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Correlation between Pressuremeter Test and Standard Penetration Test for a Clayey Soil Formation in Northern Algeria

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ملخص البحث :

يعتبر اختبارالاختراق القياسي SPT و اختبار مقياس الضغط PMT من اكثر الإختبارات الحقلية استخداما في تطبيقات مجال الهندسه الجيوتكنيكيه. ولذلك كانت دائما من نقاط البحث والدراسة محاولة إيجاد علاقة دقيقة بين نتائج هذين الإختبارين. في هذا البحث تم دراسه العلاقه بين قيم SPT- N_{60} مع PMT- P_L للتربة الطينيه اللينه والتربه الطينيه الصلده المتواجده في شمال الجزائر كلا علي حده. وتم اقتراح معادلات تجريبية لهذه العلاقه وتم توضيحها بالرسومات والجداول. وللتحقق من هذا التحليل، أجريت مقارنة بين المعادلات المستنتجه عن هذه الدراسة ومعادلات مماثلة سابقه تم اقتراحها في المراجع لنفس نوع التربة ونفس درجه الليونه والتماسك. وجد توافق كبير بين نتائج هذا البحث و مثيلاتها من الدراسات السابقه، مما يؤكد أن الاختيار الجيد للبيانات يزيد من دقه المعاملات الجيوتكنيكيه المستحدثة، وبالتالي المستخدمة في تصنيف التربه وحسابات تصميم الأساس.

Abstract:

The Standard penetration test (SPT) and the Pressuremeter test (PMT) are widely used in-situ tests carried out to estimate the soil properties, each with its pros and cons. Statistical correlations between their testing results is vital and important for many geotechnical engineering projects. In this study, the SPT- N_{60} Blow counts were correlated with the PMT parameter- P_L for clayey soils of different consistencies in Northern Algeria. Empirical equations were proposed to estimate P_L from N_{60} for soft clay and stiff to hard clay formations separately. To verify the present analysis, a comparison between the empirical correlations induced by this study with similar correlations proposed by other researches was performed. A considerable results compatibility was observed, which assures that a good selection of data increase the reliability of geotechnical parameters induced and consequently used in site classification and in foundation design.

Keywords: Pressuremeter test- Standard penetration test- Clay- Statistical Correlation

1- Introduction

In situ and laboratory tests are the two main methods used in practice to obtain either the soil strength characteristics and soil deformation properties, or to assess the in situ stress state of a soil deposit. In situ tests are often preferred to laboratory tests as they reveal more realistic and reliable results since they are carried out without soil disturbance. Therefore, in practice, in situ tests and correlations derived between the tests results are very important in geotechnical engineering.

Different in situ testing methods have been introduced in order to determine engineering soil properties. Among them are the standard penetration test (SPT) and the pressuremeter test (PMT) which are the two tests considered for correlation in the current study.

The SPT test has been developed in the United States since 1925 and is considered a well established, unsophisticated and relatively an inexpensive in situ test. The SPT is an in-situ dynamic penetration test designed to provide information of the geotechnical engineering properties of soils, and is considered one of the most commonly used in-situ tests. A detailed description and interpretation of the SPT test with correction of the number of blows recorded has been presented and discussed by several researchers [1, 2, 3, 4].

PMT test was developed by Louis Menard in the early fifties, and although PMT is mainly used in France and most of the francophone and the North African countries and not extensively used worldwide compared to SPT, it is considered a unique device amongst the different in situ devices that has the potential to derive the full stress-strain curve. The test is also unique considering the range of materials it could be used compared to other tests. PMT could be used in sandy formations, soft to firm clays and even in rocks. The original pressuremeter test introduced to the world by Louis Menard, known as Menard Pressuremeter test (MPM or PMT), is a simple test conducted in a pre-drilled borehole that is easily operated and results are easily interpreted as well.

The PMT device consists of an inflatable probe inserted in a pre-drilled borehole within a soil and is expanded radially into the surrounding ground. A detailed description of the PMT is beyond the scope of this paper; different researchers have published guidelines for testing procedures, applications and data interpretation [4, 5, 6]. Measurements of the PMT test are given by the soil pressure limit (P_L), and the Menard soil Modulus (E_m).

An interesting study has been carried out by Bustamante and Gianeselli [7] about the feasibility of the Menard pressuremeter test (MPM) compared to other in-situ tests as CPT, SPT, in addition to laboratory tests. Table 1 shows the numbers of tests that was carried out in full, compared to the number of incomplete tests or unperformed tests due to inadequacy with respect to soil nature or strength tests. It is clear from the study that the PMT was the most feasible and successful test as it was performed in all types of soils and soft rocks and was completed in full for more than 75% of the cases.

