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USE OF LIGHTWEIGHT DYNAMIC CONE PENETROMETER FOR COMPACTION CONTROL OF COHESIONLESS SOILS

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ABSTRACT: Evaluation of the adequacy of field compaction of granular soils, has always been a challenge for geotechnical engineers. The Lightweight Dynamic Cone Penetrometer (LDCP) has been established as one of the most versatile techniques, as it significantly reduces the required effort and cost. This research has been conducted to correlate the readings of LDCP laboratory tests, to compaction parameters of cohesionless soils. An experimental program has been performed on four different types of granular soils, at various compaction levels and moisture content values. The investigated soils included two sandy soils with different gradation and two different admixtures of sand with crushed dolomitic limestone. A series of LDCP and sand-cone tests have been conducted on soil samples which were compacted in a cubic steel mold, 60cm side length. The laboratory results have been integrated into a number of predictive correlations, which are capable of assessing the soil compaction parameters including; relative compaction, relative density, dry density and uniformity coefficient. Moreover, the compacted granular soils were found to be more sensitive to changes of moisture content from the optimum value, at lower ratios of relative compaction.

Keywords: Lightweight dynamic cone penetrometer (LDCP), sand cone, penetration index, relative compaction, relative density.

1. INTRODUCTION

The quality of the compacted soil is routinely measured by comparing the field dry density with the laboratory compaction test results. For practical purposes, there is much interest in finding a quick positive way to assure the presence of the desired behavioral parameters of granular compacted soil. The Dynamic Cone Penetrometer (DCP) is one of the lowest-cost alternatives for characterization of the soil compaction. The device requires no electronics; it is durable, portable and easy to operate. Different variations of the dynamic cone penetrometers established across the years were described in several codes and researches such as; [1- 6]. In 2003, ASTM published the standard test method (D6951-03) for the Standard 8-kg (17.6-lb) Dynamic Cone Penetrometer, [7]. After that in 2008, ASTM published the standard test method for soil compaction determination at shallow depths using the 2.3-kg (5-lb) Lightweight Dynamic Cone Penetrometer (LDCP) (D7380-08), [8].

Over the years, researchers have studied the relationship between the Standard 8-kg DCP results and the most common soil indices, such as the compaction properties, the soil type, modulus of subgrade reaction, Elastic modulus of soil, and strength parameters of soil, [9-18].

The lightweight 2.3-kg LDCP is a simple device, capable of being handled and operated by a single operator in field conditions. It is typically used in the compaction verification of soils, or modified material used in the subgrade, and backfill compaction in confined cuts at shallow depths. Researchers have been studying the relationship between the LDCP results and some control design parameters of compacted soils, [19, 20]. The existing correlations between LDCP and the traditional cone penetration test CPT were examined by [21] and found to be not accurate for intermediate soils, ranges from silty sand to silty clay.

The good correlations that were detected between the number of blows (N) and the common soil parameters, nominated the LDCP to be an effective tool for identifying soil characteristics. In this research, the 2.3-kg LDCP has been adopted in an experimental study to establish reliable correlations for the assessment of compaction parameters of granular soils.

2. EXPERIMENTAL PROGRAM

2.1 Properties of The Tested Soils

In the current study, four different types of soil that are widely imposed in compaction works for construction purposes were considered to investigate the applicability of the LDCP test to such soils. Sieve analysis and modified Proctor compaction tests were conducted in the laboratory for each of these soils. Table 1 summarizes the results obtained for the investigated soil types including; their constituents, classification, maximum dry densities and the corresponding optimum moisture contents. In addition, the obtained minimum dry densities curvature and uniformity coefficients, are given. The first two types consist of pure sands with different gradations.

Table 1 Results of sieve analysis and modified Proctor compaction tests for the soils tested using the LDCPTs.

Soil Type	% Sand			% Crushed dolomitic limestone	Soil Classification	$\gamma_{dmax.}$ (g/cm^3)	$\gamma_{dmin.}$ (g/cm^3)	O.M.C (%)	C_c	C_u
	% Coarse	% Med.	% Fine							
I	18.5	78.5	3	0	Medium to coarse sand (SP)	1.86	1.54	9.36	1.12	2.37
II	56.5	42.5	1	0	Coarse to medium sand (SP)	1.89	1.63	7.61	0.93	2.27
III	15.3	50.7	0.7	33.3	2 Sand: 1 Crushed dolomitic limestone mix * (SP)	2.11	1.76	6.45	0.60	3.23
IV	7.7	41	1.7	49.7	1 Sand: 1 Crushed dolomitic limestone mix * (SP)	2.19	1.91	5.8	0.15	25.71

* The crushed dolomitic limestone size ranges from 5 to 10 mm while the sand is medium to coarse.

