Bearing Capacity of Shallow Footing on Compacted Filling Dune Sand Over Reinforced Gypseous Soil

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ABSTRACT:

Existence of these soils, sometimes with high gypsum content, caused difficult problems to the buildings and strategic projects due to dissolution and leaching of gypsum by the action of water flow through soil mass. In this research, a new technique is adopted to investigate the performance of replacement and geosynthetic reinforcement materials to improve the gypseous soil behavior through experimential set up manufactured loaclally specially for this work. A series of tests were carried out using steel container (600*600*500) mm. A square footing (100*100) mm was placed at the center of the top surface of the bed soil. The results showed that the most effective thickness for the dune sand layer with geotextile at the interface, within the tested range, was found to be almost equal to the width of foundation. Therefore, under this depth, the soil was reinforced with geogrid and geotextile. It can be shown that (Collapse Settlement Reduction Factor) increases to (72%) when using two layers of geogrid and one layer of geotextile under depth of replacement equal to the width of footing. In addition, the results showed that the bearing capacity increases to (1.5-2.0) time under concentric loads and (2.5-3) under eccentric loads after replacement and reinforcement of gypseous soil.

Key Word: Gypseous Soil, Dune Sand, Bearing Capacity, Reinfrocement Materials, Collapse Settlement.

الخلاصة

ان وجود هذه الترب بنسب عاليه في بعض المواقع قد سبب عدة مشاكل معقدة للمباني والمشاريع الستراتيجية بسبب ذوبان الجبس بتأثير جريان الماء خلال كتلة التربة. في هذا البحث اقترحت تقنية جديدة شملت فحص تبديل التربة والتسليح بمواد نسيجية ومشبكات لتحسين تصرف التربة من خلال موديل مختبري صنع محليا لهذا الغرض. سلسلة من الفحوصات لنماذج جافة واخرى مغمورة في صندوق حديدي أبعاده (600*600*500) ملم وأساس مربع الشكل بأبعاد (100*100) ملم وضع في وسط نموذج التربة المفروشة في صندوق الفحص. بينت النتائج أن أفضل عمق مؤثر لتبديل التربة الجبسية بكثبان رملية هو العمق الذي يساوي عرض الأساس بعد استخدام المواد النسيجية والمشبكات وقد لوحظ أن (Collapse Settlement Reduction Factor, CSRF) تزداد الى (72%) عندما نستخدم طبقتين من جيوكرد وطبقة من الجيوتكستيل تحت عمق تبديل يساوي عرض الأساس. وأن قابلية التحمل تزداد بنسبة (1.5-2.0) في حالة التحميل المركزي و (2.5-3.0) في حالة التحميل اللامركزي.

الكلمات الرئيسية :التربة الجبسية، الكثبان الرملية، قابلية التحمل، مواد التسليح، هطول الانهيار.

INTRODUCTION

Gypseous soil is that soil which contains enough gypsum ($CaSO_4.2H_2O$) that affect 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 Mousal, Baiji, Tikrit, Sammera, North West of Baghdad, Anna, Heet, Ramadi, Falloja and they may be presented in other regions (**Al-Jananbi, 2002**).Gypseous soils are classified as collapsing soils. This is due to the fact that gypsum present in the soil provides an apparent cementation when the soil is dry but the intrusion of the water causes dissolution and softening leading generally to serious structural collapse (**Razouki, et al, 1994**).

Upon wetting, most of soils show settlement. The amount of settlement varies from soil to another and is dependent on load-induced stresses. But such settlement will eventually cease after a certain period of time. However, under certain conditions and for specific types of soils, subsequent wetting may cause additional settlement. This type of settlement is termed (Collapse) (**Casagrande, 1932**).

Many major projects suffered from several problems related to construction on or by gypseous soils, such as cracks, tilting, collapse, and leaching the soil. These problems could happen due to percolation of water into these soils causing dissolution of gypsum, which provides the cementing bonds between the soil particles. This process leads to collapse of soil structure and progressive compression, and the problem becomes more complicated if flow occurred causing continuous loss of soil mass and formation of serious cavities. For the construction of any kind of structure resting on problematic soils such as gypseous soils, there are many available methods to improve the behaviour of soil. Using Geosynthetic materials (Geotextile and Geogrid) as reinforcement, to increase bearing capacity and to decrease settlement for foundation was investigated by many researchers such as (**Das, 1988, Raymond, 1992, and Soliman** and **Hanna, 2010**). The designers have suggested partially replacing the collapsible soil with cohesionless material and using reinforcement materials and study their effects on the reduction of collapse settlement of collapsible soils when inundation was occur.