Table 1: Field and laboratory tests feasibility[7]

Test	carried out to full design length (1)	incomplete test (2)	not carried out (3)	not applicable (4)
MPM pressuremeter (p_l)	155	3	46	0
CPT (q_c)	60	79	23	42
Laboratory tests (c_u, c', φ')	21	67	69	47
SPT (N)	26	54	72	52

Based on the above, it is obvious that although SPT test is a relatively low cost test and a routine part of every soil exploration program in many countries all over the world, yet not always reliable and cannot be used in different soil formations. While, PMT test is a very accurate test with minimum constraints in using it, yet comparatively expensive and not performed in small and normal geotechnical projects. Therefore, having a correlation between these two important tests is very useful, yet crucial for the field of practice of geotechnical engineering design.

2- Previous Correlations

Many attempts have been made to correlate SPT-N values with PMT-P_L values in previous studies. One of the oldest and simplest correlations between N values and the PMT soil parameters P_L (MPa) and E_m (MPa) is that presented by Lafeuillade Marie-Pierre et al. [8] for the five principle types of soils in France: (Limons: Silt, Sables: Sands, Argilesvertes: Green clays, Argiles plastiques: Plastic clays, Marnes: Marl, Craie: Chalk-Sedimentary rocks) as presented in Table 2. Regardless of the simplicity in the usage of the derived correlations, they were generic and diverse and did not pay attention to the soil consistency or density or any other different properties within the same soil formation.

Table 2: Simplified correlations proposed between N, P_L (MPa) and E_m (Mpa)

Nature du sol	Correlation between $P_L$and N	Correlation between E_m and N
Limons	P_L= 0.029 x N	E_m= 0.35N
Sables	P_L = 0.046 x N	E_m = 0.33 N
Argiles vertes	P_L = 0.035 x N	E_m = 0.39 N
Argiles plastiques	P_L = 0.054 x N	E_m = 0.61 N
Marnes	P_L = 0.041 x N	E_m = 0.55 N
Craie	P_L = 0.154 x N	E_m = 1.38 N

In the same research, and using data of the clay formations in the city of Nice, the authors provided another generic correlation between N and P_L as follows: N = 10 to 30 (P_L - Po) where Po is the initial pressure on the borehole wall at the beginning of the test.

Meanwhile, Briaud [9] provided several correlations for the Menard pressuremeter tests based on a database of 426 PMT tests carried out at 36 sites in sand, 44 sites in clay in the USA along with other measured soil parameters. The results were presented again in Briaud [10] and Tables 3 and 4 show these correlations for sands and clays respectively. The correlations presented in this study are very useful since they correlate PMT parameters with the SPT N values as well as the q_c from the cone penetration test for each soil type.

Table 3: Correlations for sand [10]

Column A = Number in Table × Row B

A \ B	E_o (kPa)	E_R (kPa)	p_l^* (kPa)	q_c (kPa)	f_s (kPa)	*SPT N*
E_o (kPa)	1	0.125	8	1.15	57.5	383
E_R (kPa)	8	1	64	6.25	312.5	2174
p_l^* (kPa)	0.125	0.0156	1	0.11	5.5	47.9
q_c (kPa)	0.87	0.16	9	1	50	436
f_s (kPa)	0.0174	0.0032	0.182	0.02	1	9.58
SPT N	0.0026	0.00046	0.021	0.0021	0.104	1

Table 4: Correlations for Clay [10]

Column A = Number in Table × Row B

A \ B	E_o (kPa)	E_R (kPa)	p_l^* (kPa)	q_c (kPa)	f_s (kPa)	c_u (kPa)	*SPT N*
E_o (kPa)	1	0.278	14	2.5	56	100	667
E_R (kPa)	3.6	1	50	13	260	300	2000
p_l^* (kPa)	0.071	0.02	1	0.2	4	7.5	50
q_c (kPa)	0.40	0.077	5	1	20	27	180
f_s (kPa)	0.079	0.0038	0.25	0.05	1	1.6	10.7
c_u (kPa)	0.010	0.0033	0.133	0.037	0.625	1	6.7
SPT N	0.0015	0.0005	0.02	0.0056	0.091	0.14	1