Types III and IV are sands mixed with crushed dolomitic limestone (L.S.), with ratios (2 Sand: 1 L.S.) and (1 Sand: 1 L.S.), respectively.

Figures (1) and (2) assemble the particle size distribution curves and the compaction curves, for all the tested soil types. The summarizing figures reveal that as the soil coarseness increases, the maximum dry density increases and the optimum moisture content decreases.

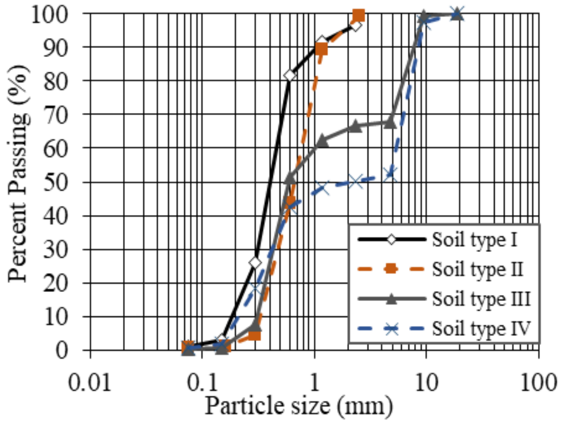


Fig.1 Particle size distribution for all soil types

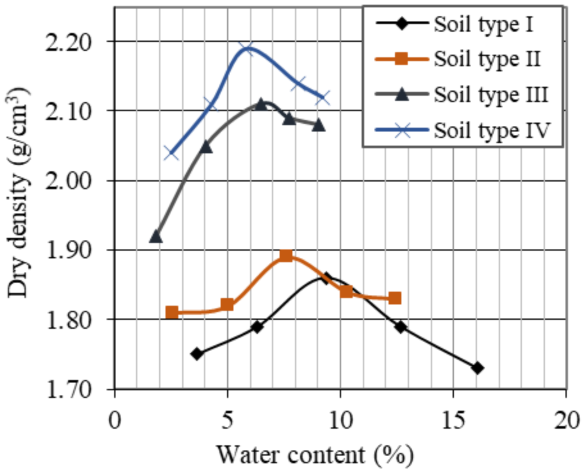


Fig.2 Compaction curves using the Modified Proctor test, for the considered soils.

2.2 The Used Devices

Beside implementation of the lightweight dynamic cone penetrometer (LDCP), the standard sand-cone apparatus, which is commonly used to determine the dry density of compacted soils placed during construction of earth fills, was also used. Figure 3 shows a schematic and real shape of the 2.3-kg LDCP that was manufactured according to ASTM standard specification (D7380–08).

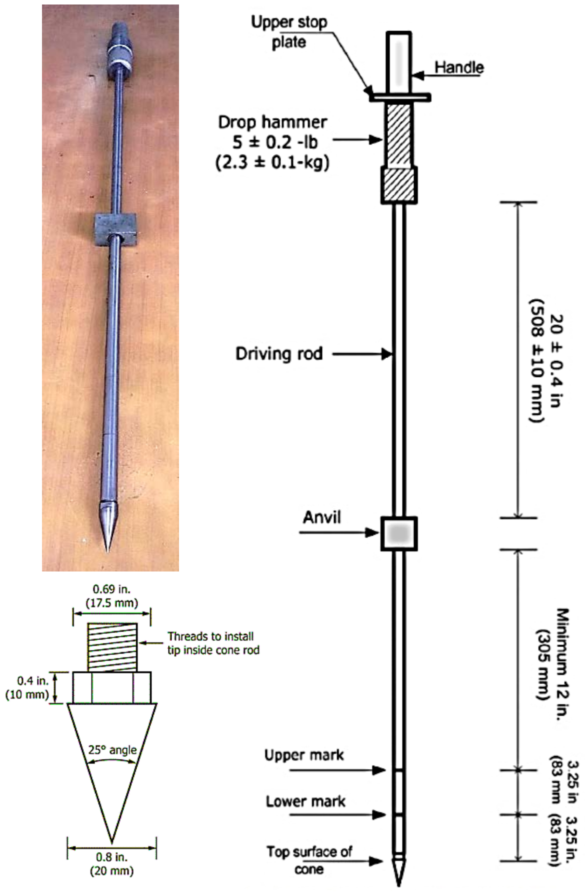
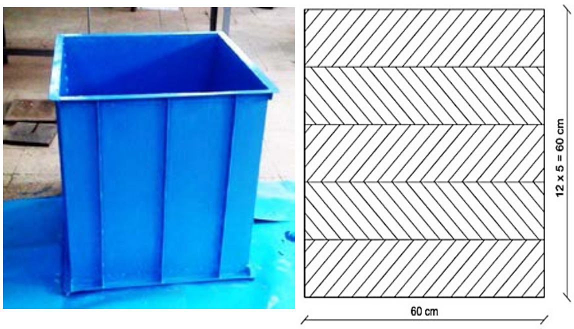


Fig.3 A schematic and real shape of the manufactured lightweight dynamic cone penetrometer, LDCP, according to (ASTM D7380–08).

