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Correlation between the Standard Penetration Test and the Dynamic Cone Penetration Test for Sandy Soil

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ABSTRACT
In geotechnical engineering, in-situ penetration tests have been widely used for site investigation in support of analysis and design. The Standard Penetration Test (SPT) is the most common in situ test for soil investigations in sandy soils. On the other hand, The Dynamic Cone Penetration Tests (DCPT) is a rapid inexpensive field test that can be used to assess the engineering properties of soils. However, correlation between the results of DCPT and soil properties or any other trusted field test is not well established yet. This study presents an evaluation of predictions SPT blow counts (N_{SPT}) using Dynamic Cone Penetrometer Test. Data consisting SPT and DCPT was utilized to develop a correlation. Data of this study was drawn from 14 different sites located in north costal of Libya (City of Tripoli), served as the subject of SPT-DCPT correlations. The soil investigation program for each site included SPT borehole and adjacent DCPT tests. The validity of the proposed correlation was verified using test results on similar soils from five new sites. The developed correlation indicates that the relationship between the results of the two penetration tests is linear for sandy soils. Positive linear relationships were found between N_{SPT} and N_{DCPT} for sandy soils. To demonstrate the differences between the proposed and previous deterministic equations, comparative studies were performed. The suggested correlations may guide future more detailed correlations between these two in situ tests. N_{SPT} predicted versus N_{SPT} actual showed high correlation coefficients of 0.70.In summary, direct correlations between SPT and DCPT were produced, showed that the light DCPT is suitable for sandy soils with low density NSPT 30 blows/0.3 m or less, and allowing estimation of N_{SPT} from DCPT.

1 BACKGROUND

In geotechnical engineering, in-situ penetration tests have been widely used for site investigation in support of analysis and design. The SPT is the most common in situ test for site investigations and most of foundation designs have been based on SPT-N values and physical properties of soils recovered in the SPT sampler. For many construction projects, it is common to use SPT for the preliminary soil investigation and several geotechnical design parameters of the soil are associated with the SPT.

The Cone Penetration Test (CPT) is also a common in situ testing method used to determine the geotechnical engineering properties of soils and assessing subsurface stratigraphy.

The DCPT is certainly the oldest of geotechnical in situ tests and it was invented to investigate mechanical soil characteristics and to design engineering work (**Error! Reference source not found.** It is a simple test device that is inexpensive, portable, easy to operate and easy to understand. It does not take extensive experience to interpret results and several correlations to more widely known strength measurements have been published. The DCPT quickly generates a continuous profile of in situ subgrade and base strength measurements.

The DCPT shows features of both the CPT and the SPT. The DCPT is similar to the SPT in test, it is performed by dropping a hammer from a certain fall height and measuring a penetration depth per blow for each tested depth. Therefore, it is quite similar to the procedure of obtaining the blow count N using the soil sampler in the SPT. The shape of the dynamic cone is similar to that of the penetrometer used in the CPT. However, a cone is used to obtain the penetration depth instead of using the split spoon soil sampler. In this respect, there is some resemblance with the CPT in the fact that both tests create a cavity during penetration and generate a cavity expansion resistance.

2 PROBLEM STATEMENT

Soil soundings are used to measure the in situ resistance of a soil against penetration of a standard device, this resistance usually gives some indication of the strength and compressibility of the soil. In addition providing qualitative information for subsoil, soundings can often be correlated with significant physical properties such as unit weight and shear strength.

The main problem which emerges from this study is that, even though the DCPT is similar to SPT (procedure test, obtaining the blow count N values), the DCPT in contrast, is not standardized yet. This was tried to be solved through the emanation of International Reference Procedures or through the European standards, which suggest guidance. But in general there are not any accurate correlations between the values obtained from DCPT and the geotechnical properties of the soils. The values deduced from the test give qualitative and quantitative indications of the characteristics of the underground and they have a great application in soil mechanics (**Error! Reference source not found.**

The advantage of the DCPT has over SPT penetration tests are its simplicity, portability, and low cost. Therefore, it is vital to correlate DCPT to SPT, so that DCPT tests can be used in the absence of SPT, especially for preliminary evaluation and design purposes.

3 RESEARCH OBJECTIVE

The main objective of the study was:

- To establish a correlation between the SPT N-value and DCPT N-value (number of blows per 100 mm).
- To verify the proposed correlation using test results at same soil from different new test site.

