Field correlations for various algerian sandy soils

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ABSTRACT: In Algeria, field and laboratory tests are two main methods for soil investigations to define geotechnical properties for use in design of structures. Various foundation design methods have been developed based on in situ test results such as the Menard Pressuremeter Test (MPT), the Cone Penetration Test (CPT) and the Standard Penetration Test (SPT). A trend currently being adopted by geotechnical engineers is establishing simple relationships between soil properties to speed up the design process. These correlations allow the designer to evaluate, compare, interpret or verify the defined soil parameters. The primary purpose of this study was to investigate the relationships between the SPT and the MPT for different type of sandy soils in Algeria. Data for this research were collected from number of projects. Three sites served as the subject of SPT-MPT correlations. The correlations were established between the limit pressure (p_{lim}), pressuremeter modulus (E_m) and the SPT blow counts (N).

Keywords: In situ tests; SPT; MPT, correlation

1. Introduction

Empiricism has an important role to play in geotechnical engineering. When no or poor soil data is available and/or only limited testing has been carried out, correlations between soil properties may be the sole weapon available to designer. In addition to giving preliminary estimates, the correlations can also be used to compare the values deduced from laboratory and in situ tests.

Laboratory and in situ tests are two main methods used in geotechnical investigations for identifying the geotechnical properties of soils. In situ tests are often preferred to laboratory tests because they provide readily, relatively economic and reliable results that can help engineers make decisions and judgments on the subsurface features and their choice of foundation type. Besides, simple laboratory tests may not be reliable in most cases while more sophisticated laboratory testing can be time consuming and costly [1], therefore, in situ testing is very important in geotechnical engineering. Although in situ tests are not without criticism, but they present on the laboratory tests some advantages whose main, besides the one we just indicated, is that they are fast and cheap, which allows on the same site, to realize a large number. It is thus possible to assess the heterogeneity of a site and to submit, for each layer encountered, the experimental results to a statistical analysis in order to be able to choose the values of the mechanical characteristics in a confidence interval.

Several in situ tests such as the Standard Penetration Test (SPT), the Cone Penetration Test (CPT, CPTU and SCPTU), the Pressuremeter Test (PMT), and the Vane Shear Test (VST) have been widely used to obtain engineering parameters needed for geotechnical design.

The SPT is a dynamic penetration test that is used extensively throughout the world. In Algeria, however, the PMT is often preferred. It is most recommended for geotechnical investigations. Therefore, it seems necessary to compare the results obtained between these two types of tests in the same geological formations and to study the possibility of correlate these results.

The primary aim of this research project was to develop empirical correlations between the parameters derived from SPT and MPT tests for different type of sandy soils in Algeria. The correlations were established between the limit pressure (p_{lim}), pressuremeter modulus (E_m) and the SPT blow counts (N). Use of such correlations would enable reducing the need for more expensive field and laboratory procedures on future projects in similar soil conditions. There are so many empirical relationships and graphs available in the literature, which are regularly used in the designs worldwide [2-11].

2. Sites location and geological context

Data for this research were collected from three projects located in north of Algeria. It consists on sites of Caroubier, Mostaganem and Terga. A total of 123 boreholes were drilled in order to identify the different types of soil encountered in these sites. The main geological formation encountered in each site are indicated as follow:

Caroubier site located in central north of Algeria. The ground is constituted on the surface by a recent quaternary deposit, it is composed by sand formation more or less clay resulting from old beach emerged from a depth varying from 1.5 m to 15 m, and gravels coming from the decalcification of marine puddings. These layers are followed by a sandy substratum corresponding to the upper Pliocene formations.

Mostaganem is located in north-west of Algeria site. the ground is constituted of recent Quaternary deposits consisting of more or less clayey sand, results of former emerged beaches (lower level) covering a marl Pliocene substratum.

Terga site is located in north-west of Algeria. The lithological formations are topped by the medium to fine sand of variable layer; from 1.50m to 13.50m, sometimes reaching 18m depth, followed by compact sandstone with beige to yellow color in depth.

The details of all three sites, location, type of soil, geological deposits and depth of sand layers are summarizing in Table 1.

Table 1. Location and description of soil

Site	Caroubier	Mostaganem	Terga
X (m)	508554	241104	661004.59
Y (m)	4065800	39898.17	392500.51
Soil type	Clayey Sand	Fine to medium grained sand	Medium graind sand
Geological deposit	Recent Quaternary	Recent Quaternary	Pliocene
Depth (m)	20	18	14

3. Geotechnical data

The SPT and MPT tests were carried out according to NF P94–115 and NF P94-110-1 respectively. The chosen data was obtained from soil investigations for three major projects in the north of Algeria. A total of 85 pressuremeter and 123 SPT tests are served this study. Three variables are representative of the data used in this research: SPT N (blows/0.3m), MPT limit pressure p_{lim} (MPa) and pressuremeter modulus E_m (MPa). Laboratory tests were also performed on disturbed and undisturbed samples to determine the physical properties of the soils. Figures 1, 2 and 3 show the profiles of SPT, N-values, limit pressure and pressuremeter modulus with depth for each site respectively. The histogram analysis of the concerned parameters was performed in order to define the quality of data and therfore the reliability of tests used for this study. For these histograms, the ideal situation is the one that would be closer to Gauss's random distribution.The histogram distribution of uncorrected SPT, N–value, and pressuremeter parameters for each site are indicated in Figures 4, 5 and 6.

For the Caroubier site, it can be noted that the histogram of SPT, N–value is closer to the ideal situation (normal distribution). The majority of SPT, N-values are ranging between 10 and 30. For the Terga site, the distribution of SPT, N–value indicates the dispersion of data and the majority of data are ranging from 10 to 40. For Mostaganem site, the distribution of SPT, N–value is more or less satisfactory.