EXPERMENTAL WORK

1. Classification Tests:

The material used in this study was distributed gypseous soil brought from Tikrit, Salah Al-Deen Governorate and dune sand used in replacement of gypseous soil was obtained from Baiji, Salah Al-Deen Governorate. A series of tests was performed on the gypeous soil and dune sand according to ASTM procedures. Gypseous soil can be classified as (SC) and dune sand can be classified as (SP) according to the Unified Soil Classification System. The minimum unit weight of gypseous soil 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 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 soil are (14.10) kN/m^3 and (10.75) kN/m^3 respectively. **Table** (1), (2), (3), and (4) show the physical and chemical properties of gypseous soil and dune sand, respectively.

2. Test Box:

The soil beds were prepared in a steel box with inside dimensions (600*600) mm and (500) mm in height. The sides and bottom were made of (5) mm thickness plate;the purpose of the thickness is to give rigidity against pressure which may generate during loading of the soil. One face of the steel box is made from Plexiglass with dimensions (300*300) mm. The box placed over (800) mm width and (1000) mm length of strong steel base, which is connected to a stiff loading frame. The frame consists of two columns of steel channels, which is in turn bolted to a loading platform. This platform 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 footing was made of steel plate of a thickness of (3) mm. . The footing was connected to suitable steel wings to facilitate the measurement of settlement. Ahydraulic jack was used to apply an axial 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 footing by two magnetic holders. Ageneral view of the manufactured testing equipment is shown in **Figure** (1).

A sketch for the test box showing some of the studied parameters is shown in **Figure** (2). The detailed description of the model is explained in the following paragraphs.

The reinforcement used is polymer geomesh (Geogrid and Geotextile). **Table** (5) shows the properties of geogrid, and **Table** (6) shows the properties of geotextile, as supplied by Building Research Center (Iraq). **Figure** (3) shows the geogrid and geotextile used in this work.

TEST PROCEDURE FOR MODEL LOADING

1. Collapse Test Procedure:

1.Using raining technique, gypseous soil is placed in the steel box at field density (12.9) kN/m^3 and in situ moisture content (3.2%). The surface was leveled and checked by a bubble ruler (Balance).
2.When reaching the desired depth of soil in the steel box, sqaure footing was placed at the center of the test box.
3.For the tests on replaced gypseous soils, geotextile sheet was placed above the gypseous soil. Dune sand was placed in the steel box above the geotextile by raining technique to reach a relative density of (75%) and a unit weight of (16) kN/m^3.
4.For testing using geogrid within the dune sand layer, the geogrid was placed at different depths.
5.The base of the proving ring is made just in touch with the footing. The zero (initial) reading was recorded. Two magnetic holders with dial gauges were connected to the edges of the box.
6.Load increments are applied until settlement readings are less than (0.01) mm.
7. When reaching the inundation stress then another increment is applied, water is added to soil in the steel box, while the applied load was kept constant. The soil becomes fully saturated. Loads and settlements are recorded for the following (24) hours.

2. Bearing Capacity Test Procedure:

The test was conducted by using non repetitive static plate load test method according to the procedures 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 uniform density. When the final layer was layed, the surface was carefully leveled with the aid of straight edge. Then, the foundation was fixed in the center of test box in x and y direction in concentric loading and at determined eccentricity in case of eccentric loading and then the two magnetic holders with dial gauges in the edge of the box was connected. The load was continuously applied through the hydraulic jack. The applied load was recorded 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 soil was completely soaked. On the second day, the test was began . 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. When the test is 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 collapse soil and geogrid was placed in two layers through dune sand layer. The for mentioned procedure was followed for concentric and eccentric loading conditions.

RESULTS AND ANALYSIS

Tests carried out in this research are divided into the following series: (tests on gypseous soil under different inundation stresses (100,150,200) kPa, and tests on replaced gypseous soil with dune sand with the inclusion of geotextile at the interface at different depths of the gypseous soil layer (10,15,20) cm, in addition to geogrid with dune sand at dg/ds=(0.3B, 0.7B, and two layers).The behaviour of collapse settlement ratio (Δ_h/B) ratio of gypseous soil is governed by studying the following factors:
1.Effect of inundation stress on collapse strain.
2.Effect of depth of gypseous soil.
3.Effect of geogrid and geotextile on collapse settlement.

Where:
B=width of shallow footing.
dg= depth of geogrid in the dune sand layer.
ds= depth of dune sand.