Several researchers also studied statistical correlations between the SPT and the PMT measurements for the silty clayey and clayey soil formations, which were investigated carefully for further comparison to this study.Yagiz et al., 2008 [11] studied the correlation between the corrected SPT N-value (N_{cor}) and both pressuremeter modulus (E_m), and limit pressure (P_L) based on results of 15 boreholes executed in the city of Denizli, Turkey. The soil formations used in this study are mixed up between sand, silt, clayey stilt, sandy clay, and silty sand with PL values ranging from 0.3 to 1.5 Mpa. The tests were carried out at depth 1.5-2.0m only and the paper did not show how to correct the SPT N-values. Although the data included different soil types with different densities / consistencies, the researchers found a linear relationship between the corrected Ncor and E_{PMT} and P_L, which is believed to be useful if used particularly in the city of Denizli.Later, Bozbey and Togrol, 2010 [12] presented the relationship between SPT and PMT results based on an extensive study conducted in Istanbul, Turkey for both sandy soils and clayey soils formations. Their results were based on 182 tests and a distinctive linear correlation for each soil type was presented. Kayabasi, 2012 [13] conducted 52 SPT and 52 PMT on medium stiff to stiff and very stiff clayey soil. Based on the obtained results, he proposed two empirical relationships for the estimation of P_L and E_{PMT} through N_{60}. Cheshomi and Ghodrati, 2015 [14] also examined the relationship between SPT and PMT silty sand and silty clay soils based on a case study in Iran comprising 54 tests from 17 exploration boreholes. The correlation derived for the silty clay soils covered low plasticity firm, stiff to very stiff clay formations as described in the paper with P_L ranging from 0.6 to 3.5 MPa. Recently, Ozvan, 2018 [15] used tests data obtained from 20 exploration boreholes drilled as a part of a soil investigation program in turkey. The study area consists of two main layers. The upper levels, between 1.0 and 5.0 m, consist of silty clays and clay, the deeper levels consist of marl/claystone. Table 5 summarizes all the empirical relationships between P_L and N_{60} as provided by the several researchers previously mentioned.

Table 5: Empirical Relationships between $N_{60}$and P_L for silty clay and clayey soil formations as proposed by several researchers.

Soil type	**E_m/ P_L**	**Empirical correlation between $P_L$and N_{60}**	**Reference**
Silt/ clayey silt / Silty clay /silty sand	12-21	P_L (KPa) = 29.45 (N_{cor})+219.7 R=0.97	Yagiz et al., 2008 [11]
Clayey soil	7-19	P_L (MPa) = 0.26 $(N_{60.})^{0.57}$ R^2=0.67	Bozbey and Togrol, 2010 [12]
Clayey soil	---	P_L (MPa) = 0.043 $(N_{60.})^{1.2}$ R^2=0.74	Kayabasi, 2012 [13]
Silty clay	---	P_L (MPa) = 0.05 ($N_{60.}$) +0.42 R^2=0.78	Cheshomi and Ghodrati, 2015[14]
Clayey soil	---	P_L (MPa) = 0.142 ($N_{60.}$) – 1.166 R^2=0.895	Ozvan et al., 2018 [15]

Correlations help the designer in evaluating, comparing, interpreting or cross-checking the soil parameters obtained from these two important in situ tests [12]. In some of the previous considered studies, high determination coefficients (R^2) between the SPT N, and Menard limit pressure (P_L) values were obtained for different soil formations. However, it has been particularly emphasized by the above-mentioned researchers that the obtained empirical formula may be misleading unless the pressuremeter test as well as the standard penetration test are applied accurately, the results for different soil classes are included, and different empirical equations are provided for different soil groups by taking into consideration the geological and geotechnical soil characteristics of the study area.

It is believed that local correlations that are developed within a specific geology setting are generally preferable to generalized global correlations because they are significantly more accurate. Therefore, it is necessary to provide empirical relations for different areas and different soil categories.

The aim of the present study is to investigate the relationship between N_{60} and $P_L$values based on data of in-situ tests that have been carried out during a geotechnical investigation that took place at different sites in Northern Algeria crossing the Soummam valley. The empirical equations were proposed for soft silty clay and stiff to hard clays formations. In order to verify the empirical equations, these equations were compared with similar equations that have been proposed by other researchers for the same soil formation.

3- Geology and Soil Formation of the Area under Study

The area under study is situated in northeastern Algeria near Soummam valley. The description of the geology at Soummam valley is of a great complexity due to the superposition of geological units that characterize the geology of northern Algeria. The geological formations of the valley are affected by numerous intense tectonic faults, indicating the complex geology of this region as shown in Figure 1 [16,18]

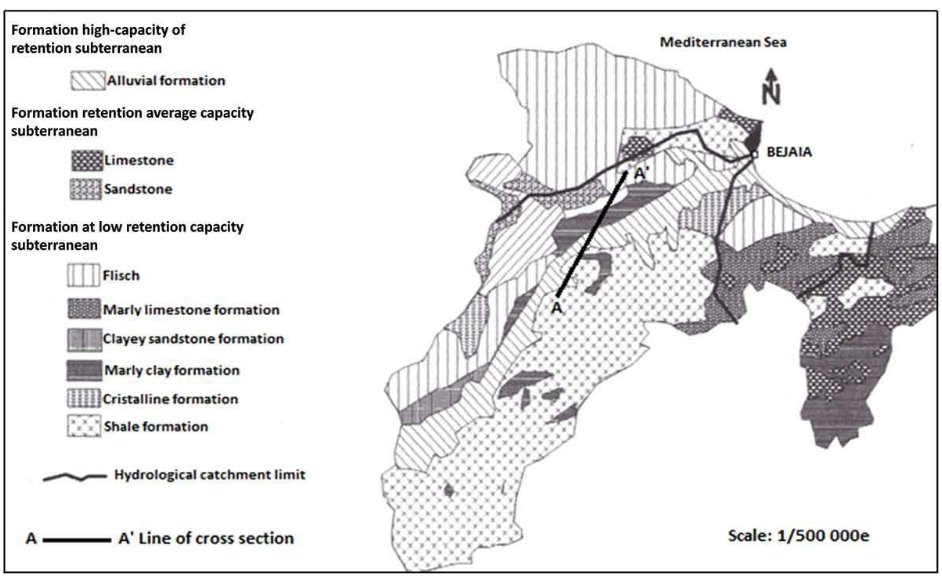

Figure 1: The geological formations of the Soummanvalley [18]

