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Improving Geotechnical Properties of Dune Sands through Cement Stabilization

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ABSTRACT. When designing and constructing highways or more generally any super structures on dune sands type of soil, it is essential to make sure that the foundation soil is stable and provides good support to the applied loads. Dune sands soil are known to spread in huge areas throughout the kingdom of Saudi Arabia in which thousands of miles of new roads and highways are being constructed every year. Replacing such kind of weak soil is not an economically feasible alternative since it is very costly; besides, the replacement soil is not always available in nearby sites. This study discusses the possibility of dune sands soil stabilization using Portland cement as the stabilizing agent. Various ratios of cement content mixed with dune sands are used to examine the improvement of engineering properties of dune sands in terms of strength characteristics, and shear strength parameters. The results indicate that mixing dune sands with cement stabilizing agents would influence the engineering properties of treated soil. It is determined that the cement stabilization of dune sands improves the strength characteristics of the treated soil so that it becomes usable as a base material for roads construction and proper foundation material for other types of super structures. It was also determined that a cement content more than 9% may not probably cause any additional improvement for the stabilized soil. A suggested relationship is introduced to predict the values of initial tangent elastic modulus for such type of cement-treated dune sands.

Key words: *Dune sands, Cement stabilization, soil improvement, Shear Strength Parameters.*

1. INTRODUCTION

Saudi Arabia as many of the Gulf countries has witnessed extensive development programs and urbanization in the last few decades. These unprecedented construction activities throughout Saudi Arabia included constructing an internationally recognized network of highways to serve the newly developed areas of the kingdom. Thousands of miles of new roads, highways and airport runways are being constructed every year in addition to newly developed societies and cities. All these activities revealed some constructional problems which have been attributed to the poor quality of soil profiles in these areas. It was found out that the soil profile in such areas consists mainly of thick layers of fine to medium, non-plastic, wind-blown sand deposits, known as dune sands. This type of soil is usually characterized with its poorly graded fine grained materials with low bearing capacity and shear strength. These properties encouraged researchers and engineers to investigate the possibility of improving these deposits through stabilization techniques.

In Saudi Arabia, sand is the predominant type of soil exists almost in all soil profiles, particularly at the shallow levels. The sandy soil usually exists in two forms; dune sand and beach sand; both of which are somewhat Aeolian in nature [1]. These Aeolian deposits have an excess of fines and exist in a rather loose state and are often mixed with soluble salts that act as a cementing agent. This soil also has high potential to collapse due to the nature of its texture and grains structure. The shallowness of the groundwater alters the compressibility of this soil and can lead to fines migration and cause instability problems. The high variation of this soil strength and compressibility leads to the possibility of differential settlement under loads. Some of the problems which resulted from founding on such soil layers have been reported in the literature. As reported in [1] and [2], the formation of depressions zones and settlements in newly constructed roads. Other typical problems associated with the abundance of sands in arid and semi-arid areas can be summarized as continuous sand movement, and ground surface erosion and dust clouds [3]. The continuous movement of dune sands, wind or rain blown, causes abrasion for existing structures and blockage of streets and highways [4]. This sandy soil cannot be used as a foundation material in their natural condition due to its loose structure and vulnerability to collapse upon wetting [5]. For the same reasons, these soils are not suitable for construction of landfill liners and covers. However, when improved, they can be utilized in many applications.

Stabilization of such soils has become a trend nowadays and several stabilization alternatives have been tried over the last few years. Mixing of desert sands with other materials such as natural clays, bentonite, cement-by-pass dust and incinerator ash were found to improve the sand properties so that it can be used to support structures and road constructions [6]. The improvement in engineering properties of cement-treated soils is believed to be mainly due to the hardening of cement in the presence of moisture and extension of curing period [7]. Results of stabilizing of fine sand with industrial by-products such as ground-granulated blast furnace slag, low-calcium fly ash and meta-kaolin were reported in [8]. Miller and Azad [9] conducted a laboratory study to investigate the influence of soil type on stabilization with cement kiln dust. The study revealed that increases in the unconfined compressive strength (UCS) of soil occurred with the addition of CKD. Increases in UCS were inversely proportional to the plasticity index (PI) of the untreated soil. Baghdadi and Rahman [10] presented the effects of cement kiln dust (CKD) on the geotechnical properties of dune sand. In their study, sand was stabilized with various mix proportions and the geotechnical properties of the stabilized sand were investigated. The results obtained for the maximum dry density, optimum moisture content, unconfined compressive strength and CBR showed that the stabilized soil can be utilized as base materials in highway construction. Peethamparana et al. [11] investigated the influence of chemical and physical characteristics of cement kiln dusts (CKDs) on its suitability for soil stabilization through investigating various samples of soil/CKD mixture. They concluded that both the compressive strength and the temperature of hydration of the CKD mix can give early indications of the suitability of particular CKD for soil stabilization. Zhiming and Herrera [12] conducted an extensive laboratory and field testing program to evaluate the effectiveness of cement kiln dust (CKD) as a stabilizer for a limestone base material. The results of this study showed that CKD has promise to be a good stabilizer for the base material if it is used properly. The comparative performances of CKD and other traditional stabilizers such as lime, cement, and fly ash were also investigated during laboratory and field testing. The unconfined compressive strength (UCS) increased substantially when the dosage of CKD was increased. The dynamic modulus also increased substantially with addition of CKD. Conductivity and colorimetry tests indicated that sulfate content increased with the added amount of CKD. A low resistivity value of CKD-stabilized base materials indicated that they cannot be used as backfill material. The field pavement evaluation indicated that the lime-stabilized section exhibited the highest modulus, followed by the CKD-stabilized section.