The effect of inundation stress on collapse settlement of square shallow footing resting on gypseous soil was studied. The relationship between inundation stress and collapse settlement ratio was drawn in **Figure** (4). It is obvious from figure that the collapse settlement ratio increases linearly with increase of inundation stress and this behaviour was expected, where the increase in load would increase the rate of solution and cause softening of the soil resulting in loss of shear strength and increase in collapse settlement. Therefore, when comparing the results of collapse settlement at different inundation stresses, greater value of collapse settlement at (200) kPa were observed. **Table** (7) shows the relationship between inundation stress , collapse settlement ratio and collapse strain.

Figure (5) shows the relationship between inundation stress and collapse strain. From figure, it can be noticed that figure the collapse strain increases due to an increase of inundation stress in gypseous soil. Also, the maximum of collapse strain was (10.3%) under inundation stress at (200) kPa.

The collapse strain can be determined by equation follows:

$$\text{Collapse Strain}=\frac{\Delta_h}{h_\circ}*100$$

Where:
Δ_h =change in height of sample due to soaking.
$h_\circ$ =original height of sample.

After studying the effect of stress level on collapse strain, it is observed that a stress level (200) kPa, has greater collapse strain. Therefore, this stress level was chosed for studying the improvement of gypseous soil. Six tests were carried out by replacing the gypseous soil with dune sand at depth of (10, 15, and 20) cm before and after placement of geotextile. **Figure** (6) shows that collapse settlement ratio increases with the increase of depth of gypseous soil before placement of geotextile. This behaviour was expected due to increase in dissolution of gypsum, while **Figure** (7) shows that collapse settlement ratio with depths of dune sand after placement of geotextile. The optimum replacement thickness ratio (ds/B) is equal to (1). The increase in settlement with increasing soil replacement depth can be explained as the sand layer acted as a surcharge on the surface of the collapsible soil causing increase in the collapse settlement, which overcame the reduction of the collapse settlement which results from the decrease of the collapsible soil depth. Therefore, this depth will be used to improve the soil with geogrid within replaced layer in addition to the use of geotextile at the interface between dune sand and gypseous soil. Three tests were carried out on gypseous soil replaced with dune sand with inclusion of geotextile at the interface in addition to geogrid within dune sand at different depths of geogrid during soaking. The settlement collapse also decreased by the presence of the geotextile, in addition, the depth of geogrid layers appear to have a profound effect on the settlement collapse ratio during soaking. The relationship between the collapse settlement ratio and depths of geogrid, was presented in **Table** (8). From the inspection of results, it is observed that best reduction in collapse settlement ratio was noticed when using two layers of geogrid. While, less reduction was noticed at depth of (0.7B).

To evaluate the improvement in soil behaviour due to sand replacement and soil reinforcement, a collapse settlement reduction factor (CSRF) is introduced as follows:

$$CSRF=\frac{\Delta_h-\Delta}{\Delta_h}$$

Where:

$CSRF$ =collapse settlement reduction factor
Δ_h=collapse settlement of homogeneous collapsible soil
Δ=collapse settlement of reinforced partially replaced collapsible soil

From the results, it can be noticed that when using geogrid within dune sand layer in addition to the geotextile layer at the interface do not give a noticeable difference reduction in the collapse settlement of the footing (CSRF equal to (71%) for one layer and (72%) for two layers) than the case of using geotextile alone (CSRF equal to (68%)).This behavior may be attributed to the geogrid and geotextile work as tension materials to resist the stress transmitted from foundation.

A series of model loading tests were carried out on gypseous soil improved by replacement with dune sand and reinforced with geosynthetics materials under concentered load. **Figure** (8) exhibits the relationship between the applied pressure and settlement of the gypseous soil in dry and soaked state. **Figure** (8) shows that the mode of failure can be described as a general shear failure. When gypseous soil is soaked for (24) hours and then loaded to failure, large draw down in bearing capacity was observed and a trend of behavior similar to that of local shear failure. This behaviour may be attributed to the breaking of bonds due to soaking. The test of soil at soaked state may be considered as a reference to measure the magnitude of improvement. **Figure** (8) illustrates the tests results at soaking state. From this Figure, it can be observed that the ultimate bearing capacity was (205) kPa; this denotes a high decreasing in bearing capacity after soaking if compared with the dry state. This is probably referred to the high dissolution rate of gypsum and generating voids which lead to reduce the friction areas between soil particles and then reduces the shear strength, in addition to increasing the ability of soil structure to roll slide, and deform to a new structure.

Dune sand was used at dense state to get the benefit of additional frictional resistance and it was placed in steel box by raining technique. This technique is simple and easily prepared to achieve desired density of dune sand.

