Dry density in relation to other geotechnical proprieties of Algiers clay

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Abstract. Geotechnical study is one of the most important stages of the project study; it is based on an objective study on the soil of the site to determine the various characteristics, whether mechanical or physical. On the other hand, in the majority of projects the number of completed tests does not allow to get reliable statistical results, but here it features the role of personal or collective experiences to use different correlations performed by researchers and statistical studies carried out for the different soil characteristics. This article shows the results of a statistical study to relate dry density to other geotechnical parameters like wet density (Dh), plasticity index (Ip), water content (w), void ratio (e), plastic limit (Wp), liquid limit (Wl), consistency index (Ic), Preconsolidation pressure (σ'p), Compression Index (Cc), swelling index (Cg), cohesion (cu), friction angle (ϕ) and liquidity index (Il); in Algiers region, and that in order to help geotechnical engineer to predict the values of this parameters from dry density considering this latter an account of the easiest calculated properties in the laboratory. More than 700 samples have been collected; over 120 geotechnical projects have been done in the Algiers area to be used in this study.

Key words: dry density, correlation, geotechnical parameters, statistical study, clay.

1. Introduction

Correlations between the different characteristics of the soil are considered as an integral part of the geotechnical study, which is based on the estimation of unknown soil properties from other properties that have been identified before; statistical studies play an important role in determining the various correlations and regression equations as well as the correlation coefficient. Due to the importance of this side, the first section of Eurocade 7 (EN 1997-1) published by the European committee for standardization (CEN), asks explicitly the use of correlations during the geotechnical study of the site[1] and imposing the use of at least two types of correlations between the results in all EU countries[2].

Many of the studies that have been made to link the various properties of the soil, though only a few cared to correlate the dry density to the rest of soil properties, where their aim is either to predict the modified dry density, such as summarized in (Nagaraj *et al* 2015) about several studies like (Jumikis 1946; Rohan and Graham 1948; Ramiah *et al* 1970; Sivrikaya *et al* 2008)[3]; either the use of dry density to predict other parameters of soil like (Mahieu 1975)[4].

Through this study, more than 700 clay samples of Algiers area have been analyzed by SPSS 20 program; it aimed to reveal the various correlations between the dry density and the rest

[1] Dysli and Steiner 2011
[2] Benbouras et al 2018
[3] Nagaraj et al 2015
[4] Mahieu 1975

of the soil properties in order to help geotechnical engineers estimating the different soil properties from dry density. It has been reached that there are some characteristics which gave high correlation ratios as well, the equations of linear regression correlation were calculated between the various properties, as well as the correlation coefficients using a SPSS program.

2. Experiments and method

2.1. The study site

The study was conducted on soil samples that were obtained from the Algiers region, which is located on the Mediterranean Sea coast and exactly in northern Algeria, at latitude 36.4635 degrees north and longitude 3.0331 degrees east of Greenwich[5], also located on the edge of the north-eastern slopes of Mt. Bouzareah, overlooking the Mediterranean Sea[6], which is protected from the north wind, North West, where more than a height of 500m above sea level. Algeria has a Mediterranean climate characterized by a long hot and dry summers and mild wet winters[7], and the snow is rare, Fig. 1 shows the samples collected from the studied area site.

2.2. Sampling and testing

Results were collected on soil samples from several geotechnical laboratories, specifically more than 150 project have been already conducting their geotechnical study , around 1340 soundings (from 10 to 40 m depth), all the private Algerian varieties of soil (clay, sand, marl, rock..), and between all of that, 723 special clay were taken for this study in Algiers region.

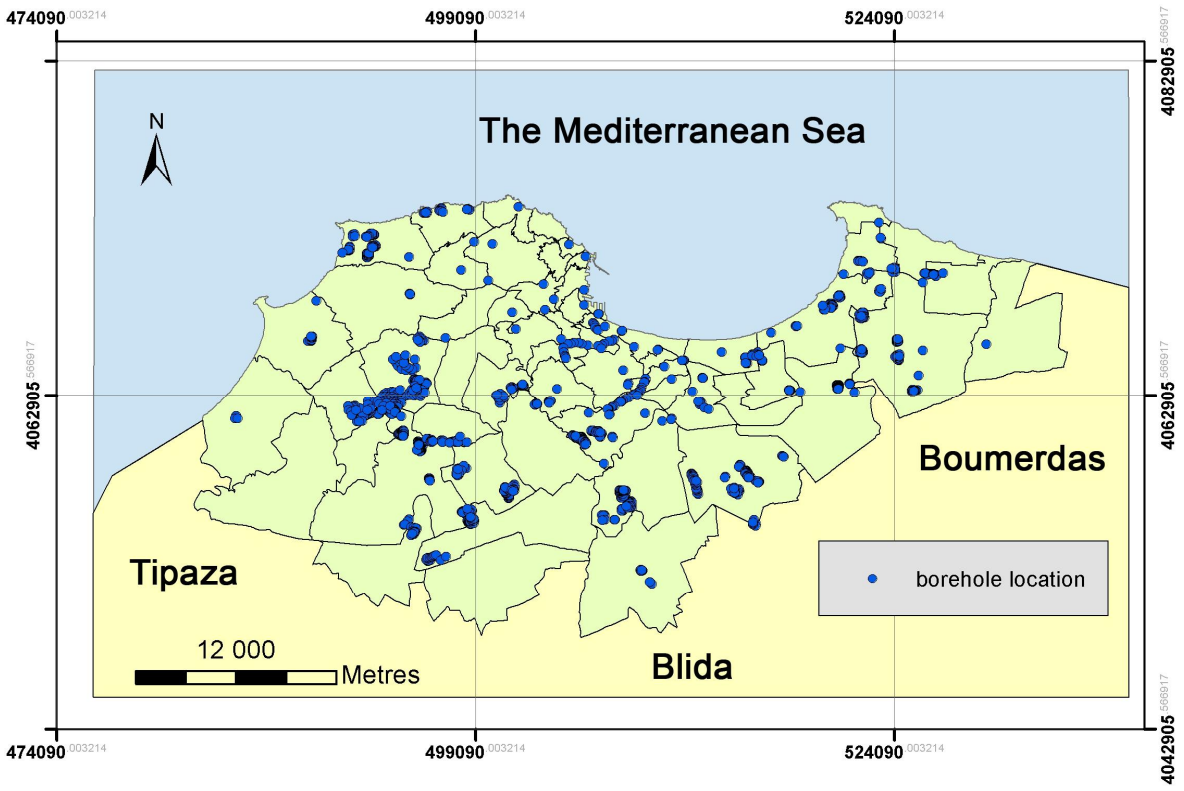

Fig. 1. Map of collected samples from the studied area site.