The lower shaft contains an anvil and a replaceable 25° cone tip. The upper shaft contains a 2.3 kg drop hammer with a 508 mm drop distance; a top grab handle is attached to the lower shaft through the anvil. All materials, except the drop hammer, are stainless steel for corrosion resistance purpose.

2.3 Sample Preparation

For laboratory investigation, compacted soil samples were prepared in a metal box (mold) of dimensions 60x60x60 cm, Fig. 4a. According to [18], the chosen dimensions are expected to eliminate the confinement effect of the mold walls and base on the penetration testing results. The soil samples were compacted in the mold in five layers, each layer was 12 cm in thickness, as shown in Fig. 4b. A manual compaction hammer was employed to compact the soil within the mold.



(a) (b)

Fig.4 (a) The metal box (mold) for soil samples preparation, (b) A schematic diagram of the compacted soil layers in the mold.

2.4 Experimental Work Program

An experimental work program was conducted on the four soil types to examine the applicability of the LDCP test in assessing soil compactness. As previously described, samples from each soil type were compacted in the 60-cm cubic mold, at different relative compaction values (R.C). Each sample was subjected to three LDCP tests and two sand-cone tests. Figure 5a illustrates the layout of locations of the sand-cone and the LDCP tests, performed on each sample. The description of the experimental work program is provided in Table 2.

2.5 Testing Procedure

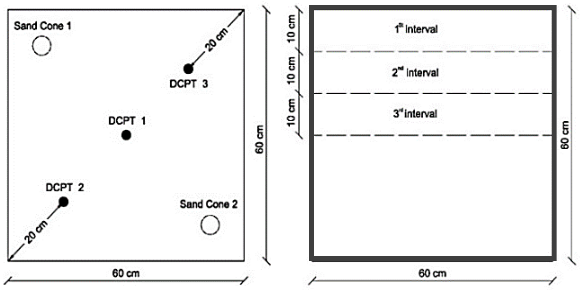
The dry density and the moisture content were routinely assessed for each compacted sample with the sand-cone test. On carrying out the lightweight dynamic cone penetration test (LDCP), two operators were working together; one person drops the hammer and the other records measurements.

Table 2 Experimental work program conducted on the different types of soil.

Soil Name	*R.C Range (%)	No. of samples (boxes)	No. of tests/ sample	
			Sand-Cone	LDCP
I	91.4 to 101.6	9	2	3
II	90.5 to 100.3	9	2	3
III	90.8 to 101.4	8	2	3
IV	90.4 to 100.9	9	2	3
Total No.		35	70	105

* R.C (Relative compaction) = dry density/ maximum modified Proctor dry density)

The test begins with the operator place the LDCP tip at the test point, and the other person records the number of blows required for a prespecified penetration of 10 cm through the soil. Each test was carried out on 3 stages each stage was 10 cm deep, the total penetration depth for each test was 30 cm. For each test, the number of blows was recorded for each stage of the test. Figure 5b illustrates the three penetration stages, each of 10 cm thickness, that were executed in the current experimental work.



(a) (b)

Fig.5 (a) Layout of LDCP and sand-cone tests locations, (b) A schematic diagram of the penetration measurement levels.

3. TESTING RESULTS AND ANALYSIS

The results of the LDCP tests performed for each soil sample, to a total penetration depth of 30-cm depth (3×10cm), were expressed in terms of penetration index (PIc). The penetration index is defined as the penetration depth of the device into the soil for each blow (cm/blow). For each 10-cm interval, PIc was calculated as the average value of the three tests conducted in any mold, PIc = $\frac{\mathbf{10}\ (\boldsymbol{cm})}{\boldsymbol{N}\ (\boldsymbol{blow})}$. In addition, in-situ dry densities obtained from the sand-cone tests, combined with the modified Proctor compaction test results, were used to calculate the relative compaction (R.C) and the relative density (Dr) for all the examined samples, where, $R.C = \frac{\gamma d}{\gamma dmax}$ and $Dr = \frac{1/\gamma dmin. - 1/\gamma d}{1/\gamma dmin. - 1/\gamma dmax.}$.

3.1 Variation of The Penetration Index with Depth

For the tested soils, Fig. 6 presents the relationships of the penetration index (PIc) versus depth for samples prepared at different relative compaction values. As shown in the figure the PIc decreases with depth for all relative compaction values. The figure exhibits also that, the PIc values of the upper first ten-cm are significantly deviated from those of the other two intervals, as the soil is still not confined enough to produce reliable resistance.