The site is represented by the fine alluvium formation of the valley. This quaternary formation is composed of layers of silts and clays and sitly clays of different consistency resting on marly clay formations.

According to the values of the limit pressures (PL) obtained from the different sites at the area under study and referring to the Ménard classification,Frank,2009 [17], the soil nature from the ground surface up to eight meters (0m to 8.00m) belongs to the category of "category A": soft clays and silts (Argiles et limons mous) where PL $\leq$ 0.7 Mpa. However, beyond this depth (from 8.00m to 20.00m and to 35.00m based on the borehole depth) the terrain is distinguished by "category B" and "category C" ranging from stiff to hard clay formations where PL $\geq$1.2 Mpa. In addition, by analyzing the different values of the E / Pl ratio, it emerges that the soil is of under-consolidated nature till almost 12 meters depth, beyond that the soil is considered over-consolidated.

4- Data Set and Methodology

An average of 15 boreholes were drilled at different locations in the area under study with a depth varying from 20 to 35 m. The analysis included only the results of tests carried out from ground surface until 20 m depth covering the area where fine alluvium deposits exist. In addition to laboratory tests, data of over 105 measurements were also made: Pressuremeter tests (50) and SPT (55), all data belonging to clay and silty clay formations and compiled from the different sites of the area of interest. Ground water was not present at some sites while the ground water level was encountered at depths ranging from 2.0 to 8.0m in other locations.

The processing of data is one of the most challenging works in the geotechnical research. Reliability of an analysis result is mostly defined by the accuracy of selected data rather than the method used for the analysis. Therefore, the selection of the most representative samples for a site is the key to a successful design. Thus, collecting pairs of PMT test data and SPT-N_{60} value, carried out at the same depth for each site, was first implemented. Secondly, any anomalous values of N_{60} or P_L were eliminated. And for the final analysis, only data of the same soil consistency and same fines percentages were considered for evaluation. The filtered compiled data including tests depths, SPT- N_{60} blow counts, P_L values in MPa, E_m/p_L ratio and the soil consistency are given in table 6.

Table 6: Tests depths, N_{60}values, $P_L$values, E_m/p_L and soil consistency of the clays and silty clay soils used in this research.

Test Number	Depth (m)	SPT-N_{60}(Blows)	P_L(Mpa)	E_m/p_L	Soil consistency
1	2	2	0.25	4.87	soft clay
2	4	4	0.4	5.00	soft clay
3	6	2	0.29	8.77	soft clay
4	8	2	0.25	10.32	soft clay
5	12	16	1.23	15.56	stiff clay
6	14	24	1.9	26.67	stiff clay
7	16	38	2.2	32	stiff to hard clay
8	20	35	1.77	30	stiff clay
9	4	4	0.44	5.2	soft clay
10	2	3	0.22	3.89	soft clay
11	4	4	0.32	4.8	soft clay
12	4	4	0.35	4.8	soft clay
13	12	15	1.51	11.5	stiff clay
14	16	35	1.7	15	stiff clay
15	20	30	1.9	26.2	stiff clay
16	2	2	0.17	3.89	soft clay
17	4	4	0.3	5.27	soft clay
18	6	3	0.26	5.3	soft clay
19	8	5	0.5	9.4	soft clay
20	12	17	1.2	11	stiff silty clay
21	14	27	1.6	13.5	stiff silty clay
22	20	35	2	22	stiff to hard clay
23	6	6	0.6	4.89	soft clay
24	8	6	0.61	5.62	soft clay
25	10	10	1.2	13	stiff clay
26	12	12	1.25	14.55	stiff silty clay
27	14	9	1.19	15.2	stiff silty clay
28	16	12	1.6	18	stiff clay
29	20	34	2	25	stiff to hard clay

In this study the SPT test was performed in accordance with ASTM D 1582-99, using a standard split-spoon sampler and a 63.5 kg donut-type hammer falling from a height of 76.2 cm. The N value obtained was standardized to N_{60} 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 according to the proposed description/method by Bowles [3]. The N_{60} values were the ones used for correlation in this study. The pressuremeter test was performed in accordance with ASTM D4719-1995 which uses a cylindrical probe placed at the desired depth in a pre-bored hole. The pure pressure limit values P_L were the ones used for correlation in this study.