The distribution of limit pressure for Terga site is closer to ideal distribution. For Caroubier site, the histogram of limit pressure indicates that the values upper to 3 MPa are considered as aberrant points. The histogram of pressuremeter modulus as indicated in Figure 6 shows a great dispersion for the three sites. It should be noted the SPT N-value upper to 50 are retaining in order to include the soil in the data set.

Table 2 presents the USCS group classification and statistical parameters (number of data, mean, maximum, minimum and standard deviation) of pressuremeter parameters and uncorrected SPT, N-value for each site.

According to the SPT et MPT classifications, the in situ compactness of the sandy soils recorded in Mostaganem site is considered relatively loose. The sand of Caroubier site is classified medium dense. The sand encountered in Terga site, can be classified medium dense in the surface and dense to very dense in depth.

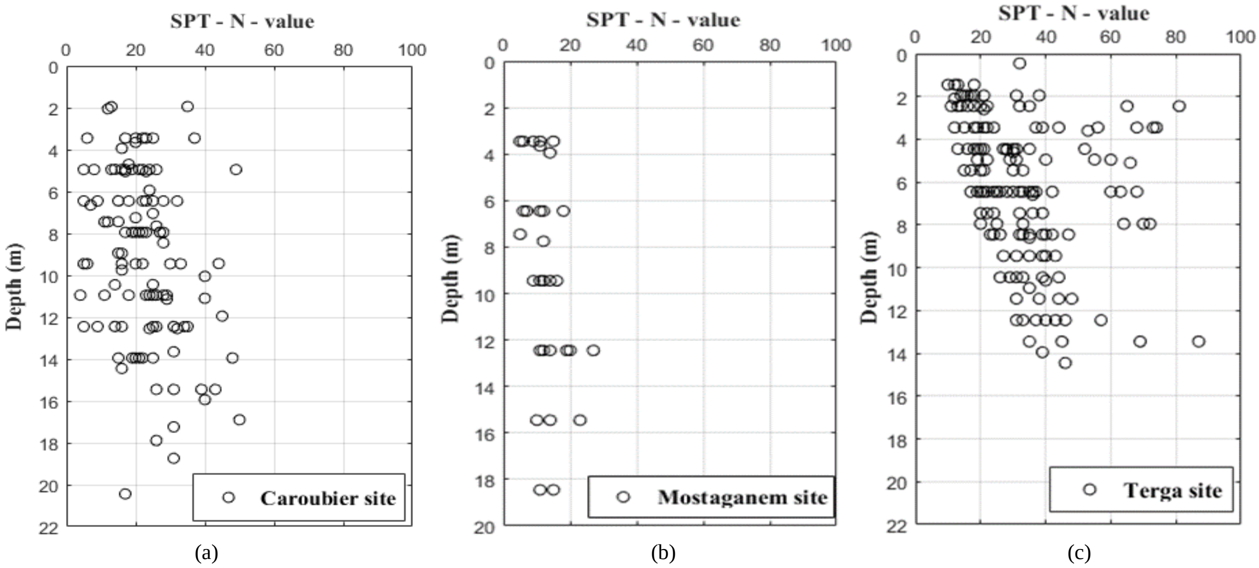
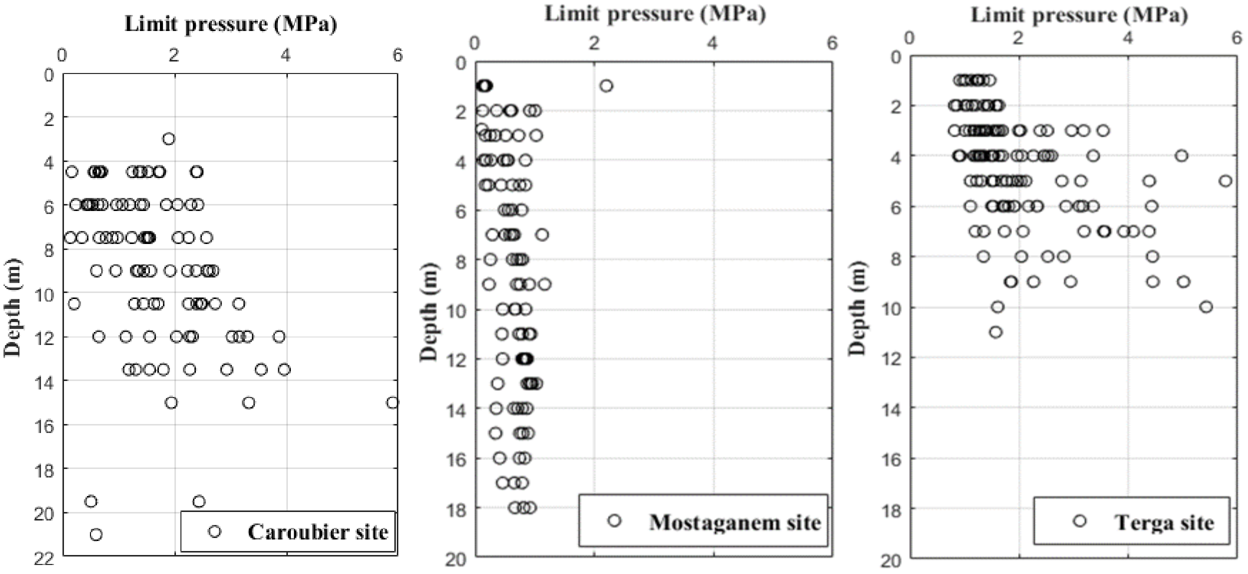
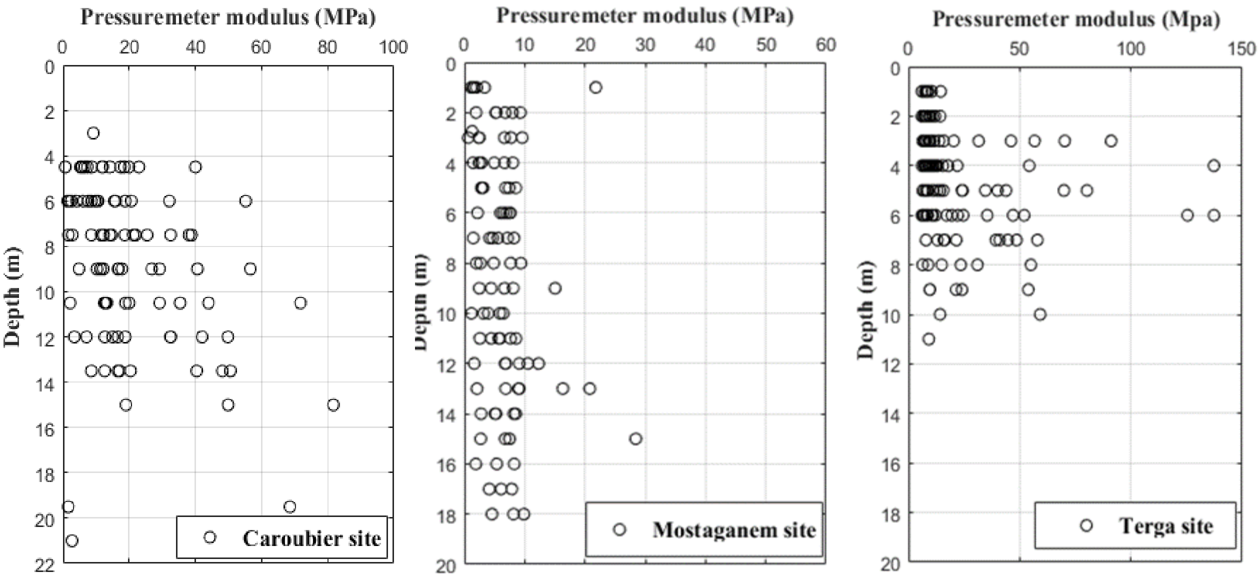