4 HISTORY OF DCPT

4.1 Development of the DCPT

The earliest record of subsoil penetration tasting device similar to the DCPT the "ram penetrometer" was developed in Germany at the end of the 17th century by Nicholaus Goldman.

The advancement of the use of modern DCPT is attributed to Scala (1956) who developed the DCPT also known as Scala Penetrometer in 1956 in response to the need for a simple and rapid device for the characterization of the subgrade soil.

The DCPT used by Scala (1965) included a 9kg (20 pound) hammer with a dropping distance of 508mm (20 inches). A 15.875mm (5/8 inch) diameter rod with a 30 degree angle cone was used to penetrate 762mm (30 inches) into the soil. Scala tried to find a correlation between DCPT results and CBR and also between DCPT results and the bearing capacity of soils estimated by a static cone.

In the late 1960's, Vuuren (1969) continued to develop the DCPT in Pretoria. He used a similar device, except for some differences in dimensions: a 10kg (22 pound) hammer was dropped from a height of 460mm (18.1 inches), forcing a 30 degree cone connected to a 16mm (0.63 inch) diameter rod into the soil up to 1000mm (39.4 inches).

In 1973, the Transvaal Roads Department in South Africa decided to use the DCPT as a rapid evaluation device for the extensive evaluation of existing roads. The drop weight of the DCPT was 8kg (17.6 pounds) and the falling height was 574 mm (22.6inches) (Kleyn et al. 1975).

Kleyn et al. (1982) reported that the relative results obtained using a 30° cone and a 60° cone. In 1982, Kleyn described another DCPT design, which used a 60° cone tip, 8 kg (17.6 pound) hammer, and 575 mm (22.6 in) free fall. He evaluated the effects of soil type, plasticity, moisture content, and density on the test results of DCPT.

4.2 Correlation between SPT and DCPT

According to the International Symposium of Penetration Tests, there are four different methods for dynamic probing DPCT: DPL, DPM, DPH, and DPSH. The abbreviation L, M, H and SH stand for the weight of the equipment, which is described as Light, Medium, Heavy and Super Heavy, respectively (Stefanoff, 1988)

Few researchers tried to find a relationship between DCPT and SPT. Summary presented in the following paragraphs and in Table 1.

Muromachi et al. (1982) introduced a relationship between N_{30} and N_{SPT} through DPSH, mass of the hammer 63.5 kg, height of fall 75cm, area of the point 40 cm², angle of the point 60° were used in this study. An equation to estimate N_{30} based on N_{SPT} is presented in Equation 1.

$$N_{30}=1.15N_{SPT} \quad [1]$$

Tissoni (1987) compares the SPT and DCPT through the DPSH, mass of the hammer 73 kg, height of fall 75 cm. The tests were conducted on sandy-silty gravels. The relation between N_{30} and N_{SPT} is shown in Equation 2.

$$\frac{N_{30\ DPSH}}{N_{SPT}} = 0.6 \quad [2]$$

Livneh et al. (1987) developed a relationship between DCPT and SPT through the DPL which is suitable for values of SPT blow count of less than 30.

$$\text{Log (PI)} = -A+B \log (N_{SPT}) \quad [3]$$

Where: PI= penetration index (mm/blow), N_{SPT} = SPT blow count.

Kassim et al. (2010) established a correlation between DCPT and SPT using DPL where, the mass of the hammer was 20 kg, height of fall 50cm. The author drawn a conclusion presented in Equation 4. Data was plotted between N_{SPT} and N_{10} concluded that fair to good correlation was developed.

$$N_{SPT}= 1.43N_{10} \quad [4]$$

Shahien et al. (2013) introduced a correlation between N_{100} and N_{SPT} using DPSH expressed in the following equation:

