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EFFECT OF FINE MATERIAL ON PENETRATION RESISTANCE

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Abstract: The Dynamic Cone Penetrometer (DCP) is an instrument that can be applied to evaluate the compaction of sand backfills and base material. Perhaps the greatest advantage of the DCP device lies in its ability to provide a continuous record of relative soil stiffness with depth and its simple use and operation. Another advantage is the fact that it can be conducted in very confined spaces without the need for trucks of heavy machines that may not have an access to the site or may damage existing installations. This study was aimed to evaluate the effect of fine material on the penetration measurement using the dynamic cone penetration test (DCPT) for sands. The soil sample was classified as poorly graded sand (SP) according to USCS. DCPTs were performed on sand samples with the addition of different silt content (1%, 4% and 8%) and different relative densities (40%, 60% and 90%) where it was compacted in a large scale circular mold (1600 mm diameter and 1500 mm height). Test results indicated that the increase in the relative density and shear strength caused a decrease in the dynamic cone penetration index (DCPI) and the sand-silt mixture with the 8% silt content exhibited the highest resistance values than the 1% and 4% of silt content. Furthermore, the results indicated that the DCPT is an operative tool in the assessment of the compaction during construction of sand backfills.

Keywords: Dynamic cone penetration test (DCPT); Dry density; Sand; Silt content; Shear strength; Pluviation and vibration techniques.

1 INTRODUCTION

Over the past three decades, Saudi Arabia has been witnessing unparalleled development of all types of construction. As a result of this massive development, special problems in the soil have emerged. For example, some projects face the nightmare of poor soils to withstand the unprecedented loads, which force engineers to develop radical solutions to eradicate this problem by stabilizing the soil or replacing the existing soil by another type that has more strength and stiffness. As a result, it is difficult to check the physical properties, such as the density of the entire area, by conventional methods, and how to assess their properties in-situ instead of getting the soils to the laboratory. Therefore, it is important to find out a way through which assessment of the soil properties using a simple, effective and inexpensive device becomes a reality. The DCPT has been used widely for field exploration and quality assessment of subsoil layers. It can be used in the characterization of subgrade and base material properties in many ways. Perhaps the most important advantage of the DCP device can be related to its ability to provide a continuous record of relative soil strength with depth (Burnham and Johnson 1993).

Literature review indicates that there have been several studies on the usage of this technique in various parts of the world (Hamid 2015). Some applications of the DCP include correlations of its results with resilient modulus, California Bearing Ratio (CBR), unconfined compressive strength and shear strength, as well as its usage in quality control of compaction of earth fills and performance evaluation of pavement layers (Amini 2003). In addition, several DCP-CBR correlations have been developed for different materials in laboratory and field (Al-Refeai and Al-Suhaibani 1997; Coonse 1999; Ese et al. 1994; Gabr et al. 2000; Harison 1989, 1986; Livneh and Ishai 1987; Smith and Pratt 1983; Truebe et al. 1995; Webster et al. 1994, 1992; and Zumrawi 2014). Salgado and Yoon (2003) have investigated the relationships between subgrade parameters and DCP and they have created correlations such as a correlation between dry density and DCP results for clayey sand in terms of the plasticity index (PI). Abu-Farsakh et al. (2005) showed that, based on laboratory and field study for DCP, PLT, FWD, and CBR, the dynamic cone penetration test can be used to evaluate subgraded and pavement layers. They also developed empirical correlations from DCP results with PLT elastic modulus, FWD resilient modulus, and CBR. In addition, they indicated that the DCP test was an efficient tool as a compaction control.

Review of the literature has recently indicated that the impact of silt content on the dynamic cone penetration test results has not been investigated (Hamid 2015, 2013). Further, this research also aimed to develop a correlation between the engineering properties of sand such as relative density, void ratio, and angle of internal friction and Dynamic Cone Penetration Index (DCPI).

1.1 Geology and Origin of Sand Dune in Saudi Arabia

Approximately one third of the Arabian Peninsula is covered by sand. Sand is the most predominant type of soil in the Eastern Province of Saudi Arabia where this region is confined by deserts from three directions with its two types: dune sand and beach sand (Aiban 1994, and Al-Gunaiyan 1998).

