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Bearing Capacity of Eccentrically Loaded Square Foundation on Compacted Reinforced Dune Sand over Gypseous Soil

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Abstract

From geotechnical and engineering geology points of view collapsible soils are classified as a problematic soils. The existence of collapsible soils has been reported in all of the world continents. In Iraq, gypseous soil is consider as collapsible soil. Existence of these soils, sometimes with high gypsum content, caused difficult problems to the buildings and strategic projects due to dissolution and leaching of the gypsum slates by the action of water flow through soil mass. The gypseous soil used was brought from Tikrit city, (Al-Qadissia district), from depth ranging (1.5-2.0) m. The gypsum content was more than (40 %). A dune sand, which used to replace gypseous soil was brought from Baiji in Salah AL-Deen Governorate from different depths to reduce the collapse that occurs during soaking. A series of model loading tests was conducted on gypseous soil improved by replacement with dune sand and using geogrid and geotextile under different values of eccentricities under condition of soaking. Tests was conducted on homogenous soil partially replaced gypseous soil with dune sand reinforced with geotextile reinforcement layer at the interface. Bearing capacity increases to (2.5-3.0) time after replacement and reinforcement of gypseous soil

Keywords: Gypseous soil, Bearing capacity, Dune sand, Eccentrically loaded

1 Introduction

Gypseous soil is that soil which contains enough gypsum (CaSO4.2H2O) that affect on the behaviour of soil. Gypsum has specific gravity of (2.32) and its solubility of gypsum in water is (2gm/liter) at 20 C$^\circ$, but the amount of dissolved gypsum can be much greater if water contains some salts (Hesse, 1971 and Khan, 2005). In Iraq, gypseous soils concentrated in Mosul, Baiji, Tikrit, Sammera, North West of Baghdad, Anna, Heet, Ramadi, Falloja and they may be presented in other regions (Al-Jananbi, 2002).Gypseous

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soils are classified as collapsing soils. This is due to the fact that gypsum provides an apparent cementation when the soil is dry but the intrusion of the water causes dissolution and softening leading generally to a serious structural collapse (Razouki, et al, 1994).
Many problems have been noticed in different structures constructed on gypseous soils in Iraq. For examples, the damage cases and collapse occurred in the soil under the foundations of the houses in AL-Thawrra Hai, 1969, in MosulCity(Al-Busoda, 1999). Other problems of gypseous soil are cavities created under the foundation of Mosul Dam due to the continuous dissolution of gypsum under the dam (Nashat, 1990).One of the problems resulting due to the dissolve of gypsum is the damages that occurred in Al-Anbar University in Al-Ramdi City, Plate (1) and cracks were pointed in Dijla Hospital, in Tikrit City, Plate (2).

Plate 1: Collapse of a building in Al-Ramadi City

Plate 2: Cracks of Walls in Dijla Hospital in Tikrit City

The use of geogrid layers could be particularly convenient when the mechanical characteristics of the soil beneath a foundation would suggest the designer in adopting an alternative solution, e.g. a deep foundation. Over the last decade, the use of geogrids for soil reinforcement has increased greatly, primarily because geogrids are dimensionally stable and combine features as high tensile modulous (low strain at high load), open grid structure, positive shear connection characteristics, light weight, and long service life. The open grid structure provides enhanced soil-reinforcement interaction.

2 Materials and Experimental Work

A series of tests was performed on the gypeous soil and dune sand according to ASTM procedures. In this study, gypseous soil can be classified as (SC) and dune sand can be classified as (SP) according to the Unified Soil Classification System. The grain size distribution curves of gypseous soil and dune sand are shown in Figures (1) and (2). The minimum unit weight of gypseous soil tested was determined according to the test described by (Head, 1984), it is widely accepted as standard test for sandy soils and the maximum unit weight of gypseous soil tested was determined according to ASTM D-64T (Bowles, 1988). Field unit weight of gypseous soil was determined by a field test (Sand Cone Method). This test was performed according to (ASTM D1556-00). The results of the maximum and minimum unit weights of gypseous soils are (14.10) kN/m^3 and (10.75) kN/m^3 respectively. While maximum and minimum unit weight are (16.7) kN/m^3 and (14.3) kN/m^3 for dune sand. Tables : (1), (2), (3), and (4) show the physical and chemical properties of the selected gypseous soil and dune sand, respectively.

