BEARING CAPACITY OF SHALLOW FOOTINGS RESTING ON DUNE SAND

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ABASTRACT

As a result of the growth of economic, demographic and building activities in Iraq, that necessitates carrying out geotechnical investigations for the dune sand to study behavior of footings resting on these soils. To determine these properties and to assess the suitability of these materials for resting shallow foundation on it, an extensive laboratory testing program was carried out. Chemical tests were carried out to evaluate any possible effects of the mineralogical composition of the soil on behavior of foundation rested on dune sands. Collapse tests were also conducted to trace any collapse potential. Loading tests were carried out for optimum water content and different shapes of footing. Loading test recommends manufacturing of steel box and footing models with different shapes and dimensions. The results indicated that, Affek dune sand is predominantly fine sand with non-plastic fines. Because the content of sulphate (as SO_3) is only 0.05%, and the alkalinity of dune sand, which reduces the corrosion potential, ordinary Portland cement can be used in concrete foundation construction in/on dune sands. The results of collapsing tests showed that Affek dune sand exhibit a slight to moderate potential depending on stress level. Due to Soaking by water, the reduction in bearing capacity of optimum state was about 45%. The bearing capacity of square footing was greater than those of the circular and rectangular footings.

المستخلص

نتيجه للنمو الاقتصادي والبشري وفعاليات البناء في العراق, اصبح من الضروري اجراء تقييم لرمال الكثبان من النواحي الجيوتكنيكيه وكفايه تصرف هذه الرمال على تحمل الاسس الضحله. تم وضع برنامج للفحوصات المختبريه الاساسيه وشمل ايضا الفحوص الكمياويه لتحديد تاثير المحتوى المعدني للرمال على تصرف الاسس الضحله. اجريت كذلك فحوص الانهيار بطرق مختلفه. واجريت بعد ذلك فحوصات التحميل على اسس مختلفه الاشكال وبتربه محدوله لحاله الرطوبه المثلى. ان رمال الكثبان في منطقه عفك تتكون من رمال ناعمه ومواد غير لدنه انعم منها. واظهرت النتائج ايضا ان المحتوى الجبسي قليل جدا(SO_3=0.05%) وعليه فان رمال الكثبان المفحوصة ملائمه لانشاء الاسس من الخرسانه باستعمال السمنت العادي بدون اي ضرر. اظهرت نتائج فحوص الانهيار ان الرمل المفحوص قد ابدى إمكانية الانهيار تتراوح من ضئيله الى متوسطة حسب مستوى الاجهاد عليه واظهرت النتائج ايضا ان تحمل الاسس قد انخفض نتيجه الغمربالماء بحدود 45% وان تحمل الاساس المربع اعلى من تحمل الاسس الدائريه والمستطيله تحت نفس الظروف.

Keyword: bearing capacity, shallow footings, dune sand, loading test

INTRODUCTION

Dune sands usually have a single-sized grading curve. They occur frequently in loose state with low in situ densities. That is due to the poor packing of uniformly graded materials deposits in a sub-arid environment. They also have low bearing capacity and large settlement due to their low density. Das (2007) mentioned some of typical properties of dune sands as follows:

1. Grain size distribution of the sands at any particular location is uniform. The uniformity can be attributed to the sorting action of the winds

2. The general grain size percentages decrease with distant from the source, because the wind carries the small particles farther than the large ones.

3. The relative density of sand deposited on the windward side of the dunes is as high as (50-65) % and decrease to about (0-15) % on the leeward.

Ismael (1994) presented a review of the geotechnical properties, composition nature and spatial variability in three main soil deposits in Kuwait (surface windblown sands was one of them). The researcher concluded that:

1. The surface windblown dune sands are sensitive to saturation. It may collapse at some location due to ground wetting, and

2. The collapse will be evident for compacted sand at low relative density.

So, that research reflected how important is to determine the collapse potential for such soils

Al-Taie (2002) assessed the suitability of “real” sand and “pseudo” dune sand as a construction material. The results showed that the real sand dune is considered suitable for use in backfilling and embankments construction. On the other hand, for construction purposes on pseudo dune sands, a combination of placement densities in lower than the maximum values and placement moisture higher than the optimums are required. That is to insure low expansion and to reduce the loss of strength. It is worth to remind that the real sand dunes are defined as the dunes that their soil have more than 90% of sand, while pseudo-sand dunes have appreciable amount of clay and silt.