Geographically, the sand dunes in the Arabian Peninsula are divided into three major zones. The great Al-Nafud in the north (57,000 km^2) links to Ar-Rub Al-Khali (the Empty Quarter) in the south (600,000 km^2) through the Arch Ad–Dahna that runs in another direction extending about 1,300 km. The sands of these two zones, Ad-Dahna and the great Al-Nafud, are medium to fine in size and bright red-orange in color due to a coating of iron oxide on the quartz grains. On the other hand, Ar Rub' Alkhali (Empty Quarter) sands are buff to tan in color due to the presence of carbonates. Figure 1 shows the distribution and the direction of the deserts in the Arabian Peninsula mentioned above.

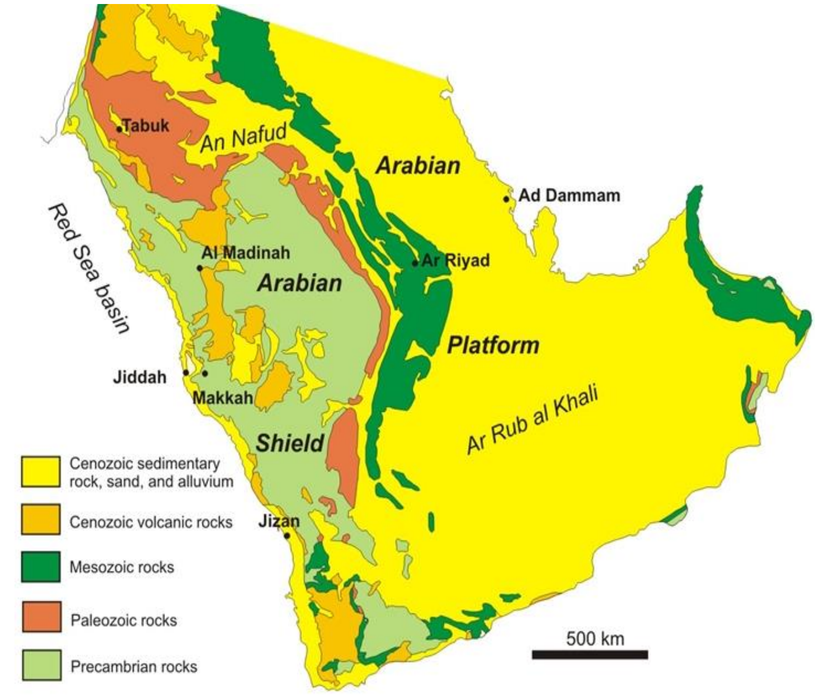


Figure 1: Sand Terrains in the Arabian Peninsula (Saudi Geological Survey).

2 EXPERIMENTAL PROGRAM

2.1 Material

The sand used in this investigation was brought from the dune sands near King Fahd University for Petroleum and Minerals (KFUPM). The soil is dune sand, light yellowish in color and has a uniform gradation. The silt content used in the testing program was brought from a stone crusher that is located approximately 200 km away from Dammam towards Riyadh. The silt material was mixed with sand in different percentages for 10 minutes of mixing.

The index properties of sand were first determined. The grain-size distribution curve is shown in Figure 2. It indicates that about 88% of the soil passes ASTM sieve No. 40 and the particles lie in the range of 0.1 to 0.9 mm. The effective size D_{10} is 0.146 mm, D_{30} is 0.20 mm, and D_{60} is 0.29 mm. The coefficient of curvature (C_c) is 0.94, and coefficient of uniformity (C_u) is 1.98. Therefore, the soil can be classified as poorly graded sand (SP) according to the Unified Soil Classification System and A-3 on the AASHTO classification system. The properties of sand for different silt content are summarized in Table 1.

