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USAGE OF DYNAMIC CONE PENETRATION TEST TO ASSESS THE ENGINEERING PROPERTIES OF SAND

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Saudi Arabia is witnessing unparalleled development for all types of construction, especially in eastern Saudi Arabia where the major oil and petrochemical industries are located. In this region, major projects are often located on sandy soils and it is difficult to assess the properties of sands using conventional methods. In this investigation, a laboratory program was conducted using the dynamic cone penetration test (DCPT) on sand samples with different relative densities (40%, 60% and 90%) that were compacted in a large scale mold (1600 mm diameter and 1500 mm height). The placement of sand was achieved through the pluviation and vibration techniques. Results of investigation indicated that the increase in the dry density was associated with a decrease in the dynamic cone penetration index (DCPI). Further, it was noted that the shear strength has a significant effect on the dynamic cone penetration test results. In summary, results of this investigation indicate that DCPT is an effective and reliable tool in the assessment of the properties of sand backfills.

Keywords: DCPT, Shear strength, Relative density, Pluviation technique, Vibration technique.

1 INTRODUCTION

Density and shear strength are two of the essential engineering properties of the soil that help in the design of foundations, dams, retaining walls, embankment, etc. Sand is the most predominant type of soil in the Eastern Province of Saudi Arabia which is confined by sand deserts from three directions (Aiban 1994).

DCPT was used in this investigation to predict the engineering properties of sand because it is difficult to obtain undisturbed sand samples, especially when loose or submerged sandy soil is encountered. Perhaps the most important advantage of the DCP device is related to its ability to provide a continuous record of the relative soil strength with depth (Burnham and Johnson 1993). Dynamic cone penetrometer device is distinguished by its economy and simplicity to operate and its superiority to provide repeatable results and rapid property assessment. DCPT has the main features that are similar to CPT and SPT (Salgado and Yoon 2003).

Some applications of the DCPT results include correlations with resilient modulus, California bearing ratio (CBR), unconfined compressive strength, and shear strengths, as well as its use in quality control of compaction of fill and performance evaluation of pavement layers (Amini 2003). In addition, several DCP-CBR correlations have been developed for different materials in laboratory and field according to many researches (Al-Refeai and Al-Suhaibani 1997; Coonse 1999; Ese *et al*. 1994; Gabr *et al*. 2000; Harison 1989, 1986; Smith and Pratt 1983).

Abu-Farsakh *et al*. (2005) reported that, based on laboratory and field studies, DCP, plate load test (PLT), falling weight deflectometer (FWD), and (CBR), dynamic cone penetration tests can be used to evaluate subgrade and pavement layers. Moreover, they developed empirical correlations from DCP results with elastic modulus, resilient modulus, and CBR.

Mohammadi *et al*. (2008) developed the relationships between the dynamic penetration index, relative density, modulus of elasticity, shear modulus, modulus of subgrade reaction, and the friction angle of the soil, using a mold with 700 mm diameter and 700 mm height and conducted DCPTs and PLTs on the soil, with a high coefficient of determination (more than 90%).

The main objective of this study was to evaluate the potential usage of dynamic cone penetration test (DCPT) to assess the engineering properties of eastern Saudi sands. Further, this research also aimed to develop a correlation between the engineering properties of sand such as density, relative density, void ratio, and angle of internal friction and dynamic cone penetration index (DCPI).

2 EXPERIMENTAL WORK

2.1 Material

The sand used in this investigation was brought from the dunes near King Fahd University of Petroleum and Mineral (KFUPM), Dhahran, Saudi Arabia. It was light yellowish in color and had a uniform gradation. The soil was classified as poorly graded sand (SP) according to the Unified Soil Classification System and as A-3 according to the AASHTO classification system. The maximum dry density (ASTM D 4253) is 1.84 g/cm^3 and the minimum dry density (ASTM D 4254) is 1.63 g/cm^3.