AL-Abdul Wahhab et al. [13] conducted an experimental program to evaluate the feasibility of using blends of dune sand--crusher fines that were stabilized with emulsified asphalt in low volume roads in Saudi Arabia. They stated that dune sand treated with emulsified asphalt alone was weak and unstable. However, the addition of crusher fines and Portland cement improved the mix properties significantly.

It can be noticed from this published literature that the research interest was devoted mainly to investigate the improvement in the characteristics of stabilized dune sands regardless of the loading conditions. However, practically wise when saturated cohesionless soils are loaded; the rate of application of load affects its general behavior and the resulting deformation. If the loads are applied slowly; any induced pore water pressure will dissipate as the loading progresses. However, under quick loading conditions the opposite occurs; the induced pore water pressure increases and may actually cause sudden failure of structures. Thus when simulating these conditions in the laboratory, the soil engineering properties and strength characteristics of interest are those developed under undrained conditions. Examples of quick loading conditions include; blast loading within soil deposits and dynamic loads due to earthquakes within the soil body, for which ground accelerations may be very high but of very short duration. Under most general earthquake loading conditions; cohesionless soils would be in undrained condition during loading and the stress/strain applications will be of cyclic nature. These undrained conditions may be simulated in the laboratory using the Triaxial loading tests which will be used herein to investigate the potential improvement in dune sands characteristics due to stabilization techniques. Portland cement is used in the current study since it has proven to be an efficient stabilizing agent in improving the inferior properties of sandy soils.

2. METHODOLGY

2.1 Tested Soil

The soil samples used for the current study are selected from local sites and are identified as uniformly graded white dune sands. The necessary laboratory tests were conducted on the soil in order to determine its physical and engineering properties. It was determined that according to the USCS classification system, this soil is classified as SP (poorly graded sand) and according to AASHTO system it is classified as A-1-b. In addition, standard compaction tests were conducted on samples of the sand and it was determined that the maximum dry density (MDD) is 18 kN/m^3 at optimum moisture content (OMC) of 9.91 %. Table (1) shows average values of the main physical and engineering properties of tested soil while Figures. (1) and (2) show the particle gradation and the compaction curves for the tested soil.

Table (1). Summary of the physical properties of the tested dune sands.

Physical and Engineering Properties	
Classification of soil	White, poorly graded sand (SP)
Specific gravity, Gs	2.67
Dry density (kN/m^3)	
γ_d **max**	18.0
γ_d **min**	15.65
Void ratio (e) max	0.7
Void ratio (e) min	0.48

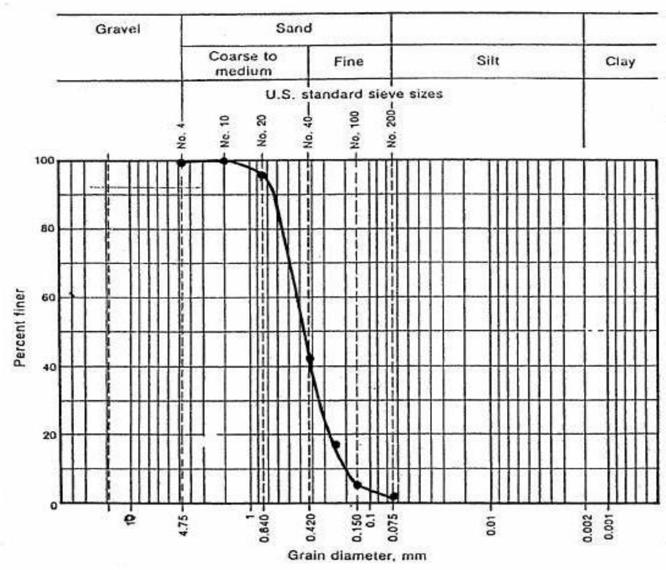

Fig. (1). Particle Gradation of the tested dune sands.

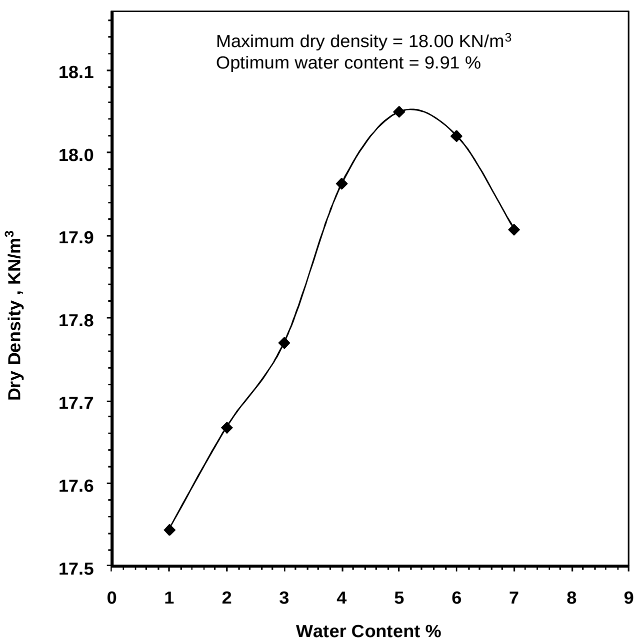

Fig. (2). Compaction curve for the tested dune sands.