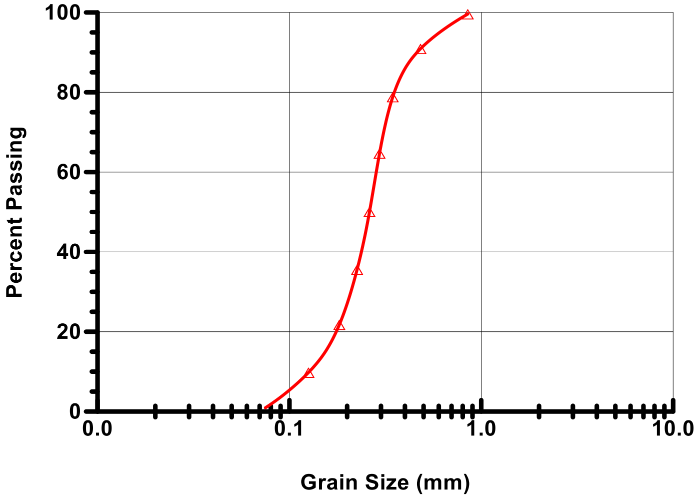


Figure 2: Grain-size distribution curve for the used natural sand.

Table 1: Sand characteristics with different silt content.

Silt Content	Max. Density (gram/cm^3)	Min. Density (gram/cm^3)	Specific Gravity	Max. Void Ratio	Min. Void Ratio
1%	1.84	1.63	2.68	0.68	0.48
4%	1.88	1.64	2.65	0.66	0.41
8%	1.92	1.65	2.62	0.63	0.33

2.2 Density control procedure

Several preliminary experimental works were conducted to determine the most appropriate and accurate way to achieve the required density. The different sand densities were calibrated in a relatively small mold (750 mm diameter and 450 mm height) by performing several trials whereby the following two techniques were used to get the required density: pluviation and vibration (Hamid 2013). For the pluviation technique, a large funnel was used to prepare the sand samples in the chamber with the desired density by controlling the following two factors: (1) the opening size of the nozzle at the bottom of the funnel, and (2) the sand drop height, as depicted in Figure 3(a). As a result of several trials, by fixing the opening size (25 mm) and changing the height of the funnel inside the small mold, the required relative densities (D_r = 60% and D_r = 90%) were achieved at the respective heights of 400 mm and 600 mm.

Unfortunately, it was difficult to calibrate 400 mm and 600 mm of the sand drop height inside the large mold (1600 mm diameter and 1500 mm height) to get the required density; hence, the pluviation technique was refused in the case of medium and dense sands. In the case of the vibration technique, several trials were conducted to assess the relationship between the vibration time and the resulting relative density of the sand in the mold. After several trials, the vibration technique was selected to attain the required density because this technique was found to be more accurate and it was easier to compact the soil inside the mold (Hamid 2013). Therefore, the required density was placed in the large scale mold (1600 mm diameter and 1500 mm height) and, thereafter, subjected to the dynamic cone penetration test.

In this study, medium and dense sand samples were prepared with the 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 a diameter of 300 mm and a weight of 17 kg. The plate contained a 50 mm opening on the middle to allow the lower 300 mm part of the rod to inter in/out the sand sample, as depicted in Figure 3(b).

(a) (b)

Figure 3: Densification and density control, (a) Pluviation technique, (b) Vibration technique.

The relative densities of medium and dense sand deposited in the chamber were controlled by the vibration time. Medium sand samples were vibrated for one second for each layer, while dense sand samples were vibrated for ten seconds, by inserting the rod in the sand sample.

For the direct shear test, the sand samples were prepared in a square shear box with 60*60 mm internal dimension and 25 mm height, as per ASTM D 5321. To achieve a uniform compaction in the shear mould of the direct shear machine, tamping by a small square wood plate with dimensions of 60*60 mm was used.

2.3 Calibration chamber

The soil chamber is a well-established laboratory setup for standardization of in-situ testing devices in sandy soils, whereby the soil sample is prepared in the chamber and tested under controlled boundary conditions (Schnaid and Houlsby 1991). The calibration chamber has been used effectively as a research tool to simulate in-situ soil in the laboratory and it has been used in creating interpretation procedures for cone penetration tests in sand (Hsu and Huang 1999). There are many applications of the calibration chamber test for other types of in-situ tests. Related to these applications, Huang et al. (1991) have presented a model by conducting pressuremeter inside the calibration chamber.