The geotechnical parameters collected for this study were determined by the following French Standards; moisture continent using (NF P 94-049-2)[8]; Atterberg limits by utilizing

[5] Boudiaf 1996
[6] Madjnoun 2014
[7] Meteocity 2016
[8] NF P 94-049-2 1993

(NF P94-051)[9]; dry and wet density according to (NF P94-061-2)[10]; Shear strength using (NF P94-071)[11]; oedometric test with employment (NF P94-090)[12].

2.3. Statistical study

Traditionally, statistical methods have been used to estimate indirect proposal between two parameters or more through mathematical equations. To develop predictive models of the relevant parameters, and often it is performed regression analysis of the soil and rock mechanics. Nevertheless, linear regression analysis for this study was carried out using SPSS 20 to obtain a correlation equation relating dry density to the soil properties, namely, wet density (Dh) , plasticity index (Ip), water content (w), void ratio (e), plastic limit (Wp), liquid limit (Wl), consistency index (Ic), Preconsolidation pressure (σ'p), Compression Index (Cc), swelling index (Cg), cohesion (cu), friction angle (ϕ) and liquidity index (Il). Then, descriptive statistics such as maximum, minimum, mode, variance, mean, median, standard deviation, skewness, kurtosis... etc. was calculated also using the SPSS20 software (see Table 1)

3. Results and discussion

3.1. Descriptive statistics

Table 1. Descriptive Statistics on collected samples.

		Dd	w	Dh	e	Wp	Wl	Ip	IL	Ic	σ c	Cc	Cg	Cu	ϕ
N	Valid	723	723	676	667	610	595	595	590	561	465	465	465	253	285
	Missing	0	0	47	56	113	128	128	133	162	258	258	258	470	438
Mean		1.690	20.17	2.022	0.625	22.757	47.533	24.203	-0.126	1.131	2.174	0.161	0.037	0.498	11.576
Std. Error of Mean		0.005	0.186	0.004	0.0058	0.232	0.374	0.236	0.010	0.011	0.044	0.003	0.001	0.015	0.401
Median		1.690	20	2.030	0.603	23.000	46.470	24.000	-0.143	1.142	1.900	0.163	0.033	0.420	10.800
Mode		1.700	20	2.000	0.501	22.000	42.000	23,00[a]	0.000	1.000	1.620	0.186	,0210[a]	0.400	9.000
Std. Deviation		0.125	5.10	0.104	0.1489	5.728	9.117	5.751	0.248	0.250	0.956	0.056	0.019	0.241	6.774
Variance		0.016	26.027	0.011	0.022	32.813	83.126	33.078	0.062	0.063	0.914	0.003	0.000	0.058	45.890
Skewness		-0.092	0.798	-0.314	1.321	-1.002	0.552	0.072	0.984	-0.812	1.577	0.007	1.221	1.407	1.796
Error of Skewness		0.091	0.089	0.094	0.095	0.099	0.100	0.100	0.101	0.103	0.113	0.113	0.113	0.153	0.144
Kurtosis		0.872	2.36	2.375	4.968	5.800	1.844	0.865	5.633	5.851	3.815	1.810	2.673	2.599	6.585
Error of Kurtosis		0.182	0.178	0.188	0.189	0.198	0.200	0.200	0.201	0.206	0.226	0.226	0.226	0.305	0.288
Range		0.960	41.96	0.970	1.431	48.390	67.740	38.190	2.710	2.710	6.670	0.455	0.134	1.490	50.310
Minimum		1.190	3.54	1.650	0.2791	0.000	23.900	7.210	-1.085	-0.625	0.360	0.001	0.000	0.110	0.000
Maximum		2.150	45.5	2.620	1.310	48.390	91.640	45.400	1.625	2.085	7.030	0.456	0.134	1.600	50.310

Table 1 shows the results carried out the statistical study (descriptive statistical) on the collected samples using SPSS 20 software as (Mean, Error of Mean, Median, Mode, Std. Deviation, Variance, Skewness, Error of Skewness, Kurtosis, Error of Kurtosis, Range, Minimum and Maximum). From these results we can classify Algiers soil as a dense soil with an average 1.69 according to French norms (XP P 94-011)[13]. In addition to be a little plastic clay with an average plastic index 24.2 Depending on SONGLIRAT's classification[14]; in the other class on compressibility that can classify it as a moderately compressible clay with Cc equal 0.16 and swelling clay with Cg=0.037.

[9] NF P94-051 1993
[10] NF P94-061-2 1996
[11] NF P94-071 1994
[12] NF P94-090 1997
[13] XP P 94-011 1999
[14] Costet et al 1969

3.2. Correlation between geotechnical parameters

Table 2 shows the results of statistical study, which was conducted on soil samples, that describes the results of linear regression curried out using SPSS20; a High correlation has been found between dry density with wet density Dh; void ratio e and water content W with correlation coefficients R (0.808, 0.7 and 0.708) Successively, and an average correlation with liquid index IL (R=0.547) and low correlation with Cc and Cu (0.495; 0.483); Due to the absence of any link with the rest of variables; These results seem largely logical compared with the research results of (Mahieu 1975) that has been made to more than 100 samples where concluded there is a strong relationship between dry density and (water content W, wet density Dh and Compression Index Cc) with correlation coefficients R (0.9, 0.74 and 0.83) Successively[15].

Table 2. linear regression analysis to correlate dry density with other geotechnical parameters.