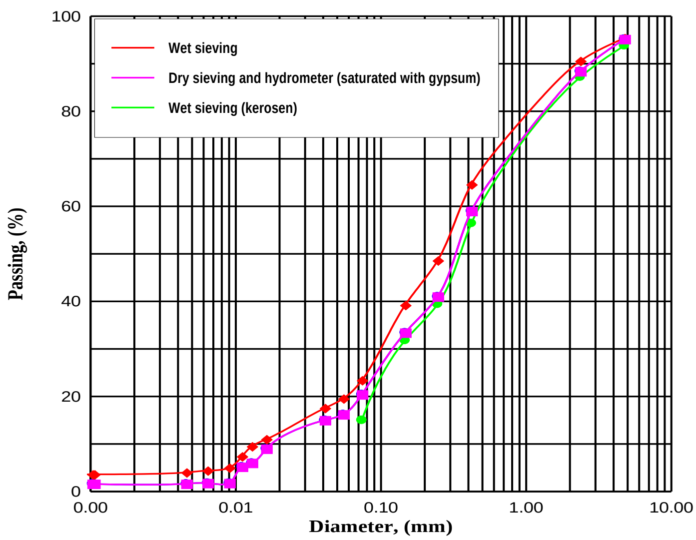


Figure 1: Grain Size Distribution Curves of Gypseous Soil

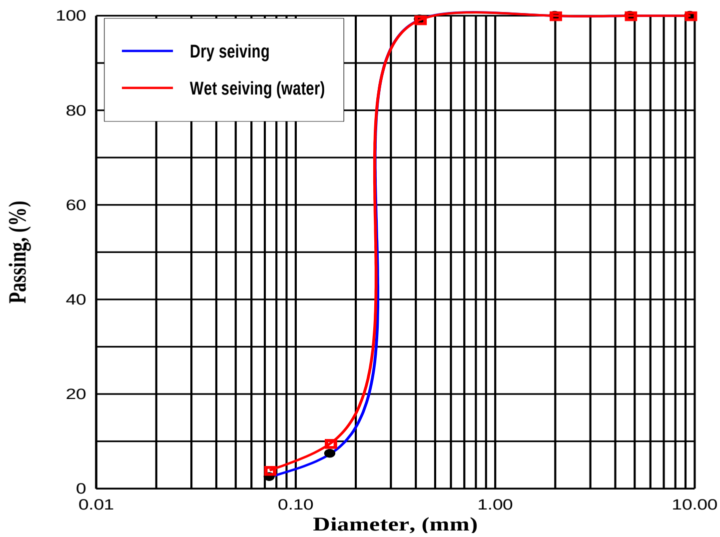


Figure 2: Grain Size Distribution Curves of Dune Sand

Table 1 : Physical Properties of Gypseous Soil

w_c , (%)	3.2
γ_{field} , (kN/m^3)	12.9
G_S	2.41
L.L, (%)	36
P.L, (%)	22
k, (cm/sec), (variable head)	$2.358*10^{-5}$
C_u	2.12
C_C	1.46

Table 2: Chemical Properties of Gypseous Soil

Chemical Composition	Percentage, (%)
SO_3	20.86
Cl	0.053
Gypsum Content	45
T.S.S	47.4
$CaCO_3$	13.30
Organic Content	0.44
pH	8.8-9.2

Table 3: Physical Properties of Dune Sand

γ_{used}, (kN/m^3)	16.2
G_S	2.71
k, (cm/sec)	$3.452*10^{-4}$
C_u	1.67
C_c	0.979

Table 4:Chemical Properties of Dune Sand

Chemical Composition	Percentage, (%)
SO_3	0.055
Cl	0.053
Gypsum Content	0.24
T.S.S	0.33
Organic Content	0.13
pH	8.75

Qualitative identification of both, clay and non clay minerals, in a soil can be made using X-ray diffraction which is the most widely used method for identification of fine grained soil minerals and the study of their crystal structure. This test was conducted by the State Company for Geological Survey and Mining (Ministry of Industry and Minerals). **Tables**: 5 and 6 show the results of X-ray diffraction analysis of gypseous soil and dune sand.

Table 5: Mineralogical Composition of Gypseous Soil

Non-Clay Minerals	Clay Minerals
$CaSO_4.2H_2O$ (Gypsum)	Polygosikte
$CaCO_3$ (Calcite)	
Quartz	
Dolomite	

Table 6: Mineralogical Composition of Dune Sand

Description of Mineral	Mineral
Non-clay Minerals	Silicon Oxide (Quartz)
Non-clay Minerals	Calcium Carbonate (Calcite)
Non-clay Minerals	Sodium Aluminum Silicate

Tests were carried out in a steel box with inside dimensions of (600) mm width (600) mm length and (500) mm height. The sides and bottom were made of (5) mm thickness plate. One face of the box was made from plexiglass with dimensions (300) mm width and (300) mm length. The test box was placed over (800) mm width and (1000) mm length of strong steel base, which was connected to a stiff loading frame. The frame consists of two columns of steel channels, which in turn bolted to a loading platform. This platform was allowed to slide along the columns and can be fixed at any desired height by means of slotting spindles and holes provided at different intervals along the columns. The model footing was made from steel plate of thickness (3) mm and having dimensions (100*100) mm. The footing was connected to suitable steel wings to facilitate the measurement of settlement. A hydraulic jack of (10) tons capacity was used to apply the axial system loading on footing. The load on the footing was measured using proving ring of (20) kN capacity, while the settlement was measured by two dial gauges (0.01) mm fixed on the middle of the footing by two magnetic holders. The water level in the test box was kept constant during the test. In order to obtain a uniform density of soils, hopper was used with height (75) mm and having valve to control the sand raining by hand. Figure (3) shows the general view of testing equipment.