The soil chamber used in this study was a cylindrical glass reinforced plastic (GRP) pipe that was designed and manufactured at the Future Pipe Industries, Dammam, Saudi Arabia, with a 1600 mm diameter and a 1500 mm height. The GRP pipe was fixed on a stiff steel plate (width = 1700 mm, long = 1700 mm, height

= 300 mm) that was manufactured at the General Workshop, KFUPM, using adhesive material (epoxy), as depicted in Figure 4.

Figure 4: Soil chamber in the laboratory.

2.4 Testing procedure

The DCP tests were conducted in accordance with ASTM D 6951, using an 8 kg hammer. DCP tests were performed to evaluate the effect of the silt-sand mixture on DCPT results for a total penetration depth of 1500 mm, i.e. three DCP tests for each relative density (40%, 60%, and 90%), and each silt content (1%, 4% and 8% ± 0.2). The DCP index (DCPI) value was obtained by dividing the total penetration of the sample in mm by the number of blows (Vandre et al. 1999) 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 DCP investigations performed on sands (loose, medium, and dense), the effect of variations in the percentage of silt content on the penetration resistance was studied. The trend in variations of the dynamic cone penetration index (DCPI) measured in mm/blow can be shown as in Figure 5. It was observed that an increase in the percentage of relative density from 40% to 90% has resulted in a corresponding decrease in the dynamic cone penetration index (DCPI) from 63 to 8 mm/blow. This is probably due to the reason that the maximum and minimum density change by mixing sand and silt in different proportions. Silt particles fit into the voids between larger sand particles, so the void ratio of sand-silt mixtures decreases with increase in silt content that indicated a significant positive influence on the sand density (Mitchell and Soga 2005).

Based on the laboratory results of this investigation, correlations were established between DCPI with relative densities of sand. The relative densities of sand were calculated by using the following equation (Bowles 1970):

[1] $D_r = (\frac{\gamma_d - \gamma_{min}}{\gamma_{max} - \gamma_{min}})(\frac{\gamma_{max}}{\gamma_d})$

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.

A statistical approach was used to determine the best correlations of the results, as summarized in Table 2. It is observed that an increase in the relative density of sand resulted in a corresponding decrease in the DCPI. The correlation between DCPI and relative density is presented in Figure 5 and Table 2.

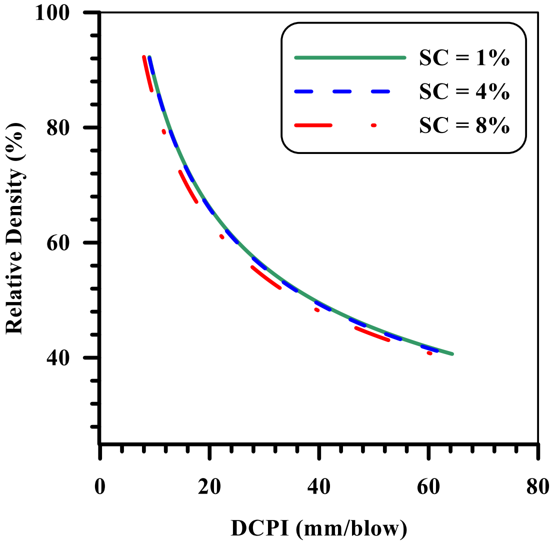


Figure 5: Correlation between DCPI and relative density.

Table 2: Developed equations between DCPI and relative density.

Parameter	Silt content (SC)	Equations	Determination coefficient (R^2)
D_r - DCPI	1%	$D_r = 230.55/ (DCPI)^{0.417}$	0.98
	4%	$D_r = 231/ (DCPI)^{0.419}$	0.98
	8%	$D_r = 214/ (DCPI)^{0.405}$	0.98

It could be noted from the data in Figure 5 that the resistance was very weak in the case of loose density for the various silt contents by increasing the DCPI, whereas the resistance was increased significantly in the case of very dense sand for the various silt contents by decreasing the DCPI. This is perhaps due to the fact that compacted dry soils have higher stiffness and offer greater resistance to the penetration in the case of sandy and silty soils (Kim and Kim 2006). In addition, Figure 5 shows that the sand-silt mixture with the 8% silt content exhibited the highest resistance values than the 1% and 4% of silt content. This could be ascribed to the fact that the silt particles tended to fill the voids between the sand particles, thereby achieving the lowest void ratio and highest density (Mitchell and Soga 2005).