2.2 Preparing Samples and Testing Procedure

The objective of the current study is to investigate the effect of cement stabilization on the strength characteristics of dune sands soil. To achieve that goal, a comprehensive Triaxial testing program is proposed utilizing the typical consolidated undrained conditions. The testing program aims to evaluate the strength of selected samples of stabilized dune sands under a constant pore pressure. A back pressure (U) is applied during the tests in order to maintain 100% saturation. The value of (U) is kept constant during the loading where the deviator stress is increased until the failure is reached; this procedure is repeated for different (σ_c). Different mixtures of sand with cement are prepared with cement content of 5%, 7%, and 9% by weight.

The mixture is prepared in dry conditions and then the water is added to the mix carefully. Mixing with water must be carefully observed, because there is a risk that the addition of water needed for hydration and compaction will wash the fine cement particles downwards through the permeable mass of dune sands. This would result in an inhomogeneous strength, or in other words, an excessively strong lower layer and a virtually unstabilized upper layer. This risk can be averted by adding the water to the soil before mixing in the cement. Preparing the mixture this way allows for cement hydration and mixture compaction; while at the same time observing the homogeneity of the sand-cement mixture. The used percentage of water is chosen based on preliminary tests where the mix workability is important. Compaction of cement treated soil must follow mixing stage as soon as possible, and certainly not more than two hours later because of the initial cement hydration reaction. Any source of water may be used, but sulphate-rich water should be avoided. The mixture is properly cured for three days before preparing the test samples. Curing of cement treated soil is conducted to avoid the loss of moisture before gaining mixture strength. It was found that the strength of cement-stabilized soil increase marginally with time of curing, but after 28 days should not merit consideration in design.

The Triaxial test samples are prepared according to ASTM standards. Samples size is 35.5 mm in diameter and 71 mm in height and they are compacted in the split mold in three equal layers to reach the desired density. The samples are set up in the Triaxial chamber; and a cell confining pressure of 40 kPa is applied. The sample is allowed to reach saturation (within 24 hours). Drainage valves are then opened and the confining pressure is increased to the desired value. The sample is allowed to consolidate under this confining pressure for 24 hours. Upon completing the consolidation stage, the desired value of back pressure is applied, which is kept constant during the test. The sample is then loaded at an axial strain rate of 0.3 mm/min, with full sample drainage permitted. The readings of axial load, axial displacement, and volume change are recorded continuously up to the sample failure. The recorded data are then analyzed; the soil shearing strength parameters and the necessary plots are prepared. Table (2) presents the details of the conducted testing program.

Table (2). Conducted testing program on the cement-treated sand.

Testing Series	Back Pore Water Pressure U (kPa)	Confining Pressure σ_c (kPa)	Cement Percent (%)
I	100	400 ،300 ،200	5
II	100	400 ،300 ،200	7
III	100	400 ،300 ،200	7

3. RESULTS AND DISCUSSION

The resulted data of the testing program which are herein discussed included deviator stress at failure, σ_d, initial modulus of elasticity (E_i), softening modulus of elasticity (E_p), reference stress (f_o), and the shear strength parameters (ϕ) and (C) (drained and undrained values).

3.1 Experimental Results

Figures (3) – (5) show typical results of the Triaxial testing program in the form of p-q curves, total Mohr's circles, and volumetric change behavior of the cement stabilized dune sands at various confining pressures.

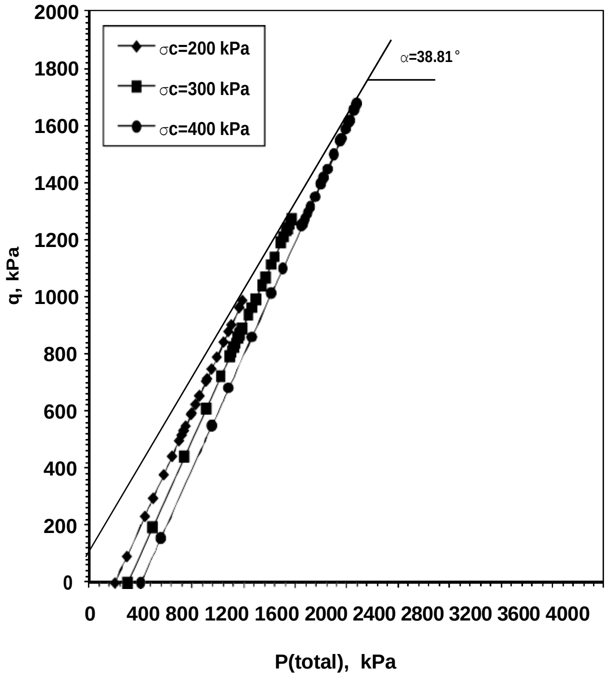

Fig. (3). pq curve for stabilized dune sands at various confining pressure (9% cement).