Figure 1. Profile of SPT, N-value for sites: (a) Caroubier, (b) Mostaganem, (c) Terga.



(a) (b) (c)

Figure 2. Profile of limit pressure of sites: (a) Caroubier, (b) Mostaganem, (c) Terga.



(a) (b) (c)

Figure 3. Profile of pressuremeter modulus for sites: (a) Caroubier, (b) Mostaganem, (c) Terga

Table 2. Descriptive statistics for each site

site	Classification USCS	Parameter	Number	maximum	minimum	mean	Standard Deviation
Caroubier	SA / SM	SPT, N	128	50	4	23	9.46
		p_{lim} (MPa)	93	5.89	0.14	1.68	0.99
		E_m (MPa)	93	81.77	0.71	20.37	16.84
Mostaganem	SA / SM	SPT, N	33	27	5	13	4.86
		p_{lim} (MPa)	96	2.20	0.11	0.64	0.31
		E_m (MPa)	96	28.43	0.64	6.21	4.42
Terga	SP	SPT, N	166	87	10	32	15.80
		p_{lim} (MPa)	134	5.78	0.82	1.99	1.02
		E_m (MPa)	134	137.34	6	21.28	24.20

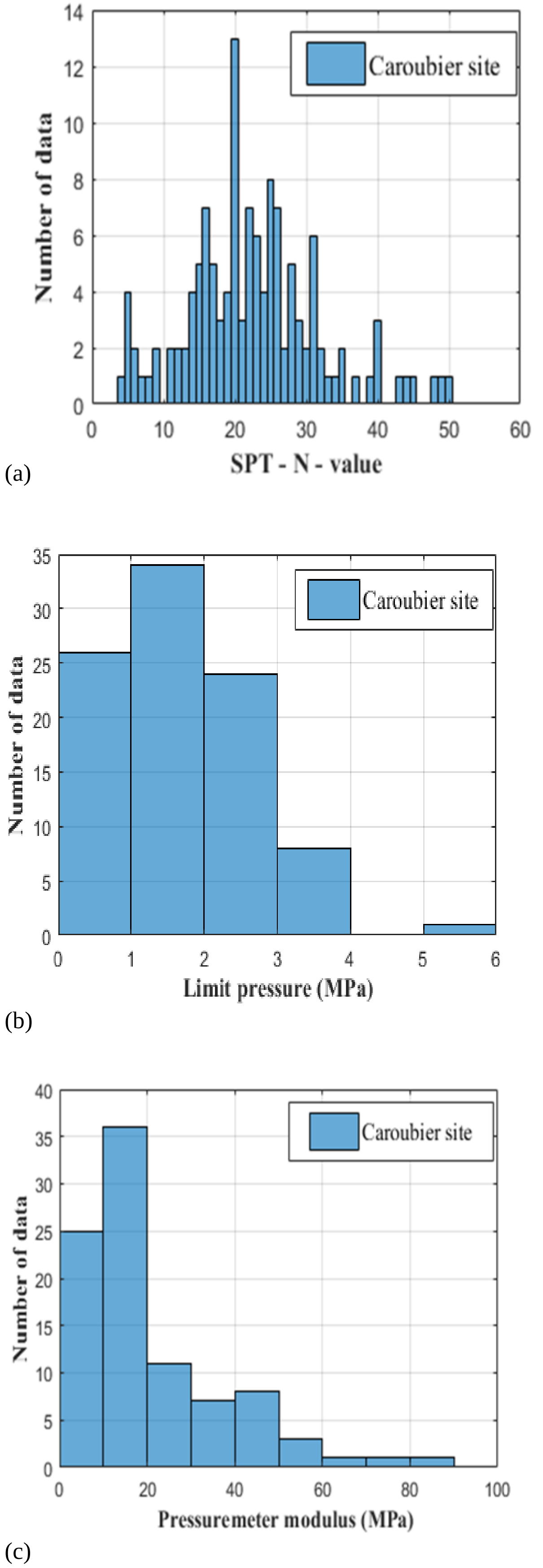


Figure 4. Histogram of Caroubier site parameters: (a) SPT N- value, (b) limit pressure, (c) pressuremeter modulus.

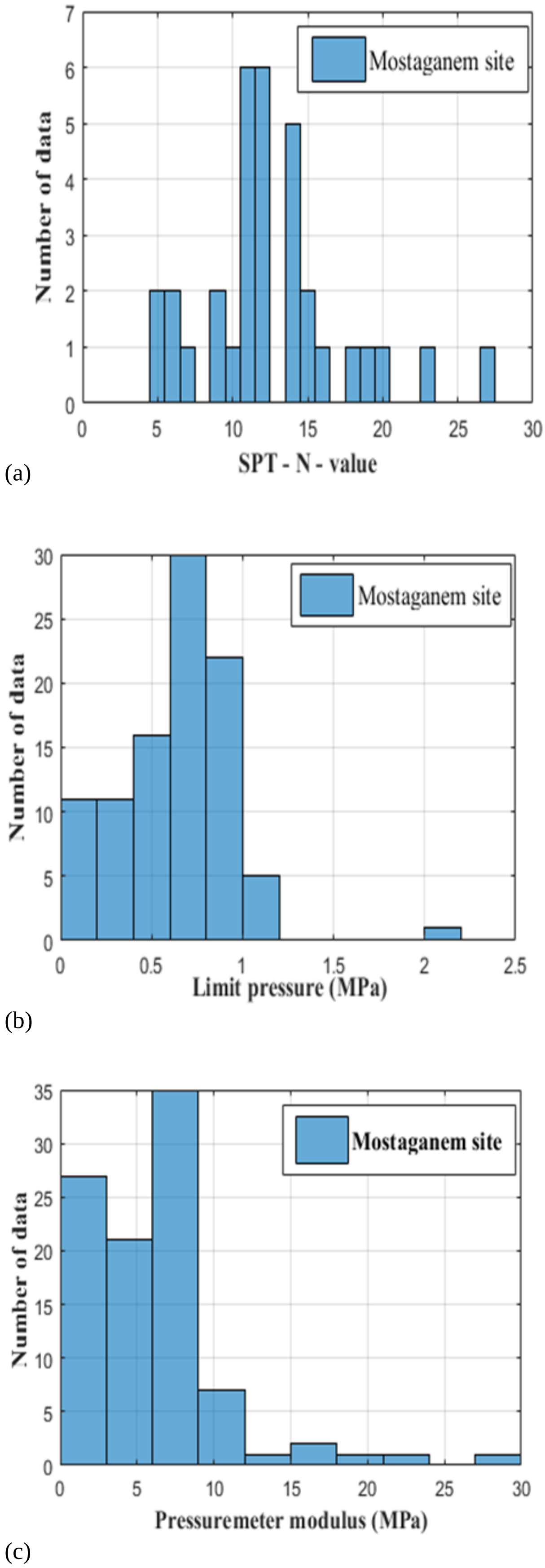
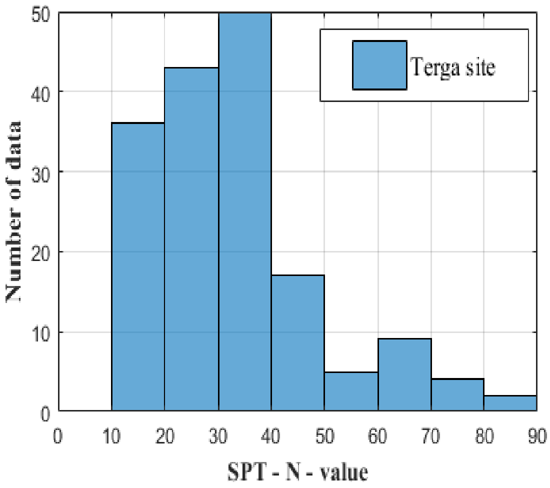
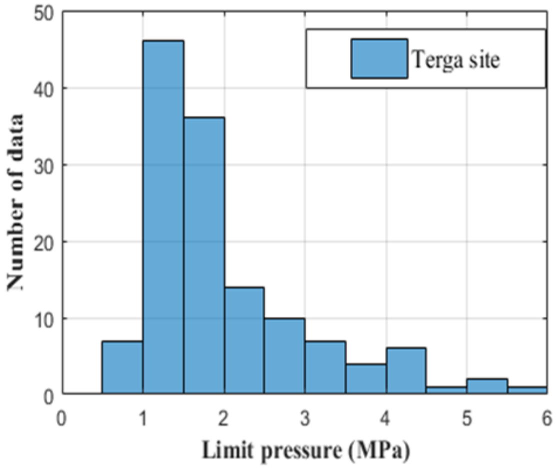