MATERIAL PROPERTIES

Dune Sand

Affek dune sand was chosen in this study. It is located between Diwaniya and Kut governorates, more precise, it is 15 km away from the town “Affek” or “Effech” as the local people use to call it. The grain size distribution curves of the soil sample are shown in Fig. 1

Affek dune sand is predominantly fine sand with non-plastic fines. According to the Unified Soil Classification System, the soil is classified as SP-SM material.

Physical properties, shear strength and compressibility parameters could be seen in Table 1, while the Chemical tests results are shown in Table 2. Chemical tests were done in the State Company for Geological Survey and Mining, and National Center for Construction Laboratories and Research (NCCLR).

Also, small difference can be noticed between the maximum and minimum unit weights, this may attributed to the poorly grading of dry soil. On the basis of permeability, the soil may be classified as low permeability soil (Terzaghi and peck, 1967).

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The results showed that the silica is the main component in the dune sand. Because the low content of sulphate (as SO_3) and the alkalinity of dune sand, which reduces the corrosion potential, Ordinary Portland cement can be used in construction of foundations in/on the dune sand tested.

Collapse Tests

Collapse is a typical feature of unsaturated, loose and low plasticity soils, which are typical features of dune sand. Collapse is defined as the significant volume reduction observed when wetting an unsaturated sample under load. Janning and Knight discussed the problem in 1957. Then, in 1963, they proposed a test method by which they determined the collapse potential for one specimen under an applied vertical stress of 200 kPa, after one day of soaking. ASTM–D5553-00 were used to determine the magnitude of one-dimensional collapse that occurs when the soil inundated with fluid (water). The expended Knight's criterion, the Double Oedometer Method, was followed to estimate the amplitude of possible collapse as below:

$$C_p = \frac{\Delta e}{1 + e_o}$$

C_p =*collapse potential (%)*
e_o = *initial void ratio*
Δe = *change in void ratio due to soaking.*

The relation of collapse potential to the severity of foundation problems according to ASTM-D5333, is shown in Table 3

The results showed "slightly collapsible" trends of behavior as shown in Table 3 and Fig. 2. The results of single collapse tests on compacted soil following Janning and Knight (1975) procedure are shown in Figure 3. This Behavior may be attributed to two reasons: **first**, the effect of compaction, which decrease the void ratio of soil and make it more dense and **second**, the effect of initial water content of compacted specimens. It is clearly shown that an increase in collapse potential (C_p) with the decrease of initial water content.

In order to determine the collapse potential of the dune sand in loose and dense states, and to show the effect of compaction on such soils, single collapse tests were carried out. The results of these tests are shown in Fig. 4. The loose state specimens exhibited higher collapse potential than the dense state. In accordance with the Janning and Knight (1975) procedure the results show that "Moderate collapsing" behavior. The collapse potential was about 6%, while the collapse potential of dense state was about 2%. This collapse behavior could be attributed to the dry, uncompacted, cohesionless, natural state of the dune sand.

The results of double Oedometer tests are shown in Fig. 6, which indicate that the level of stress plays a major role compared to that of compaction, Fig. 5. The Figure also shows that the collapse potential increase with increase of level of stress for both dry and wet side conditions. While on the optimum, the collapse potential did not show the same trend. The effect of compaction is an accepted reason for that behavior.

LOADING TESTS

A shallow footing model tests were carried out in a test box having dimensions of (360 × 360) mm in plane and 250 mm in depth. The size of the box was decided suitable for the size of footing and the range of load influence. (Depending on Bossineq's approach; three footing models were used to fulfill the objectives of this work: square(S) 60*60 mm, circular (C) 60 mm in diameter, and rectangular(R) 30*60mm).