Dune sand was placed at a depth of (B) and geotextile layer was used at the interface between dune sand and gypseous soil. From the results of collapse tests shown in **Figure** (6), it can be noticd that the best depth which gives minimum collapse settlement is (ds=B). Therefore, this depth is used in calculating bearing capacity after replacement. The test results are shown in **Figure** (9). It can be noticed that bearing capacity increases when replacing the gypseous soil with dune sand.

The reinforcement with geotextile was used at the interface between collapsible soil and dune sand, while, the geogrid was used on two layers (at depth of 0.3B and 0.7B) within the dune sand layer, in addition to the insertion of geotextile layer at the interface. **Figure** (10) shows the relationship between the bearing pressure and settlement for gypseous soil before and after reinforcement. From **Figure** (10), it can be noticed that after reinforcement, there is a high growing in bearing capacity and reduction in settlement when compared with the unreinforced gypseous soil during soaking.

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)= qult (Layered) /qult

Where:

BCR) (Layered) =bearing capacity ratio after replacing gypseous soil with dune sand at soaked state.

BCR) (Reinforced)= qult (Reinforced) / qult (Unreinforced)

Where:

BCR) (Reinforced) =bearing capacity ratio after replacing gypseous soil and reinforcing sand at soaked state.

The value of (BCR) when replacing the gypseous soil with dune sand was (1.7), while it was (2.0) when using reinforcement materials. From the results, it can be shown that the bearing capacity increases and that the settlement was reduced as compared with unreinforced tests 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.

Figure (11) illustrates the load - settlement at 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), respectivelly. These results show that the behaviour of load – settlement curves seem to be like the general shear failure curve. This behaviour was expected because soil was in dense state.

The main problem of gypseous soil appeared during soaking because of the dissolution of gypsum. Therefore, many tests are conducted on gypseous soil during soaking under different values of eccentricity. From **Figure** (12), it can be observed that there is a high decrease in bearing capacity after soaking if compared with 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 is a small value. But, this difference increased with the increase in eccentricity vslue. Therefore, the settlement decreases in dial guage reading at center increase in dial guage reading at edge with increasing the eccentricity value.

Tables (9) and (10) show the values of experimental and theroetical bearing capacity under dry and soaked states at different values of eccentricities.

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 in effectiveness in improving the bearing capacity, and reducing the settlement value. **Figure** (13) 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 examining 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 (14) illustrates bearing pressure-settlement at edge and center curves for gypseous soil after replacing 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 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 take 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.

CONCLUSION

1.Dune sand appeared successful in improvement of collapsible soil together with geogrid and geotextile.
2.The behaviour of collapsible soil is governed by its collapse strain, depth of the collapsible soil layer, and the inundation stresses. From the results, it can be conclded the collapse settlement increases with increasing collapse strain, depth of collapsible soil layer, and inundation stresses.
3.Collapse settlement increases due to an increase of the inundation stress and depth of the gypseous soil layer and decreases due to the insertion of the reinforcement material.
4. From the reuslts, using the geogrid within dune sand in two layers in addition to the geotextile layer at the interface gives lower values in collapse settlement than the case of using one layer of geogrid.
5. For concentric loads, the value of (BCR) when repacing the gypseous soil with dune sand was (1.7) time increase in ultimate bearing capacity, while (2) time when using reinforcement materials.
6. For eccentric loads, the load carrying capacity decreases with increase of eccentricity value.
7. At high values of eccentricity (e=0.2 B) high value obtained of (BCR), that equal to (2.8) time when using gysonthetics materials on replaced soil.

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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)	$2.358*10^{-5}$
cofficient of uniformity, c_u	2.12
cofficient of curvity, 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)	$3.452*10^{-4}$
cofficient of uniformity, c_u	1.67
cofficient of curvity, 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

Figure (1) general view of testing equipment

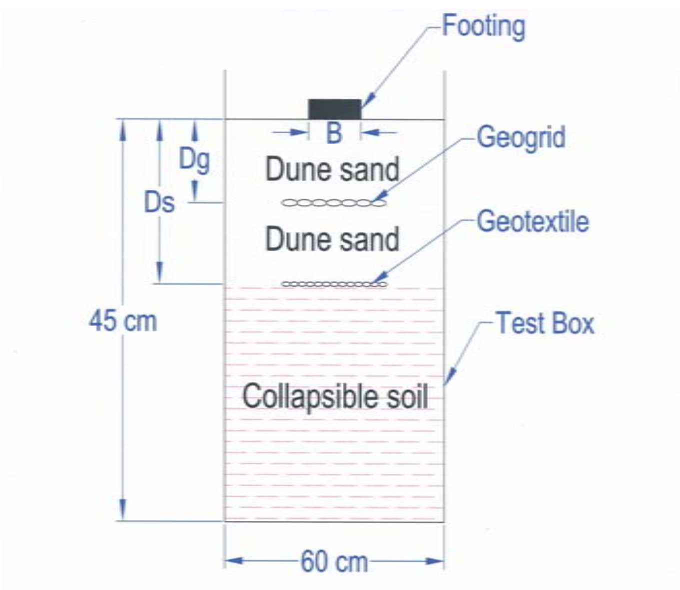

Figure (2) sketech for the test box illustrates some of the studied parameters

Table (5) properties of geogrid used, as supplied by building research center (iraq)

grid dimension, (mm)	8*6
thickness, (mm)	3.3
grid weight, (kg/m^2)	0.73
tensile strength (kn/m)	7.68

