Use of Neural Networks to Predict Correlations Between CPT and PMT Tests for Clay and Marl Soils

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Abstract The Menard pressuremeter (PMT) and the cone penetrometer (CPT) are the most widely used in situ tests for geotechnical investigations of sites in Algeria. Due to the quick and accurate results, they allow for field surveys, geotechnical design parameters and quality control assessments. Numerous correlations of geotechnical parameters measured from these two tests have been established in the literature. In this work, it is proposed to establish correlations between the gotechnical parameters deduced from the pressuremeter and the cone penetrometer tests for the clays and marls of the Algiers region in Algeria using the artificial neural networks approach (ANN). The parameters taken into account are the cone resistance of the CPT, the deformation modulus and the limit pressure deduced from the PMT. The results obtained will be discussed and compared to empirical relationships in the literature. The obtained correlations are relatively low compared to those from the literature.

Keywords Correlations · Pressuremeter · Cone penetrometer · Clay · Marl · ANN

1 Introduction

The geotechnical engineer is often confronted with heterogeneous soils during geotechnical investigations. This heterogeneity makes the mission more difficult, costly and increases the error of soil characterization. Geotechnical investigations are generally based on in-situ and laboratory tests. In this context the use of correlations be-tween the different geotechnical parameters is essential in order to obtain more reliable results. In the practice of soil mechanics, correlations between parameters are also used as a means of controlling the results of in situ and laboratory tests,

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and as a means of producing complementary values for certain parameters in relation to others, especially for preliminary evaluation and design purposes.

In Algeria, among the wide range of in-situ tests, the cone penetrometer test (CPT) and the Menard pressuremeter (PMT) are distinguished, which occupy an important place in a geotechnical investigation campaign. Because of their rapidity of implementation and quickness of results obtained, their cost and because they adapt to most of the soils present on the surface, especially when these soils are generally soft and clayey. The CPT provides continuous evaluation of the subgrade profile with im-proved repeatability and reliability of test data. It measures continuous profiles of cone tip resistance (q_c) and sleeve frictional resistance (f_s). The PMT is an important field test that can be used to determine soil settlement and bearing capacity by direct measurement of the geotechnical properties of the soil, such as deformation modulus and limit pressure [1]. In the majority of projects, to minimize the costs associated with geotechnical testing, the investigation campaign often involves only one type of testing, which justifies the need to use specific correlations for each type of soil. The objective of this paper is to establish correlations between the geotechnical parameters derived from the CPT and PMT tests for the clay and marl formations encountered in the Algiers region using neural networks.

2 Review of Existing PMT-CPT Correlations

Several geotechnical researchers have presented relationships between the two most commonly used in-situ soil investigation tests, the PMT and CPT. These relationships allow engineers to take an empirical approach to evaluating and analyzing soil properties by converting the available database from either test into the parameter(s) of the other tests. Many studies have focused on fine soils (clays and silts) and have interpreted a number of correlations between PMT and CPT such as those published by several authors [1–5]. In general, these correlations are based on the ratio of the cone tip resistance (q_c) of the CPT and the limit pressure (P_l) of the PMT. The ratio of the net values q_c*/P_l*, would be more representative. The (q_c*) and (P_l*) are the net cone resistance of the CPT and the net limit pressure of the PMT, respectively, and can be calculated from:

$$q_c^* = q_c - q_0 \quad (1)$$

$$P_l^* = P_l - P_0 \quad (2)$$

q_o and P_o are total vertical stress and total horizontal pressure in the ground respectively.