$$N_{100}= \frac{0.18N_{SPT}}{1-\sqrt{0.012N_{SPT}}} \quad [5]$$

Table 1. Summary of developed correlations

No.	Correlation	Soil	Reference
1	$N_{100}(SH) = 0.38N$[1]	Sandy soils (Japan)	Muromachi et al. (1982)
2	$N_{100}(SH) = 0.2N$	Sandy-silty gravels	Tissoni (1987)
3a	$N_{100}(SH) = 0.33N$	Alluviall gravel (UK)	
3b	$N_{100}(SH) = 0.37N$	Flood Plain Gravel (UK)	Card et al. (1988)
3c	$N_{100}(SH) = 0.47N$	Sands (UK)	
4	$N_{100}(SH) = 0.013N^2 + 0.009N$	Coarse grained soils	
5a	$N_{100}(SH) = 0.6N$	Fine sand	
5b	$N_{100}(SH) = (0.1 - 1.0) N$	Medium sand	Cearns et al. (1989)
5c	$N_{100}(SH) = 0.27N$	Coarse sand	
5d	$N_{100}(SH) = 0.33N$	Gravel	
6	$N_{100}(SH) = 0.2N$	Coarse soil (Italy)	Cestari (1990)
7	$N_{100}(SH) = 0.5N$	Coarse soil (Germany)	DIN (2002)
8	$N_{100}(SH) = 0.17N$	Sandy-silty with fine gravel (Italy)	Spagnoli (2007)
9	$N_{100}(SH) = 0.3N$	Highly weathered limestone (Sudan)	Kassim et al. (2010)
10	$N_{100}(SH) = \frac{0.267N}{1-0.02N}$	Sandy soils (South Africa)	MacRobert et al. (2011)

[1]SPT blow counts (blows/300mm)

5 IN-SITU TESTING PROGRAM

The aim of in-situ testing is to define soil stratigraphy and measurements soil parameters. In many cases, the information obtained can be correlated to other design parameters. It have the advantage of testing the soils in their natural with savings in both cost and speed when compared to laboratory testing.

5.1 Penetration Tests

The simplest and most widely used method of determining in situ soil properties is the penetration test, the testing procedure consists of measuring the resistance offered by the soil to the advancement into the ground of a penetrometer. The measured resistance, which usually gives some indication of the strength of soil and can be correlated to other design parameters. Many forms of in situ penetration test are in use worldwide. Penetrometers can be divided into two broad groups.

The two most common penetration tests, which are used virtually worldwide are the dynamic SPT and the static CPT.

5.1.1 The Standard Penetration Test (SPT)

The SPT is very widely used for subsurface investigation in many applications like field explorations, design parameters, and quality control assessment. Many soil index and engineering properties have been correlated to SPT, and various foundation design methods were developed based on the outcome of SPT. The SPT can be used for all types of soil, but in general, the SPT is most often used for sand deposits.

The SPT is considered the oldest in situ soil test technique. It is early version dates back to the beginning of the 19th century. In 1902, Charles R. Gow, owner of the Gow Construction Co. in Boston, began making exploratory borings using 2.5cm (1in) diameter drive samplers driven by repeated blows of a 50kg (110-lbs) hammer to aid in estimating the cost of hand excavating belled caissons (MacRobert et al., 2011)

In the 1920's and early 1930's, the procedure was standardized by Harry Mohr, one of Gow's engineers. Mohr measured the numerical values of driving force employed by Boston area drilling crews, determined to be 63.5kg (140-lbs) average driving weight with an average 76.2cm (30in) drop, recording the number of blows required to drive the sampler 30.5 cm (12in) (Fletcher,1965).

In 1958, became a nation-wide standard when the apparatus and procedures were officially adopted by the American Society of Testing and Materials (ASTM) as Test Method (**Error! Reference source not found.**).

Variations on the SPT procedure have been adopted by many foreign countries. In 1988, the International Reference Test Procedure for the SPT was adopted by the International Society for Soil Mechanics and Foundation Engineering (Rogers, 2006).

5.1.2 The Dynamic Cone penetration Test (DCPT)

The DCPT is a dynamic in situ penetration test. The DCPT consists of upper and lower shafts. The upper shaft has an 8 kg drop hammer with a 575 mm drop. The lower shaft contains an anvil and a cone attached at the end of the shaft. The cone is replaceable and has a 60° degree cone angle.