Table (6) 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

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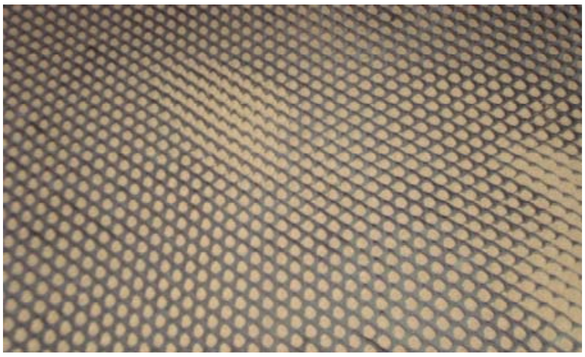


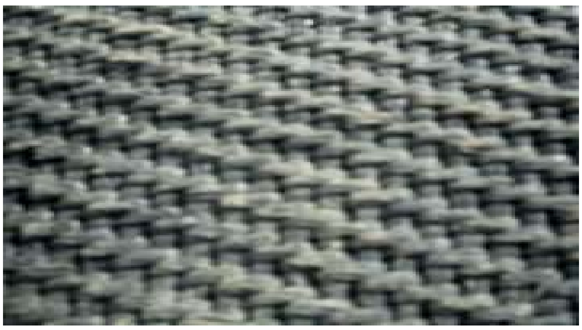


Figure (3) geogrid and geotextile used

Table (7) results of collapse settlement under different inundation stress

inundation stress, (kpa)	100	150	200
collapse settlement ratio, $\frac{\Delta_h}{B}$	0.0786	0.2448	0.4635
collapse strain, $\Delta_h / h_\circ$	1.75%	5.44%	10.3%

Table (8) relation between depth of geogrid and collapse settlement ratio

depth of geogrid	**collapse settlement ratio, ($\frac{\Delta_h}{B}$)**
0.3 b	0.1338
0.7 b	0.143
0.3band 0.7b (two layers)	0.128

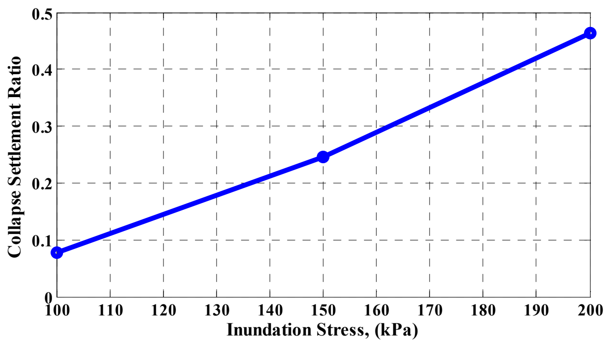


Figure (4) relationship between inundation stress and collapse settlement ratio

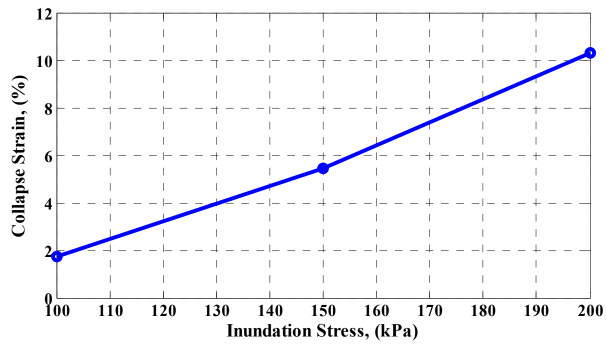


Figure (5) relationship between collapse strain and collapse settlement ratio

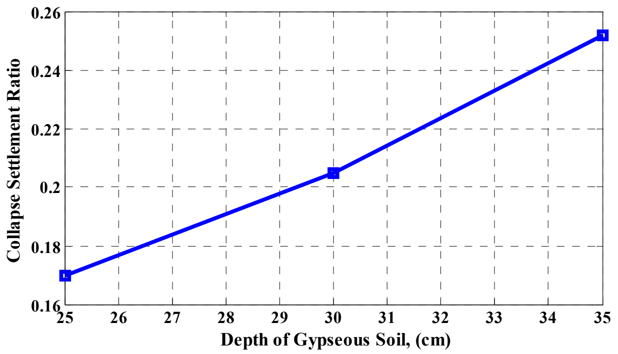


Figure (6) relationship between depth of gypseous soil and collapse settlement ratio

