



## Investigation of the Bearing Capacity and Collapsibility of Gypseous Soil Using Geotextile Reinforcement

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### HIGHLIGHTS

- The bearing capacity ratio of gypseous soil was improved using different geotextile reinforcement patterns.
- The maximum degree of improvement of gypseous model soil was achieved using a triple-layer at depth (0.5B+1B+1.5B) of geotextile reinforcement with the wet case.
- Increasing the number of geotextile reinforcement layers increases the ultimate bearing capacity values of for Gypseous Soil model.

### ARTICLE INFO

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### ABSTRACT

This study aims to increase the bearing capacity of the soil by using geosynthetics in a single, double, or triple distribution pattern. The gypseous soil samples were brought from a site near Sawa Lake in Al-Muthanna Governorate with a gypsum content of about (37%), the Soil-Model apparatus of dimensions (60 × 60 × 50) cm with the proposed square footing of dimensions (10 × 10) cm are used in the experimental program of this study. To achieve this goal, a series of (48) different model tests were used on gypseous soil subjected to vertical stress in both dry and wet (saturation) conditions. Depending on the results of load-settlement curves relationships, the ultimate bearing capacity of dry and wet gypseous soil models was determined using the Two Tangent Intersection technique. The results also showed that the number of geotextile layers and the relative density of the gypseous soil samples significantly impact the improvement of the bearing capacity of gypseous soil models. Furthermore, the results showed that the improvement ratio in bearing capacity (BCR%) for gypseous soil models tested after being reinforced with geotextile layer for dry and wet (saturation) at relative density (RD) of 30% and 60% in single, double and triple distribution pattern. The percentage of the improvement in the wet case was higher than in the dry case. It was 143 % in the wet case when using triple-layer geotextile at different depths of reinforcement, while it was 96 % in the dry case.

## 1. Introduction

Collapsible soils are regarded as problematic soils that are directly affected by the wetting process from a geotechnical and engineering geology standpoint. Large deformations, differential settlement, and collapse in engineering structures are all caused by the wetting process [1].

Gypseous soil presents a high collapse potential due to its metastable structure. It has low dry density and moisture content in its natural state due to cementation bonds and an open gypsum structure, particularly in unsaturated states or in arid or semi-arid regions. Moreover, large deformations, rapid settlement, and a high decrease in the void ratio of a metastable soil structure can occur. Large volume changes and sudden collapses occur when the soil is inundated under constant vertical stress. Soil deformation occurs due to the dissolution of the cemented gypsum bonds, which causes a pronounced increase in the compressibility of the soil. The leaching phenomenon facilitates additional softening and large and complex deformations in gypseous soil due to the movement of underground water [2]. Gypseous soil is defined as soil that contains enough gypsum (CaSO<sub>4</sub>.2H<sub>2</sub>O) to impact soil behavior. In addition, gypseous soils are categorized as collapsing soils. This effect may be attributed to gypsum display inside the soil, providing visible cementation while the soil is dry. Still, the soil disintegrates and softens when the water is interrupted, leading to actual fundamental collapsing [3]. Gypseous soil is hard and has a high bearing capacity unless water assaults it; however, gypsum softens and dissolves when water enters the soil. The dissolution of gypsum is affected by various variables, including gypsum content, temperature, air pressure, and other variables [4].

The major geotechnical difficulty these soils confront is a substantial loss of shear strength and volume reduction when exposed to extra water from rainfall, irrigation, broken water or sewer lines, and moisture percentage due to capillarity groundwater increases [5].