In contrast, an increase in the void ratio of sand resulted in an increase in the DCPI, as shown in Figure 6. The void ratio of different dry densities with different silt content was calculated by using the following equation (Bowles 1970):

$$[2] \quad e = \frac{G_s}{\gamma_d} - 1$$

where e is the void ratio, G_s is the specific gravity, and γ_d is the dry density of sand. The best correlation between DCPI and the void ratio is presented in Figure 6 and Table 3.

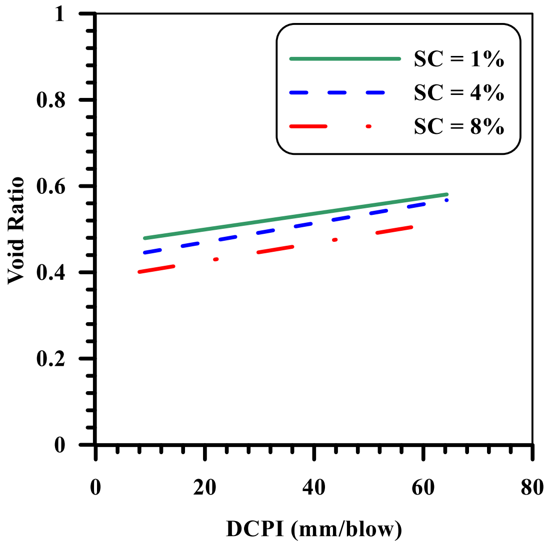


Figure 6: Correlation between DCPI and Void ratio.

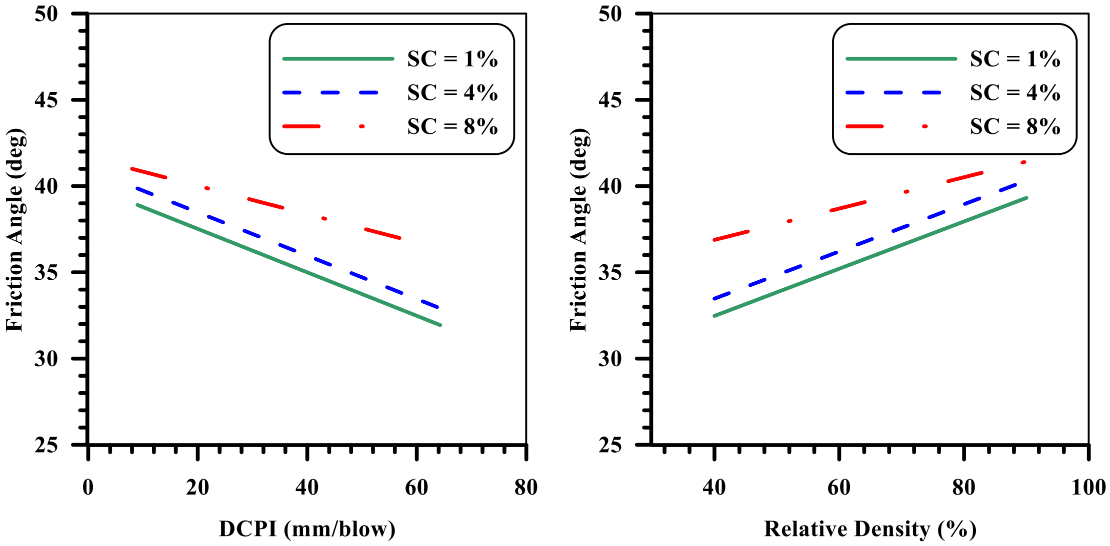
Table 3: Developed equations between DCPI and void ratio.

Parameter	Silt content (SC)	Equations	Determination coefficient (R^2)
e - DCPI	1%	e = 0.002 (DCPI) + 0.463	0.96
	4%	e = 0.002 (DCPI) + 0.426	0.91
	8%	e = 0.002 (DCPI) + 0.384	0.97

In this investigation, the correlations of relative density and dynamic cone penetration index (DCPI) with the friction angle of sand were illustrated by Figure 7. It could be observed that an increase in the relative density from 40 to 90% resulted in an increase in the friction angle. Further, it was also noted that an increase in the friction angle resulted in a decrease in the DCPI. The best correlation between the friction angle with DCPI and the relative density are presented in Figure 7 and Table 4.