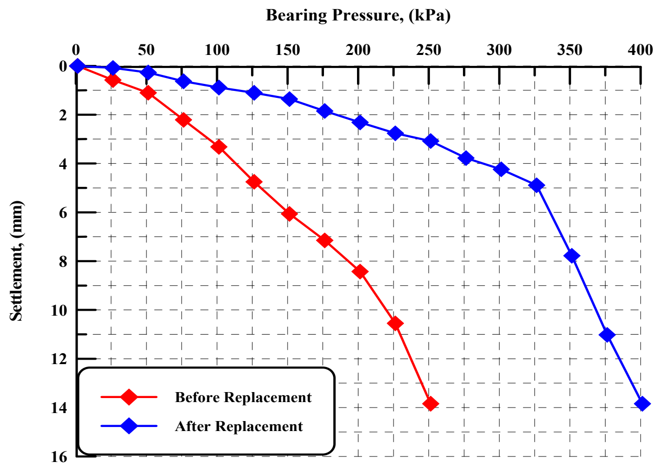


Figure (9) pressure - settlement relation of gypseous soil before and after replacement (soaked soil)

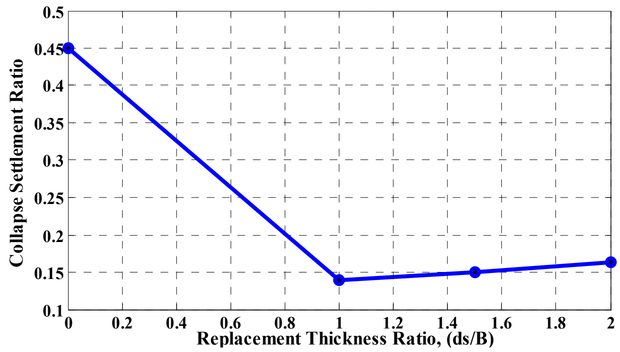


Figure (7) effect of replacement thickness ratio (ds /b) on the collapse settlement ratio within inclusion of geotextile

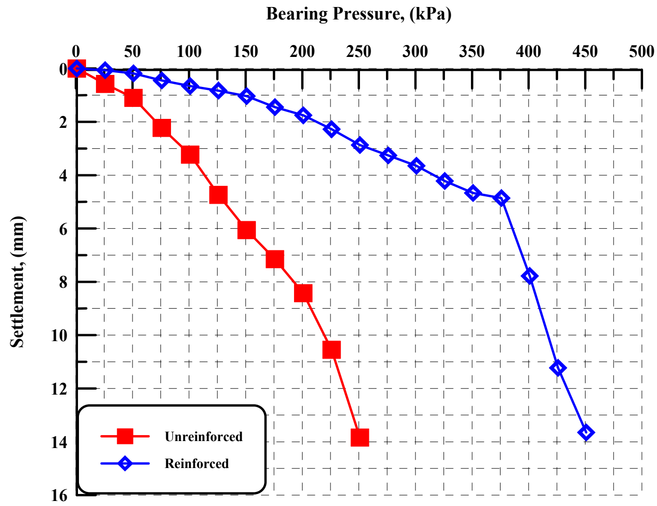


Figure (10) pressure - settlement relation of gypseous soil before and after reinforcement on replaced soaked soil

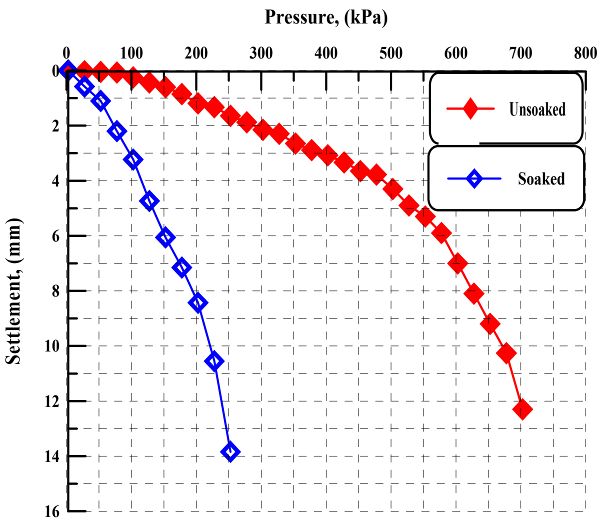


Figure (8) pressure - settlement relation for gypseous soil at dry and soaked state