The following sections summarize the predictive equations that were derived for the examined soil types, on the basis of the LDCP test results of the second 10-cm penetration interval, rather than the third interval. The reason is that the majority of the second interval data has produced a higher coefficient of determination values than the third interval, which indicates more accurate best-fit lines.

3.2 Relative Compaction Predictive Equations

For all soil types I to IV, relationships between relative compaction and penetration index of the 2nd interval, are compiled in Fig. 7. As shown in the figure, R.C values of some samples have exceeded 100%, indicating a compaction effort that was higher than the exerted by modified Proctor test. The figure confirms that increasing the soil coarseness decreases the penetration index values at the same relative compaction. This can be attributed to the point that, as the soil gets coarser, it gains higher dry density that makes to increase its strength and consequently, its resistance. The established equations for the soil types I to IV are, respectively, given by:

Soil I: $$R.C = -11.08PIc + 112.73 \tag{1}$$

Soil II: $$R.C = -9.09PIc + 108.57 \tag{2}$$

Soil III: $$R.C = -10.29PIc + 107.19 \tag{3}$$

Soil IV: $$R.C = -20.06PIc + 109.49 \tag{4}$$

The data in Fig. 7 is expressed in a different way in Fig. 8. In this figure, the number of blows (N) (for the second 10cm depth interval) is used instead of the penetration index (PIc) in Fig. 7.

The figure shows, roughly, that at a relative compaction more than 95%, at least 7 blows are required for sandy soils, 9 blows for a replacement soil mix of 2 sand : 1 crushed dolomitic limestone, and 15 blows for a soil replacement of a mix of 1 sand : 1 crushed dolomitic limestone.

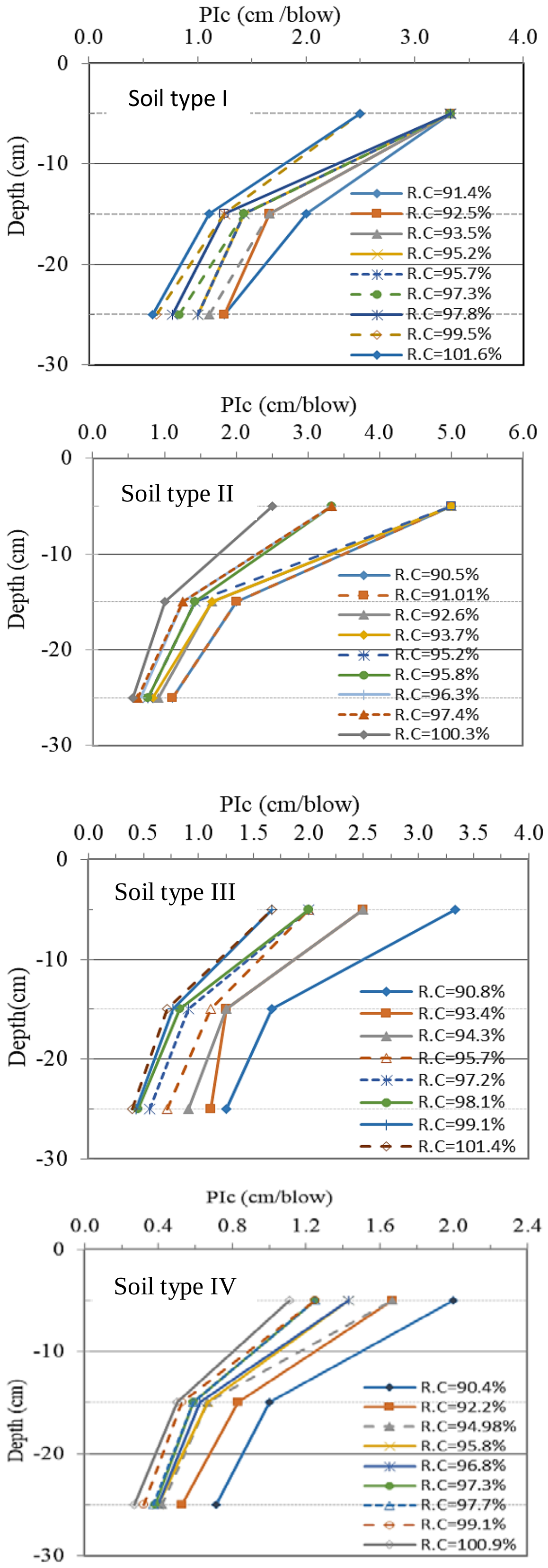


Fig.6 The penetration index (PIc) versus depth at different relative compaction values for the four soil types.