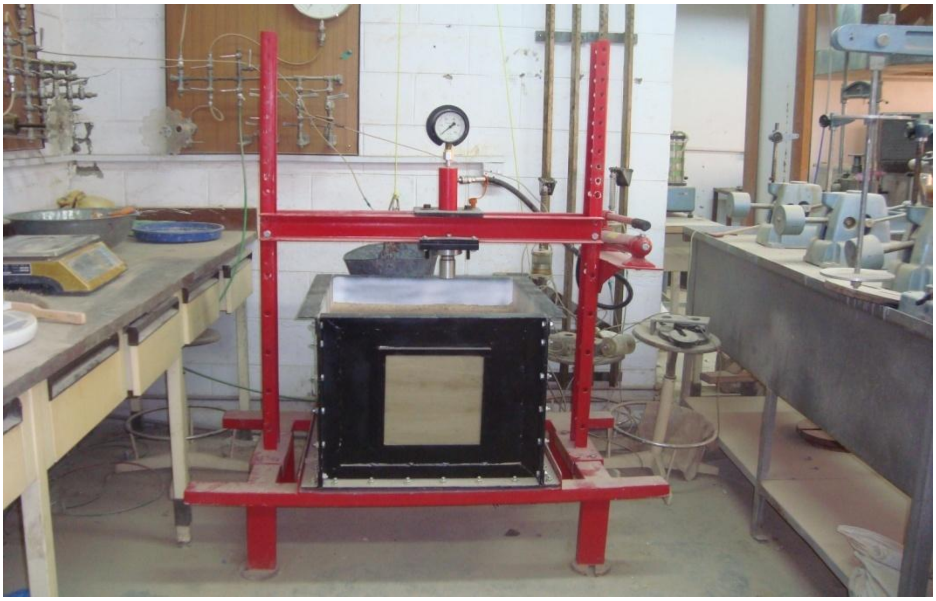


Figure 3: General View of Testing Equipment

The reinforcement used is polymer geomesh (Geogrid and Geotextile). **Tables :** 7 and 8 show the properties of geogrid, and geotextile, respectively as supplied by Building Research Center (Iraq).

Table 7: Properties of Geogrid Used, as Supplied By Building Research Center (Iraq)

Roll Dimensions, (m)	30*2
Grid Demension, (mm)	8*6
Thickness, (mm)	3.3
Grid Weight, (kg/m^2)	0.73
Tensile Strength (kN/m)	7.68

Table 8: Properties of Geotextile Used, as Supplied By Building Research Center (Iraq)

Width of Meshes, (mm)	0.10
Thickness, (m)	$2.26*10^{-3}$
Weight, (gr/m^2)	729
Tensile Strength Warp, (N/5cm)	10870
Tensile Strength Weft, (N/5cm)	2020

3 Test Procedure for Model Loading Test

3.1 Placement of Soil

The density of the gypseous soils and dune sand used through the experiments was controlled by means of the raining technique. This technique includes raining the soil by different heights of drop that give different placing densities. Many investigators such as Lee, et al, (1973), Denver, (1983), and Sanjeev, (2007) used this technique. The relations between height of drop, placement density, void ratio and relative density of gypseous soils and dune sand are shown in Figures (4) and (5). It was decided to employ unit weight (12.9) kN/m^3 of gypseous soils, which corresponds to the height of drop of (29) cm and unit weight (16) $kN/m^3$of dune sand, which corresponds to height of drop of (34) cm.

3.2 Bearing Capacity Test Procedure

The test was conducted by using non repetitive static plate load test method according to the procedure of ASTM D1194-94. The bearing capacity was determined for various thicknesses of gypseous soil beds. In each test, the gypseous soil was placed in layers (5) cm thick. The placement density was controlled using raining technique. The gypseous soil was carefully spreaded in two perpendicular directions to ensure a uniform density. When the final layer was placed, the surface was carefully leveled straight edge. Then, the foundation was fixed in the center of the test box in x and y directions in eccentric loading and then the two magnetic holders using dial gauges in the edge of the box was connected. The load was continuously applied through the hydraulic jack. The applied load was obtained from the proving ring reading while the settlement was measured by the dial gauges. When soaking is conducted, the steel box is left for (24) hours to ensure that all the soil was completely soaked. The application of load was continued up to failure. The failure was indicated by the increase of settlement at a constant magnitude of load intensity. During the test was done by replacing gypseous soil with dune sand, dune sand was placed in certain depth in the steel box by using raining technique and using geotextile at interface between gypseous soil and dune sand. Dune sand was carefully spreaded in two perpendicular directions to ensure uniform density. In reinforced condition, the gypseous soil was placed in the steel box by using raining technique. Before the construction of the next layer, the geotextile was placed above the collapse soil and geogrid was placed in two layers through dune sand layer.

