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Developing an Empirical Correlation between DCPT Test Results and Relative Compaction for Sandy Soils

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ABSTRACT

The dynamic cone penetrometer (DCPT) is a simple portable in-situ testing instrument. It is usually used to measure the resistance of cohesionless granular soil. An attempt has been made to find a correlation between the DCPT results and the in-situ dry density for local Tripoli sand. Laboratory and fieldwork were carried out to investigate the relationship between the dry and wet densities and DCPT blow count (N_{10}, Blows/100). In this study, the relationships between laboratory N_{10} and dry density were developed and verified. The work was conducted in two stages; in the first stage the samples were tested normally, while in the second stage the tests were conducted using surcharge load discs. Due to the lack of confinement at shallow depths, surcharge load disc was used on soil sample surface to evaluate the effect of the unconfinement on the results of the DCPT at the shallow depth (i.e. 250 mm to 300 mm). The test results in the first stage showed a good impression for the dry density of sandy soil (SP-SM) at depths greater than 250 mm. As results, the aid of the surcharge discs showed better trends. The validity of the proposed correlations was verified using test results on soils at new sites. The obtained results gave a more representative and reliable correlation. Measured densities versus estimated ones were plotted, shown the ability of the proposed correlation in estimating dry density from DCPT at proposed site. The proposed correlations are useful tools to help engineers in the practice to use in geotechnical investigation and to assess the dry density of soils.

Keywords: *DCP; Relative Compaction ; dry density;*

1. Introduction

Determination of the in situ engineering properties of foundation materials has always been a challenge for geotechnical engineers and, thus, several methods have been developed so far. The construction duration is an important factor where any delay in construction process costs a lot of money and causes big losses. Therefore, researchers started searching for alternative methods that are more economic, faster and easier to conduct than the basic known methods. For this reason, alternative methods have raised to test the compaction state for soils in the field, among these methods is the DCP test. Therefore, a safer and easier alternative way for the compaction control of road and general construction practice is desired. Up to date, not much research has been conducted into the use of DCPT. Dynamic probing is a continuous soil investigation technique and is assumed as one of the simplest soil penetration tests. The DCP is a lightweight dynamic penetrometer which is considerably faster and cheaper tool than boring, particularly when the depth of exploration is low and the soils being investigated are not coarse gravel. This research focuses on DCP, which is used to assess the mechanical properties of sandy soils.

2. Background and History of DCP

Penetration tests have a very long history [1]. In the 15th century, test piles were used to determine the required length of pile foundations. Thus, pile driving can be regarded as an early type of penetration testing. The earliest dynamic penetrometer may have been a "ram penetrometer" developed in Germany at the end of the 17th century by Nicholaus Goldmann. The DCP was first developed by Scala in South Africa as an in-situ pavement evaluation technique for evaluating pavement layer strength [2]. In 1982, the final conclusion about the DCP was drawn by Kleyn after comparing sound pavement sections with failed pavement sections where he found a minimum strength or suitability for the base course.

It has been extensively used in South Africa, United Kingdom, Australia, New Zealand and several States in the U.S.A. such as California, Florida, Illinois, Minnesota, Kansas, Mississippi and Texas for the characterization of the pavement layers and subgrades. The U. S. Corps of Engineers has also used DCP as an in-situ testing tool. Many correlations were developed between DCP penetration resistance parameter N_{10} and soils properties. Yet, there are no direct correlations between DCP and dry density and wet density. Table 1 summaries developed correlations and soil properties.

Table 1. History of Developed Correlations

Author (Year)	**Soil Properties**	**Soil Type**
Azad (2008) [3]	Relative density	Granular soils
Luo, et al [4]	resilient modulus	Granular soils
Rahim, et al. [5]	cohesion, internal friction angle and initial porosity	Granular soils
Meyerhof [6]	relative density and friction angle	Granular soils
Mohammadi [7]	relative density and friction angle	Granular soils
Ayers, et al.[8]	shear strength properties of cohesionless	Granular soils
Truebe, et al.[9]	CBR	Granular soils
Gabr, et al. [10]	CBR	Granular soils
Harison [11]	CBR	Granular soils
Smith, et al. [12]	CBR	Granular soils

3. Objectives of study

The main objectives of this paper were to:

1- Develop a correlation between DCP blow counts (N_{10}) and dry density of a sandy soil (SP-SM),
2- Verify and examine the developed correlation with field data.
3- Find solutions for large distribution and scatter in empirical correlations between the readings of the dynamic cone penetration blow counts and the insitu dry density of the compacted soil surface layer.