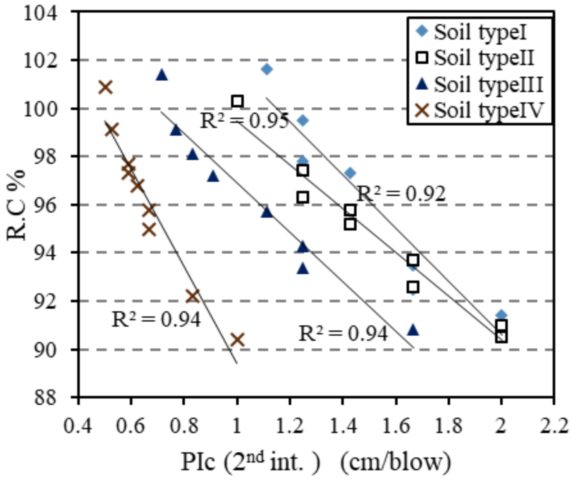


Fig.7 The relationship between relative compaction and penetration index for the second testing interval.

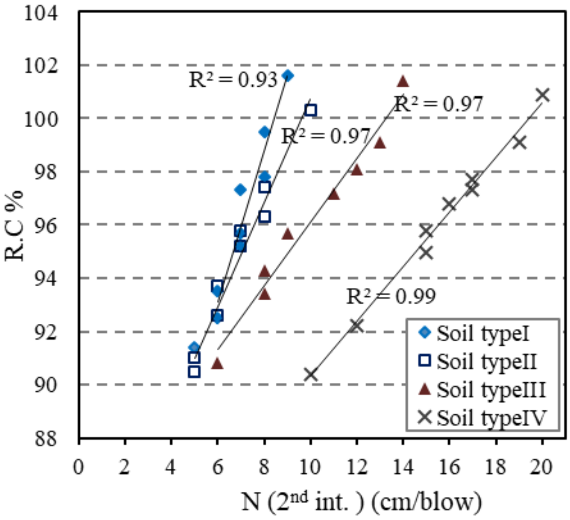


Fig.8 The relationship between relative compaction and number of blows (N) for the second testing interval.

3.3 Relative Density Predictive Equations

Figure 9 compiles the experimental data of the four types of soils, to determine the relationships between the relative density and the penetration index. The figure confirms that increasing the soil coarseness results in lower penetration index values, at the same relative density.

The estimated equations for the soil types I to IV are, respectively, given by:

Soil I: $D_r = -60.45\ \text{PIc} + 168.57$ (5)

Soil II: $D_r = -63.15\ \text{PIc} + 160.65$ (6)

Soil III: $D_r = -55.35\ \text{PIc} + 138.83$ (7)

Soil IV: $D_r = -151.19\ \text{PIc} + 172.57$ (8)

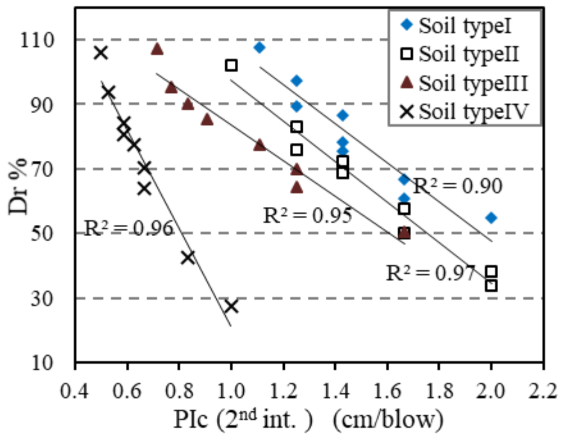


Fig.9 The relationship between relative density (Dr) and penetration index for the second testing interval.

3.4 Dry Density Predictive Equations

In this section, equations for prediction of the field dry density (γ_d) from LDCP test results, were derived for the four examined soils. Figure 10 exhibits the relationship between the dry density and the penetration index for the 2nd interval. To obtain more precise equations, the odd values of the laboratory test results of each of the tested soils were omitted. The estimated equations for the soil types I to IV are, respectively, given by:

Soil I: $\gamma_d = -0.19\ \text{PIc} + 2.06$ (9)

Soil II: $\gamma_d = -0.17\ \text{PIc} + 2.05$ (10)

Soil III: $\gamma_d = -0.21\ \text{PIc} + 2.26$ (11)

Soil IV: $\gamma_d = -0.44\ \text{PIc} + 2.397$ (12)

Figure 10 shows that, soils type I and II exhibit lower dry densities and, consequently, higher penetration indices than soils type III and IV. This may be referred to the existence of the crushed stone in soils III and IV that increases the stiffness of the soil and consequently the penetration resistance.