Parameters	Equation (these study)	R	Standard error	Mahieu 1976
W (Dd)	W=-8.999Dd+69.111	0.708	3.59	W=0.37/Dd R=0.9
Dh (Dd)	Dh=0.703Dd+0.833	0.808	0.061	Dh=Dd+0,37 R=0.74
e (Dd)	e=-0.859Dd+2.080	0.7	0.106	
Wp (Dd)	Wp=-0.013Dd+29.532	0.086	5.71	
WL (Dd)	WL=-7.262Dd+59.775	0.098	9.08	
Ip (Dd)	Ip=-3.367Dd+29.679	0.072	5.74	
IL (Dd)	IL=-1.102Dd+1.731	0.547	0.208	
Ic (Dd)	Ic=0.315Dd+0.599	0.147	0.248	
σc (Dd)	σc=1.974Dd-1.149	0.26	0.923	
Cc (Dd)	Cc=-0.222Dd+0.534	0.495	0.0491	Cc=-0.53Dd+1 R=0.83
Cg (Dd)	Cg=-0.023Dd+0.076	0.153	0.018	
Cu (Dd)	Cu=1.004Dd-1.184	0.483	0.212	
Φ (Dd)	ϕ=-4.826Dd+20.458	0.098	6.33	

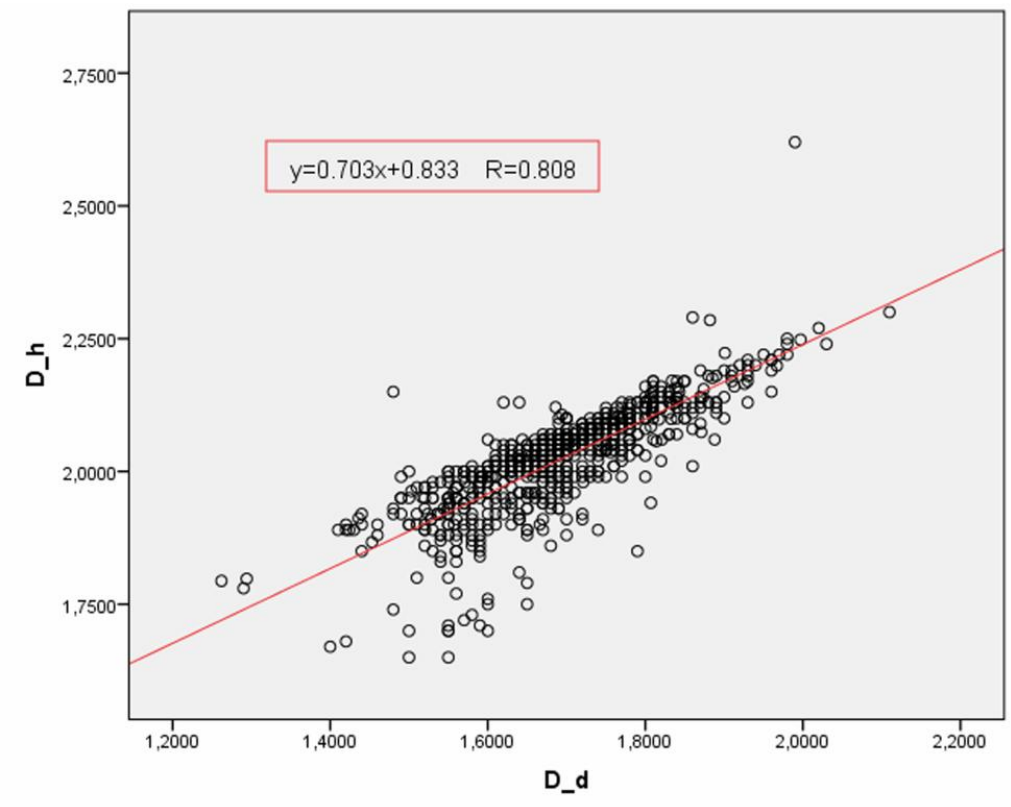

Fig. 2. Correlation between Dh – Dd.

[15] Mahieu 1975

3.2.1 Correlation between dry density Dd and wet density Dh

Through Fig. 2, it has been observed a positive high relationship between wet density and dry density; Where wet density rise with the increase of this last.

3.2.2 Correlation between dry density Dd and void ratio e_0

Fig. 3 shows the correlation between dry density and void ratio where it was noted a negative high correlation with R=0.7. On the other hand, this result is considered logical in terms of increasing dry density means increasing volume of the solid particles in the soil samples with low pore size, which means lower void ratio.