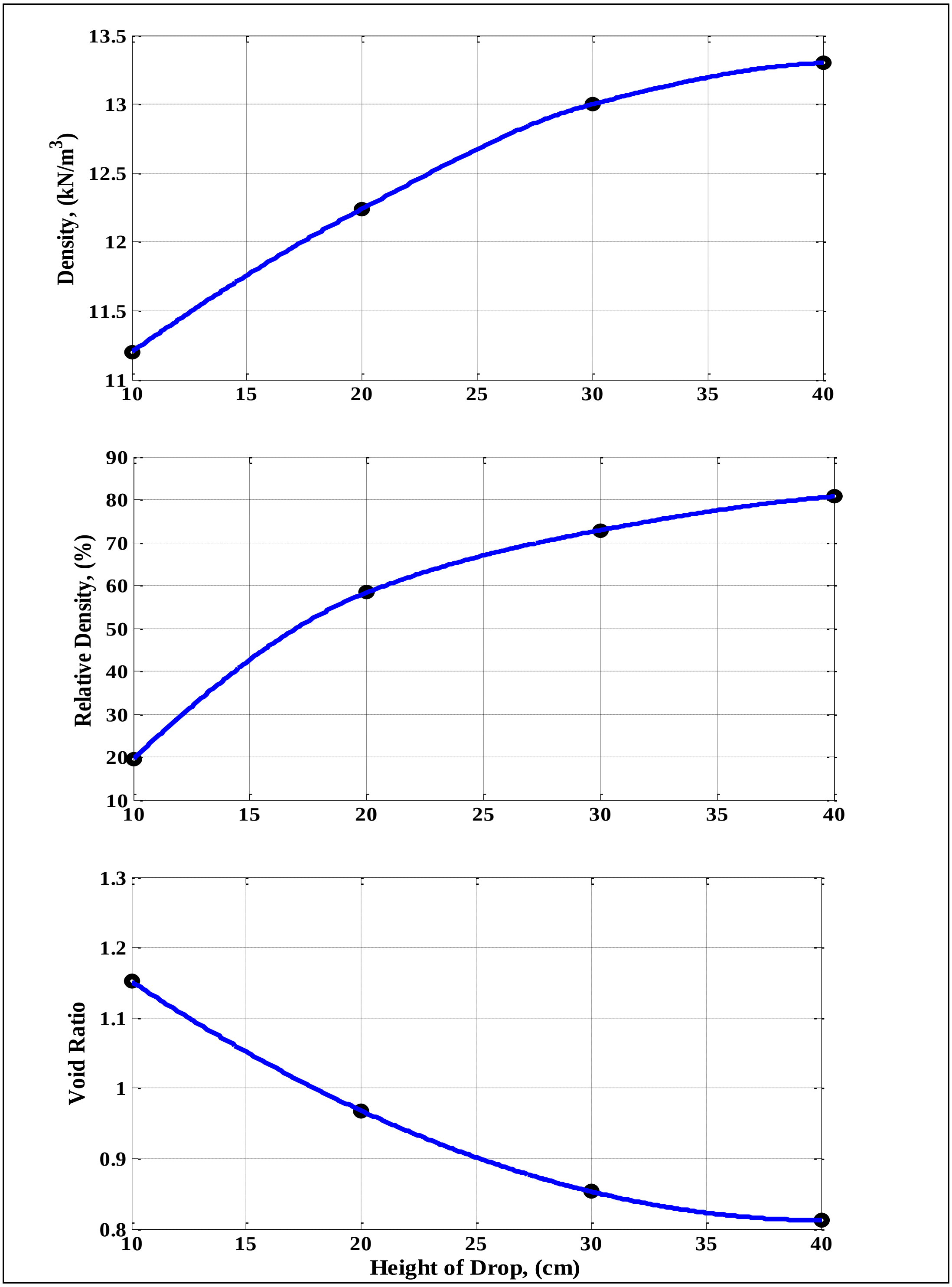


Figure 4: Density Calibration Curves for Gypseous Soil By Raining Technique.

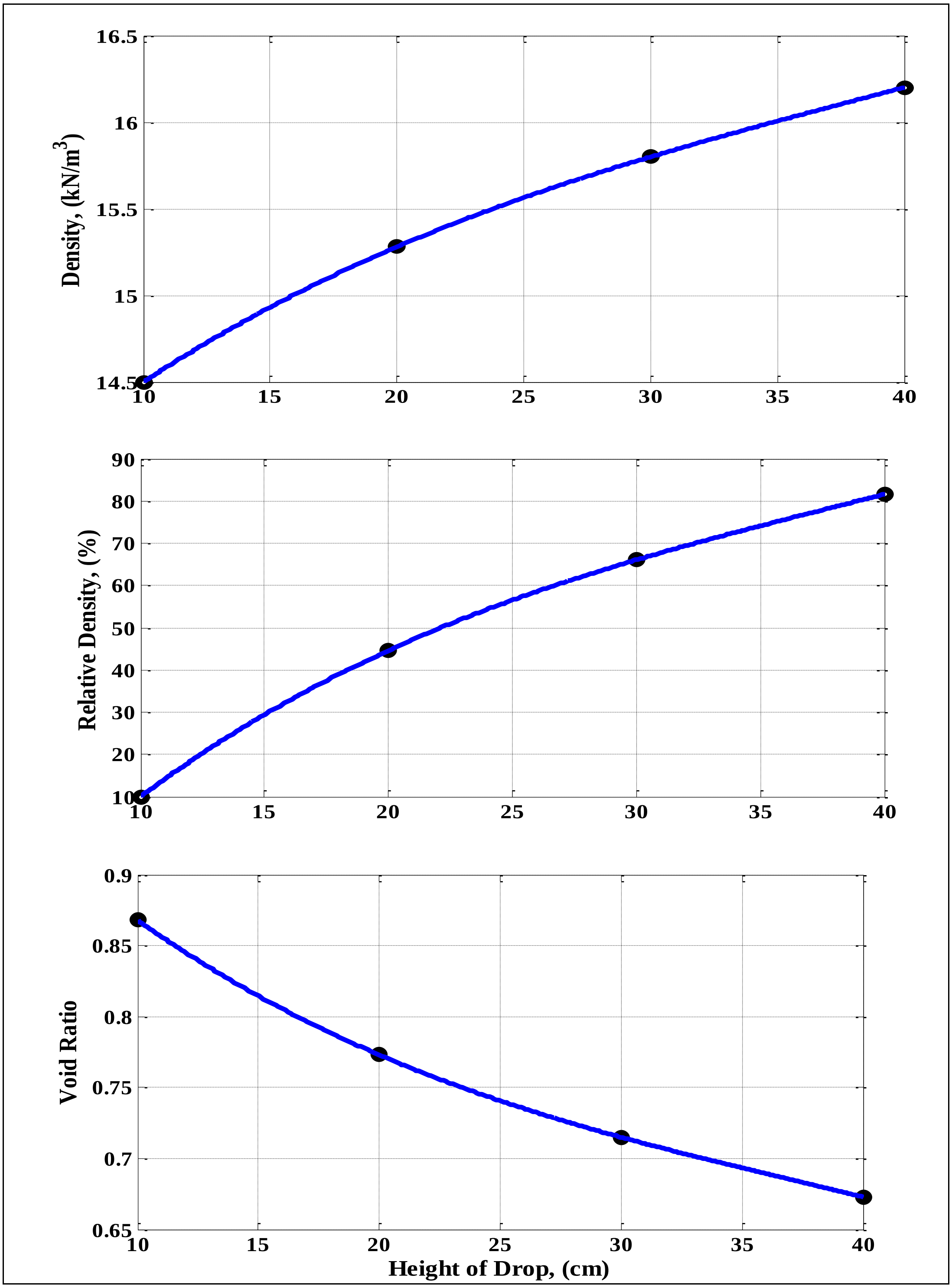
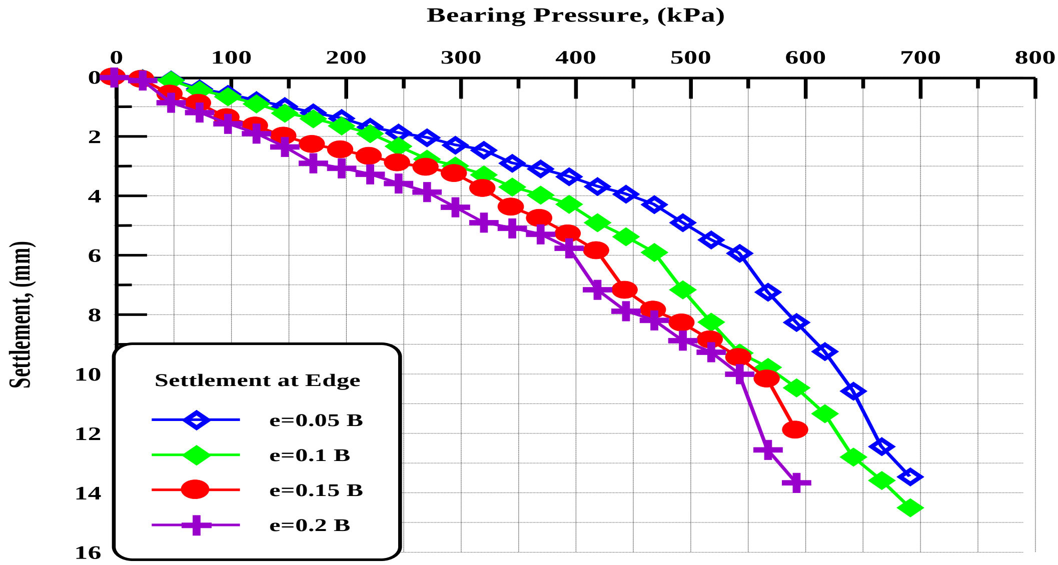