4. Materials and Experimental Work

4.1 *Sampling and Properties*

Several soil samples have been taken from various zones in Tripoli, where most of the samples were classified as silty sands with fines content ranging from 3 to 8%. The soil sample chosen for this research, which was collected from area near Miitiga airport, had fines content 5% to 7%. The soil is described according to BS 5930 [13] as light brown poorly graded silty sand and on the unified soil classification system (USCS) [13], the soil was classified as SP-SM. Table 2 presents the basic soil properties. These soils were chosen due to limitation of such correlations between DCP and soils properties in Tripoli area. The developed correlations thought to be in light construction project where other insitu tests are expensive.

Table 2. Physical and mechanical properties of used soils

Soil properties	**values**
Sand Percent	92%
Percentage Passing 75μm sieve	7%
Gravel Percent	0.3%
Plasticity index (PI)	NP
Specific gravity (GS)	2.65
Maximum dry density (MDD)	1.679 g/cm^3
Optimum moisture content (OMC)	13.5%

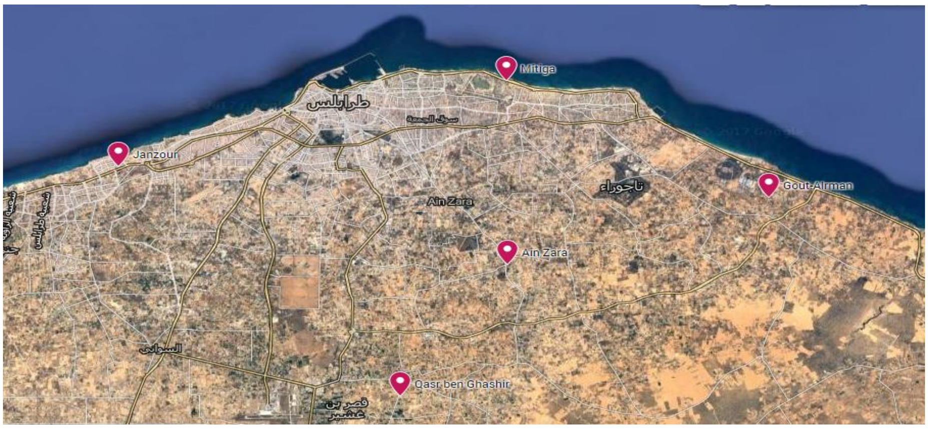


Figure 1: Location of Sampling in Tripoli

4.2 *Experimental work*

To simulate field condition in the laboratory, a large-scale mold was used. The mold was made with a diameter of 550 mm designed based on the study of Mohammadi, Nikoudel, Rahimi, & Khamehchiyan (2008), that stated, in order to neglect the effect of the mold sides on the DCP results, the minimum distance between the DCP tip and the side of the mold not be less than 250 mm. The mold's height was 700 mm. A proper amount of grease is spread between the mold and the underlying base. A 20 kg hammer was used to compact the soil into the mold, through a guiding tube as shown in Figure 2. The DCP used in this study is based on the penetrometer developed by Scala (1956), which later was developed by the Transvaal Road Department (TRL), is driven by a hammer with a mass of 8 kg falling from a height of 575 mm.

The testing program was divided into two main stages. In the first stage the test was applied without using surcharge load discs, while in the second stage the tests were applied using the aid of surcharge discs to reduce the effect caused by soil unconfinement. Where researchers have commented on the DCP results of the shallow 200 to 300 mm as misleading and inaccurate, so surcharge discs with a total mass of 53 kg and a diameter of 400 mm have been used to resemble the 200 mm of soil. Preparations of soil samples in both cases; dry and wet conditions, are described here as follows:

a. **Dry sample preparation:** The dry soil sample was placed into the mold in lifts of 200mm and compacted by either pulverization, hammering or vibration. Different densities have been achieved through the different compaction methods and energies

b. **Wet Sample Preparation:** Testing DCP on wet samples with water content close to the optimum water content for the same sample (13% ± 0.5%), due to the large amount of soil, moisture was applied to the dry sample and mixed using a small single unit concrete mixing drum. The use of the concrete mixer was to ensure that moisture in the soil sample was distributed as evenly as possible within the soil mass. The sample was then placed inside the mold in lifts of 200 mm. The sample was densified using a compaction hammer of 20 kg mass.