As a reading device, an additional rod is used as an attachment to the lower shaft with marks at every 10 mm. All materials (except the drop hammer) are stainless steel for corrosion resistance. An optional depth-reading device can be attached**,** to eliminate the need to measure penetration depth at ground level. Figure 1 shows a typical configuration of the DCPT**.**

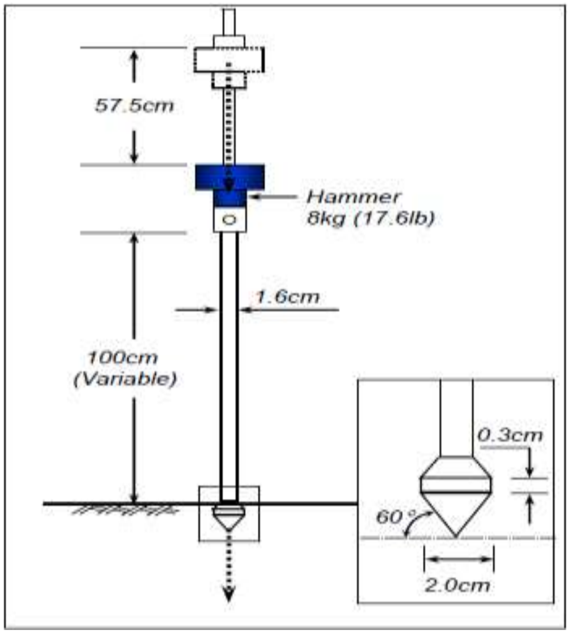

Figure 1. Schematic of the used DCPT

6 RESULTS AND DISCUSSION

6.1 Geology and soil condition

Data used in this study are from the city of Tripoli, Libya. Tripoli city was area geologically mapped by the Industrial Research Centrer (1975). Tripoli city is located at the coastal strip Jeffara Plain, which is covered by Jeffara formations. The Jeffara formation consists mainly of fine materials, mostly sand and gravel. It covers an extensive area with thickness ranges from 20 to 50 (Industrial Research Centre 1975). The soil profile at these sites were mainly sand with varying percentages of silts and clays. It classified as SM, SC, and SP.

6.2 Correlation Analysis

6.2.1 SPT vs. DCPT

At each site, a statistical analysis was performed to develop a correlation between DCPT and SPT.
Linear correlations between the N_{SPT} and N_{100} at each site, are presented in Figure 2 through 6. It consistently produced strong linear correlations with regression coefficients R_2 of 0.6 or higher.