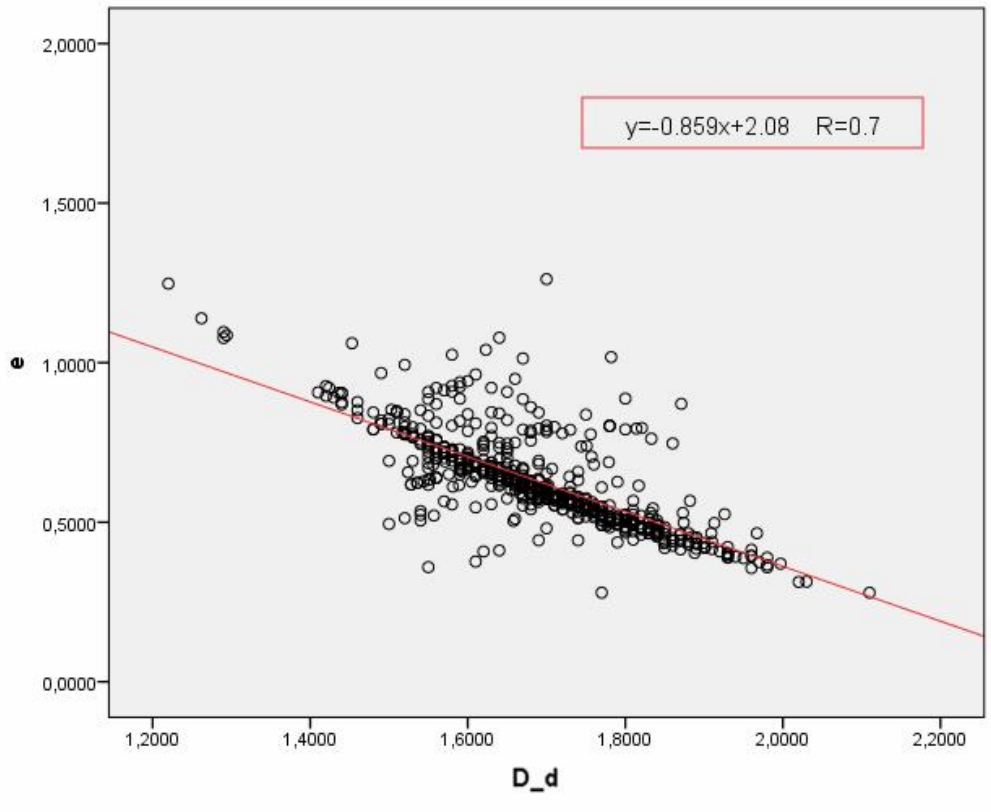

Fig. 3. Correlation between e – Dd.

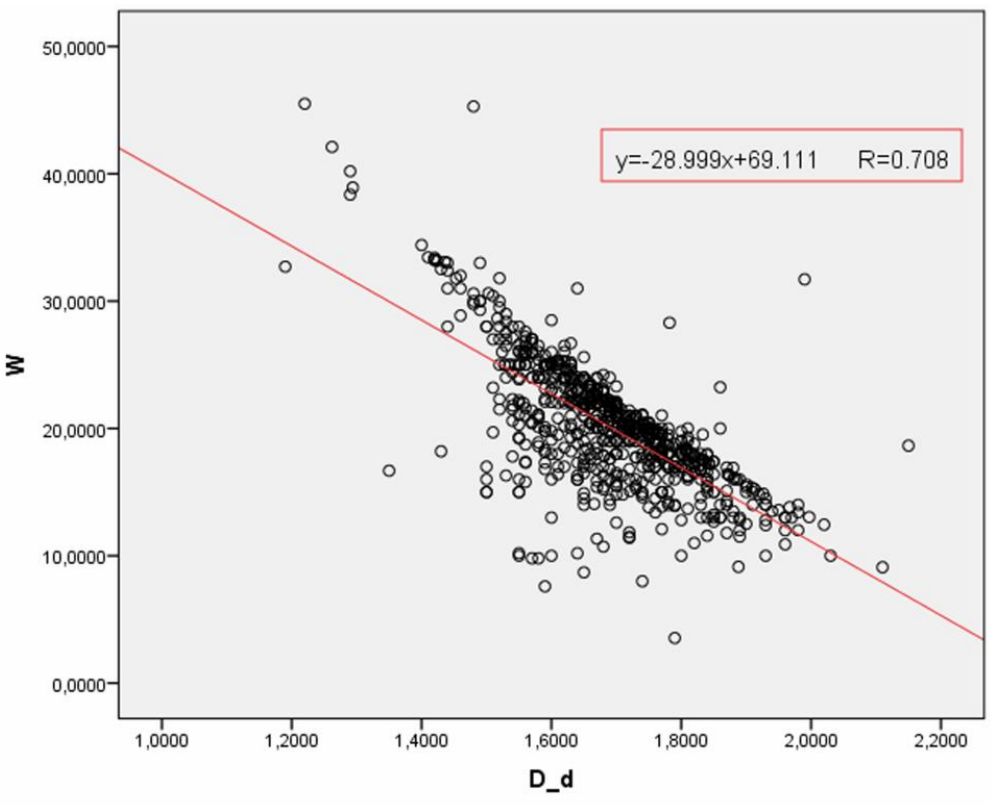

Fig. 4. Correlation between W - Dd.

3.2.3 Correlation between dry density Dd and water content w

Fig. 4 illustrates the relationship between dry density and water content; so height dry density meant the rise of solid particles mass than offset by the decrease in the mass of water in the pores and this means a lower proportion of water content; thus, a negative strong relationship was observed, with a 0.708 correlation coefficient.

3.2.4 Correlation between dry density Dd and liquid index IL

Fig. 5 represents correlation between dry density and liquid limit where it has noted an average correlation with R=0.55 where here liquid index decreases with the increase of this last.

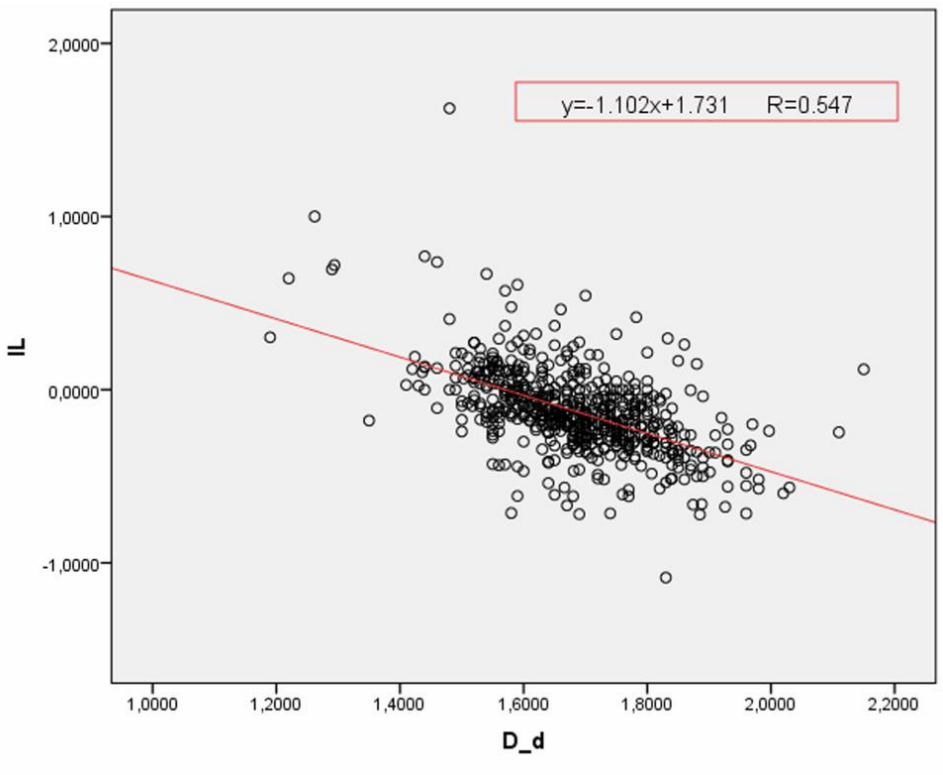

Fig. 5. Correlation between IL – Dd.