Jezequel et al. [2] studied the influence of the depth on q_c*/P_l* on hydraulic fill dikes of a tidal power project in Rance, France [2]. The fill used was composed of clean sand with a dry density equal to 1500 kg/m^3. The ratio q_c*/P_l* in the top 1.5 m

Table 1 The ratio (q_c*/P_l*) for different soil types according to Baguelin et al. [3]

Soil description	q_c*/P_l*
Very soft to soft clays	Close to 1 or From 2.5 to 3.5
Firm to very stiff clay	From 2.5 to 3.5
Very stiff to hard clay	From 3 to 4
Very loose to loose sand and compressible silt	From 1 to 1.5 and From 3 to 4
Compact silt	From 3 to 5

Table 2 The q_c/P_l ratio for different soil types according to Briaud et al. [2]

Soil type	PMT parameter	Correlation to CPT
Clay	P_l	0.2 q_c
	E_m	2.5 q_c
Sand	P_l	0.11 q_c
	E_m	1.15 q_c

of fill was from 9.11 to 12.03. Although qc varied from 2 to 10 MPa, $qc*/P_l*$ was approximately 6.7 in the rest of the 20 m thick backfill. According to [3] soil type has the greatest effect on q_c*/P_l*, and for depths of about 5−20 m there appears to be a close correlation between $q_c*$and P_l*. Baguelin et al. [3] consider that reasonable averages of q_c*/P_l* can be considered as those presented in Table 1. Wambekce [6] proposed, based on theoretical and experimental studies, that qc/Pl ratio be equal to 3 [6]. A total of 82 PMT borehole data from various projects from 1978 to 1985 were collected by Briaud et al. (1992) and the correlations in Table 2 were proposed [4]. Furthermore, many correlations have also been proposed to relate Menard's modulus (E_m) to cone tip resistance (q_c) in a form of a ratio E_m/q_c in the literature [7, 8].

Many studies have been carried out on clays and silts. According to a study carried out on 165 comparative tests, Cassan [7] proposes an E_m/q_c ratio of between 2.5 and 3.3 [7]. Bahar et al. [8] propose from a campaign of tests conducted in Algeri-an clays values of E_m/q_c between 3.0 and 4.9 [8].

2.1 Situation, Geological and Hydrogeological Contexts of Studied Site

The study area is located in the region of Baraki, about 10 km East of the capital Algiers and relatively close to the coast of the Mediterranean Sea (around 5 km). The site covers an area of nearly 45 ha is intended for the future project of Baraki stadium and its associated structures. Within the framework of this project, several geotechnical investigation campaigns have been conducted between 2007 and 2013. The selected data were obtained from soil studies that were carried out in 2013 for the four megapiles supporting the roof of the stadium. Geologically, the main formations encountered are brownish to greenish clays, grayish muds, blackish peats, deposits of coarse sand with the presence of gravels and pebbles (alluvium with passage of conglomerate) and marls. According to the hydrogeological map of the Algiers region, the study area is characterized by a generally high permeability with important water resources.

2.2 Geotechnical Data and Soil Properties of the Site

Several geotechnical investigation campaigns have been completed since 2007 for the project. The first was carried out in 2009 and the second in 2013. The results of the second campaign have been exploited in this communication [9]. In the site of inter-est, the geological formations outcropping are essentially constituted by clays and alluvium (filling of the Mitidja plain). The synthesis of the boreholes carried out allowed distinguishing in general two horizons. A superficial horizon from 0 to 12 m or even 30 m deep in the right of the East mega pile composed of brownish to greenish marly clays slightly pebbly, greyish vases and blackish peat in some places. The second horizon, beyond 6.0−30 m depth in some places consisting of alluvium resting on marl. Beyond about 30 m depth, the main formation encountered is the layer of yellowish grayish marl with grey stain little to pebbly becoming grayish with yellowish stain in depth (Pliocene marly substratum). The piezometric water level were made varied from −2.0 to −10.0 m.

Samples collected from boreholes at different depths were subjected to physical–mechanical tests in the laboratory. The results of these tests are shown in Table 3. The main formations encountered in site are essentially fine soils (Fig. 1). The results of the laboratory tests reveal formations not very dense to dense, not very plastic to plas-tic with the presence of some very plastic formations on the surface, soft to consistent, moderately compressible with passages rather to highly compressible by place, not swelling to relatively swelling.