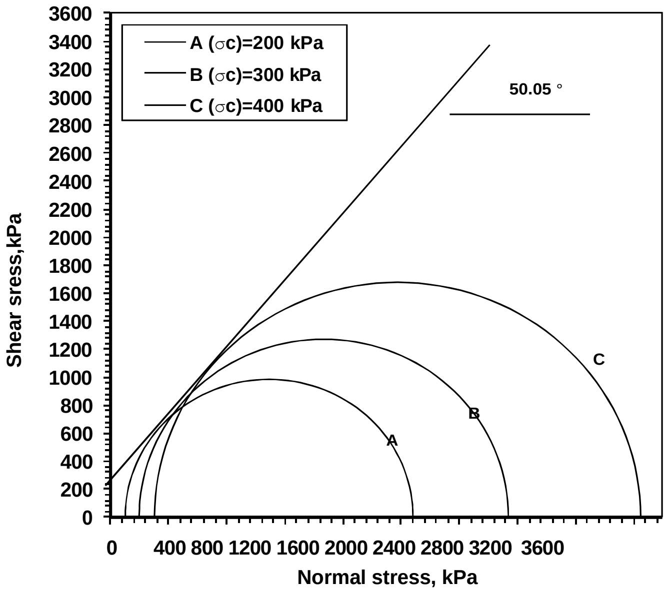

Fig. (4). Total Mohr's circle (9% Cement).

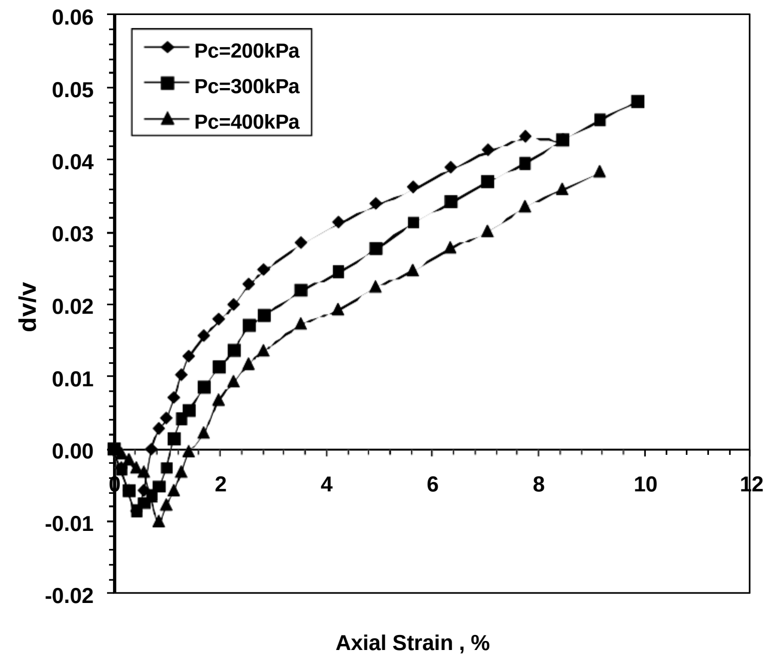

Fig. (5). Volumetric change behavior of cement stabilized dune sands (9% Cement).

3.2 Characteristics of Stabilized Dune Sands

From these results, the characteristics of the stabilized dune sands are presented in the following tables. Tables (3) – (5) show the resulted values for these parameters for the three prepared cement-sand mixtures of 5%, 7%, and 9% at different values of confining pressure and constant back pressure of 100 kPa. Tables (6) and (7) show a comparison of these values at the three sand-cement mixtures.

Table (3). Test results of cement-sand (5%) at different confining pressure and constant back pore water pressure U = 100 kPa.

P_c (kp)	σ_d (kPa)	E_i	E_p	f_o (kPa)	A	α'	Φ	Φ'	C
200	1261.2851	818.5	191	1725					
300	1530.335	954.93	14.23	1820	33.62	32.8	40.91°	40.69°	120
400	2023.2259	1548.5	91.96	2230					

Table (4). Test results of cement-sand (7%) at different confining pressure and constant back pore water pressure U = 100 kPa.

Pc (kPa)	σ_d (kPa)	E_i	E_p	f_o (kPa)	A	α'	Φ	Φ'	C
200	1604.8	958.33	33.3	1755					
300	1911.7	1166.7	37.3	2070	32.52	33°	40.7°	40.5°	195
400	2339.6	2000	37.03	2480					

Table (5). Test results of cement-sand (9%) at different confining pressure and constant back pore water pressure U = 100 kPa.

Pc (kPa)	σ_d (kPa)	E_i	E_p	f_o (kPa)	A	α'	Φ	Φ'	C
200	1965.3	1000	185	2570					
300	2541.4	1125	175	2980	38.81°	38.2°	50.6°	50°	140
400	3350.3	2000	125	3645					

Table (6). Comparison of sand-cement mixture characteristics at different percentages of cement.

% of cement	σ_c (kPa)	σ_d (kPa)	E_i	E_p	f_o
5 %	200	1261.3	818.5	191	1725
	300	1530.355	954.93	114.23	1820
	400	2023.226	1548.5	91.96	2230
7 %	200	1604.8	958.33	33.3	1755
	300	1911.7	1166.7	37.3	2070
	400	2339.8	2000	37.03	2480
9 %	200	1965.3	1000	185	2570
	300	2541.4	1125	175	2980
	400	3350.3	2000	125	3645

Table (7). Comparison of sand-cement mixture strength characteristics at different percentages of cement.

% of cement	α	ά	Φ	Φ'	C
5 %	33.62	32.8	40.9	40.7	120
7 %	32.52	33	40.7	40.5	195
9 %	38.81	38.2	50.6	50	140

Figures (6) – (8) show the variation of the deviator stress σ_d with axial strain at different values of confining pressure (σ_c) for the stabilized soil. Figure (9) shows a comparison of deviator stress variation with axial strain for different percentages of cement stabilizer at a confining pressure of 400 kPa and a back pressure of 100 kPa.