Linear regression analysis was performed between the corrected SPT blow counts N_{60}, and soil limit pressure P_L for all available data, then an analysis for the soft clay formations as well as the stiff to hard clays/silty clays was performed discretely. The accuracy of the developed relationships have been examined through the R^2 correlation coefficients.

5- Results and Discussion

Field test results, SPT-N_{60} and PMT –P_L, are statically presented for in Figures 2 and 3 respectively. The range of SPT-N_{60} values are provided in figure 2 using box plots for a) all data "all filtered data given in Table 6.", b) for soft clays, and c) for stiff to hard clays. The box plot provides the 5 main statistical properties of the data are shown in the figures. The N_{60} values varied from 2- 6 for soft clay with a mean value of 3.6, while it ranged from 9 to 38 for the stiff/hard clay formation with a mean value of 23.

Similarly, the range of P_L values are provided in figure 3 using box plots for a) all data, b) for soft clays, and c) for stiff to hard clays. The P_L values varied from 0.17- 0.61 for soft clay with a mean value of 0.35 while it ranged from 1.19 to 2.2 for the stiff/hard clay formation with a mean value of 1.61.

A statistical regression analysis was carried out between the soil parameters to get the best-fit regression in a linear combination. The equations were created and displayed on the graph and the correlations were evaluated using the r^2 values to determine the accuracy of the correlation.

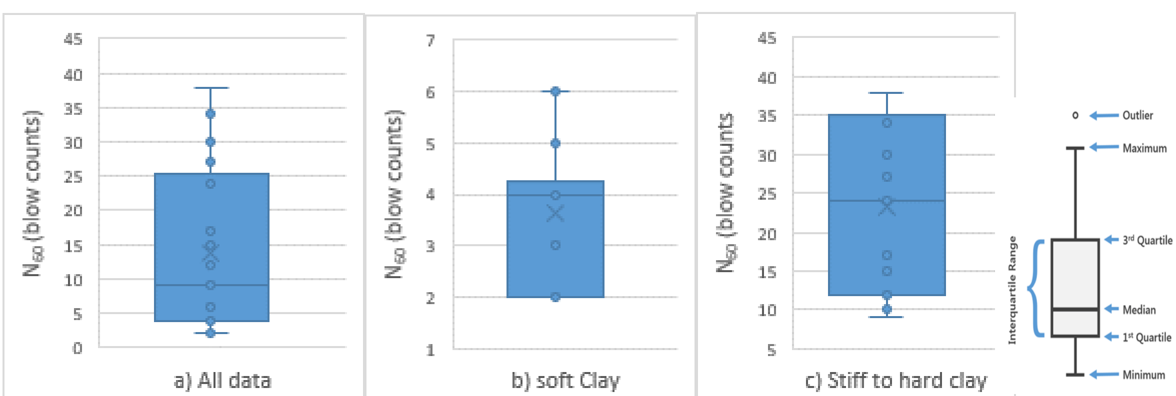

Figure 2: Range of SPT-N_{60} valuesfor a) all data b) soft clay C) Stiff to hard Clay

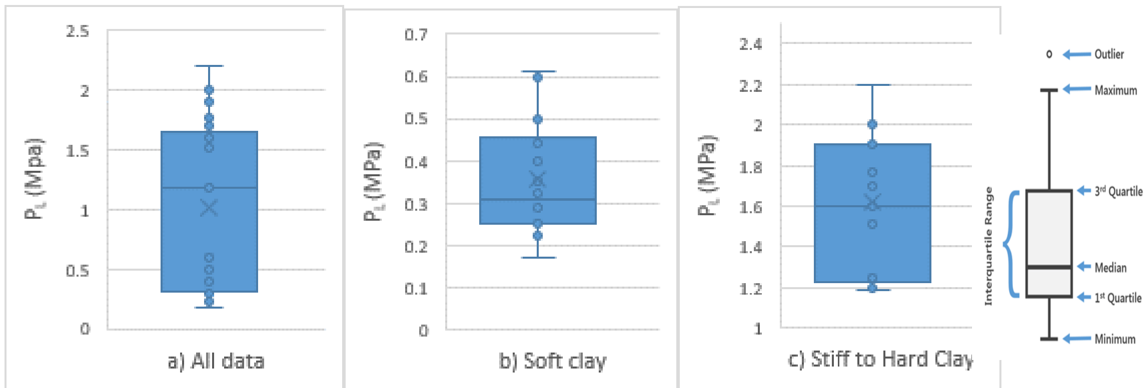

Figure 3: Range of measured PMT-PL values for a) all data b) soft clay C) Stiff to hard Clay