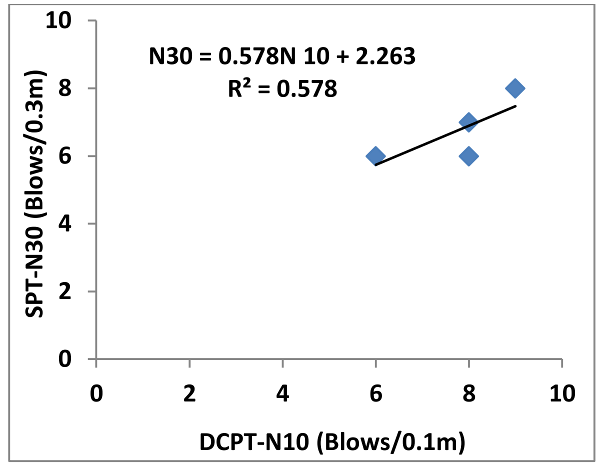

Figure 2. SPT vs. DCPT for Site 1

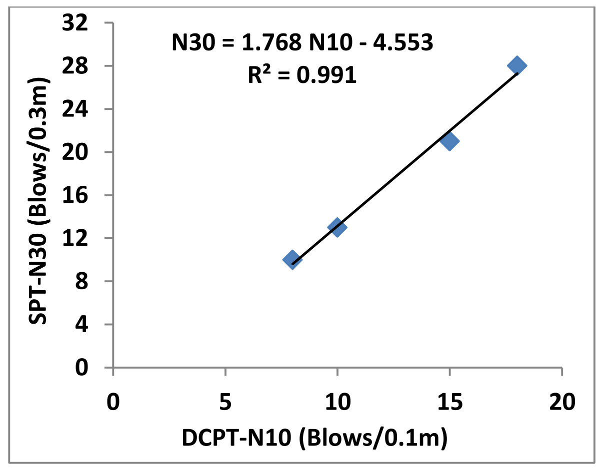

Figure 3. SPT vs. DCPT for Site 2

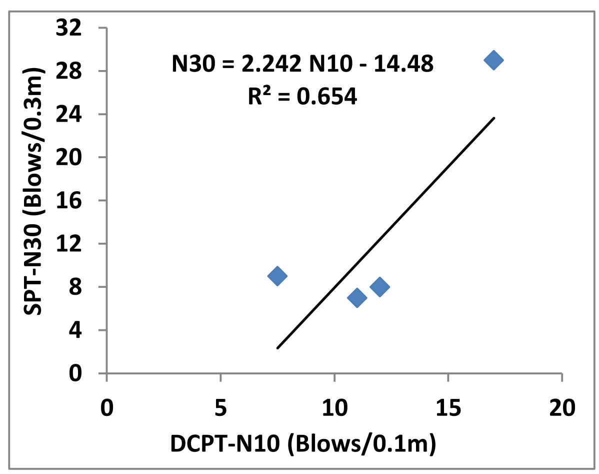

Figure 4. SPT vs. DCPT for Site 3

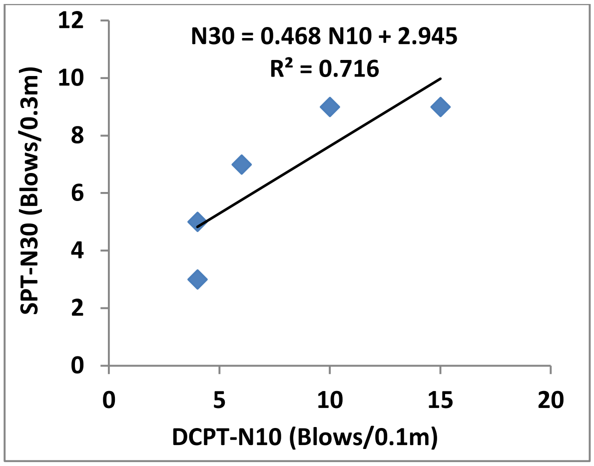

Figure 5. SPT vs. DCPT for Site 6

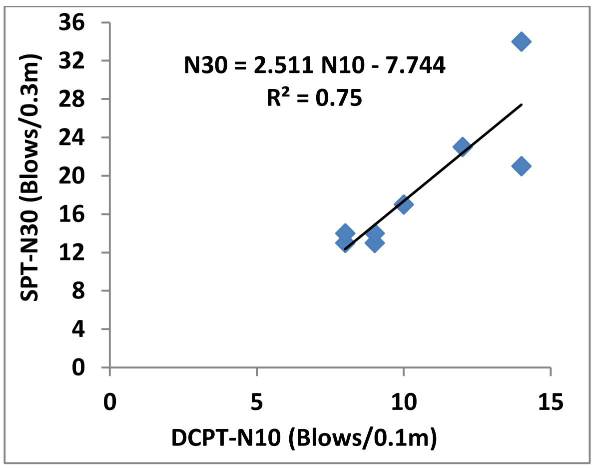

Figure 6. SPT vs. DCPT for Site 7

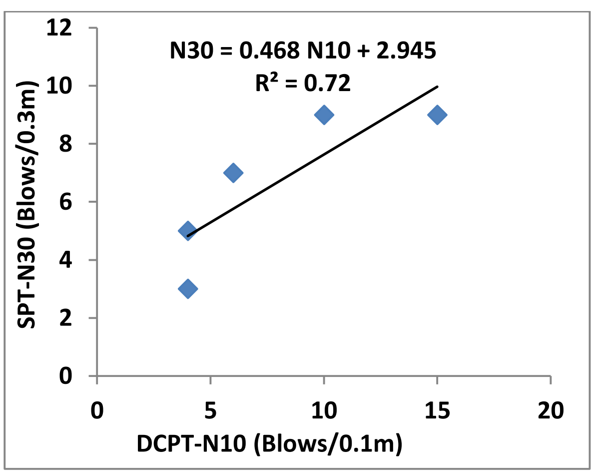

Figure 7. SPT vs. DCPT for Site 8

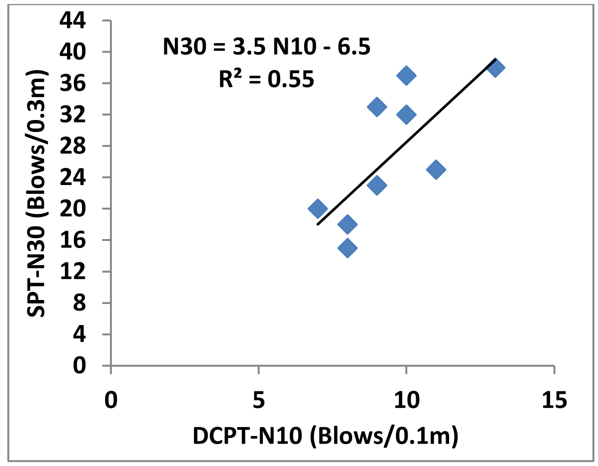

Figure 8. SPT vs. DCPT for Site 9

The data at the nine sites were then combined to produce the correlation. These correlations presented in Figure 9 showed a good relations between DCPT and SPT with R^2 of 0.8.