It is known that the method of sample preparation can have a major influence on the measured response of soil. To place the soil in the box reliable as much as possible, static compaction method was used by compression machine of (10,000 kg). The preparation of the soil was done in two stages:

(1) Soil was compacted in dense, dry unit weight as in (ASTM D2049-64T), then

(2) Layer with 1.5B thickness at three unit weights and the corresponding water contents, (Fig. 7).

Samples were tested and compacted as quickly as possible, to avoid losing the water. The inside of the box was lined by plastic sheets to lessen the friction between the soil and the box sides.

Through the preparation of soil and loading test performance, the following points were considered:

1. When soaking conditions were conducted, the box was left to soak for 24 hours to ensure that all the soil was completely soaked.

2. After the test completed, the sand was spread for air drying over night (It looked enough in hot Summer days where the temperature was more than 42C^{o}) and the soil lumps were crashed by rubber hammer.

Model loading tests were carried out on dune sand as given in the test program. To evaluate the bearing capacity in this work, the failure point considered at settlement equal to 10% of the width of footing (B) as ASTM (D1194-94) recommended. Also, the effects of the following factors were taken in consideration:

1. Effect of Soaking

It is important to carry out a model test in soaking condition to trace any susceptible collapse potential in soil. Model tests were carried out with optimum initial water content and different shapes of footing. Fig. 8

The results showed that the reduction in bearing capacity ratio of the dry side and optimum states were about 45%. It is further recommend that for non-cohesive soils, the values shall be reduced by 50% if the water table expected to be above or near the base of footing.

2. Effect of Shape of Foundation

From the Terzaghi equations, it's clear that for granular soil, the bearing capacity of square footing is greater than that of circular footing by 33%. These results coincide with the results of this research work (Fig 9) .The bearing capacity of square footing is greater than that of circular footing in the present work by about 12%-27%.

In addition, the rectangular footing showed a smaller bearing capacity than both of the circular and square footings. This behavior may be attributed to the scale effect that depends directly on B (width of footing). Since B= 60 mm for circular and square footings, while B= 30 mm for rectangular footing. Accordingly, the bearing capacity for rectangular footing was smaller, Fig. 10.

Comparison between the Ultimate Bearing Capacity from the Model Loading Test and Its Values From Well-known Theories

In comparison with the well known theories of ultimate bearing capacity determinations, the ultimate bearing capacity from the loading tests are shown in Table 4

The results showed a lack of agreement between theoretical and experimental findings. By re-examining Table (4-8), same trend can be seen between the different shapes and different initial water content. The large differences between theoretical and experimental finding, which may be attributed to:

1. It was found that theoretical solution based on plane strain angle of internal friction which is

higher than that based on direct shear. A variation in friction angle of only 2° may result in a variation in the value of N γ 50% (White, 2008). Consequently, the bearing capacity will be increased.

2. The above mentioned theories are more conservatives. Meyerhof (1963) and De Beer (1970) propose a conservative estimate for shape factor acceptable for design only for low internal friction angle and a small aspect ratios (Zhu and Michalowski, 2005).
3. The physical model for shallow footing have many short comings included: 1 the self weight variations between actual self weights of the model elements, 2 temperature also different to assess in different levels in the models, 3 moisture movements cannot model with time.

CONCLUSIONS

1. Affek dune sand is predominantly fine sand with non-plastic fines. Water effectively influenced the cementation agents between the particles.

2. The results showed that silica is the main component in Affek dune sand. Because the low content of sulphate (as SO_3) and the alkalinity of dune sand, which reduces the corrosion potential. Ordinary Portland cement can be used in construction of foundations in/on dune sand.

3. Compacted dune sand showed a slight collapse potential when tested by single collapse test, while it showed moderate collapse potential under high stress level .

4. The reduction in bearing capacity ratio due to soaking of the dry side and optimum states were about 45%.

5. The results showed a lack of agreement with theoretical and experimental findings, as these theories are more conservatives.