## 2. Materials Utilized and Technique

### 2.1 Materials Utilized

#### 2.1.1 Soil

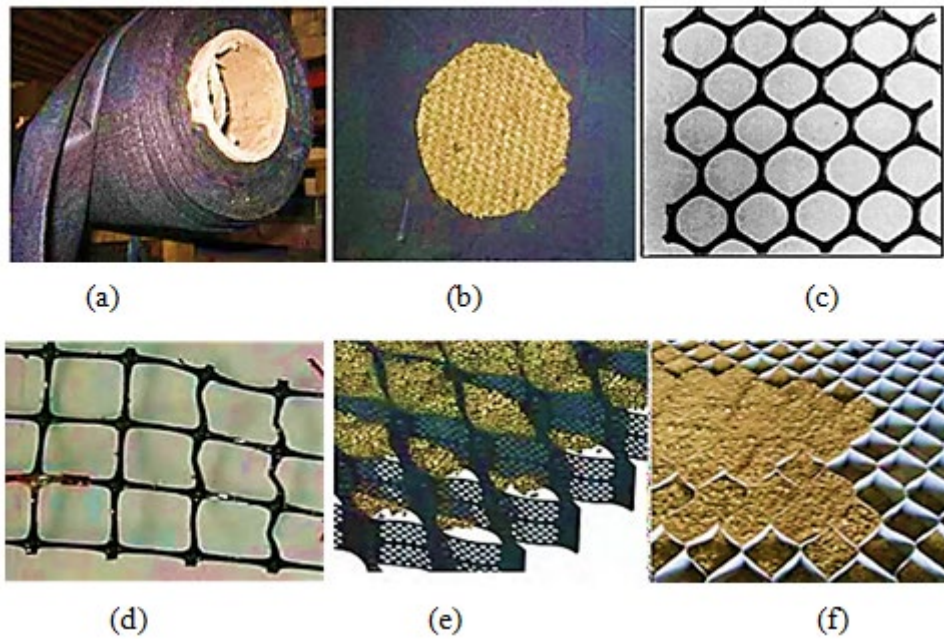
The soil was brought from a site near Sawa Lake, Al-Muthanna Governorate, from a depth of (3.0) m high under the ground surface by coordinates (31°18'42.83"N, 45°00'49.36"E). This region considers an arid area, and the soil can be defined as the medium to dense light brown silty sand with white traces of gypsum particles. The soil classification was (SP-SM) according to the Unified Soil Classification System (USCS). Table (I) lists the soil's physical and chemical characteristics.

**Table 1:** Physical and chemical properties of the soil

Property	Value	Standard
Water content, w% <sub>w</sub>	6.1	ASTM D 2216 [6]
Passing Sieve No.200, %	9.2	
Gravel content, %	5	
Sand content, %	85.8	
Silt content, %	9.2	
D <sub>10</sub> , mm	0.08	
D <sub>30</sub> , mm	0.115	ASTM D 422 [7]
D <sub>60</sub> , mm	0.31	
Coefficient of uniformity, Cu	3.87	
Coefficient of curvature, Cc	0.53	
Specific gravity, G <sub>s</sub>	2.37	ASTM D 854 [8]
Maximum Dry density (kN/m <sup>3</sup> )	16.2	ASTM D 1557 [9]
Minimum Dry density (kN/m <sup>3</sup> )	11.8	ASTM D 1557 [9]
Void ratio, e <sub>max</sub>	1.008	
Void ratio, e <sub>min</sub>	0.46	
Optimum Moisture Content%	13.5	ASTM D 1557 [9]
Cohesion( C), kPa:		ASTM D3080 [10]
For RD, 30%	4	
For RD, 60%	5.3	
Angle of Internal Friction (Ø), deg.		ASTM D3080 [10]
For RD, 30%	28.5	
For RD, 60%	30	
<b>Chemical Properties</b>		
Gypsum content, G %		37.3
Sulfite, SO <sub>3</sub> %		17.8
Total soluble solids, TSS %		12.4

#### 2.1.2 Geosynthetics reinforcement

Geosynthetics are factory-manufactured products (mainly polymers) used for geotechnical applications. They can be classified into the following types in Figure 1 ( geotextile, geogrid, geonet, geomembrane, geosynthetic clay liner, geocell, geofoam, and geocomposite). All other geosynthetics are two-dimensional or planar, except geocell manufactured in a three-dimensional honeycomb shape and geofoam in a cubic block. In addition, geotextile can be nonwoven or woven. Woven geotextile is manufactured through a weaving process in which fibers are arranged essentially at right angles in varying configurations. Nonwoven geotextile is formed by a random arrangement of fibers bonded together by heat melting, needle punching, or resin. Most geotextiles are constructed of polypropylene (PP) polymers [11].

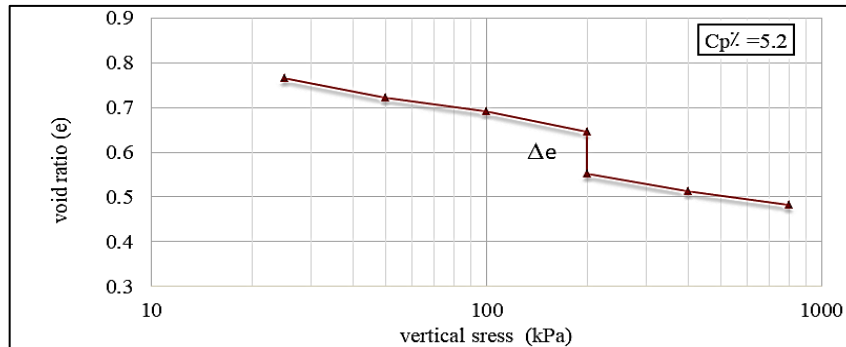


**Figure 1:** Geosynthetics are classified into several types. a) Geotextile [12]. b) Geotextiles made of jute [13]. c) Geogrid Circular [14]. d) Geogrid Square [15]. e) Geocell with perforations [16]. f) Geocell [17]