The correlation between SPT-N_{60} and P_L using all data of the clay soils with different consistencies is demonstrated in Figure 4. The correlation coefficient, R^2, between the investigated parameters was found as 0.717. The empirical equation proposed for clayey soils is expressed as:

$$P_L \text{ (MPa)} = 0.062\ N_{60} + 0.027 \quad R^2 = 0.717 \tag{1}$$

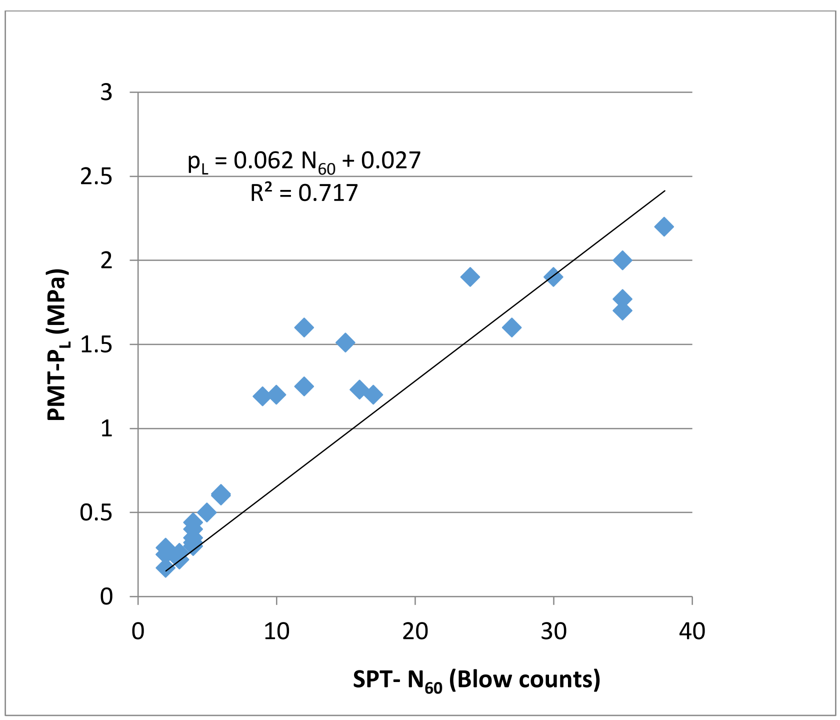

Figure 4: Relation between PMT-P_L values and SPT-N_{60} values using all soil data

The correlation between SPT-N60 and P_L for soft Clays formations and stiff to clays is shown in Figure 5 and 6 respectively. The correlation coefficient between the investigated parameters are calculated as 0.841 and 0.842, respectively. It is obvious that when data is divided and clays with different consistencies were treated separately a higher correlation was obtained. The empirical equations proposed for soft Clays formations and stiff to clays were expressed as:

$$P_L\ (\text{MPa}) = 0.09\ N_{60} + 0.23 \qquad R^2 = 0.841 \qquad \text{soft clays} \quad (2)$$

$$P_L\ (\text{MPa}) = 0.027\ N_{60} + 0.97 \qquad R^2 = 0.842 \qquad \text{stiff to hard clays} \quad (3)$$