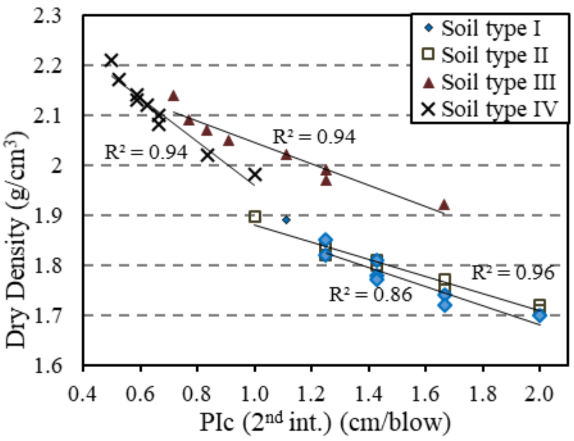


Fig.10 Relationship between the dry density (γ_d) and the penetration index of the second testing interval.

3.5 Moisture Content Predictive Equations

The experimental data of the LDCP tests conducted on the four soil types, at different moisture content values are compiled in Fig. 11. A linear regression model with a correlation coefficient of 0.45, has been constructed to show the effect of water content on the PIc value. The general trend of the obtained relationship indicates increasing penetration index with the increase of moisture content, for water content range of 3% to 10%, according to the following equation:

$$Wc\ \% = 2.83\ PIc + 2.84 \qquad (13)$$

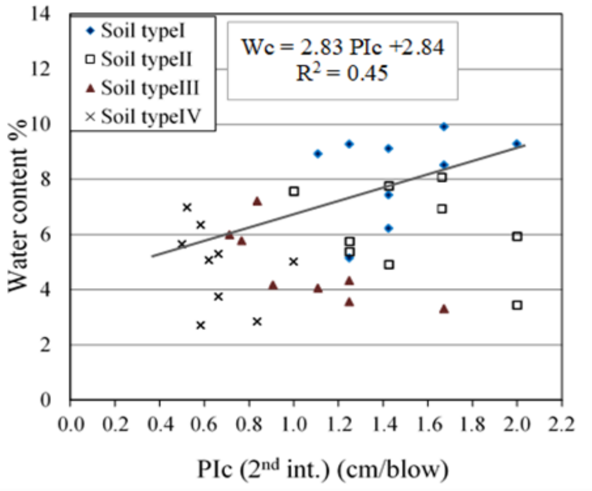


Fig.11 Variation of the penetration index with the water content value.

To have more significant correlations, the deviation of the actual water contents from the optimum moisture content was investigated at two practical values of relative compaction. The difference (wc% – omc %) was plotted against the LDCP blow count (N), at relative compaction values of 95% and 98%, Fig. 12. The figure delineates that, as the water content difference gets lower, the number of blows (N) required to penetrate the soil reduces.

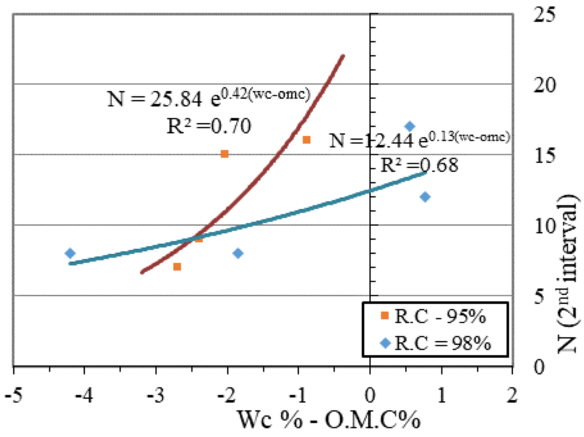


Fig.12 Relationship between (wc %- o.m.c %) and (N) for the second testing interval.

It is obvious that, the rate of blow count (N) variation with water content difference, is significantly higher for case of R.C. equals 95%, compared with that at 98% R.C. In other words, the sensitivity of compacted granular soils due to variation in water content difference, increases at lower ratios of relative compaction. However, further testing is required to develop a more robust correlation for water content versus LDCP test results.

3.6 Uniformity Coefficient Correlations

For more significant and applicable correlations, further three soils were tested at 95% and 98% relative compaction values. Table 3 presents the classification, the compaction test results and the coefficient of uniformity C_u ($C_u = D_{60}/D_{10}$) obtained for these soils. The coefficient of uniformity Cu was plotted against the LDCP blow count (N) at relative compactions of 95% and 98%, as shown in Figs. 13 and 14, respectively.

Table 3 Classification and results of modified Proctor tests for the additional soils.

Soil Type	Soil Classification	$\gamma_{dmax.}$ (g/cm³)	O.M.C (%)	C_c	C_u
VI	1 Sand: 2 Crushed dolomitic limestone size1* (GW)	2.23	6.03	1.61	15.56
VII	1 Sand: 2 Crushed dolomitic limestone size2* (GP)	2.30	5.61	0.64	38.89
VIII	1 Sand: 1 limestone size1: 1 limestone size2* (GW)	2.26	5.75	1.79	20.51

size1: 4.5 to 9 mm & size2: > 9 to 19 mm.