In addition to the boreholes and laboratory tests, the following measurements were also made the pressuremeter tests (08) and CPT (08). The selected data were obtained from PMT and CPT tests that were performed as part of a soil investigation program at the four stadium mega-piles. The minimum and maximum depths of the CPT tests were 7.0 and 30 m respectively. However, PMT test depths were performed to 30 and 45 m. The obtained results in term of pressuremeter parameters (P_l and E_m) are shown in Fig. 2. Also, the results obtained of cone penetrometer test parameters (q_c) is illustrated in Fig. 2. The type of the penetrometric machine employed on the site is Gouda type of 20 tons. The tip of the cone has an angle of 60° and a base area of 10 cm^2. The sleeve lateral surface is 150 cm^2, placed on top of the cone, in the zone influenced by the displacement bulb. The assembly is driven into the ground by means of a hydraulic system at a speed of 2 cm/s. The measurements of the characteristics are made every 20 cm.

Table 3 Physical and mechanical characteristics of the main formations of soils

Characteristics of the soil	Marly clay brownish to greenish with yellowish spots	Grayish marl (Pliocene marly substratum)
Horizon	Superficial horizon	Second horizon
Classification	Fine soil	Fine soil
γ_d (kN/m^3)	13.80 – 16.30	15.30 – 19.00
γ_h (kN/m^3)	18.65 – 20.05	19.20 – 21.00
w (%)	18.80 – 46.50	9.40 – 34.20
Sr (%)	92.00 – 100.00	48.00 – 100.00
w_L (%)	43.30 – 52.30	34.00 – 63.75
Ip (%)	19.65 – 25.40	16.50 – 33.00
φ (°)	4.95 – 13.44	8.05 – 25.93
C (kPa)	38.00 – 74.00	48.00 – 120.00
Compressibility	Medium to very compressible	Low to medium compressible

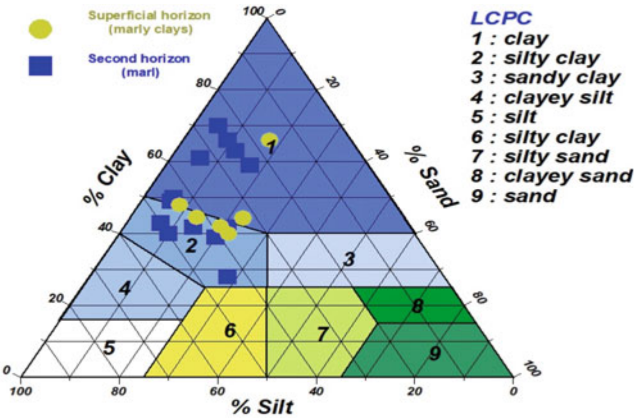

Fig. 1 Textural soil classification in a ternary diagram with LCPC denomination

From the examination of the lithological profiles of the PMT and CPT soundings, we can see that the soil is essentially constituted by two horizons, characterized by distinct pressuremeter and cone penetrometer parameters. The first horizon of very low to low resistance from 0 to 5 MPa (occasional exceeding 8 MPa) with an average of about 2.1 MPa, represented by the brownish to greenish marly clays and the second horizon with an average to quite resistant from 3 to 7 MPa up to exceed 9 MPa or even 10 MPa corresponding to the greyish marls (substratum). The first horizon, also characterized by limit pressures varying between 0.3 and 0.9 MPa with an average of 0.45 MPa and deformation modulus varying between 2 and 20 MPa with an average of about 5 MPa. E_m/P_l ratio indicates subconsolidated to normally consolidated clays. Whereas the second horizon, which corresponds to the yellowish