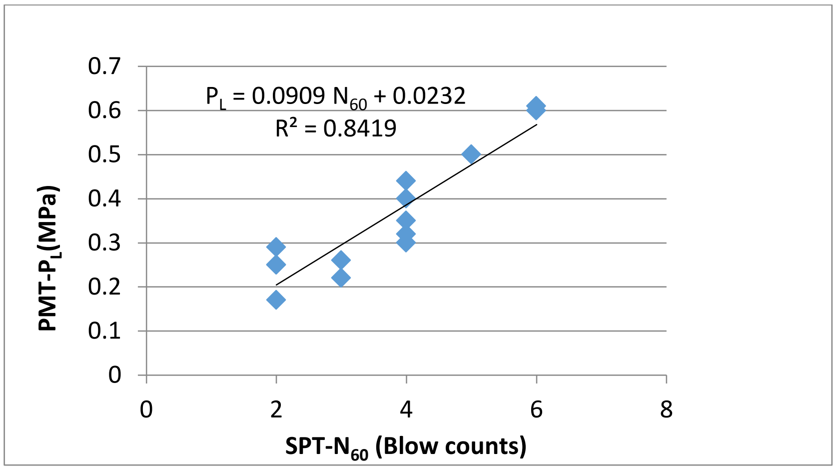

Figure 5: Relation between PMT-P_L values and SPT-N_{60} for soft clays

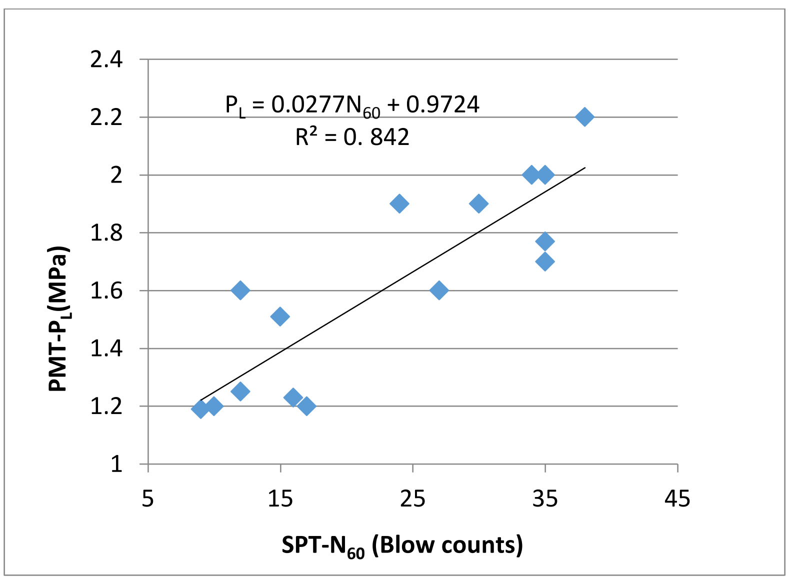

Figure 6: Relation between PMT-P_L values and SPT-N_{60} for stiff to hard clays

The correlations between SPT-N_{60} and PMT-P_L as proposed by Bozbey [12], Yagiz et al. [11], and Cheshomi et al [14] were plotted on Figure 7 together with the correlation induced by the present study. The comparison was carried out only for data of stiff to hard clay, as the previous researchers did not cover data for soft soils thus it was not useful to include all data for the comparison. This figure clearly shows that a similar linear relationship exists between N_{60}–P_L in all previous studies. The data used by Bozby [12] and cheshomi [14] are for medium stiff and stiff to very stiff clay and silty clay formations. Thus a great compatibility between these formulas and the one induced form the present study was observed. However, the equation proposed by Yagiz et al. [11] was different and lower as different soil lithologies was used in the analysis, which would cause inaccurate results. In addition, it should be noted that different classification of $P_L$values used to differentiate between clay different consistencies was not mentioned in the previous studies, which could cause variable results.

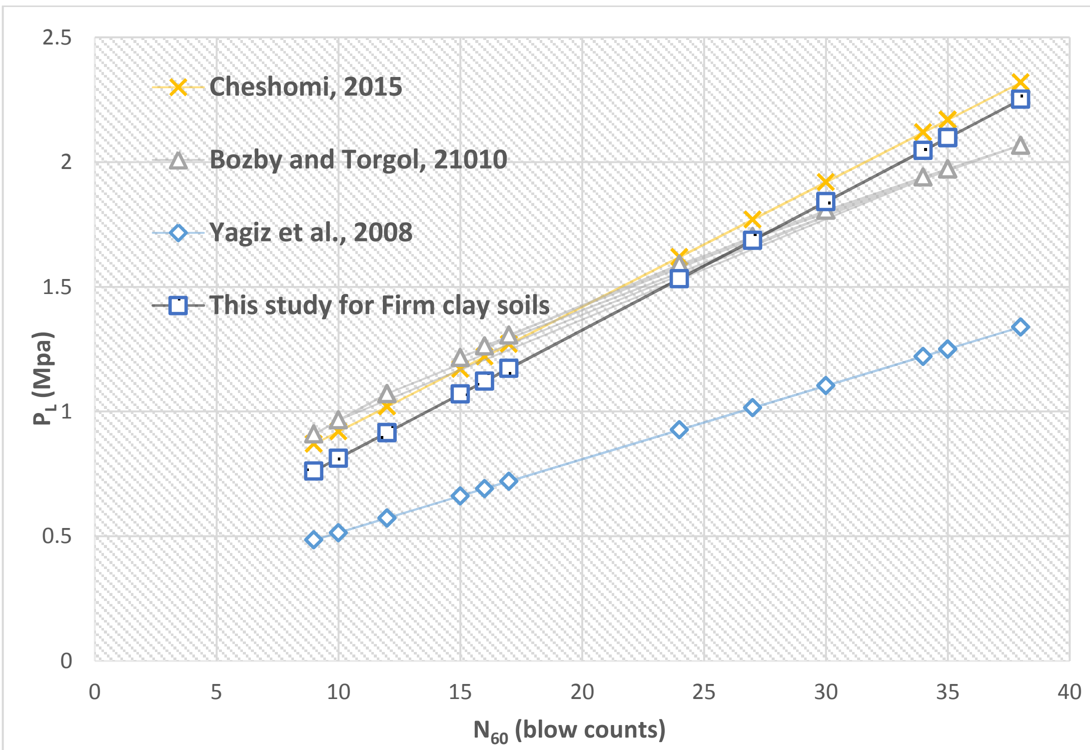

Figure7: Comparison between the relationships induced between P_L and N_{60} for stiff to hard clays from this study and previous researchers