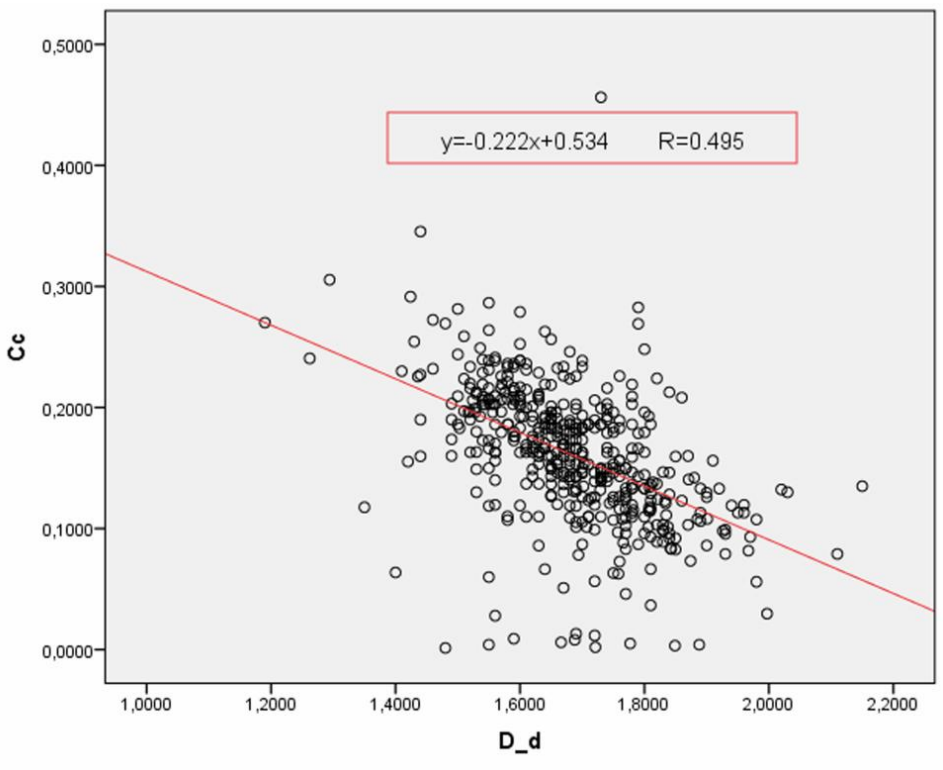

Fig. 6. Correlation between Cc – Dd.

3.2.5 Correlation between dry density Dd and compression index Cc

Fig. 6 shows correlation between dry density and compression Index where it has noted a low correlation with R=0.495 where compression Index decrease with the increase of dry

density; this is due to the decrease in the volume of pores in the soil and thus the lack of compressibility.

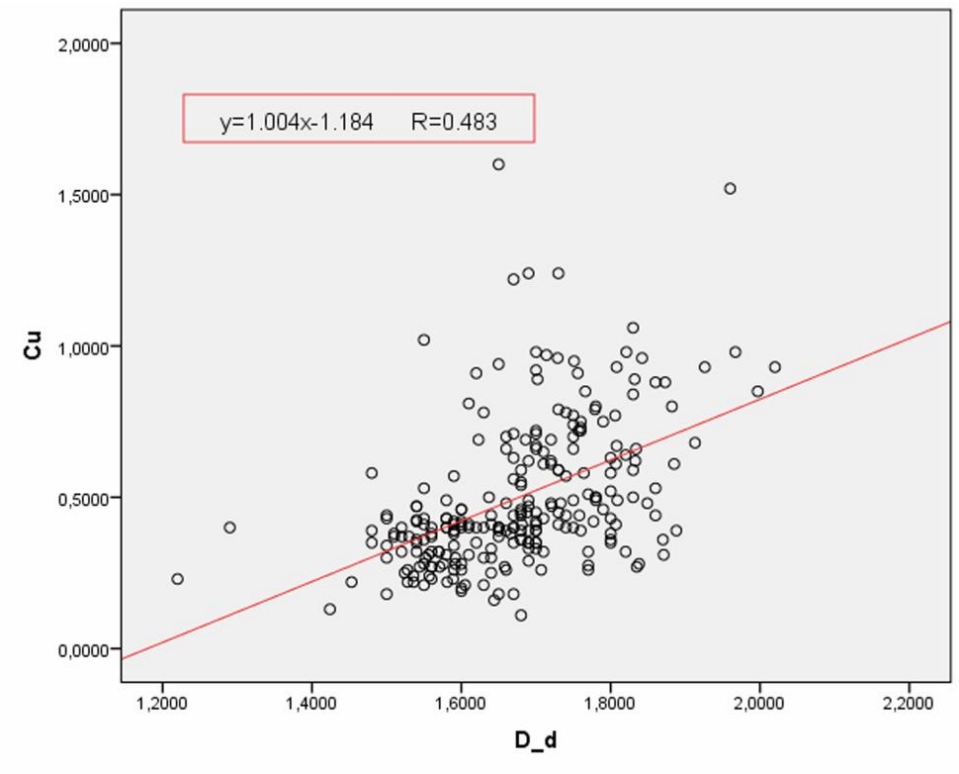

Fig. 7. Correlation between Cu – Dd.