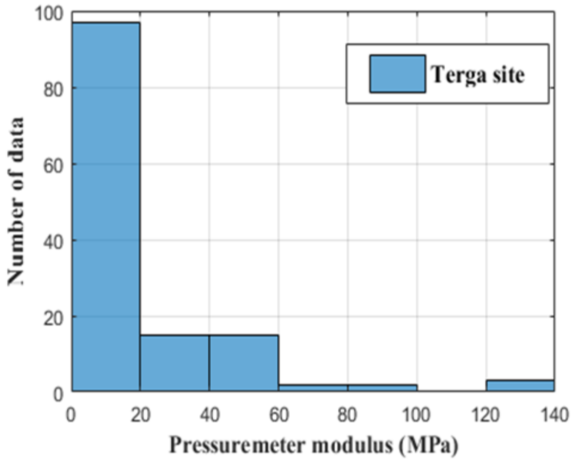
Figure 5. Histogram of : a) SPT N value, b) limit pressure, c) pressuremeter modulus of Mostaganem site.



(a)



(b)



(c)

Figure 6. Histogram of all site: SPT, N – value, (b) limit pressure, (c) pressuremeter modulus of site.

4. PMT and SPT correlations

This study on correlations between pressuremeter and SPT parameters was performed statistically on a total of 85 pressuremeter and 123 SPT measurements. A unit of depth, geographical location and geological formation was respected, that is to say that the comparison only concerned tests carried out at the same depth, in the same formation and for distant surveys of less than about thirty meters from each other in plan and at comparable altitudes.

To obtain a relationship between the pressuermeter parameters (p_{lim}, E_m) and the uncorrected SPT, N-value, simple regression analysis was applied. This technical is widely used in literature which allows to control the reliability on one parameter on the basis of used another parameter. The principle is to associate to each value obtained by pressuremeter test (E_m and p_{lim}) a value obtained by standard penetration test (SPT) at the same depth and soil type. In this study, the statistical analysis were performed in two different steps:

1. PMT and SPT correlation for each site (Caroubier, Mostaganem and Terga site)
2. PMT and SPT correlation for all sites

In order to develop more accurate correlations, it should be noted that the data used for this study come from different investigation sites and may not have optimal conditions for statistical analysis. For this reason, all SPT and PMT drillings with a high degree of disturbance have been removed. In addition, the distance between the holes SPT and PMT was respected.

The results of the regression analysis are shown in figures 7 to 14. As we can seen in Table 3, the linear model presents a high regression coefficient R^2. It is appropriate to retain only the points inside the prediction bounds with 95 % confidence level. Several points were removed due to the scatter of data. As we can seen in Figure 8 and 14. Due to the scatter of data of Mostaganem site, it was difficult to obtain a relationship beteween E_m and SPT, N-value. In addition, the correlations of Terga site and all sites presented a high coefficient of regression compared with Mostaganem site and Caroubier site. This can be explained by the importance of number data employed in Terga site and all sites.

The correlations obtained between limit pressure (p_{lim}), pressuremeter modulus (E_m) and SPT, N-value are given by the following equations:

- Caroubier site

$$p_{lim} = 0.061\, N - 0.269 \quad (1)$$

$$E_m = 0.613\,.\,N - 2.32 \quad (2)$$

- Terga site

$$p_{lim} = 0.037\,.\,N + 0.67 \quad (3)$$

$$E_m = 0.66\,.\,N - 3.16 \quad (4)$$

- Mostaganem site

$$p_{lim} = 0.027\,.\,N + 0.34 \quad (5)$$

- All site

$$p_{lim} = 0.043\,.\,N + 0.35 \quad (6)$$

$$E_m = 0.632\,.\,N - 2.497 \quad (7)$$

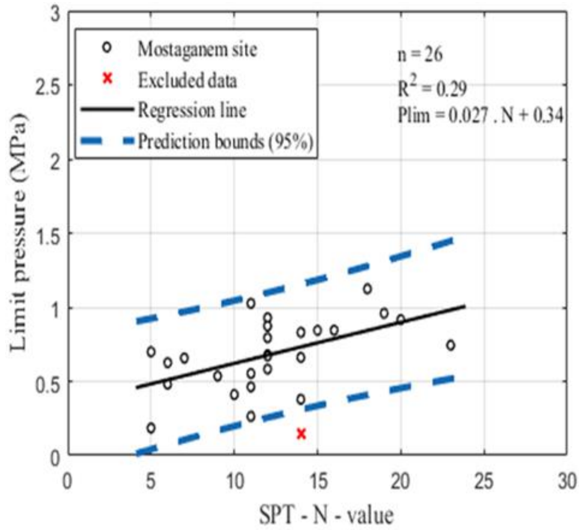


Figure 7. Relationship between limit pressure and SPT, N-value for sand of Mostaganem site

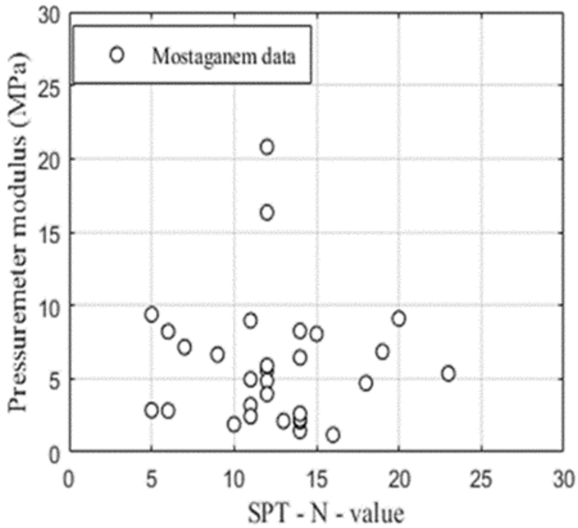


Figure 8. Relationship between pressuremeter modulus and SPT, N-value for sand of Mostaganem site