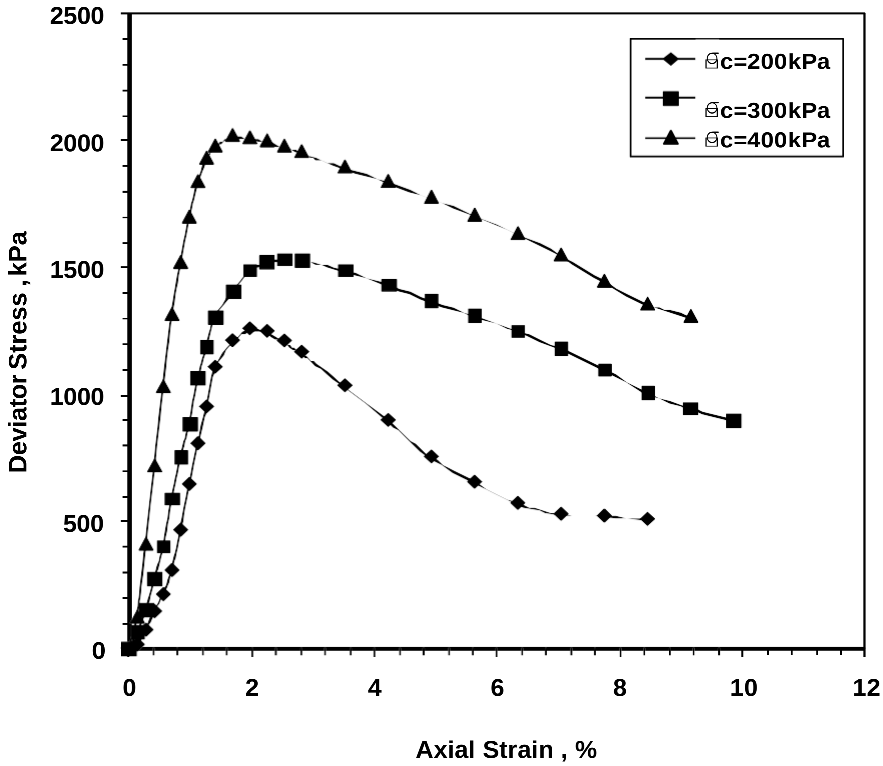

Fig. (6). Variation of deviator stress with axial strain for cement-sand mixture (5%) at different values of confining pressure σ_c.

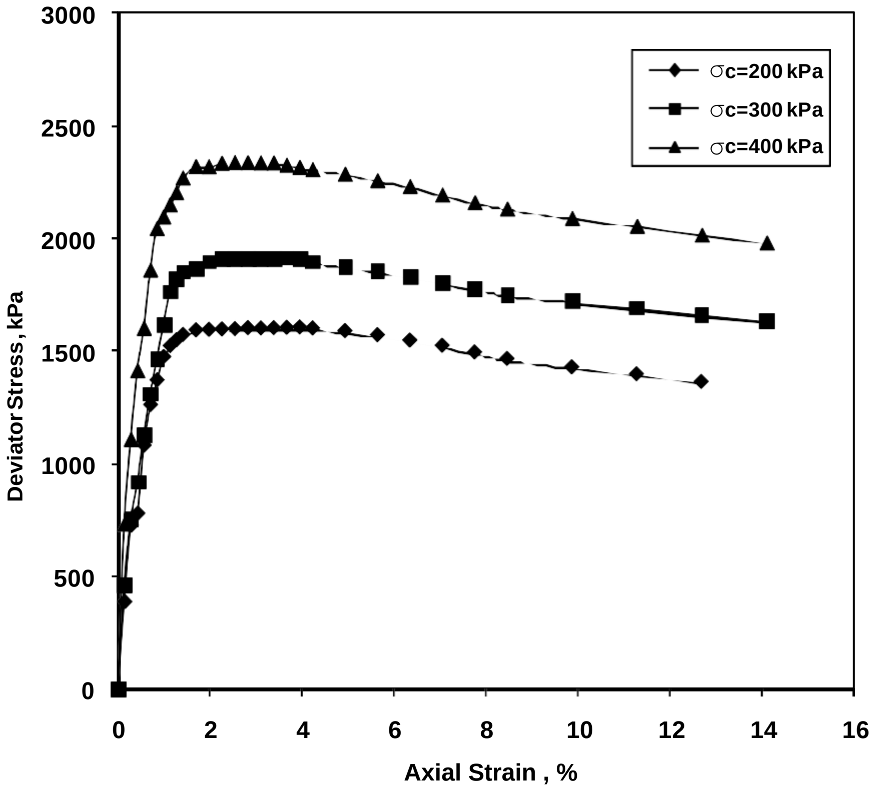

Fig. (7). Variation of deviator stress with axial strain for cement-sand mixture (7%) at different values of confining pressure σ_c.