Compaction of soils was achieved by different means depending on the soil moisture content and the required sample density. For soil in dry condition, and to achieve low density, the air pulverization method was used. Medium and high densities for dry sand have been achieved height of limit at 575 mm. The densification process is done by placing the soil sample into the mold in three equal shifts. The number of hammer blows and the drop height as shown in Figure 2 controls compaction energy in this process. Field tests have been conducted in the site of sample origin and in other similar sites to verify the results obtained in the laboratory using filed cone test as shown in Figure 3.

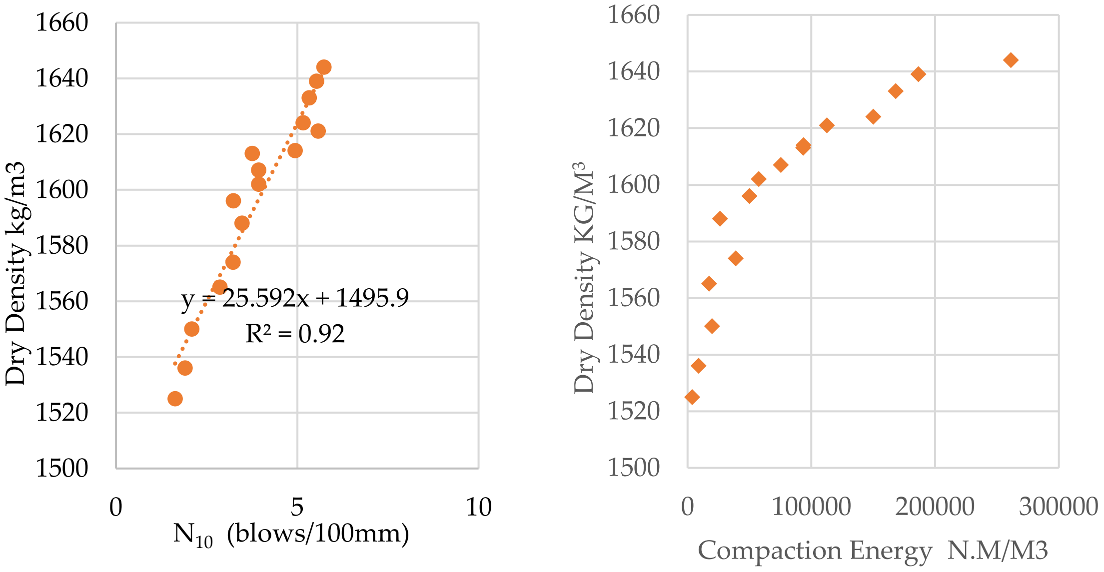
Figure 2: Compaction Testing Process Lab work

Figure 3: DCP and Field Cone Tests Process

5. Results and Discussion

5.1 Dry samples without surcharge disc

For the data obtained in this study between dry densities and N_{10} without using Surcharge Disc, the correlations are presented in Figure 3. The generalized correlation between dry density and N_{10} from the laboratory test results suggest a good correlation between these two parameters. The determination coefficient of is 0.92, which is indicative of a significant relationship between the two parameters.

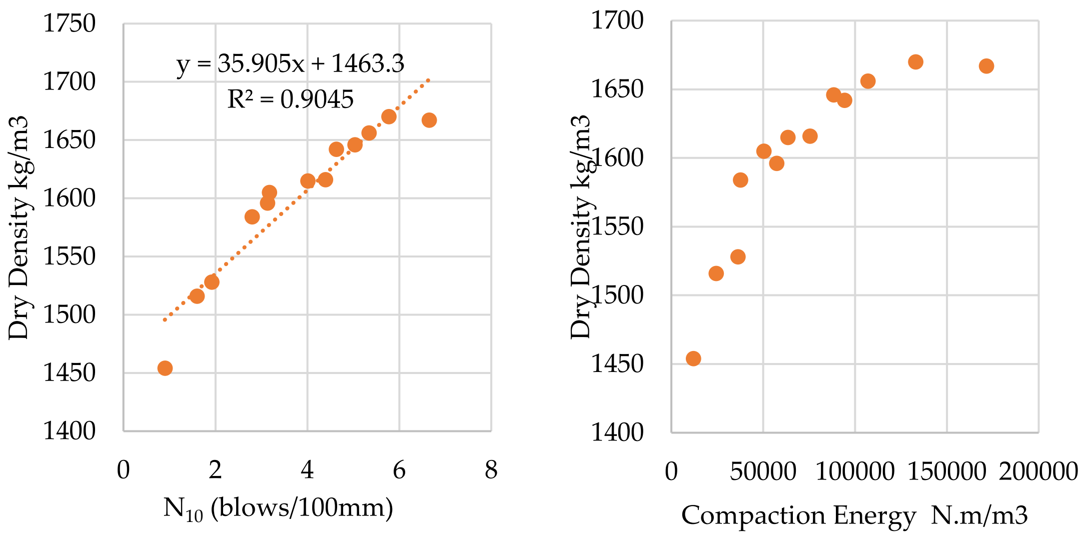


(a) (b)