2.2 Density Control Procedure

The achievement of the required densities was a challenging task in this study. To meet this task, several preliminary experimental trials were conducted to determine the most appropriate and accurate way to accomplish the required density. The different sand densities were calibrated in a small mold (750 mm diameter and 450 mm height) by performing several trials. Then, the required density was placed in the large scale mold (1600 mm diameter and 1500 mm height) and subjected to the dynamic cone penetration test. The soil chamber used in this study was a cylindrical glass reinforced plastic pipe (GRP pipe) that was designed and manufactured at Future Pipe Industries, Dammam, Saudi Arabia, with 1600 mm diameter and 1500 mm height. GRP pipe was fixed on stiff steel plate (width = 1700 mm, long = 1700 mm, height = 300 mm) that was manufactured at the General Workshop, KFUPM, using adhesive material (epoxy).

In this study, the following two techniques were conducted to obtain the required density: pluviation and vibration. For the pluviation technique, a large funnel was used to prepare loose sand samples in the chamber with the desired density, as shown in Figure 1(a). The relative density of the loose sand deposited in the chamber was controlled by two factors: (1) the opening size of nozzle at the bottom of the funnel (25 mm maximum diameter), and (2) the sand drop height (1000 mm), as shown in Figure 1(a). However, the medium and dense sand samples were prepared with vibration technique; whereby the sample in the testing mold was compacted in five 300-mm thick lifts. Compaction effort was applied using a 500-mm vibrating rod and circular plate with 300 mm diameter and 17 kg weight whereby the plate contained 50-mm opening on the middle to allow the lower 300 mm part of the rod to inter in/out the sand sample. The relative density of medium and dense sand deposited in the chamber was controlled by vibration time. Medium sand samples were vibrated for one second while dense sand samples were vibrated for ten seconds, by inserting the rod in the sand sample, as depicted in Figure 1(b).

(a) (b)

Figure 1. Density control procedure, (a) pluviation technique, (b) vibration technique.

2.3 Testing Procedure

Nine (9) DCP tests were performed to assess the density of sand for a total penetration depth of 1500-mm; i.e., three DCP tests for each relative density (40%, 60%, and 90%). The DCP index (DCPI) value was obtained by dividing the total penetration in mm by the number of blows (mm/blow) and reported for each sample. It is to be noted that the data/readings for the top 300 mm were always neglected due to the disturbance.

3 RESULTS AND DISCUSSIONS

Based on the laboratory results of this investigation, correlations were established between DCPI with density, relative density and void ratio of sand. Statistical approach was used to determine the best correlations of the results. It is observed that an increase in the density and relative density of sand resulted in a corresponding decrease in the DCPI, as shown in Figure 2(a, b). The relative density of sand was calculated by using the following equation (Bowles 1970):

$$D_r = \left(\frac{\gamma_d - \gamma_{min}}{\gamma_{max} - \gamma_{min}}\right)\left(\frac{\gamma_{max}}{\gamma_d}\right) \quad (1)$$

where D_r is the relative density, γ_d is the dry density, γ_{max} is the maximum dry density, and γ_{min} is the minimum dry density of sand.

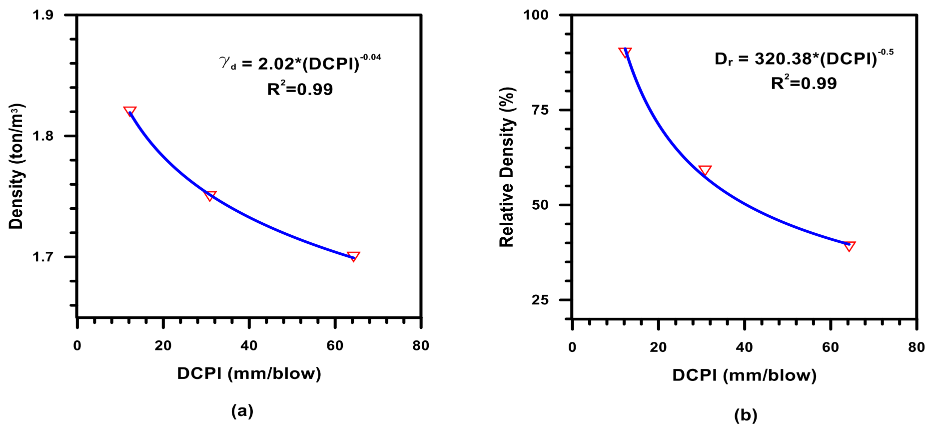


Figure 2. Correlation between DCPI with (a) Dry density and (b) Relative density.