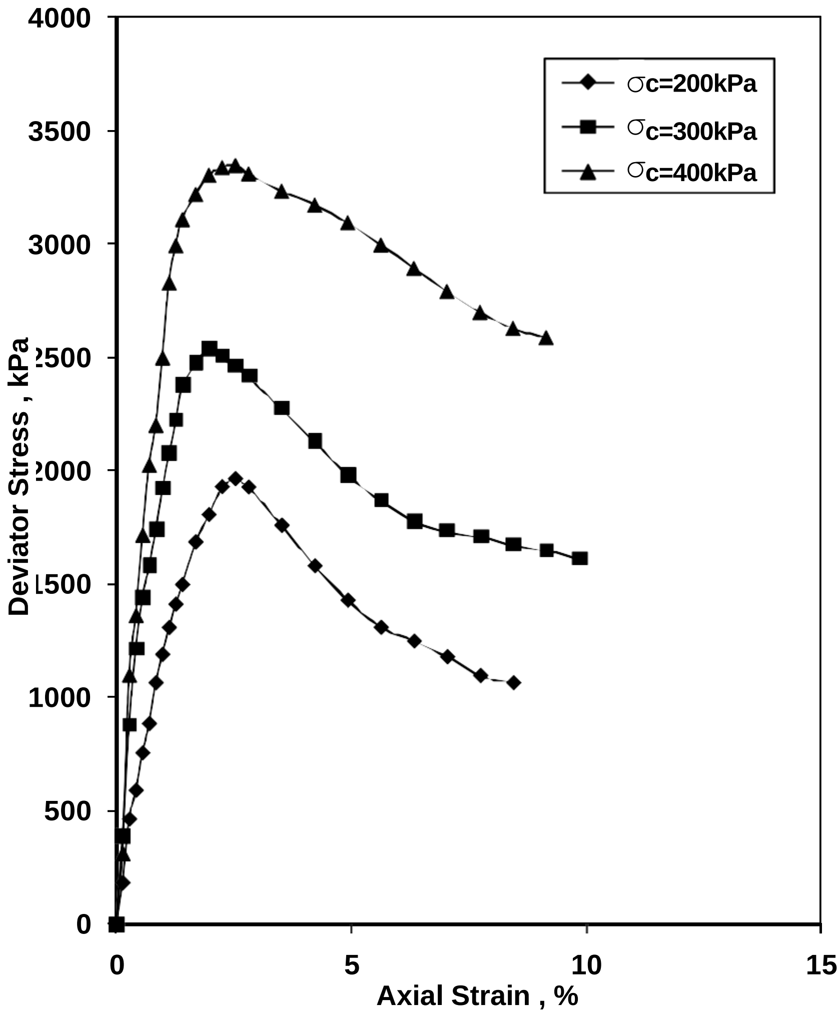

Fig. (8). Variation of deviator stress with axial strain for cement-sand mixture (9%) at different values of confining pressure σc .

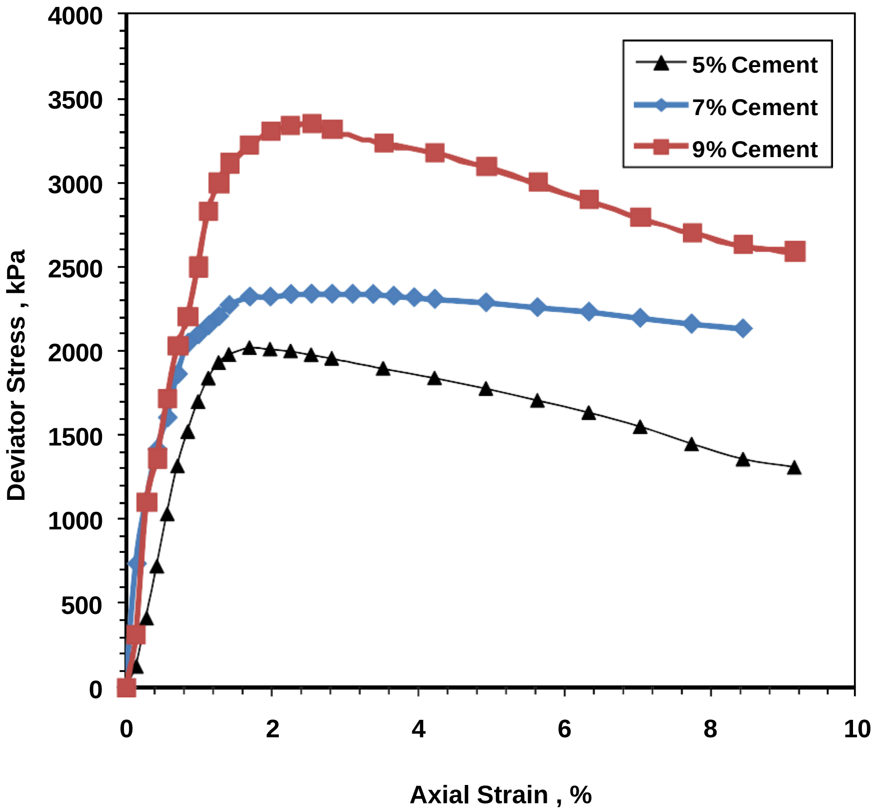

Fig. (9). Variation of deviator stress for various cement-sand mixing percentages.

The experimental results of the tested cement stabilized dune sands clearly show that the behavior of dense sand soil not that of loose poorly graded dune sands. The strength characteristics of the soil improved dramatically due to cement stabilization.