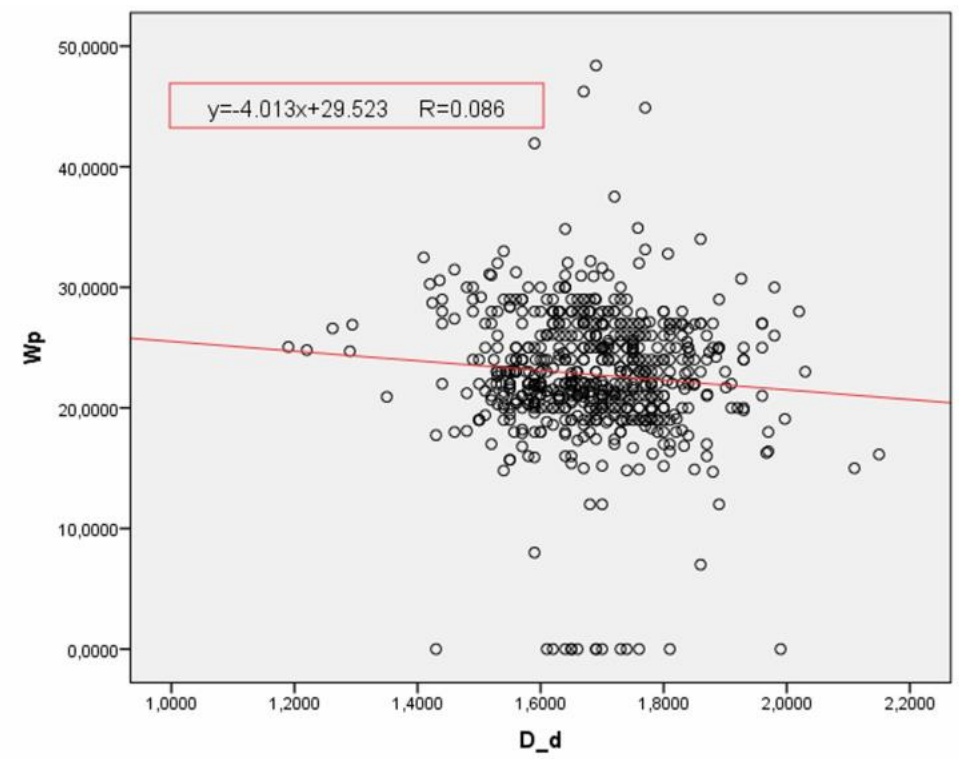

Fig. 8. Correlation between Wp – Dd.

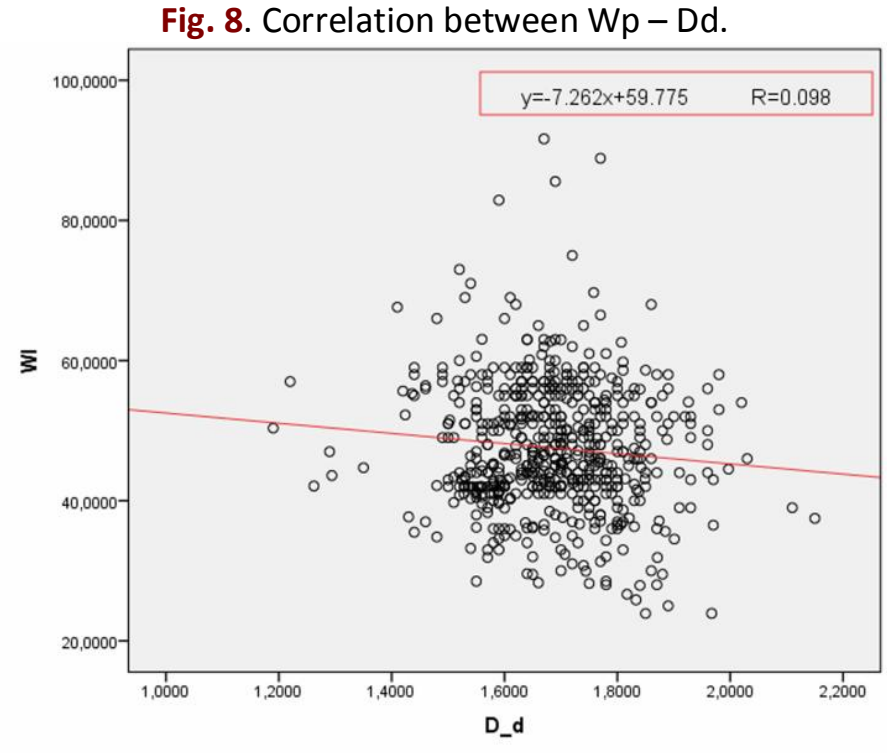

Fig. 9. Correlation between Wl - Dd.

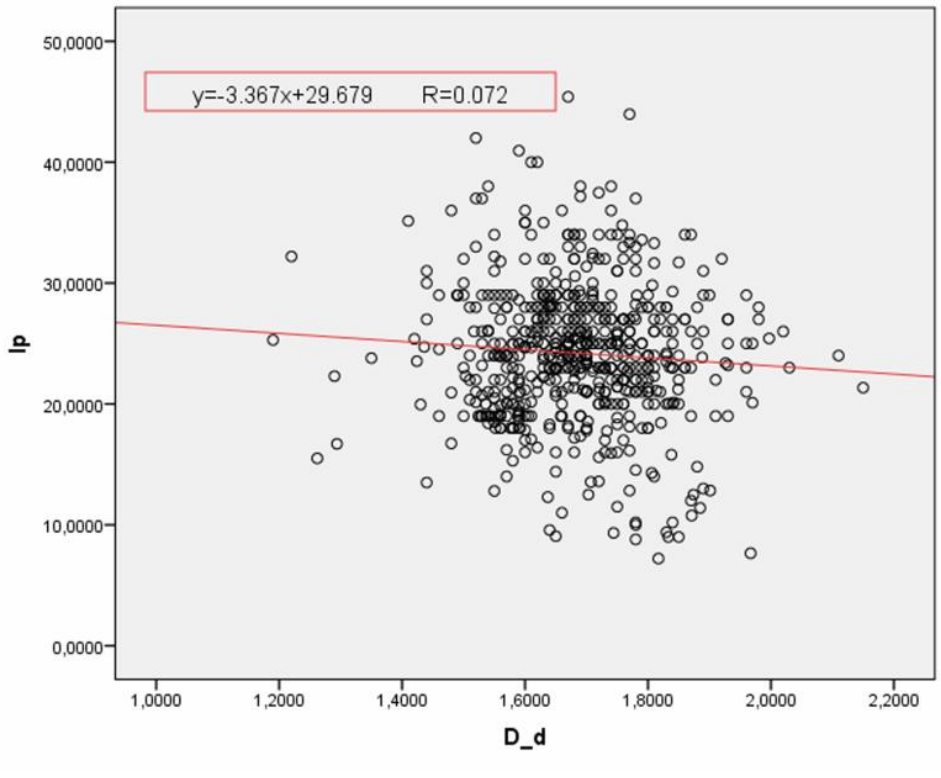

Fig. 10. Correlation between Ip- Dd.