Figure 3: Dry Density versus (a) N_{10}, and (b) versus Compaction Energy for Dry Sample without using Surcharge Disc

5.2 Wet Samples Without Surcharge Disc

DCP testing was performed on wet soil samples with water content close to the optimum (OWC ≈ 13.5%) at different densities. Figure 4 presents the dry densities versus N_{10} for data without using Surcharge Disc. Figure 4 (b) shows the achieved dry density of soil sample versus used compaction energy for wet samples. The determination coefficient also showed good a significant relationship between the two parameters.



(a) (b)

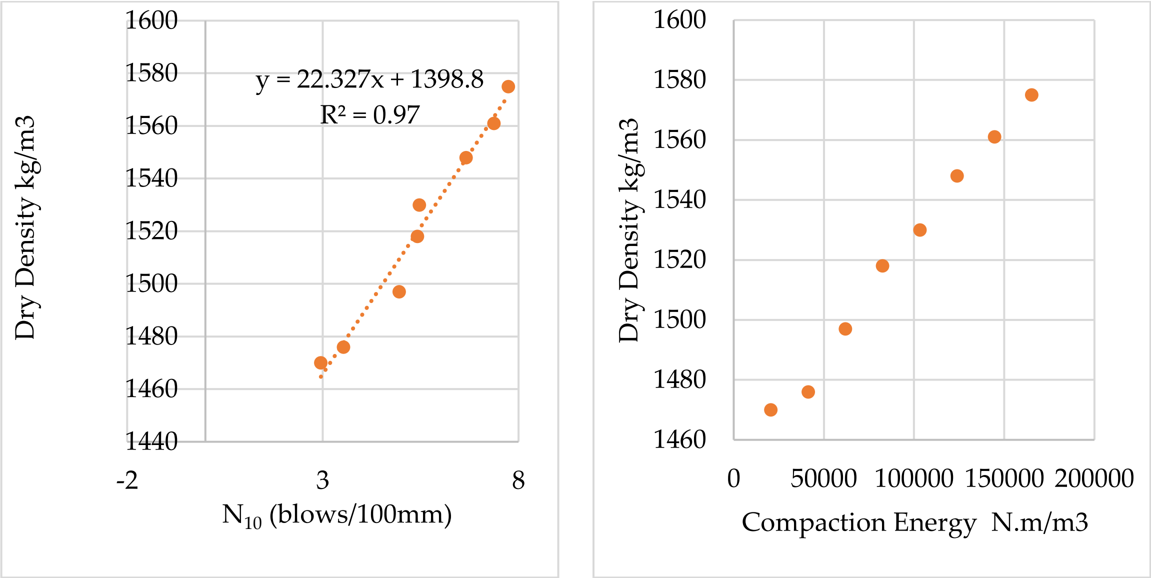
Figure 4: Dry Density versus (a) N10, and (b) versus Compaction Energy for wet Sample without using Surcharge Disc

5.3 *Dry samples with surcharge load disc*

DCP testing was performed on dry soil samples at various densities using the aid of a surcharge load disc. The densities of soil samples had been achieved through air pluviation, falling hammer and vibration compaction methods. Figure 5 shows the different dry densities of soil samples versus DPC N_{10}. The relation between the dry density of soil and the amount of energy used for compaction. The generalized correlation between dry density and N_{10} from the laboratory test results showed a excellent correlation between these two parameters. The determination coefficient of is 0.97, which is indicative of a significant relationship between the two parameters when using surcharge load.