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SYMBOLS	DEFINITION
B	Width of Footing
c	Cohesion
C	Circular Footing
C_c	Compression Index
C_p	Collapse Potential
C_r	Rebound Index
e	Initial Void Ratio of Soil
Gs	Specific Gravity
k	Coefficient of Permeability
L.L	Liquid Limit
$N\gamma$	Bearing Capacity Factors
NP	Not Plastic
R	Rectangular Footing
S	Square Footing
ø	Angle of Internal Friction
γ	Unite Weight of the Soil

Table 1 Physical properties, shear strength and compressibility parameters

Property	Value	Type of test	Standard
L.L	23%	Atterberg limits	BS 1377:1975 test No.2
PI	NP		
Gs	2.67	Specific Gravity of Solids	ASTM D-854
γ_{max}	15.9 kN/m^3	Maximum Unit Weights	ASTM D4253
γ_{min}	13.0 kN/m^3	Minimum Unit Weights	ASTM D4254
γ_{dmax}	18.5 kN/m^3	Standard Compaction	ASTM 698-70
k	1.6×10^{-4} cm/s	Coefficient of Permeability	ASTM D2434-64T
e_o	0.508	One-dimension Compression	ASTM D2435
C_c	0.120		
c	0	Direct Shear Tests	ASTM D3080-72
ø	42.7º		

Table 2 Results of Chemical Tests

Chemical Composition	Percentage (%)
SiO_2	41.25
CaO	16.39
MgO	6.70
SO_3	0.05
Cl^{-1}	0.11
$CaCO_3$	30.60
Gypsum Content	0.09
Organic Material	0.20
T.S.S	0.21
L.O.I	15.34
pH	8.7

Table 3 Relation of Collapse Potential to the Severity of Foundation Problems

Degree of Collapse	Collapse Potential %
None	0
Slight	0.1 to 2.0
Moderate	2.1 to 6.0
Moderately severe	6.1 to 10.0
Severe	>10

Table 4 Ultimate Bearing Capacity (kPa) from the Model Loading Test and Well-Known Theories

The Shape	Terzaghi	Meyerhof	Model Loading Tests
Square	107	154	400
Circular	80	154	350
Rectangular	-	64	335

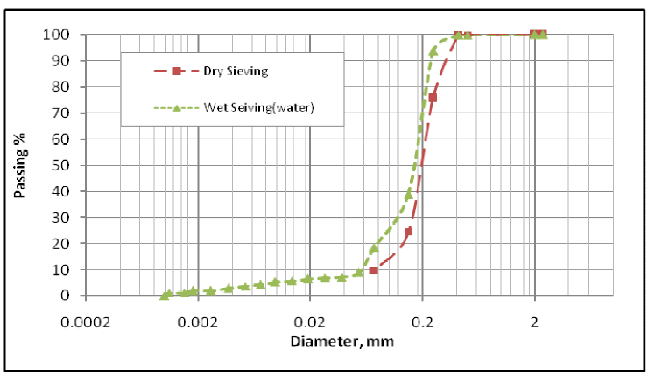

Fig. 1 Grain Size Distribution Curves

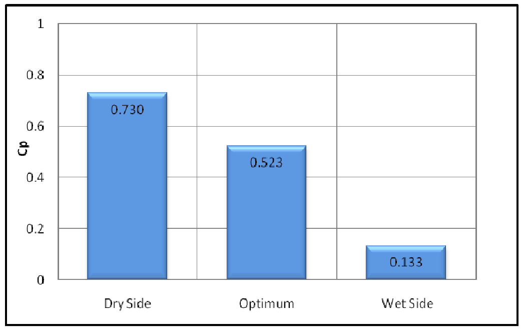

Fig 2 Results of Single Collapse Tests:
Variation of Collapse Potential with Initial water contents