Table 4: Developed equations between friction angle with DCPI and relative density.

Parameter	Silt content (SC)	Equations	Determination coefficient (R^2)
ϕ - DCPI	1%	ϕ = 40 – 0.126(DCPI)	0.99
	4%	ϕ = 41 – 0.125(DCPI)	0.99
	8%	ϕ = 41.66 – 0.082(DCPI)	0.90
ϕ - D_r	1%	$\phi = 0.14(D_r) + 27$	0.96
	4%	$\phi = 0.4(D_r) + 28$	0.96
	8%	$\phi = 0.09(D_r) + 33.25$	0.99



(a) (b)

Figure 7: Correlation between friction angle with (a) DCPI, and (b) Relative density.

It is to be reported that several correlations between relative density and friction angle 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.

CONCLUSIONS

The dynamic cone penetration test (DCPT) has proven to be an operative tool in the assessment of the compaction during construction of sand backfill and can be utilized for confined spaces and between pipes that often exist in sandy soils. This research develops proper correlations of relative density, void ratio, and angle of internal friction with the dynamic cone penetration index (DCPI). The results show that the DCPI decreases significantly as the relative density of sand increases for different silt content (1%, 4% and 8%). This is probably due to the reason that compacted dry soils have higher stiffness and the vertical confining pressure have increased with depth. In addition, the sand-silt mixture with the 8% silt content exhibited the highest resistance values than the 1% and 4% of silt content. Furthermore, the shear strength has a significant effect on DCPT results. It is observed that an increase in the friction angle resulted in a decrease in the DCPI.

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REFERENCES

Abu-Farsakh, M.Y., Nazzal, M.D., Alshibli, K. and Seyman, E. 2005. Part 2: Soil Parameters for Pavement Design and Subgrade Resilient Modulus: Application of Dynamic Cone Penetrometer in Pavement Construction Control. Transportation Research Record: *Journal of the Transportation Research Board*, **1913**: 52-61.

Aiban, S. A. 1994. A study of Sand Stabilization in Eastern Saudi Arabia. *Engineering Geology* **38** (65-79).

Al-Gunaiyan, K. A., 1998. *Assessment of the geotechnical properties of stabilized sand-marl mixtures for constructional purposes*, MS. Thesis, Department of Civil Engineering, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

Al-Refeai, T. and Al-Suhaibani, A. 1997. Prediction of CRR using Dynamic Cone Penetrometer. *Journal of King Saud University: Engineering Sciences*, **9** (2): 191-204.

Amini, F., 2003. *Potential Applications of Dynamic and Static Cone Penetrometers MDOT Pavement Design and Construction*. Final Report, Mississippi Department of Transportation, USA.

Bowles, J. E., 1970. *Engineering Properties of Soil and Their Measurement*, New York, USA.

Burnham, T. R. and D. Johnson, D., 1993. *In-Situ Foundation Characterization Using the Dynamic Cone Penetrometer*, Report MN-93/05. Minnesota Department of Transportation, Maplewood.

Coonse, J. 1999. *Estimating California Bearing Ratio of Cohesive Piedmont Residual Soil Using the Scala Dynamic Cone Penetrometer*. Master's Thesis, North Carolina State University, Raleigh, N.C., USA.

Ese, D., Myre, J., Noss, P. and Vaernes, E. 1994. The Use of Dynamic Cone Penetrometer (DCP) for Road Strengthening Design in Norway, *Proceeddings, 4th International Conference, Bearing Capacity of Roads and Airfields*, Minneapolis: 3-22.

Gabr, M., Hopkins, K., Coonse, J. and Hearne, T. 2000. DCP Criteria for Performance Evaluation of Pavement Layers. *Journal of Performance of Constructed Facilities, ASCE* **14**(4): 141-148.