Looking at the results presented in Tables (3) – (7); one can find out that there is some kind of relationships among the strength characteristics of the stabilized soil. Figure (10) shows the variation of failure deviator stress with the confining pressure for the three cement content percentages (5%, 7%, 9%). While Figure (11) shows the variation of failure deviator stress with the change in cement content percentage in the stabilized soil at the different confining pressure and constant back pressure. Figure (12) shows the variation of initial tangent modulus with the variation of confining pressure at constant back pressure; noticing that the confining pressure as well as the initial tangent modulus are normalized by dividing them by the atmospheric pressure (102.3 kPa).

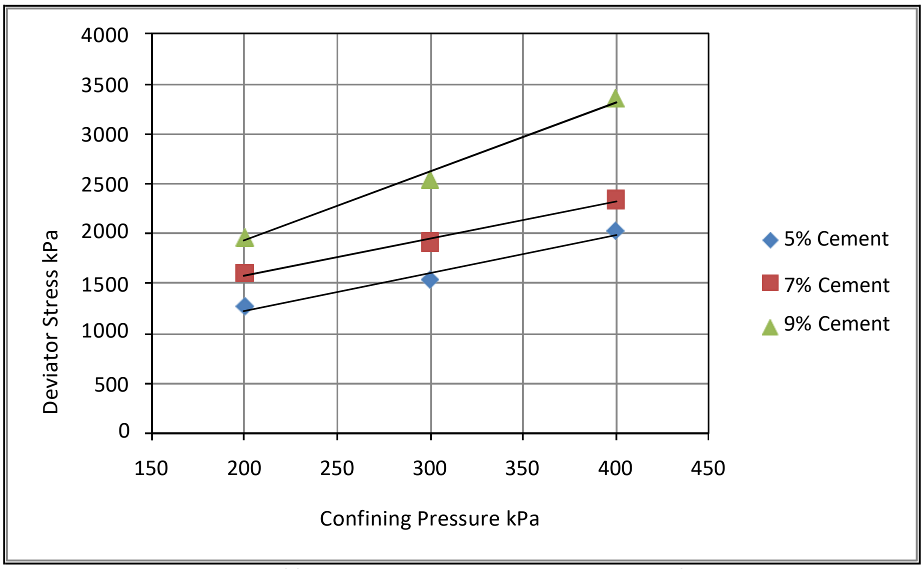

Fig. (10). Variation of failure deviator stress vs the change in confining pressure.

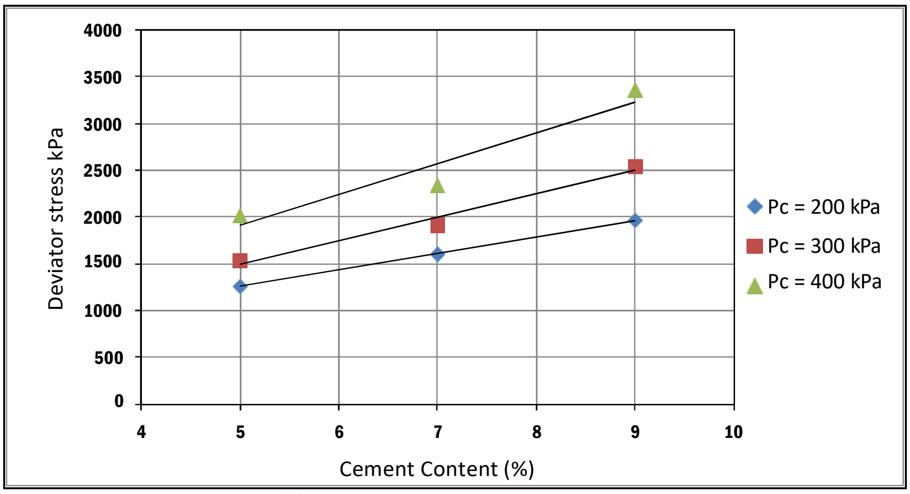

Fig. (11). Variation of failure deviator stress vs the change in cement content %.

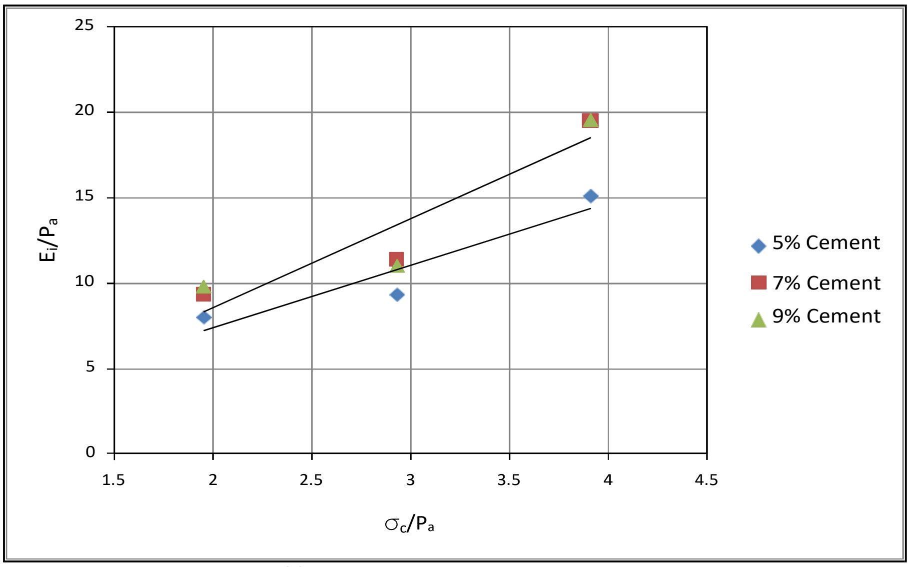

Fig. (12). Variation of failure deviator stress vs the change in cement content %.