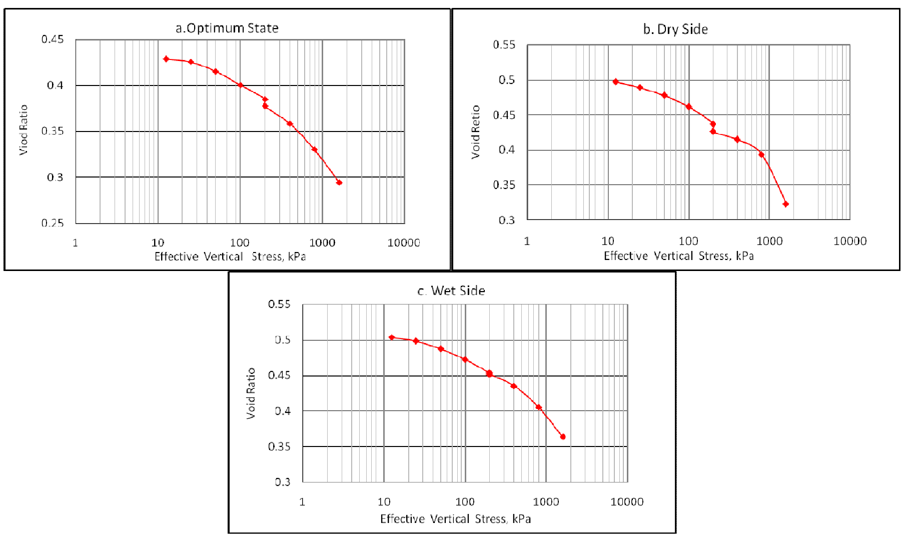

Fig. 3 Results of Single Collapse Tests at Different Initial Water Contents

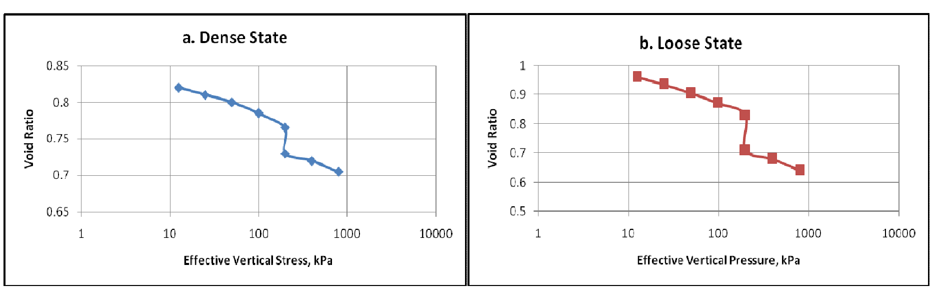

Fig. 4 Single Collapse Test Results of Dune Sand (**a.** Dense, **b.** Loose)

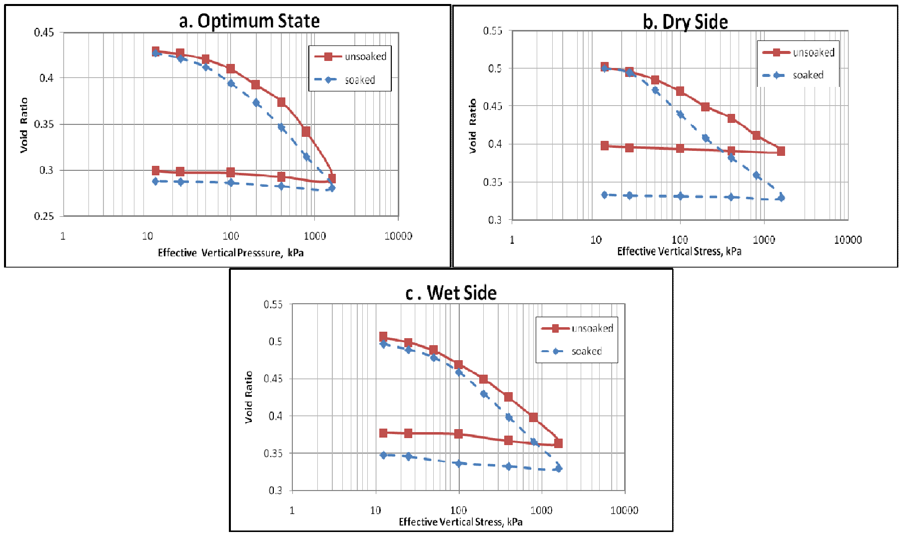

Fig. 5 Results of Double Oedometer Test at Different Initial Water Contents

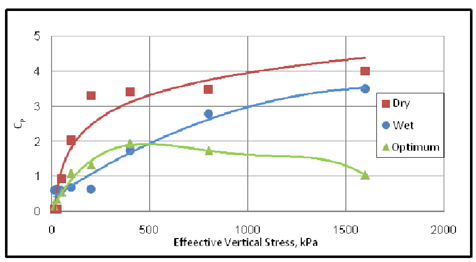

Figure 6 Results of Double Oedometer Tests: Variation of Collapse Po tential with Effective Stress Level at Different Initial Water Content