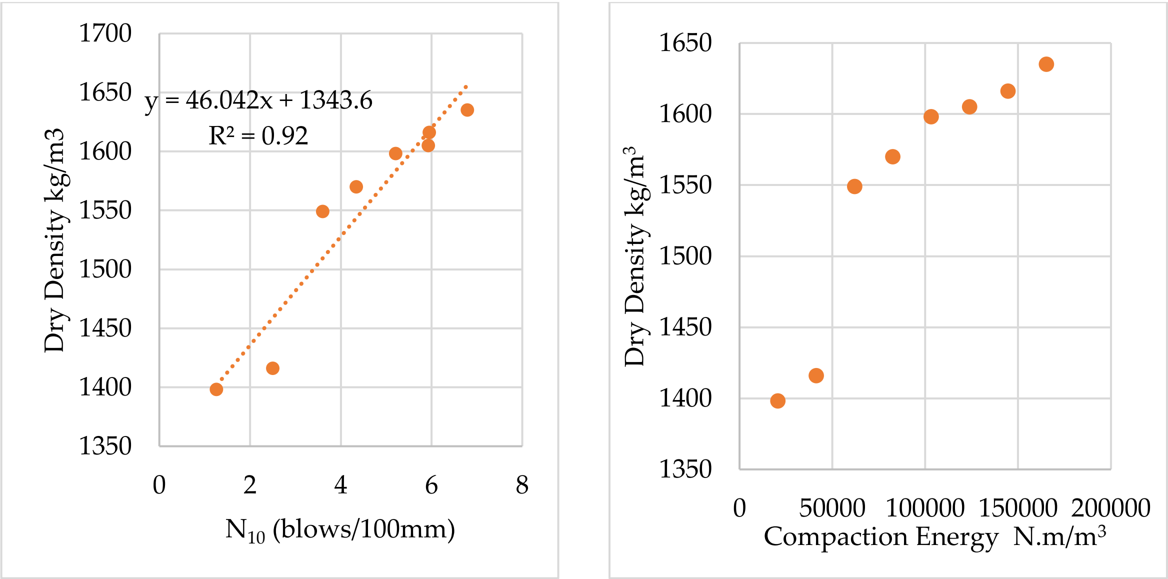
5.4 *Wet samples with surcharge disc*

DCP testing was performed on wet soil samples with a water content close to the optimum (OWC ≈ 13.5%) at various sample densities. The density of soil samples had been achieved through compaction using falling hammer method. The different dry densities achieved, and the amount of compaction used energy are shown in Figure 6. The relationship between DCP per blow versus depth for all tested wet samples with surcharge disc showed good a significant relationship between the two parameters.



(a) (b)

Figure 5: Dry Density versus (a) N_{10}, and (b) versus Compaction Energy for Dry Sample using Surcharge Disc



(a) (b)

Figure 6: Dry Density versus (a) N_{10}, and (b) versus Compaction Energy for Wet Sample using Surcharge Disc

6. Data Statistical Analysis and Observation

The data of test results have been analyzed using Statistical Package for the Social Sciences software (SPSS). It is used to find out the effect of each variable on the outcome. The SPSS software can also neglect all the unreliable or odd data during the process. In this research work, the dependent variable is the soil dry density. The independent variables are the number of blows, the depth, the penetration index, and the water content. A linear correlation has been determined between the soil dry density and the DCP number of blows(N), the penetration index(PI), the water content(Wc) and the depth of penetration(D). The total number of data points that have been used for this case are 434 points. Table 3 contains the statistical model summary for the used data. Findings without using surcharge discs showed coefficient of determination R^2 of 0.885, which is indicative of a significant relationship between the two parameters. Moreover, the data using using surcharge discs also presented the coefficient of determination R^2 of 0.92 which also an excellent indicator of the relationship.

Table 3. Regression Model Coefficients

Case	**R**	**R^2**	**Adjusted R^2**	**Std. Error of the Estimate**
Without using surcharge	0.941	0.886	0.885	13.94
Using surcharge	0.962	0.925	0.924	13.63

6.1 *Proposed Developed Equations*

The correlative study as performed in this research work between soil dry density and dynamic cone penetration index (as expressed in terms of N_{10}) was used to develop equations to predict the dry densities as follows:

- *For soil conditions without using surcharge load*

$$\rho_d = 1755.706 - 0.461D - 1.250PI + 0.101w_c + 5.405N \tag{1}$$

- *For soil conditions using surcharge load*

$$\rho_d = 1673.131 - 0.469D - 2.158PI + 4.888w_c + 4.589 \tag{2}$$

Where ρd= *Soil dry density* (kg/m^3)

N_{10}= *number of DCP blows to penetrate 100 mm*
PI = Penetration index for depth D (mm/blow)
D=Depth of penetration (mm)
wc = Water content (%)
N = Cumulative number of DCP blows at depth D

7. Justification of Proposed Equations

The generalized correlation between dry density and N_{10} from the laboratory test results was field-verified at many locations. These sites have similar soils with different percentage of fines materials. Equations 1 and 2 (dry and wet conditions) were used to estimate the predicted dry densities. The applicability of these equations was evaluated by plotting the predicted dry densities versus the measured dry densities by the sand cone method. It can be noticed (Figure 7 and 8) both correlations have approximate similar liner pattern with moderate to high coefficient of R^2 of 0.89, which suggest a good estimation.