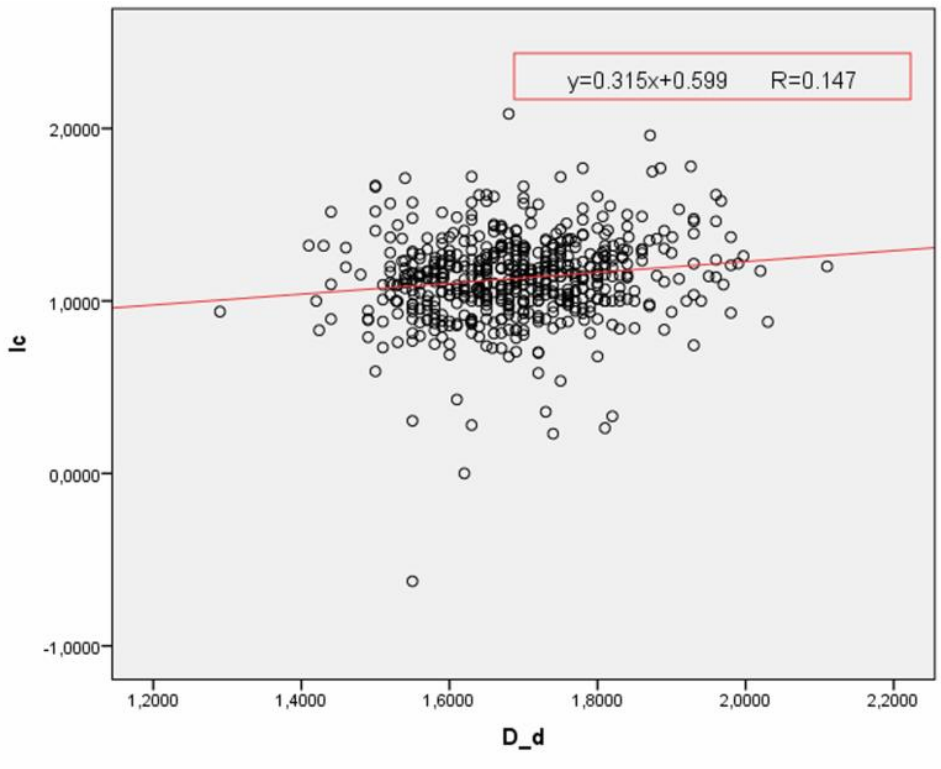

Fig. 11. Correlation between Ic - Dd.

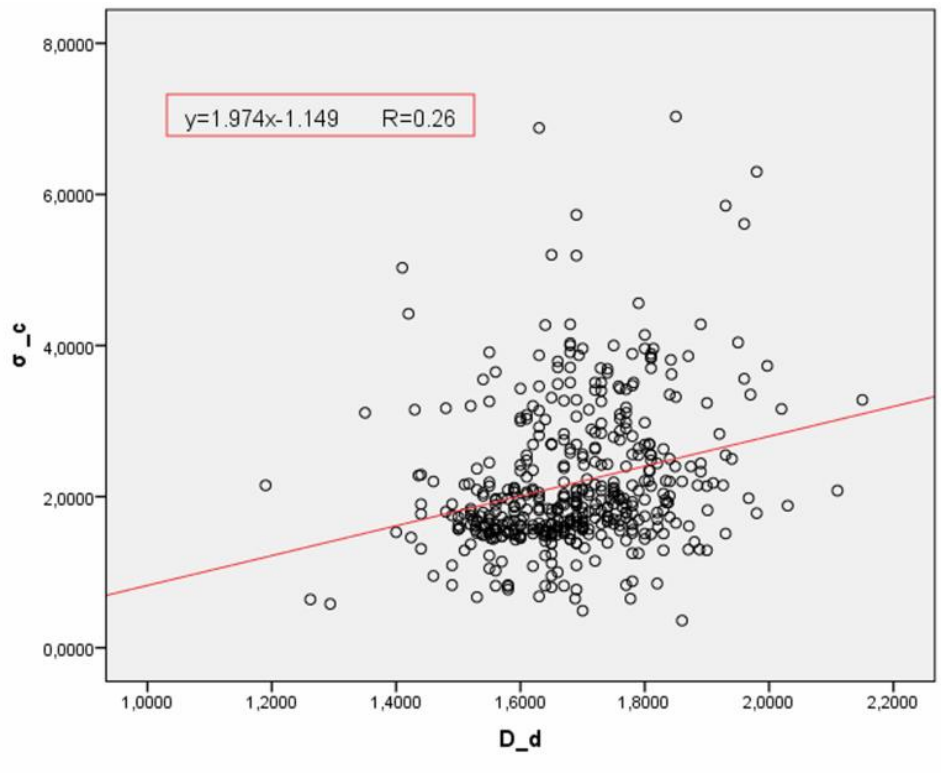

Fig. 12. Correlation between σc - Dd.