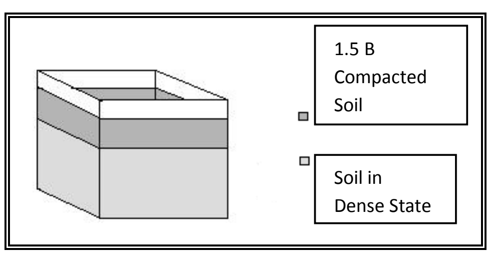

Fig. 7 Box Preparation

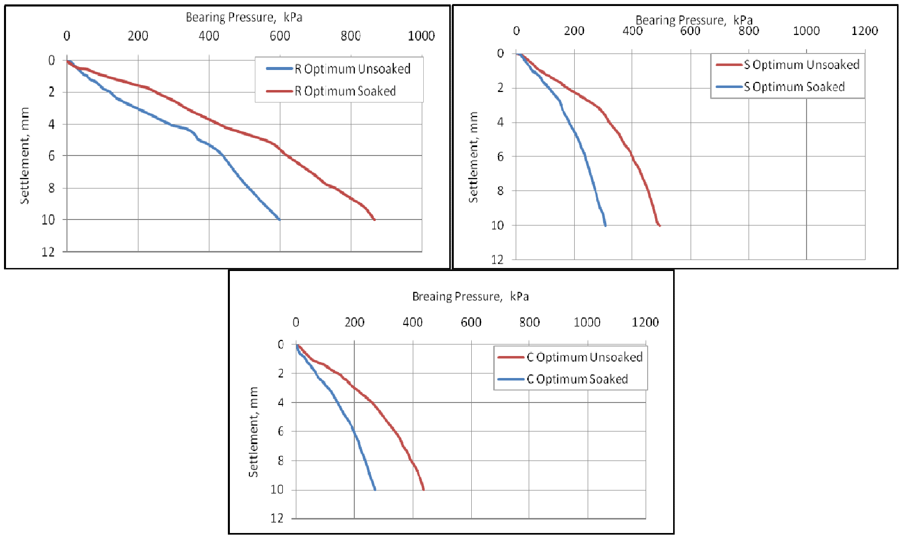

Fig. 8 The results of the Model Test on Soaked Soil in Relative with Unsoaked Soil (Optimum State)

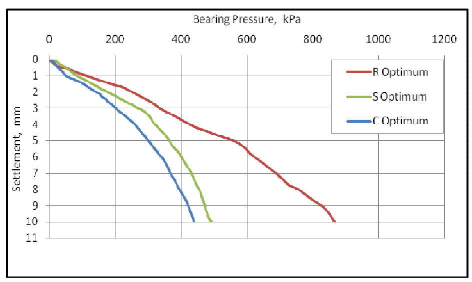

Fig. 9 Bearing Pressure-Settlement Curves for Different Shapes of Footing on Soil with Different Initial Water Contents

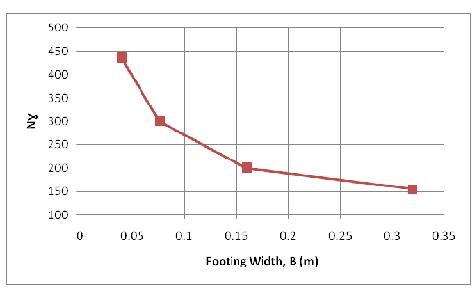

Fig. 10 Influence of Footing Size on Bearing Capacity Factors Nγ (From Cerato and Lutenegge, 2007)