A number of geological variables in soil profiles, as a result of the various depositional environments that formed the profiles, led to the differences in penetration resistance values recorded by the two tests. Although similar specific energies were imparted to the probes of the respective tests. All of these can result in variable blow counts that can be misinterpreted.

$$N_{SPT} = 2N_{DCPT} - 8 \qquad [6]$$

The above equation is suitable for values of N_{SPT} less than 30. In previous studies, there was also similar equation developed by Livneh et al. [13], the author identified N_{SPT} less than 30 blow to be applicable of being applied the proposed equation. This may conclude that the DCPT is not applicable to use at sites where SPT higher than 30.

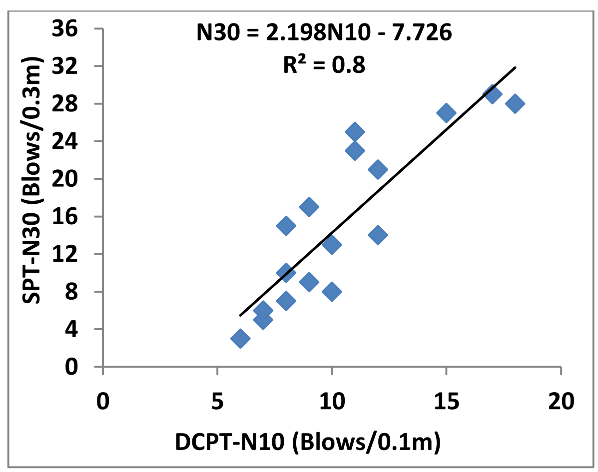

Figure 9. SPT- DCPT correlation at nine sites

6.3 Verification of the Correlation

The validity of the developed DCPT-SPT correlation was tested using five new sites in Tripoli which not used in developing the proposed equation.

The applicability of Equation 6 was evaluated by plotting the predicted N_{SPT} versus actual N_{SPT}. Figure 10 shows the ability to predict N_{SPT} using DCPT data. The equation produced R^2 values of 0.6.

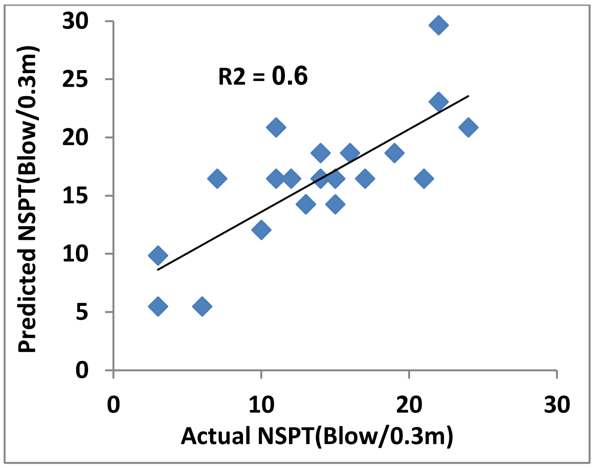

Figure 10. Predict vs. actual N_{SPT}

The proposed equation was also assessed using the data from the 14 sites. Both correlations (using five new sites and nine sites) have approximately similar linear pattern as shown in Fig.45 with high coefficient R^2 of 0.7.