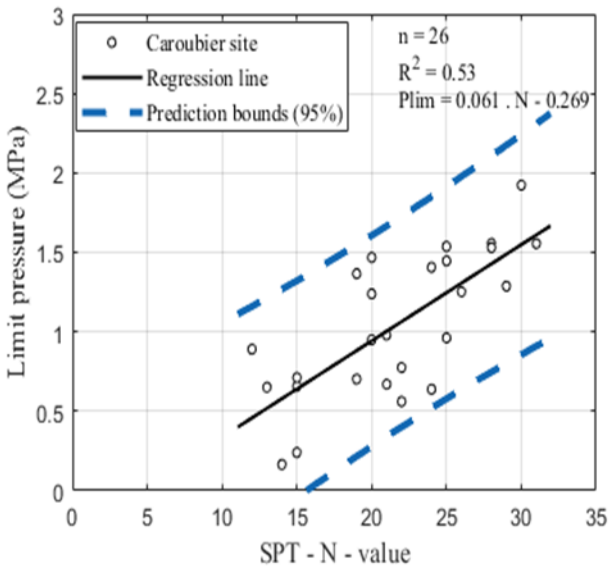


Figure 9. Relationship between limit pressure and SPT, N-value for sand of Caroubier site

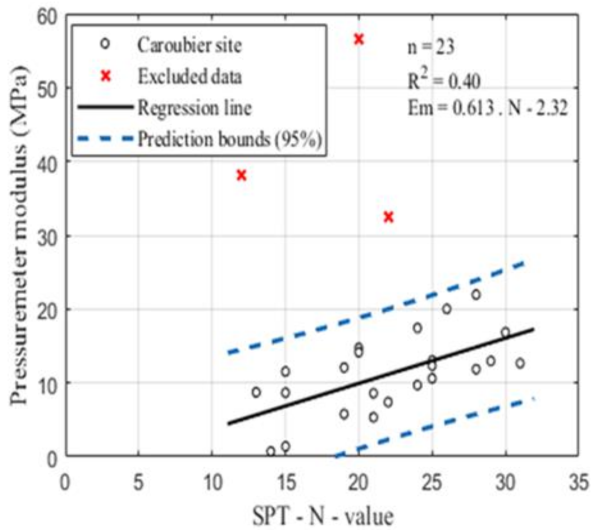


Figure 10. Relationship between pressuremeter modulus and SPT, N-value for sand of Caroubier site

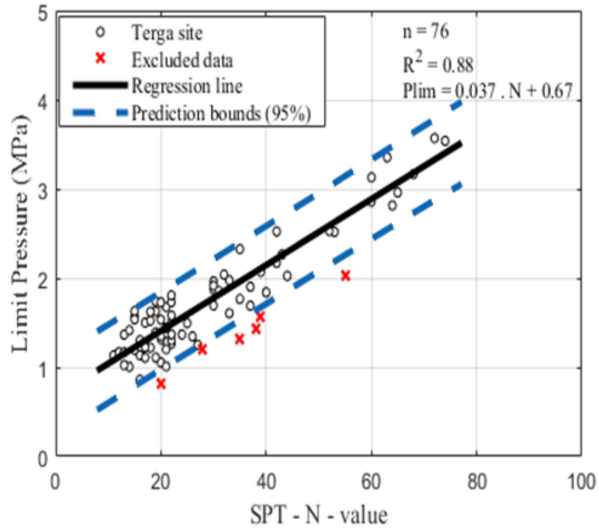


Figure 11. Relationship between limit pressure and SPT, N-value for sand of Terga site

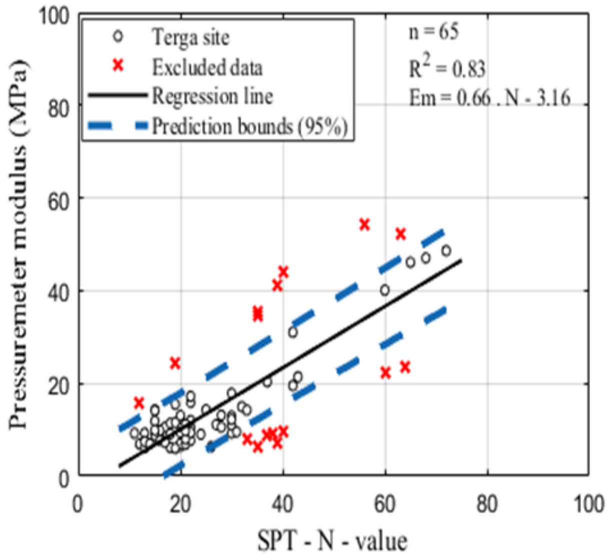


Figure 12. Relationship between pressuremeter modulus and SPT, N-value for sand of Terga site

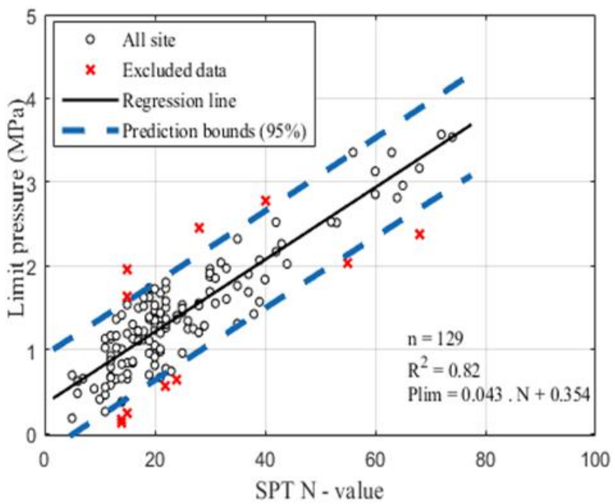


Figure 13. Relationship between limit pressure and SPT, N-value for sand of all sites