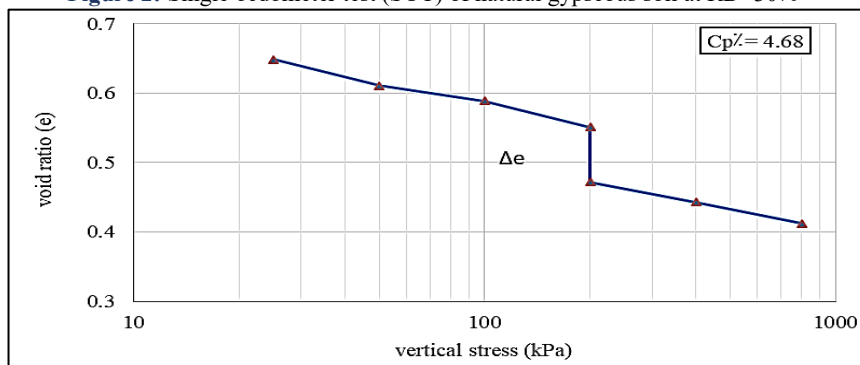
## 2.2 Collapse Potential

### 2.2.1 Single oedometer test

Figures (2) and (3) show the results of the Single Oedometer Test (SOT). This test shows that the soil sample has been gradually loaded in natural settings until it achieves a vertical pressure (200 kPa). Then, it allowed the soil sample to soak in water for 24 hours, then added leveling was on record at 200 kPa pressure levels due to the soaking process observed. According to equation (2.1), the value of collapse potential ( $C_p$ ) of gypseous soils was (5.2) at a relative density of 30% with an initial void ratio of 0.84, so according to the Table (2.2), it is classified as a Trouble soil. On the other hand, the collapse potential ( $C_p$ ) of gypseous soils was (4.68) at a relative density of 60% with an initial void ratio of 0.68, so it is classified as a Moderate Trouble soil.



**Figure 2:** Single oedometer test (SOT) of natural gypseous soil at RD=30%



**Figure 3:** Single oedometer test (SOT) of natural gypseous soil at RD =60%

### 2.2.2 Double oedometer test

Figures (4) and (5) show the results of the test Double Oedometer (DOT). It can be noted that the double collapse test was done on two samples of gypseous soil. The first sample was examined after being soaked in water, while the second was tested in its natural state. It can be seen that stress has been linked to an increased chance of collapse. The sudden disintegration of the soil structure when water is introduced at a stress level of 200 kPa is responsible for the fast reductions in the void percentage. When connections between soil particles and products dissolve during soil test settling, the quantity of voids expands due to the expansion of water. The value of the double collapse test was (8.37 percent) at 30 %relative density and (6.67) at 60 % relative density.