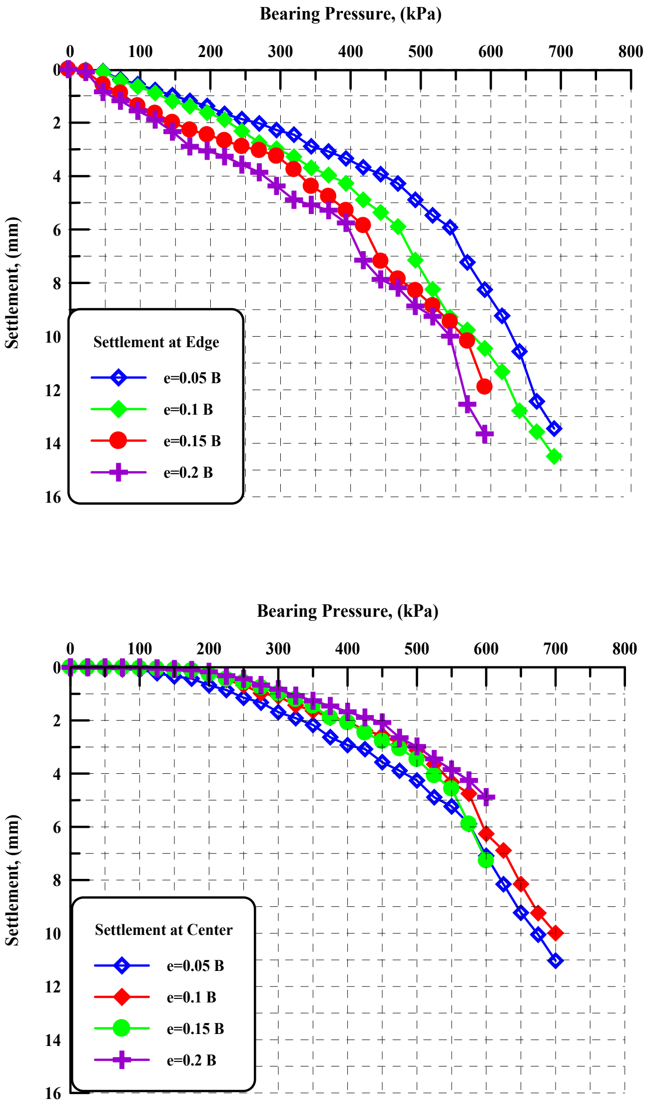


Figure (11) pressure - settlement curves at edge and center for gypseous soil at dry state