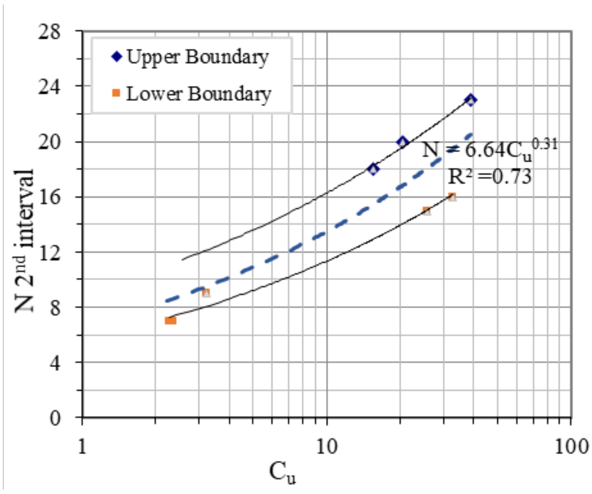


Fig.13 Relationship between coefficient of uniformity (C_u) and (N) for the second testing interval at R.C.= 95%.

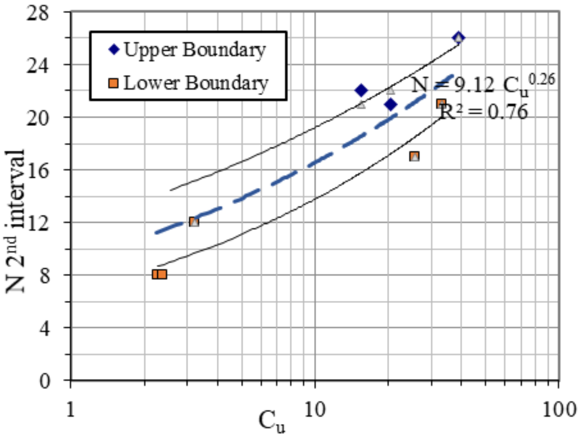


Fig.14 The relationship between the coefficient of uniformity (C_u) and (N) for the second testing interval at R.C. = 98%.

The figures show that the upper boundary values are obtained for soil types having sand portions less than 50%, mixed with crushed dolomitic limestone. Whereas, the lower boundary values are related to the soil types having sand portions equal to or more than 50%. The figures reveal that, as the coefficient of uniformity increases; the soil exhibits a greater LDCP blow count (N), indicating a denser compacted state (because a wider range of particle sizes is present). The average curves between lower and upper boundaries in both cases of relative compaction values, 95% and 98%, are represented by the following two equations, respectively:

$$N = 6.64\, C_u^{\,0.31} \tag{14}$$

$$N = 9.12\, C_u^{\,0.26} \tag{15}$$

4. CONCLUSIONS

The current study was conducted to experimentally identify some of the properties of the granular soils using the lightweight dynamic cone penetrometer (LDCP) device. Relationships to assess the relative compaction, relative density and dry density of the compacted granular soils, were established from the obtained results of the considered four types of granular soil. Although some relationships between some soil properties and the penetration index (PIc) showed some scatter, the general trend indicated that increasing the dry density leads to a decrease in the penetration index. However, when all laboratory data were combined, satisfactory relationships were established. The conclusions obtained from this study can be summarized as follows:

1. The LDCPT results of the upper first 10-cm interval are so deviated from those of the other intervals, as the soil is still not confined enough to produce consistent results. The results of the second (middle) 10-cm interval are more consistent.
2. For the investigated soils, relationships between the penetration index (PIc) and each of; the dry density (γ_d), relative compaction (R.C), and relative density (Dr), show that the PIc decreases with increasing the soil dry density, and consequently with increasing each of relative compaction and relative density.
3. At the same value of any of the investigated compaction parameters, an increase of the soil coarseness produces lower penetration index values.
4. The sensitivity of compacted granular soils due to variation in water content difference (w_c% – omc %), increases at lower ratios of relative compaction.
5. As the coefficient of uniformity Cu increases, a denser compacted state can be achieved, and thus the soil exhibits a greater LDCP blow count (N).
6. The LDCP test can be used as a quality control tool for field compaction works for sandy soils and mixtures of sand with crushed stone.

5. REFERENCES

[1] DIN 4094, German Standard, Penetration Testing of Soil with the Supplement1, 1990.

[2] Egyptian Code of Practice for “Soil Mechanics and Foundation Design and Execution”, Part 1, 2007.

[3] Kleyn, E. G., Maree, J. H., and Savage, P. F., The Application of a Portable Pavement Dynamic Cone Penetrometer to Determine in Situ Bearing Properties of Road Pavement Layers and Subgrades in South Africa, European Symposium on Penetration Testing, Amsterdam, Netherlands, 1982, pp 277-282.