6- Conclusions

The standard penetration and pressuremeter tests are widely used in situ tests for estimating soil properties in different geotechnical engineering projects. PMT test is an accurate test yet comparatively expensive while the SPT test is relatively inexpensive and usually performed in all geotechnical projects around the world. Therefore, finding a reliable correlation between these two tests results is very important yet crucial in different geotechnical applications. The literature review showed that there is not a unique relationship between SPT N values and PMT pressure limit values P_L, as the correlation is affected by the geological conditions of the area under study, the soil type and its consistency/density, and also on the accuracy of the data used for the analysis. The aim of the present study is to investigate the relationship between N_{60} and $P_L$values based on data of in-situ tests that have been carried out during a geotechnical investigation that took place at different sites in Northern Algeria. The empirical equation were first proposed for the entire data available at the site, then for the soft silty clay and medium stiff to hard clays formations separately. Based on the present study, the following findings could be noted:

- The processing of all data available for statistical analysis is one of the most challenging works in the geotechnical research. Reliability of an analysis result is defined by the accuracy of the selected data. Therefore, collecting pairs of PMT-P_L values and SPT-N_{60} values, carried out at the same depth for each site, was first implemented. Secondly, any anomalous values of N_{60} or P_L were eliminated. And for the final analysis, only data of the same soil type and consistency were considered for evaluation.
- A better correlation was obtained when separate statistical regression analysis was performed for each soil consistency and for each range of N and P_L values.
- A considerable compatibility was observed between the correlation induced by this study for the stiff clay and other correlations found by different researches that used similar soil type and conditions in their analysis.
- The proposed empirical correlation for the stiff clay formation is only applicable for clays with N> 8 and is considered reliable if used for soils of the same type and consistency.
- Local correlations developed for a specific geology setting and soil formation are considerably preferable to generic global correlations.

References:

[1] Seed, H.B., Arango, I. and Chan, C.K.(1975) Evaluation of soil liquefaction potential for level ground during earthquakes. A Summary report. United States.

[2] Liao S, Whitman RV (1986) Overburden correction factor for SPT in sand. J Geotech. Eng. ASCE 112(3):373–377.

[3] Bowles JE (1997) Foundation analysis and design, 5th edn. McGrawHill, Singapore.

[4] Menard L (1975) The Menard pressuremeter: interpretation and application of the pressuremeter test results to foundations design. Sols–Soils No. 26-1975.

[5] Baguelin F, Je´zeque´l JF, Shileds DH (1978) The pressuremeter and foundation engineering. Trans Tech Publications, Clausthal-Zellerfeld, Germany.

[6] Mair RJ, Wood DM (1987) Pressuremeter testing – methods of and interpretation. Butterworth, London.

[7] Bustamante, M., Gianeselli, L. (2006). "Règles de calcul de la portance des pieux aux ELU. Méthodepressiométrique". Proceedings Int Symp on ULS of Geotechnical Structures, Marne-la-Vallée, Droniuc, Magnan et Mestat (ed.), Editions du LCPC, Paris.

[8] Marie-Pierre Lafeuillade,GoninH., VandangeonP. (1992) Etude sur les corrélations entre le standard penetration test et le pressiomètre "Correlation study between standard penetration and pressuremeter tests", Rev. Fr. Géotech. N° 58, 67–78.

[9] Briaud JL.(1992) The Pressuremeter. A.A. Balkema, Rotterdam, Netherland.

[10] Briaud JL (2013) The pressuremeter test: expanding its use, Menard Lecture. Proceedings international conference on soil mechanics and geotechnical engineering, Paris, vol 1, pp 107–126.

[11] Yagiz S, Akyol E, Sen G (2008) Relationship between the standard penetration test and the pressuremeter test on sandy silty clays: a case study from Denizli. Bull Eng Geol Environ 67:405–410.

[12] Bozbey I, Togrol E (2010) Correlation of standard penetration test and pressuremeter data a case study from Estunbol Turkey. Bull EngGeol Environ 69:505–515.

[13] Kayabas¸ı A (2012) Prediction of pressuremeter modulus and limit pressure of clayey soils by simple and non linear multiple regression techniques: a case study from Mersin, Turkey. Environ Earth Sci 66:2171–2183.

[14] Cheshomi A, Ghodrati M (2015) Estimating Menard pressuremeter modulus and limit pressure from SPT in silty sand and silty claysoils. A case study in Mashhad, Iran. Geomech Geoeng 10(3):194–202.

[15] Özvan, A., Akkaya, İ. &Tapan, M. (2017). An approach for determining the relationship between the parameters of pressuremeter and SPT in different consistency clays in Eastern Turkey. Bulletin of Engineering Geology and the Environment, 77(3), 1145-1154.

[16] Duplan, L. (1952) Monographierégionale. La région de Bougie, 1ère série, Algérie N°17. In: XIXéme congrés géologique international, plaquette in 8, Algiers, 48 pp. 15.

[17] Frank R (2009) Design of foundations in France with the use of Menard pressuremeter tests (MPM). Soil Mech Found Eng 46(6):219–231.

[18] Benhamiche N. (2016), Spatial and temporal variability of groundwater quality of an Algerian aquifer: the case of SoummamWadi, Hydrological Sciences Journal, VOL. 61, NO. 4, 775–792.