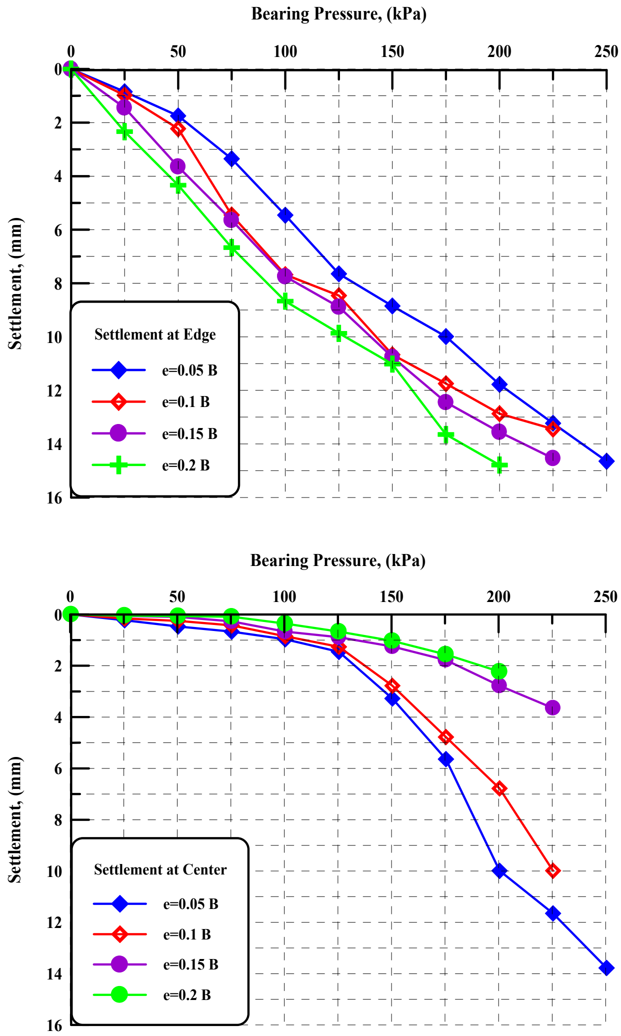


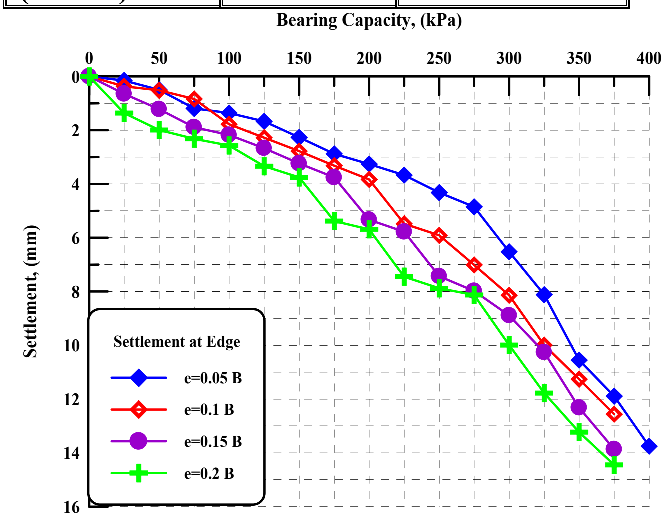
Figure (12) pressure - settlement at edge and center curves at center for gypseous soil at soaked state

Table (9) 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 (10) 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



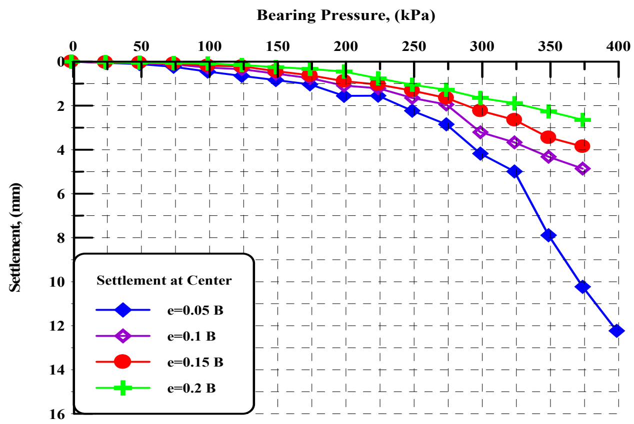
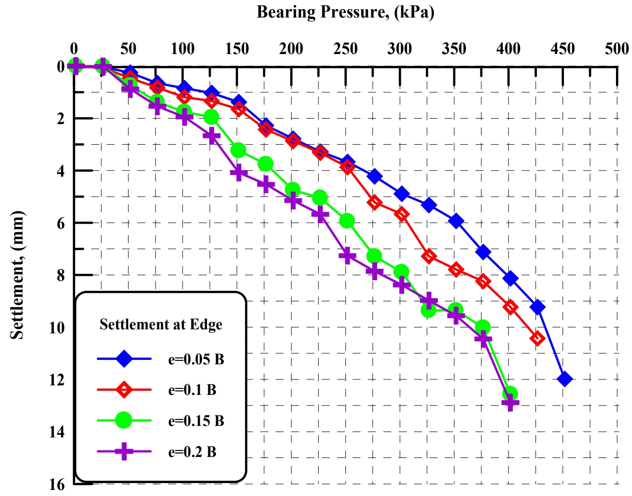


Figure (13) pressure - settlement at edge and center curves for gypseous soil after replacement



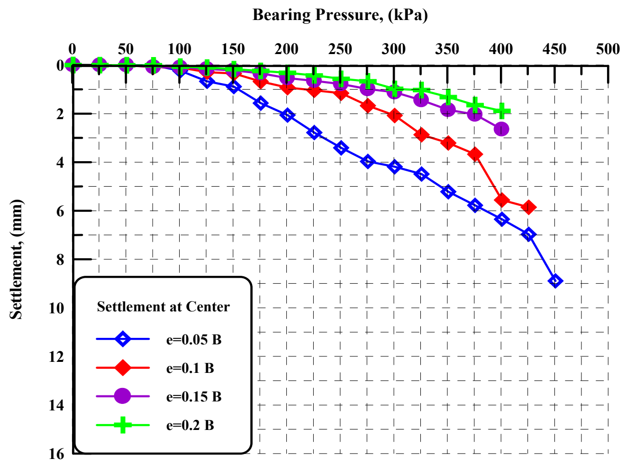


Figure (14) pressure - settlement at edge and center curves for gypseous soil after reinforcement on replaced soaked soil