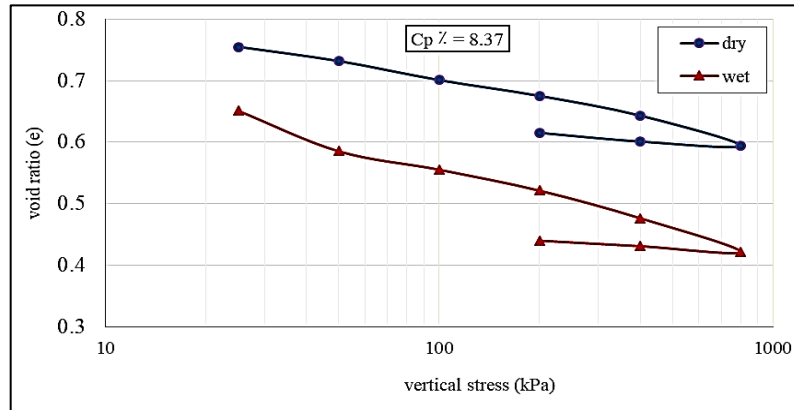


Figure 4: Double Oedometer Test of natural gypseous soil at RD=30%

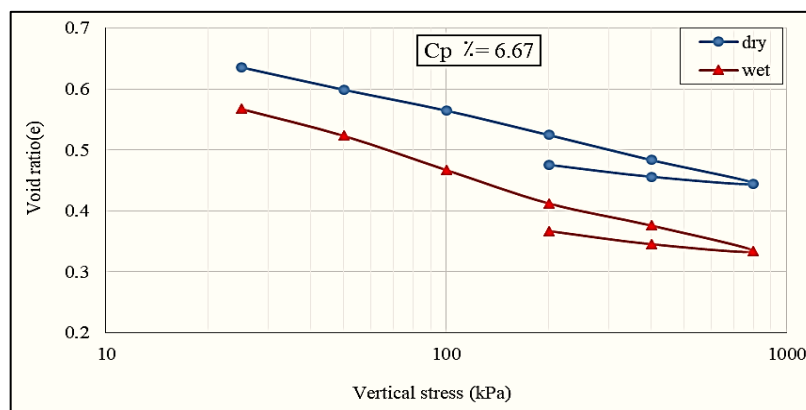


Figure 5: Double Oedometer Test of natural gypseous soil at RD=60%

### 2.3 Sample Preparation and Test Arrangement

The soil samples are produced in a test box model for natural soil with a dry unit weight of (12.84 kN/m<sup>3</sup>), which corresponds to a relative density of 30%, and with a dry unit weight of (14.09 kN/m<sup>3</sup>), which corresponds to a relative density of 60%. To obtain the requisite dry unit weight, the box is divided into layers with 50 mm height for each layer and an area of (60 x 60) cm until the entire height of 50 cm is reached. The total number of layers is ten, and the weight of the sandy soil for each layer was (23.11 and 25.36) Kg with a dry unit weight of (12.84 kN/m<sup>3</sup>), (14.09 kN/m<sup>3</sup>), equivalent to a relative density of 30%, 60% respectively. Every layer is stored using a level plane and then leveled with a manual compactor instrument until the appropriate density is obtained for all layers, then for the wet state. The model sample was soaked in water for about one day. The soaking process involves lifting water from the base of the container to the top of the soil surface.

The compression (i.e., bearing capacity) test is demonstrated using the ASTM D1194-94 test procedure of non-repetitive static plate load. . With a dry gypseous soil model, the bearing capacity of various layers of geotextile reinforcement is tested. The gypseous soil was placed in (5) cm depth layers in each test condition. The density position was determined using the raining approach. The gypseous dirt was carefully put on two opposing sides to ensure a comparable density. After applying the last coat, gently level the surface with a straight edge. The foundation was placed in the middle of the test box in x and y trends in unexpected loading, and the two appealing holders using dial gauges were then connected to the box's edge. The load is applied continuously by the hydraulic jack. The load cell provided the applied force, while the dial gauges calculated the settlement. Continuously apply load following ASTM D1194-94 until failure occurs. The failure was revealed by a rise in the settlement at a constant load when the water was allowed to move into the soil in an upward direction (from bottom to top of the model) in the soaking state. This was used to simulate site conditions when groundwater flow is upward-directed through soil layers, as shown in Figure (6).



Figure 6: Loading system

### 3. Results and Discussion

These results explained determining ultimate bearing or allowable bearing capacity using two tangent intersections for dry and wet cases. Furthermore, the bearing capacity ratio (BCR) for gypseous soil models was determined after being treated with a geotextile layer for dry and wet (soaking) at RD=30% and 60%. In addition, the effect type of the relative density on the gypseous soil behavior was studied. Also, these results showed the effect of the geotextile’s number and depth of reinforcement layers on the improvement of the bearing capacity ratio of gypseous soil at different patterns. These results are categorized as follows:

#### 3.1 Effect Number of Geotextile Reinforcement Layers on Ultimate Bearing Capacity of Gypseous Soil Models

##### 3.1.1 The results at dry state with relative density (30%) and (60%)

Figures (7) and (8) explain the relationship between the stress and the settlement for dry gypseous soil models at (30%) and (60%), which are treated with single, double, and triple geotextile in the single-layer phase pattern of geotextile reinforcement the best improvement in bearing capacity at depth equal 0.5 B, in the double layer phase pattern of geotextile reinforcement the best improvement in bearing capacity at depth (0.5B+1B), while in the triple-layer phase pattern of geotextile reinforcement the best improvement in bearing capacity at depth (0.5B+1B+1.5B). The triple-layer phase pattern of geotextile reinforcement at depth (0.5B+1B+1.5B) gives a higher value of ultimate bearing capacity equal to 310 kPa at a relative density of 30% while equal to 490 kPa at a relative density of 60%. This means when the number of geotextile reinforcement layers increases, the ultimate bearing capacity increases for dry gypseous soil.