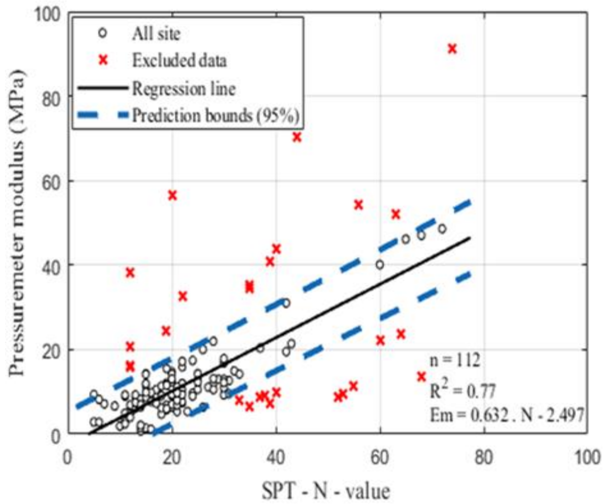


Figure 14. Relationship between pressuremeter modulus and SPT, N-value for sand of all sites

Table 3. Descriptive statistics for each site

Relati-onship	R^2	Sites			
		Caroubier	Mostaganem	Terga	All sites
P_{Lim} - N-SPT	Linear	0.53	0.29	0.88	0.82
	Power	0.44	0.26	0.78	0.70
	Exponential	0.45	0.25	0.81	0.62
	Logarithmic	0.50	0.28	0.79	0.73
E_M – N-SPT	Linear	0.40	-	0.83	0.70
	Power	0.37	-	0.63	0.43
	Exponential	0.35	-	0.72	0.47
	Logarithmic	0.39	-	0.65	0.52

5. Comparison between correlations of this study and literature

The principle of this comparison is to estimate the limit pressure and pressuremeter modulus from the empirical models developed in this study. The results thus obtained were compared with the pressuremeter parameters measured in situ and with correlation proposed in the literature.

In this study, we chose a site of Mohammadia that did not apply the regression analysis. This site is located in central north of Algeria, near to Caroubier site at a distance of about 6 kilometers.

The ground of Mohammadia site is constituted of recent Quaternary deposits with thickness of up to 30m, covering a sandy substratum corresponding to the upper Pliocene (Astien) formations.

The geotechnical investigation was carried out using Standard Penetration Test (SPT) and Pressuremeter Test (PMT). The results of PMT and SPT are presented in Table 4.

Table 4. Descriptive statistics of Mohammadia site

	SPT, N-value	p_{Lim} (MPa)	E_m(MPa)
Maximum	99	10.46	837
Minimum	11	0.61	2.91
Mean	51	3.91	97.32
Standard Deviation	16.50	0.77	73.75

As we can observed, the mean value of SPT, N-value, limit pressure and pressuremeter modulus is 51, 3.91 MPa and 97.32 MPa respectively. This site is classified dense to very dense.

Tables 5 and 6 show the statitical results of the limit pressure and pressuremeter modulus estimated from models developped in the present study and models proposed in the literature. The figures 15 and 16 show the box plot of the predicted limit pressure and pressuremeter modulus for some correlation of literature and correlations of this study

The standard deviation and variance are the important measures of despersion. When statistical serie is less dispersed, the observations (p_{lim} and E_m) have a low standard deviation and thus a low variance. The average also is a good statistical parameter. The best model is respresented by an average closer to the pressurmeter test results measured in Mohammadia site and with a lower variance and standard deviation. The results of comparative study indicate that the correlation developped in Caroubier site is more appropriate than the other correlation and give a similar result to the measured value of pressuremeter test (PMT) in Mohammadia site. Although this model has been developed on SPT, N-value ranging from 10 to 32 and limit pressure (p_{lim}) and pressuremeter modulus (E_M) ranging from 0.14 to 5.89 MPa and from 0.71 to 81.77 MPa respectively.

The average calculated by the empirical model developed on the soil of Mostaganem was very small. In this case, the correlation obtained by this model can not be valid and applied for soil considered to be very dense. In the case of correlations of literature, the average estimated by [1] is almost similar to the average measured in situ, but the variance which is equal to 3.84 MPa for the limit pressure and 391 MPa for the pressuremeter modulus. The results mean that are very dispersed. This results shows that the geology of site and the range value of mechanical parameters of soil obtained from in situ test (pressuremeter parameters and SPT, N-value in this case) have an influence on empirical models.

Table 5. Statistical results of predicted limit pressure for empirical model proposed

Model number	Reference	Empirical equation	Average	Standard Deviation	Variance
Model 1	Study of Caroubier site	$P_{Lim} = 0.061 . N - 0.269$	2.83	1.01	1.51
Model 2	Study of Mostaganem site	$P_{Lim} = 0.027 . N + 0.34$	1.71	0.54	0.30
Model 3	Study of Terga site	$P_{Lim} = 0.037 . N + 0.67$	2.55	0.61	0.56
Model 4	Study of all site	$P_{Lim} = 0.043 . N + 0.354$	2.54	0.71	0.75
Model 5	Gonin et al. (1992)	$P_L = 0.046 . N$	2.34	0.76	0.86
Model 6	Yagiz et al. (2008)	$P_{Lim} = 0.02945. N_{corr} + 0.2197$	1.72	0.49	0.35
Model 7	Bozbey and Togrol (2012)	$P_{Lim} = 0.33\ N_{60}^{0.51}$	2.39	0.41	0.26
Model 8	Cheshomi and Ghodrati (2015)	$P_{Lim} = 0.1\ N_{60}$ - 2.08	3.01	1.62	3.84