In contrast, an increase in the void ratio of sand resulted in a marginal increase in the DCPI, as shown in Figure 3. The void ratio of different dry densities was calculated by using the following equation (Bowles 1970):

$$e = \frac{G_s}{\gamma_d} - 1 \tag{2}$$

where e is the void ratio, G_s is the specific gravity, and γ_d is the dry density of sand. It is to be noted that George *et al*. (2009) reported that an increase in the void ratio resulted in an increase in the penetration index DCPI.

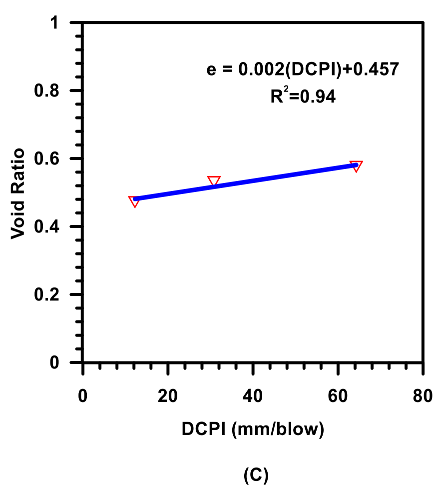
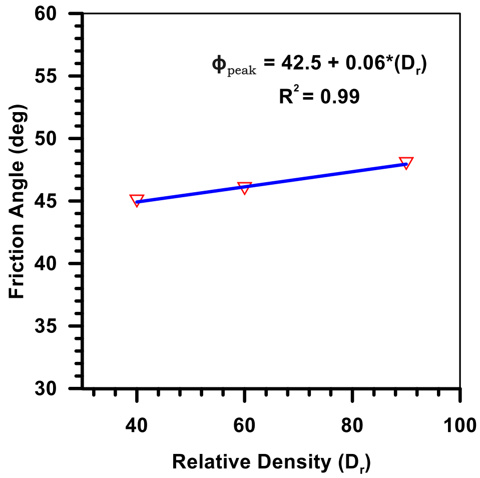
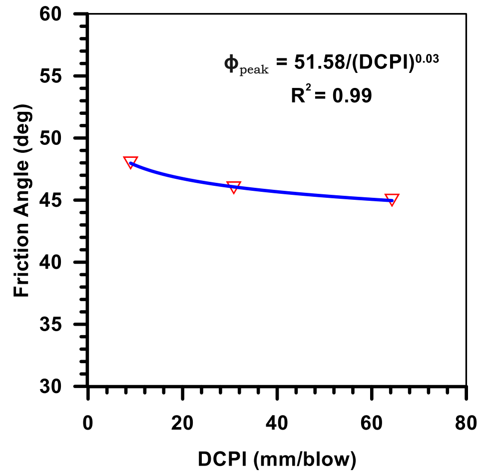


Figure 3. Correlation between DCPI and Void ratio.

In this investigation, the correlations of relative density and dynamic cone penetration index (DCPI) with peak friction angle of sand are illustrated by Figure 4. It could be observed that an increase in the relative density from 40 to 90% resulted in a marginal increase in the peak friction angle. It was also observed that an increase in the friction angle resulted in a decrease in the DCPI. Several correlations between relative density (D_r) and friction angle (ϕ) have been proposed by different researchers including Meyerhof (1959) and Mohammadi *et al.* (2008). These researchers indicated that an increase in the relative density resulted in an increase in the friction angle of sand.



(a)



(b)

Figure 4. Correlation between DCPI with (a) Dry density, (b) friction angle.

4 CONCLUSIONS

Based on the laboratory results presented in this investigation, the following conclusions could be drawn:

1. The blow counts per unit depth increased significantly as the density of sand increased. On the contrary, an increase in the percentage of relative density from 40% to 90% resulted in a corresponding decrease in the DCPI from 63 to 11.6 mm/blow. This is probably due to the fact that compacted dry soils have higher stiffness and the vertical confining pressure have increased with depth.
2. The shear strength has a significant effect on dynamic cone penetration test results. It was observed that an increase in the friction angle resulted in a decrease in the DCPI, as reported in Figures 2 to 4.
3. There are proper correlations of dry density, relative density, void ratio and angle of internal friction with DCPI.
4. The dynamic cone penetration test (DCPT) has proven to be an effective tool in the assessment of in situ strength of sand backfill.

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