Figure 5: Density Calibration Curves for Dune Sand By Raining Technique.

4 Results and Analysis

A series of model loading tests was conducted on gypseous soil improved by replacement with dune sand and using geogrid and geotextile under different values of eccentricities under condition of soaking. Figure(6) illustrates the load - settlement at the edge and center curves for dry gypseous soil under different eccentricity values (e=0.05 B, 0.1 B, 0.15 B, 0.2 B), respectively. These results show that the behavior of load – settlement curves seem to be like the general shear failure curve. This behavior was expected because soil was in a dense state.



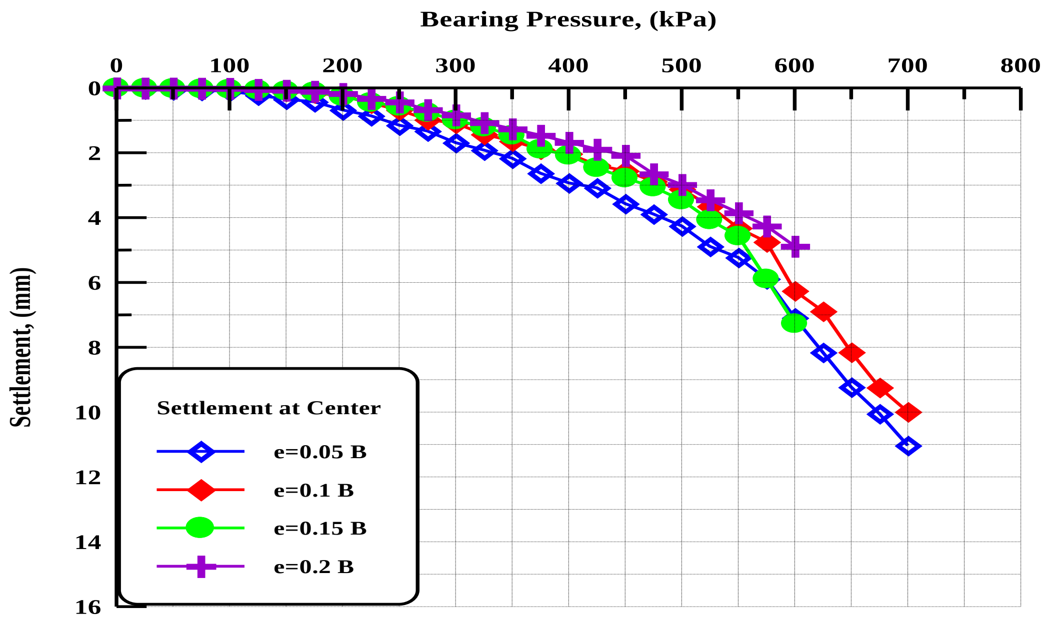


Figure 6: Pressure - Settlement at Edge and Center Curves for Gypseous Soil at Dry State

The main problem of gypseous soil appeared during soaking because of the dissolution of gypsum. Therefore, many tests were conducted on gypseous soil during soaking under different values of eccentricity. From Figure (7) , it can be observed that there is a high decrease in bearing capacity after soaking compared with test conducted under dry state. The maximum load carrying increased with the decrease of eccentricity (e=0.05 B), and decreased when (e=0.2 B).For small value of eccentricity, the difference in settlement between edge and center dial guage was a small value. But this difference increased with the increase in eccentricity. Therefore, the settlement decreases in dial guage reading at center increase in dial guage reading at edge with increasing the eccentricity value.