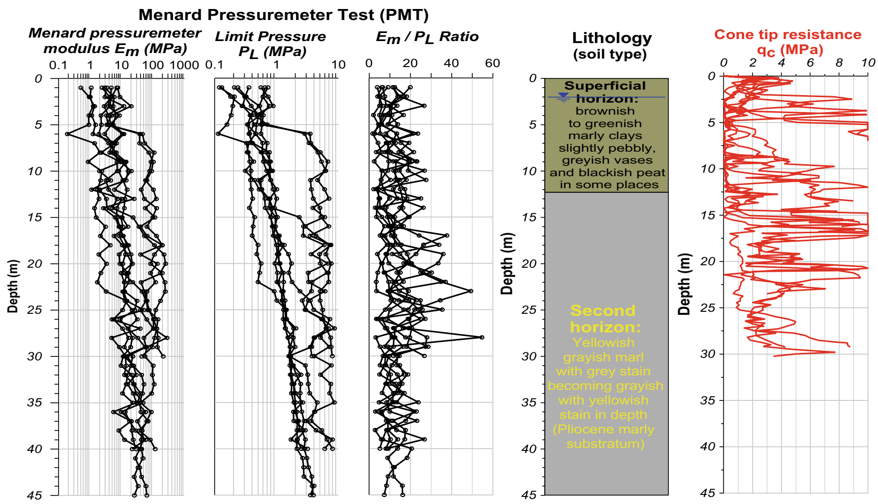

Fig. 2 Pressuremeter and penetrometric parameters results measured in the study area

to grayish marls, characterized by pressure limits ranging from 0.4 to 2.9 MPa with an average of 1.25 MPa, and pressure modulus ranging between 65 and 500 MPa with an average of around 140 MPa. The second horizon, E_m/P_l ratio indicates mainly marls normally consolidated to over consolidated.

2.3 Analysis of CPT and PMT Data Using ANN

The practice of ANNs (Artificial Neural Net-works) in geotechnical engineering has developed considerably over the past decades. Several studies have suggested that neural networks were used for evaluating pile capacity prediction, soil behavior mod-eling, slope stability calculations, etc. [10]. It should be noted that soil engineering properties have a wide variety of uncertainties due to the heterogeneity of soil associated behavior. The ANNs are likely the best option for establishing a reliable relation-ship model with nonlinear data points. Recently, several studies have been conducted on the correlation of soil engineering properties with geotechnical and geophysical parameters of soils by incorporating neural networks [11].

ANNs are systems capable of adjusting their own internal configurations according to the desired objective. They are specially designed to solve problems with nonlinear variables. The processing elements of neural networks are called "nodes", which is the basic element of this technique. The system consists of the various input and output nodes that communicate with other nodes or with the environment provided by the network. In addition, each network has its own functions that transform input into output, as shown in Fig. 3. In this study, the training process was performed by MATLAB, which includes a number of training algorithms, including

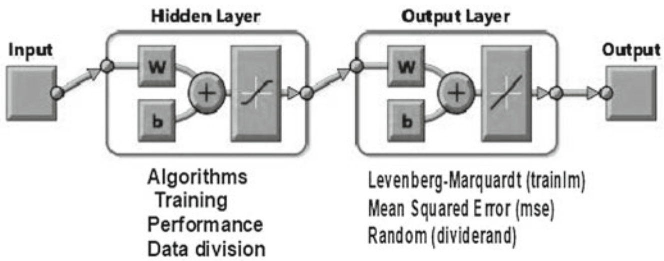

Fig. 3 Schematic showing a processing element containing a neuron to compute an output from an input

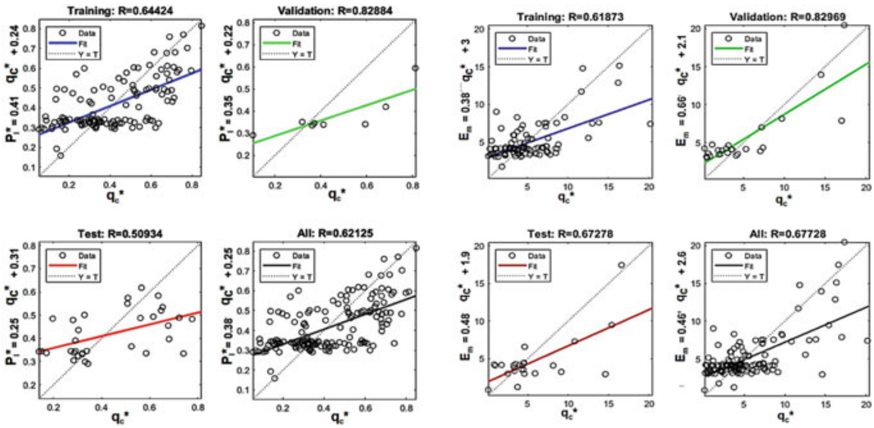

Fig. 4 Correlations q_c*(MPa) versus P_l* and q_c*(MPa) versus E_m(MPa) in the superficial horizon (clay and marl clay) using ANN