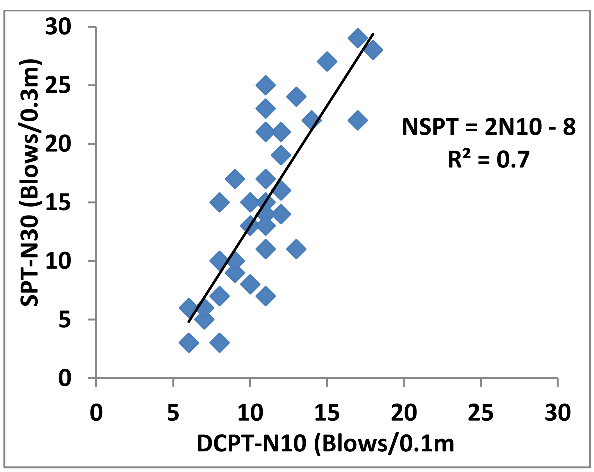

Figure 11. SPT-DCPT correlation using 14 sites

6.4 Factors Affecting SPT-DCPT Correlations

Although the similarity between the DCPT and the SPT in procedure test, but there are many factors affect in SPT/DCPT relationship. The most two important factors is the DCPT extension cone at the end of the rod and the amount of energy delivered to the drill rods. The factors can be identified as:

- Human factors (testing procedure and operation).
- Mechanical conditions (the impact energy, geometry of the penetrometer, cone apex, the diameter and the enlargement of the rod, the mass of hammer and the fall height).
- Material factors (gradation, compressibility, density, moisture content).
- In addition, the distance between SPT and CPT to establish the correlation may have a significant influence on the quality of the correlation

6.5 Comparison with previous correlations

A number of researchers have suggested SPT-DCPT correlation N-values, mostly of these correlations were published using Super Heavy penetrometer (DPSH). Few-used Light Penetrometer (DPL) similar used in the current study. One of these correlations developed by Kassim et al. (2010) has studied a correlation for highly weathered limestone in Eastern Sudan. The author developed an equation to estimate N_{SPT} based on N_{10} as presented in the Equation 4 with coefficient of correlation $R^2 = 0.85$.

The data from this study plus the data presented by Kassim et al. (2010) was combined (see Figure 12), using the data at the 14 sites. The data from agrees with the results of this study.

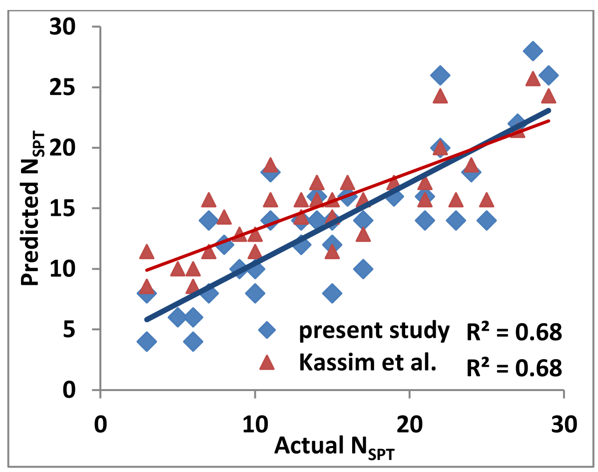

Figure 12. N_{SPT} Value estimated by equation 4 and Kassim et al. (2010)

7 CONCLUSIONS

The Standard Penetration Test (SPT) is the most common in situ test for soil investigations in sandy soils. On the other hand, The Dynamic Cone Penetration Tests (DCPT) is a rapid inexpensive field test that can be used to assess the engineering properties of soils. However, correlation between the results of DCPT and soil properties or any other trusted field test is not well established yet.

This study presents an evaluation of predictions SPT blow counts using Dynamic Cone Penetrometer Test. Database consisting of 39 SPT and 21 DCPT data sets was utilized to develop the correlation. Data of this study was drawn from 14 different sites located in north costal of Libya (City of Tripoli), served as the subject of SPT-DCPT correlations. The soil investigation program for each site included SPT borehole and adjacent DCPT tests to depths of 6 m. The distances between SPT and DCPT tests locations varied between 1.0 to 6.0 m.

The validity of the proposed correlation was verified using test results on similar soils from five sites. The developed correlation indicates that the relation between the results of the two penetrometer tests is linear for sandy soils. Positive linear relationships were found between N_{SPT} and N_{DCPT} for sandy soils.

To demonstrate the differences between the proposed and previous deterministic equations, comparative studies were performed. The suggested correlations may guide future more detailed correlations between these two in situ tests. N predicted versus N actual showed correlation coefficients of 0.6

In summary, direct correlations between SPT and DCPT were produced, showed that the light DCPT is suitable for sandy soils with low density N_{SPT} 30 blows/0.3 m or less, and allowing estimation of N_{SPT} from DCPT.

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