Table 6. Statistical results of predicted pressuremeter modulus for empirical model proposed

Model number	Reference	Empirical equation	Average	Standard Deviation	Variance
Model 1	Study of Caroubier site	$E_M = 0.613 . N - 2.32$	28.82	10.12	152.70
Model 3	Study of Terga site	$E_M = 0.66 . N - 3.16$	30.37	10.89	177.01
Model 4	Study of all site	$E_M = 0.632 . N - 2.497$	29.62	10.43	162.31
Model 5	Gonin et al. (1992)	$E_M = 0.33 . N$	16.77	5.45	44.25
Model 6	Yagiz et al. (2008)	$E_M = 0.38867\ N_{corr} + 4.554$	24.30	6.41	61.39
Model 7	Bozbey and Togrol (2012)	$E_M = 1.33 . N^{0.77}$	26.98	6.89	70.93
Model 8	Cheshomi and Ghodrati (2015)	$E_M = 0.98 . N_{60} - 9.43$	40.36	16.17	390.27

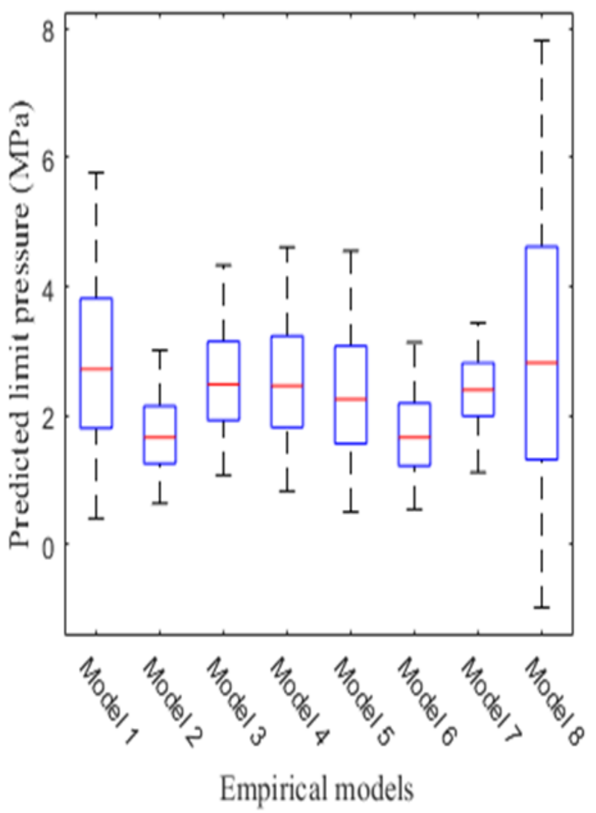


Figure 15. Box plot of the predicted limit pressure for some correlation of literature and correlation of this study

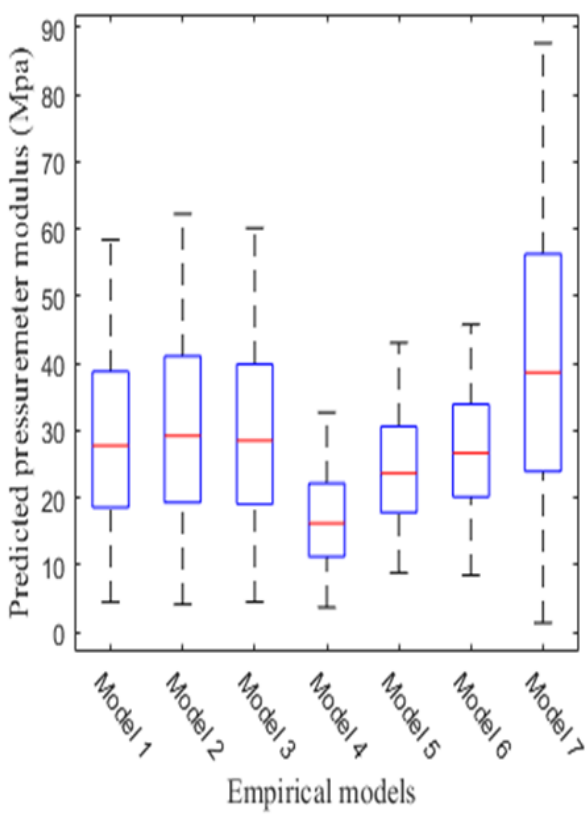


Figure 16. Box plot of the predicted pressuremeter modulus for some correlation of literature and correlation of this study.

6. Conclusion

Among the in situ tests used in geotechnical investigations, the pressuremeter and the standard penetration tests are used for estimating the soil properties in geotechnical projects in Algeria. The study carried out on three characteristic geological formations from the northern Algeria has made it possible to establish correlations between pressuremeter and SPT results, by simple regression analysis.

Relalionships were proposed between uncorrected SPT, N-value, limit pressure and pressuremeter modulus for sandy soils with acceptable correlation coefficients. The comparison between the redults obtained for each site showed that there exists a similar linear relationship between them but their line slope is different. It can be concluded that line slopes are related to the geological condition, soil type, and range of test results. Thus, these correlations are valid for the range of N values measured on the three sites.

Empirical equations presented in this paper were also compared with similar equations in other research. These comparisons showed the the line slope of these linear relationships are also different. Hence, it is necessary to present empirical equations between SPT and PMT tests for each soil type and for each area separately.

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