the back propagation training algorithm. The collection of measurements from PMT and CPT tests performed on the two different soil horizons (surface horizon: marl clay and second horizon: marl), located in the province of Baraki, Southeast of the capital of Algiers. Figures 4 and 5 show the results obtained from the cone tip resistance with net pressure limit and pressuremeter modulus for the two different types of soil horizons encountered mainly on site.

2.4 *Result and Discussion*

A total of 165 sets of clay and marly clay and 140 sets of marl soil data from site were collected using the results of the CPT and PMT tests. Data subdivided in three sets: 15% of the data for testing, 15% of data for validation and the remaining 70% of the data were used for training. According to the trend shown in the graphs above,

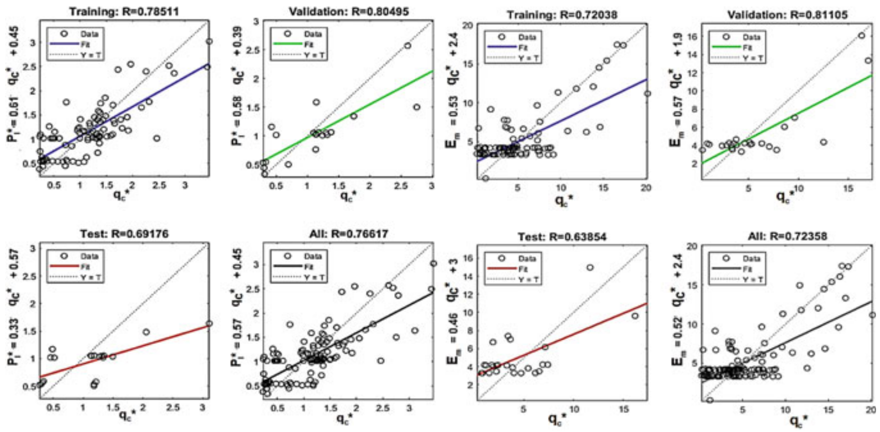

Fig. 5 Correlations q_c*(MPa) versus P_l* and q_c*(MPa) versus E_m(MPa) in the second horizon (marl) using ANN

the limit pressure and pressure modulus increase with the cone tip strength and the re-gression coefficient R^2 is from 0.80 to 0.82 for the validation data, from 0.61 to 0.78 for the training and between 0.62 and 0.76 for all the tested values. This result can be considered a good regression value. The adjustment relation obtained between the net limit pressure (P_l*) and the net cone tip resistance (q_c*) for the very soft marly clays is of the form: $P_l* = 0.38\ q_c* + 0.25$ and for the marl is of the form: $P_l* = 0.57\ q_c* + 0.45$. However, the adjustment relation obtained between the pressuremeter modulus (E_m) and the net cone tip resistance (q_c*) is as follows: $E_m = 0.46\ q_c* + 2.6$ for clays and marly clays and for marls is of the form: $E_m = 0.52\ q_c* + 2.4$.

3 Conclusions

The correlation between CPT and PMT parameters was studied using ANN for a heterogeneous site, located in the province of Baraki, South-East of the capital of Al-giers. For clays and marly clays examined, the average E_m/q_c ratio is about 3.47, this value is in agreement to those proposed by Bahar et al. (1999) and Van Wambekce. The average q_c*/P_l* ratio is about 2. This value is relatively lower compared to the litera-ture, due to the marly clay studied which is very soft. For the marl studied (1982), it has been shown that, the ratio q_c/E_m is in the order of 1.5 and ratio q_c*/P_l* is 1.3. This range is lower compared to the literature, due to the marl studied which is soft. The work will continue for other marls in the study area with a bigger database in the future for a more reliable characterization of this formation.

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