[4] Ampadu, S. I. K., A Correlation Between the Dynamic Cone Penetrometer and Bearing Capacity of a Local Soil Formation, The 16th International Conference on Soil Mechanics and Geotechnical Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, 2005, pp 655–658.

[5] Look, B. G., Handbook of Geotechnical Investigation and Design Tables, London, UK: Taylor & Francis, 2007.

[6] Awuku, D. D., Correlation Between Dynamic Cone Penetrometer (N-Value) and Allowable Bearing Pressure of Shallow Foundation Using Model Footing, Faculty of Civil and Geomatic Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, 2008, Master of Philosophy Thesis.

[7] ASTM D6951-03, Standard Test Method for Use of the Dynamic Cone Penetrometer in Shallow Pavement Applications, ASTM International, West Conshohocken, PA, 2003, “https://www.astm.org”

[8] ASTM Standard D7380-08, Standard Test Method for Soil Compaction Determination at Shallow Depths Using 5-lb (2.3 kg) Dynamic Cone Penetrometer, ASTM International, 2008, “https://www.astm.org”

[9] Luo, X., Salgado, R., and Altschaeffl, A., Cone Penetration Test to Assess the Mechanical Properties of Subgrade Soils, Publication FHWA/IN/JTRP-98/13, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 1998.

[10] Seyman, E., Laboratory Evaluation of In-Situ Tests as Potential Quality Control - Quality Assurance Tools,” M.Sc. thesis, 2003, The Department of Civil and Environmental Engineering, Louisiana State University and Agricultural and Mechanical College.

[11] Farrag, K., Vetter, D., Hill, B., and Esposito, R., Evaluation of Soil Compaction Measuring Devices, Report by Distribution & Pipeline Technology Division Gas Technology Institute, for Gas Research Institute, 2005.

[12] Chen, D. H., Lin, D. F., Pen-Hwang Liau, P. H., and Bilyeu, J., A Correlation Between Dynamic Cone Penetrometer Values and Pavement Layer Moduli, Geotechnical Testing Journal, 38(1), 2005. Cited from Rao, 2008.

[13] Mohammadi, S. D., Nikoudel, M. R., Rahimi, H., and Khamehchiyan, M., Application of the Dynamic Cone Penetrometer (DCP) for Determination of the Engineering Parameters of Sandy Soils, Article in Engineering Geology Journal, 2008, Tehran, Iran.

[14] Mukesh, A., and Patel, H. S., Experimental Study on Various Soils to Correlate DCP with PBT, UCS and CBR Results, International Journal of Earth Sciences and Engineering, 2012, ISSN 0974-5904, Vol. 05, No. 05 (01), pp. 1298-1304.

[15] Jordão, H. P., Lucena, A. E., Filho, M. B., Rodrigues, J. K., and Gama, D. A., Contribution to the Project of Urban Pavement of Low Volume of Traffic by Use of the Dynamic Cone Penetrometer, Article in Soils and Rocks J., São Paulo, 2012, 35(2).

[16] Kumar, R. S., Ajmi, A.S., and Valkati, B., Comparative Study of Subgrade Soil Strength Estimation Models Developed Based on CBR, DCP and FWD Test Results, International Advanced Research Journal in Science, Engineering and Technology, 2015, VOL. 2, Issue 8.

[17] Rao, N., George, V., and Shivashankar, R., PFWD, CBR and DCP Evaluation of Lateritic Subgrades of Dakshina Kannada, India, The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), 2008, Goa, India.

[18] Ayers M. E., Rapid Shear Strength of In Situ Granular Materials Utilizing the Dynamic Cone Penetrometer, University of Illinois at Urbana-Champaign, 1990, Ph.D. thesis.

[19] Juntasan P., Narong S., Kaewhanam N., Evaluation of Highway Subgrade Compaction by Dynamic Cone Penetrometer, Mahasarakham International Journal of Engineering Technology, 2015, Vol. 1, No. 1, Department of Civil Engineering, Mahasarakham University, Maha Sarakham, Thailand.

[20] Eshan Ganju, Hobi Kim, Monica Prezzi, Rodrigo Salgado & Nayyar Zia Siddiki, Quality Assurance and Quality Control of Subgrade Compaction Using the Dynamic Cone Penetrometer, International Journal of Pavement Engineering, 2016, DOI: 10.1080/10298436.2016.1227664

[21] Pinheiro C, Molina-G´omez F, Rios S, Viana da Fonseca A and Miranda T, Correlations Between Dynamic Penetrometer Light and Cone Penetration Tests in Intermediate Soils: A Statistical Comparison; XIX Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica, at: Salvador, Bahia, Brasil, 2018.