0.25 q_c^* to 0.33 q_c^*
Firm to very stiff Clay	P_L^* = 0.29 q_c^* to 0.4 q_c^*
Very soft to soft Clay	P_L^* = 0.29 q_c^* to 0.4 q_c^*

Table 2
CPT-PMT correlation by Briaud et al. [5] and Hamidi et al. [8].

Soil type	Formula	Researcher
Clay	$P_L = 0.2q_c$ $E_p = 2.5q_c$	Briaud et al. [5]
Sand	$P_L = 0.11q_c$ $E_p = 1.15q_c$	Briaud et al. [5]
Sand	$P_L = 0.22q_c$ $E_p = 1.35q_c$	Hamidi et al. [10]

Farid et al. [9] studied the correlation between the PENCEL pressuremeter and cone penetrometer engineering parameters. They proposed a CPT- PENCEL PMT correlation for sandy soil as q_c/P_L ratio of 5 to 5.16 function of depth.

3. Field tests

CPT, American Standards Testing Methods ASTM D5778 [10], is recognized as one of the most traditional, quick, uncomplicated, and affordable in-situ soil investigation tests to decide soil properties. In this test, an instrumented cone is pushed into the ground at a controlled rate. The results of the test give cone tip resistance (q_c) and sleeve friction (f_s). The test can be used for sand, silt, and clay but cannot be used for rocks.

PMT is considered one of the most useful in-situ tests and is widely used in soil investigations. It is used to estimate the at-rest lateral earth pressure at a particular depth by measuring the lateral deformation characteristics of the soil. The test was developed by Menard [1] and known as Menard PMT.

The pressuremeter test setup consists of two units: the measuring unit and the probe unit. The measuring unit is installed on the surface consisting of several gauges to record pressure and volume changes. The probe unit is penetrated into the ground and consists of three cells--a measuring cell and two guard cells. When the probe is inserted at the tested soil depth, as the pressure increases in the measuring cell, the borehole walls deform [5]. ASTM D4719-00 [11] standard was used to perform PMT in this study.

3.1. Data collection and processing

A major part of the study area is covered by fine desert sandy soils that become denser with depth and change to silty sands. Most of these soils are windblown, highly calcareous, and usually contain sulfates in the form of gypsum.

CPT-PMT pairs were investigated from several project sites in the GCC region for sandy desert soils. A total of 126 CPT-PMT pairs were investigated. Table 3 provides information about the collected data. It should be noted that data was collected from nine project sites in the GCC region. Table 4 presents a breakdown of the collected CPT-PMT pairs based on the geographical location. The collected data included depth of testing and water table depth.

Table 3
Collected data.

No. of CPT-PMT pairs	126
Depth (m)	2–12
Water Table Depth (m)	1–4
q_c (MPa)	3–14
σ' (kPa)	13.73–137.34
P_L (MPa)	1.05–2.5
E_P (MPa)	7.5–41
CPT friction ratio (R_f %)	0.05–1.45
Soil Behavior Type (SBT)	6 and 7
Soil Type based on SBT	– Clean Sand to Silty Sand – Gravelly Sand to Sand