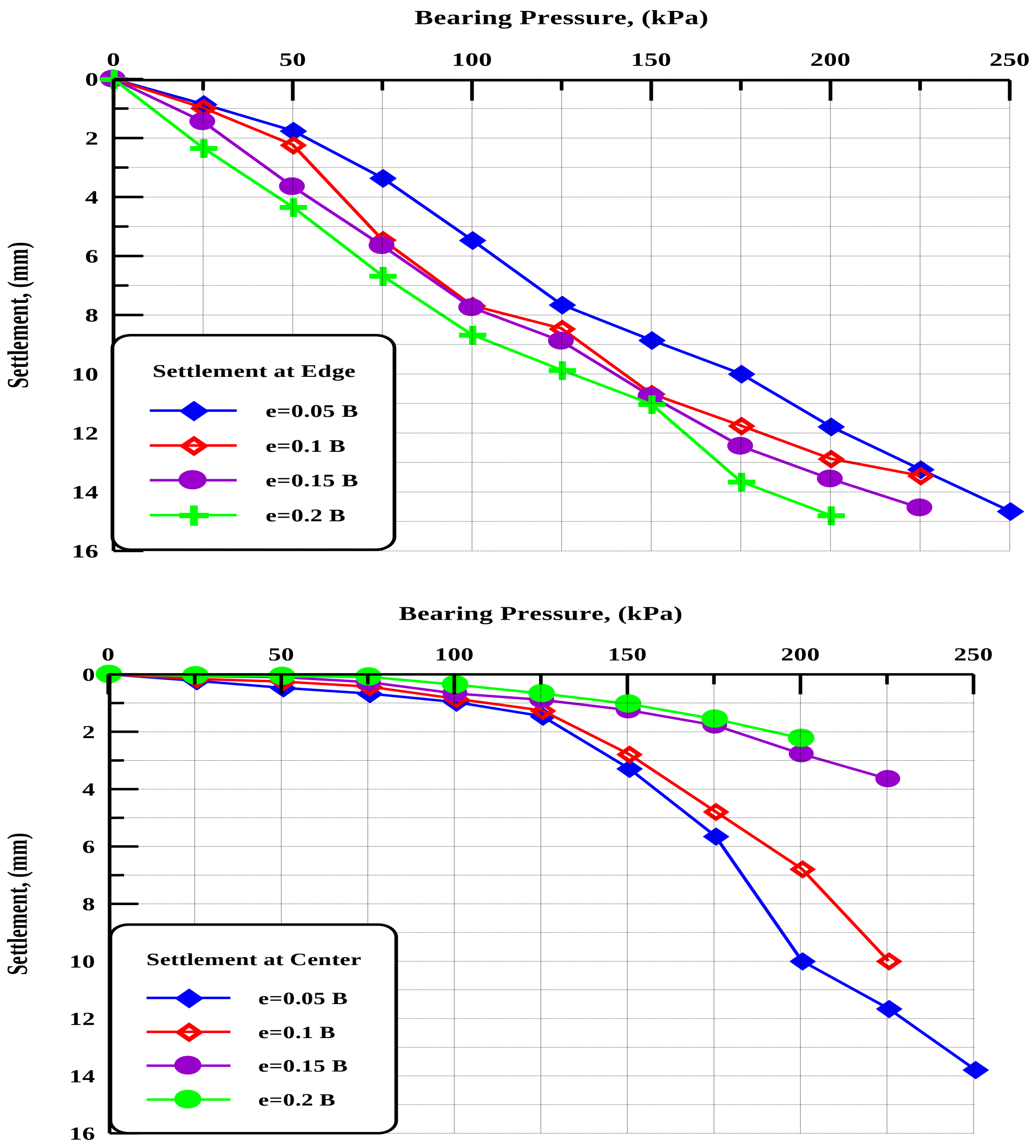


Figure 7: Pressure - Settlement at Edge and Center Curves at Center for Gypseous Soil at Soaked State.

Tables (11) and (12) show the values of experimental and theroetical bearing capacity under dry and soaked states at different values of eccentricities.

Table 11: Experimental and Theoretical Ultimate Bearing Capacity of (Dry State)Under Different Values of Eccentricities

Ultimate Bearing Capacity, (kPa)	Theoretical	Experimental Results
Bearing Capacity at (e=0.05 B)	551.23	648
Bearing Capacity at (e=0.1 B)	540.63	635
Bearing Capacity at (e=0.15 B)	530	565
Bearing Capacity at (e=0.2 B)	519.40	540

Table 12: Experimental and Theoretical Ultimate Bearing Capacity of (Soaked State) Under Different Values of Eccentricities

Ultimate Bearing Capacity, (kPa)	Theoretical	Experimental Results
Bearing Capacity at (e=0.05)	134.85	187.5
Bearing Capacity at (e=0.1 B)	134.60	182
Bearing Capacity at (e=0.15 B)	134.36	140
Bearing Capacity at (e=0.2 B)	134.14	125

An attempt was introduced to improve the bearing capacity of collapsible soil upon wetting by partially replacing the soil by dune sand. The geogrid and geotextile have proved its effectiveness in improving the bearing capacity, and reducing the settlement values. Figure (8) represents load – settlement at edge and center curves after replacing gypseous soil with dune sand under depth equal to (ds=B) in a soaked state under different values of ecentricities. From the figures, it can be observed that the bearing capacity increases after replacement. Also, it is noticed that the gypseous soil shows less settlement.