From Figure (12); it may be noticed that the variation of initial tangent elasticity modulus with confining pressure did not change between 7% and 9% cement contents. This means that increasing the cement content more than 9% would probably not cause any more increase in the initial tangent modulus. Therefore, it can be used to introduce the following suggested equation to describe the relationship between them with a correlation factor R^2 = 0.9 (implying a strong correlation).

This equation can be used as a preliminary prediction for the values of E_i which can be used for the purpose of preliminary design and settlement calculations for this cement percent and should be checked for different mixtures with different types of dune sands.

4. CONCLUSIONS

The results of the testing program clearly show that the engineering properties of the dune sands soil improved considerably due to stabilizing with cement material. The deviator stress as well as volumetric change behavior shows similarity to those known for dense sand. The maximum deviator stress increases with the increase of confining pressure and the strength parameters of dune sands improved the most when mixing it with 9% cement. The resulted values of friction angles (Φ and Φ`) are as high as those of the dense sand soil. Moreover, cohesion intercept values appeared; which also increases the shear strength of the cement stabilized soil. These improved shear strength parameters would considerably reduce the deformations and settlement under structures to acceptable and limited values and will help in reducing and optimizing the thickness of base materials under roads and highways. The results also indicate that increasing the cement content above 9% may not probably improve the strength characteristics much more. However, other factors should also be investigated in order to examine its effect on the behavior of the treated soil, especially the effect of changing the value of the back pore pressure and the curing time before conducting the laboratory tests in order to reach the optimum treatment conditions. Moreover, the effect of cement stabilization on the values of soil CBR and MR should also be investigated for. These factors will be investigated and presented in future articles.

5. REFERENCES

[1] Aiban, S. A., “A Study of Sand Stabilization in Eastern Saudi Arabia”, Engineering Geology, *Elsevier*, Vol. 38, (1994), pp. 65–79.

[2] AL-Abdul Wahhab, H.I. and Ramadhan, R.,”Prediction of Pavement Rutting in the Eastern Saudi Arabia”, *Arabian J. Sci. Eng*., Vol. 15, No. 3, (1990), pp. 385-402.

[3] Stipho, A. S., “Aeolian Sand Hazards and Engineering Design for Desert Regions”, *Quarterly Journal of Engineering Geology & Hydrogeology*; Vol. 25, No. 2, (1992), pp. 83-92.

[4] Al-Khanbashi, A., Mohamed, A. M. O., Moet, A., and Hadi, B., “Stabilization of Desert Sand Using Water-Born Polymers”, Proceedings of the *First International Conference on Geotechnical, Geo-environmental Engineering and Management in arid Lands*, Al-Ain, United Arab Emirates, (2000), pp. 143-148.

[5] Elsharief, A. M., Mohamed Zein, Y. E. A., and Hussein, Y., ”Geo-technical Properties of QOZ Soil”, Proceedings of the *Twelfth Regional Conference for Africa on Soil Mechanics and Geotechnical Engineering*, Durban, South Africa, (1999), pp. 317-320.

[6] Mohamedzein, Y. E. A., Al-Aghbari, M. Y. and Taha, R. A., “Stabilization of Desert Sands Using Municipal Solid Waste Incinerator Ash”, *Geotechnical and Geological Engineering*, Vol. 24, No. 6, (2006), pp. 1767-1780.

[7] Al-Aghbari, M.Y. and Dutta, R. K., “Suitability of Desert Sand Cement Mixes for Base Courses in Highway Pavements”, *Electronic Journal of Geotechnical Engineering*, Vol. 10, No. 4, (2005).

[8] Buchwald, A. and Schulz, M., “Alkali-Activated Binders by Use of Industrial By-Products”, *Cement and Concrete Research*, Vol. 35, No. 5, (2005), pp. 968-973.

[9] Miller and Azad, “Influence of Soil Type on Stabilization with Cement Kiln Dust”, *Construction and Building Materials*, Vol. 14, No. 2, (2000), pp. 89-97.

[10] Baghdadi, Z. A. and Rahman, M. A., “The Potential of Cement Kiln Dust for the Stabilization of Dune Sand in Highway Construction”, *Building and Environment*, Vol. 25, No. 4, (1990), pp. 285-289.

[11] Peethamparana, S., Olekb, J., and Lovell, J., “Influence of Chemical and Physical Characteristics of Cement Kiln Dusts (CKDs) on Their Hydration

Behavior and Potential Suitability for Soil Stabilization", *Cement and Concrete Research, Elsevier*, Vol. 38, No. 6, (2008), pp. 803-815.

[12] Zhiming, S. and Herrera, C. H., "Laboratory and Field Evaluation of Base Stabilization Using Cement Kiln Dust", *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 19, (2007), pp. 42-49.

[13] AL-Abdul Wahhab, H., Bayomy, F., and Al-Halhouli, A., "Evaluation of Emulsified, Asphalt-Treated Sand for Low-Volume Roads and Road Bases", *Transportation Research Record No. 1106, Fourth International Conference on Low-Volume Roads*, Vol. 1, (1988).

تحسين الخصائص الجيوتكنيكية للكثبان الرملية عن طريق التثبيت بالأسمنت

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