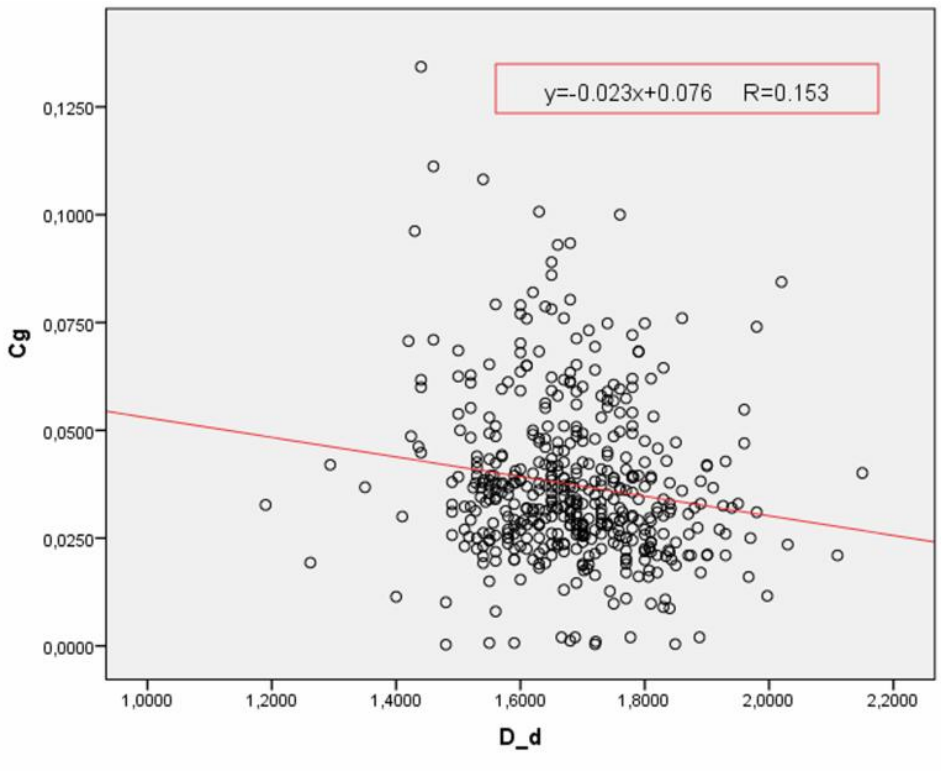

Fig. 13. Correlation between Cg - Dd.

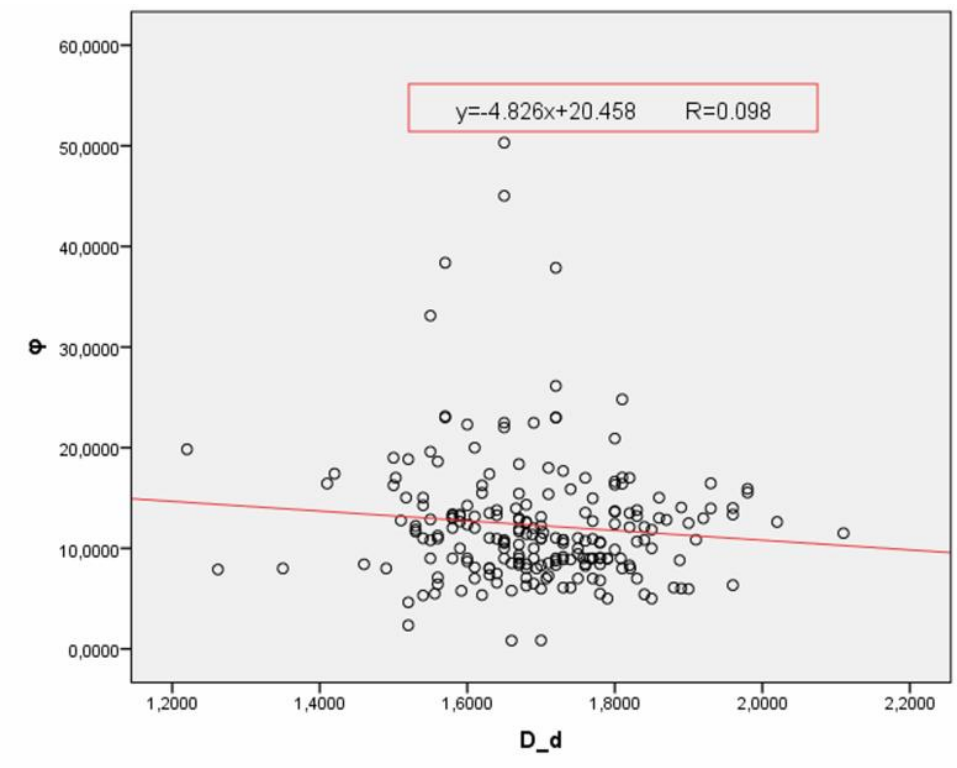

Fig. 14. Correlation between ϕ - Dd.

3.2.6 Correlation between dry density Dd and cohesion Cu

Logically high dry density accompanied by a rise in the number of grains solid in a soil sample, with a lower pores, which means high cohesion between the clay particles, and it has been observed low positive relationship between the two variables R=0.483 (Fig. 7).

3.2.7 Ineffective correlations

And last but not least, statistical studies have shown that there is ineffective linear relationship between dry density and plasticity index (Ip); plastic limit (Wp); liquid limit (Wl), consistency index (Ic), Preconsolidation pressure (σ'p), swelling index (Cg), friction angle (ϕ) and liquidity index (Il); as illustrated by the graphs.

4. Conclusion

This study is a qualitative addition to the research carried out by Mahieu, J. (1976), it has treated more than 700 sample of Algiers clays which were collected from the laboratory;

using the SPSS 20 program to extract the various linear regression relationships between dry density and the rest of the soil parameters in the Algiers region in order to help the geotechnical engineers to predict the characteristics of the soil through the dry density and it has been reached the following results:

- A High correlation between dry density Dd with wet density Dh, void ratio e and water content W.
- Average correlation with liquid index.
- Low correlation with compression Index Cc and cohesion Cu.
- Ineffective Correlations between dry density with plasticity index (Ip); plastic limit (Wp); liquid limit (Wl), consistency index (Ic), Preconsolidation pressure (σ'p), swelling index (Cg), friction angle (ϕ) and liquidity index (Il).

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