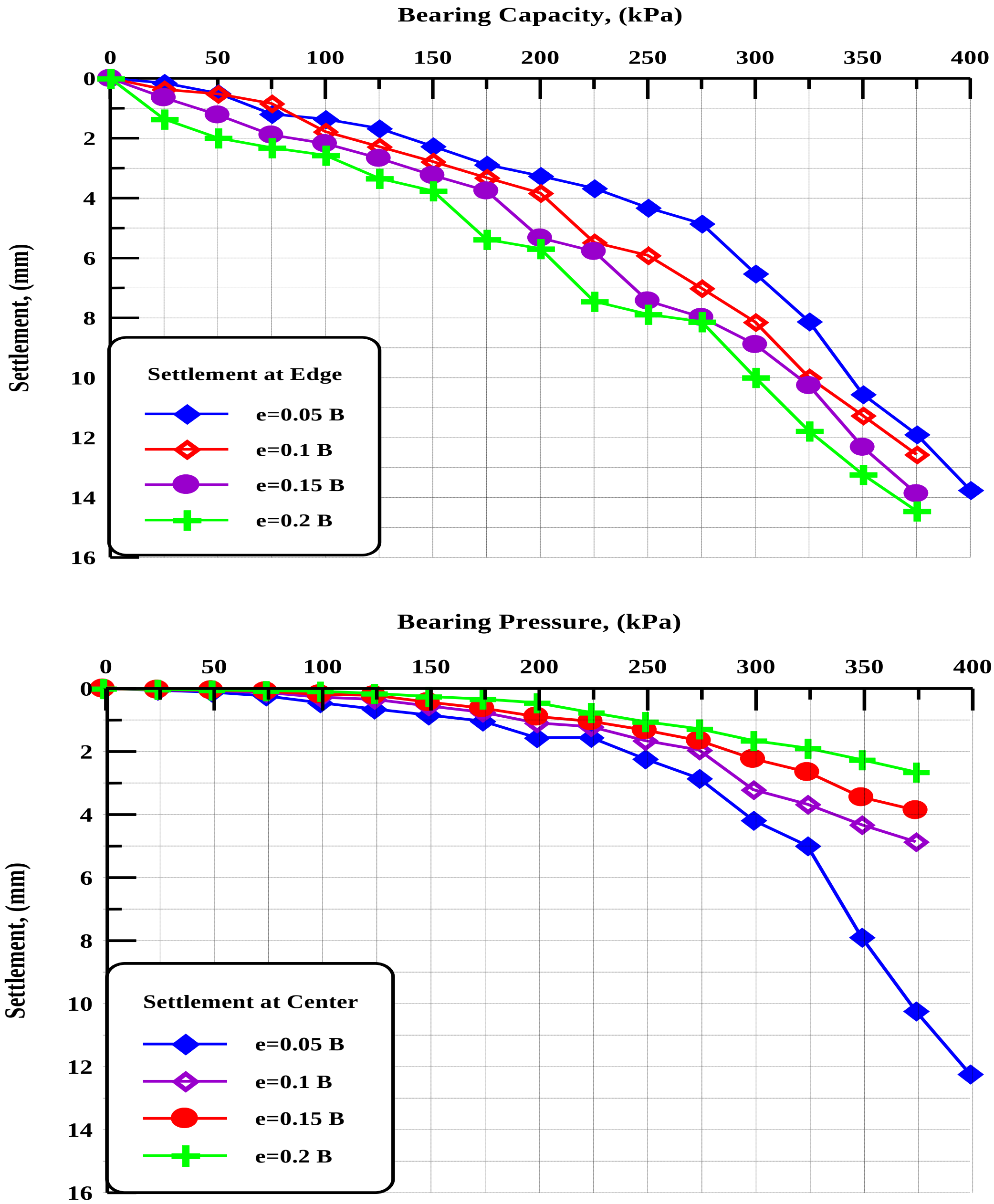
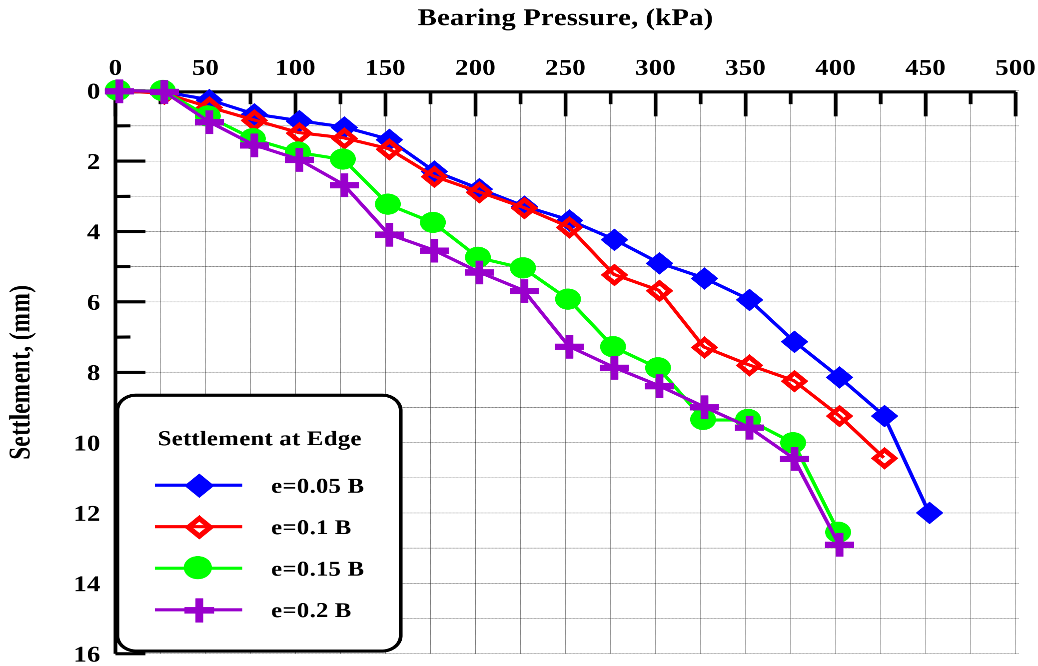