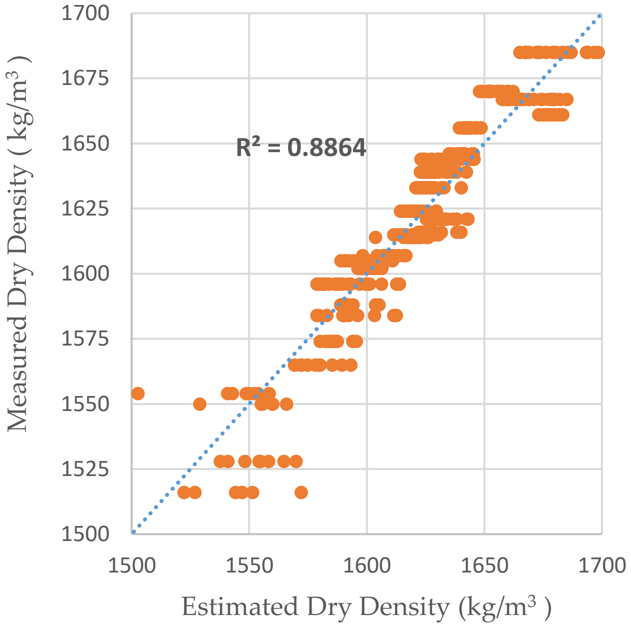


Figure 7: Measured vs. Estimated dry density (without using surcharge load)

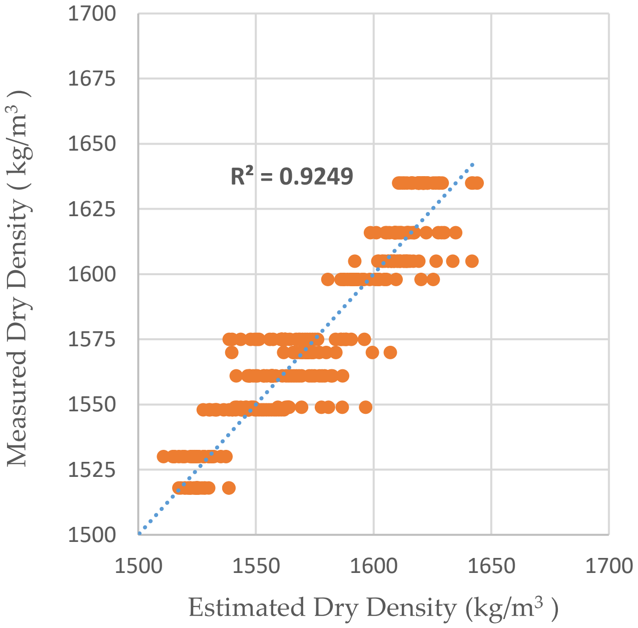


Figure 8: Measured vs. Estimated dry densities (using surcharge load)

8. Conclusions

A correlative study was performed to develop a valid correlation between in-situ dry density of soil and DCPT test results for local Tripoli sands. Two soil conditions were tested for this study; one at dry soil condition, and the other at the optimum water content value of the tested soil. Due to the lack of confinement at shallow depths, surcharge load disc was used on soil sample surface. Useful correlations were obtained between dry density of granular soil and DCP test results for dry soil and soils at optimum water contents using statistical analysis software(SPSS). The obtained equations were verified at new data by plotting the measured densities versus estimated densities, shown the ability of the proposed correlation in estimating dry density from DCPT at proposed site. The proposed equations are useful tools to help engineers in the practice to use in geotechnical investigation and to assess the dry density of soils.

9. Recommendations

i) Soil preparation in the laboratory using compaction hammer results in non-uniform density profile across the sample depth. Further study is needed to examine such effect.

ii) More elaboration is required to examine the effect of using various surcharge discs.

iii) Due to the fact that this correlative study was made on sandy soil at specific and limited percentage of silt content. It is recommended to extent the research to various silt contents to make correlations available at wide range of fines for wider application on local soils.

iv) More field verification tests, on soils having relevant characteristics, are required to enhance validity of obtained correlations.

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