Hamid, A. M. 2013. *Assessment of Density and Shear Strength of Eastern Saudi Sands Using Dynamic Cone Penetration Testing (DCPT)*. Master's Thesis, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

Hamid, A. M. 2015. The Dynamic Cone Penetration Test: A Review of Its Correlations and Applications. *International Conference on Advances in Civil and Environmental Engineering*, Pulau Pinang, Malaysia.

Harison, J.A. 1986. Correlation of CBR and Dynamic Cone Penetrometer Strength Measurement of Soils. *Australian Road Research*, **16**(2), 130-136.

Harison, J.A. 1989. In Situ CBR Determination by DCP Testing Using a Laboratory-Based Correlation. *Australian Road Research*, **19**(4): 313-317.

Hsu, H.H., and Huang, A.B., 1999. Calibration of Cone Penetration Test in Sand. Department of Civil Engineering. National Chiao-Tung University, Hsinchu, Taiwan, R.O.C. *Proceedings from National Science Council*, ROC (A), 23: 579-590.

Huang, A.B., Holtz, R.D. and Chameau, J.L. 1991. Laboratory Study of Pressuremeter Tests in Clays. *Journal of Geotechnical Engineering, ASCE*, **117**(10): 1549-1567.

Kim D, Kim RJ (2006) Resilient Behavior of Compacted Sub-grade Soils under the Repeated Tri-axial Test. *Science Direct-Construction Build Material* **21**(7):1470–1479.

Livneh, M. and Ishai, I. 1987. Pavement and Material Evaluation by a Dynamic Cone Penetrometer, Proceedings, *6th International Conference on the Structural Design of Asphalt Pavement*, Ann Arbor, Michigan, USA, **1**: 665-674.

Meyerhof, G.G., 1959. Compaction of sands and the bearing capacity of piles. *JSMFD, ASCE* **85**, 1–29 SM6

Mitchell, J. K., Soga, K., 2005. *Fundamentals of Soil Behavior*. Third Edition, Hoboken, New Jersey.

Mohammadi, S.D., Nikoudel, M.R., Rahimi, H. and Khamehchiyan, M. 2008. Application of the Dynamic Cone Penetrometer (DCP) for determination of the engineering parameters of sandy soils. *Engineering Geology*, **101**: 195-203.

Salgado, R., Yoon, S., 2003. *Dynamic Cone Penetration Test (DCPT) for Subgrade Assessment*. FHWA/IN/JTRP-2002/30, Purdue University, West Lafayette, IN.

Schnaid, F., Houlsby, G.T., 1991. Assessment of Chamber Size Effects in the Calibration of In situ Test in Sand. *Geotechnique* **41**: 437–445.

Smith, R.B. and Pratt, D.N. 1983. A Field Study of In Situ California Bearing Ratio and Dynamic Cone Penetrometer Testing for Subgrade Investigation. *Australian Road Research*, **13**(4): 285-293.

Truebe, M.A., Evans, G.L. and Bolander, P. 1995. Lowell Test Road: Helping Improve Road Surfacing Design, *Transportation Research Board Conference Proceedings*, Minneapolis, Minnesota, **2**: 98-107.

Vandre, B., Budge, A., and Nussbaum, S. 1999. "DCP – A useful tool for characterizing soil properties at shallow depths." *Proceedings. 34th Symposium on Engineering Geology and Geotechnical Engineering*, Utah State University,Logan, UT, 287-301.

Webster, S.L., Brown, R.W. and Porter, J.R. 1994. *Force Projection Site Evaluation Using the Electric Cone Penetrometer (ECP) and the Dynamic Cone Penetrometer (DCP)*. Technical Report, GL - 94- 17, U.S Army Engineers Waterways Experiment Station. Vicksburg, USA.

Webster, S.L., Grau, R.H. and Williams, T.P. 1992. *Description and Application of Dual Mass Dynamic Cone Penetrometer*. Report GL-92-3, Department of the Army, Washington, USA.

Zumrawi. M. M. E. 2014. Prediction of In-situ CBR of Subgrade Cohesive Soils from Dynamic Cone Penetrometer and Soil Properties. *IACSIT International Journal of Engineering and Technology*, **6**(5): 439 – 442.