Figure 8: Pressure - Settlement at Edge and Center Curves for Gypseous Soil after Replacement.

Figure (9) illustrates bearing pressure-settlement at edge and center curves for gypseous soil after replacing by sand dune and reinforcing with geogrid and geotextile at different values of eccentricity during soaking. It can be seen that the maximum bearing capacity under soaking is achevied at (e=0.05 B). This behaviour may be attributed to the stiffening effect created by reinforcement. This stiffening refers to the frictional interaction which takes place within the mass of reinforced soil with increasing the number of geogrid layers. In addition, geotextile also causes more bond between soil and reinforcement and result in more stable mass structure.



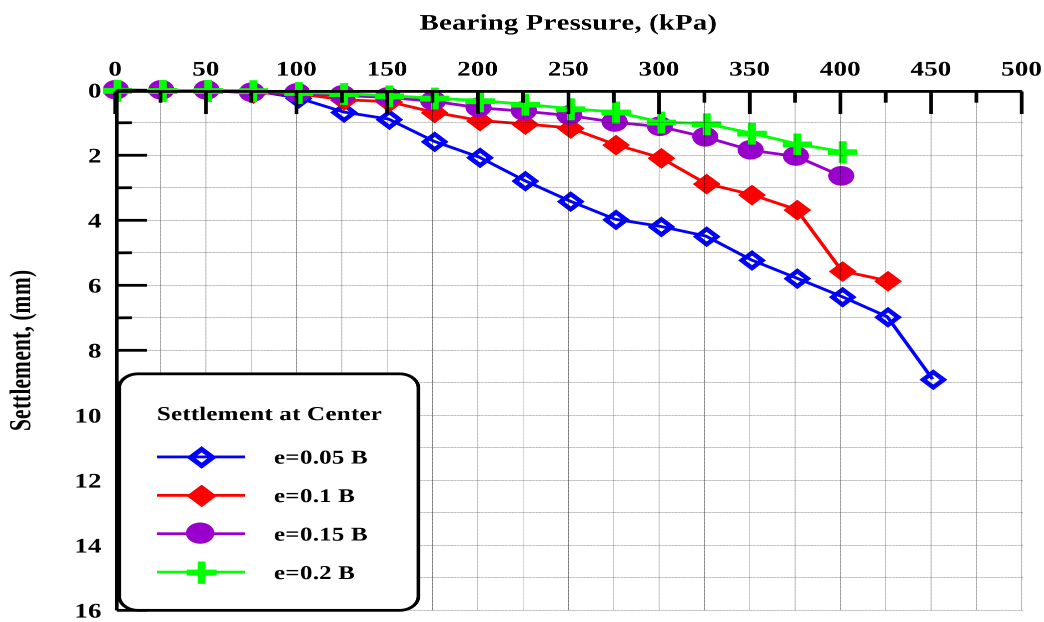


Figure 9: Pressure - Settlement at Edge and Center Curves for Gypseous Soil after Reinforcement on Replaced Soaked Soil.

Specific ratio was employed in the tests to investigate the limit of improvement in bearing capacity. This limit represents the ratio between ultimate bearing capacity of gypseous soil replaced by dune sand to the bearing capacity of collapsible soil without replacement. The term was calculated for both reinforced and unreinforced soil.

$BCR)_{(Layered)} = q_{ult\ (Layered)}/q_{ult}$

where:
$BCR)_{(Layered)}$ =bearing capacity ratio after replacing gypseous soil with dune sand at soaked state.

$BCR)_{(Reinforced)} = q_{ult\ (Reinforced)} / q_{ult\ (Unreinforced)}$

where:
$BCR)_{(Reinforced)}$ =bearing capacity ratio after replacing gypseous soil and reinforcing sand at soaked state.

4 Conclusions

1. The values of experimental bearing capacity for unreinforced soil was higherwhen than that obtained fromtheoretical equation.
2. Dune sand provides a better solution to problems of gypseous soil after reinforcement with geosynthetic materials where using these material increased the bearing capacity and reduced the collapse settlement, especially when soil is exposed to water.
3. The most effective thickness for dune sand layer with geotextile at the interface, within the tested range, was found to be equal to the footing width.
4. For eccentric loads, the load carrying capacity decreases with the increase of eccentricity value.
5. At high values of eccentricity (e=0.2B), a high value obtained of (Bearing Capacity Reduction), that equal to (2.8) time when using gysnothetics materials on replaced soil.

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