##### 3.1.2 The results at wet (soaking) state with relative density (30%) and (60%)

Figures (9) and (10) explain the relationship between the stress and the settlement for wet gypseous soil models at (30%) and (60%), which are treated with single, double, and triple geotextile in the single-layer phase pattern of geotextile reinforcement. The best improvement in bearing capacity at depth equals 0.5 B. The best improvement in bearing capacity at depth is in the double-layer phase pattern of geotextile reinforcement (0.5B+1B). While in the triple-layer phase pattern of geotextile reinforcement, the best improvement in bearing capacity at depth (0.5B+1B+1.5B) .in the triple-layer phase pattern of geotextile reinforcement at depth (0.5B+1B+1.5B) gives a higher value of ultimate bearing capacity equal to 135 kPa at relative density 30% while equal to 280 kPa at relative density 60%. This means when the number of geotextile reinforcement layers increases, the ultimate bearing capacity increases for wet gypseous soil.

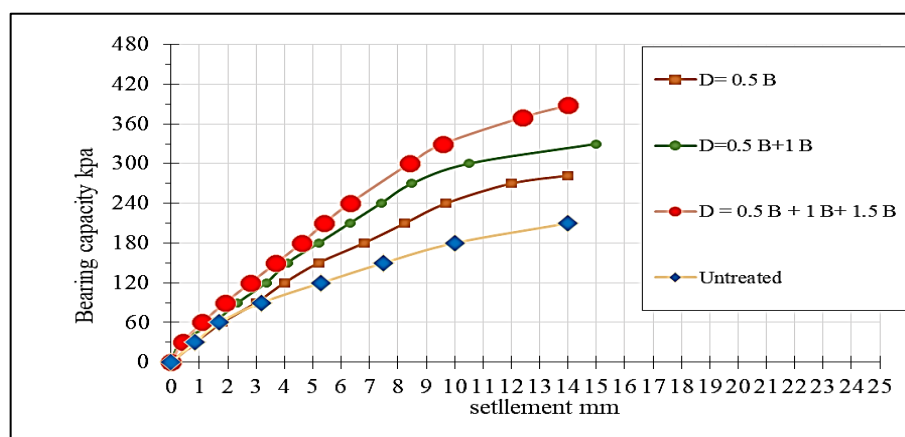


Figure 7: The Relation between the stress and the settlement for Gypseous Soil in dry-State experimental Results at RD 30% [the best treated with single, double, and triple geotextile]

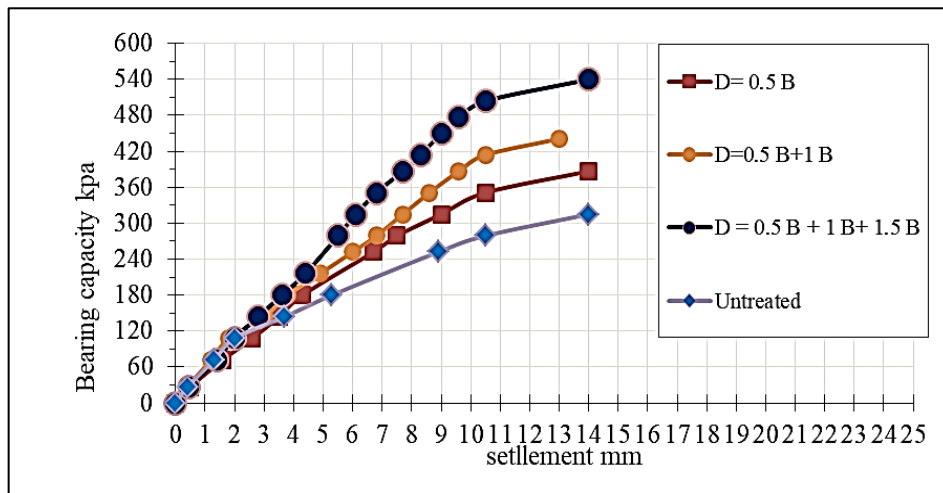


Figure 8: The Relation between the stress and the settlement for Gypseous Soil in dry State experimental Results at RD 60% [the best treated with single, double, and triple geotextile]

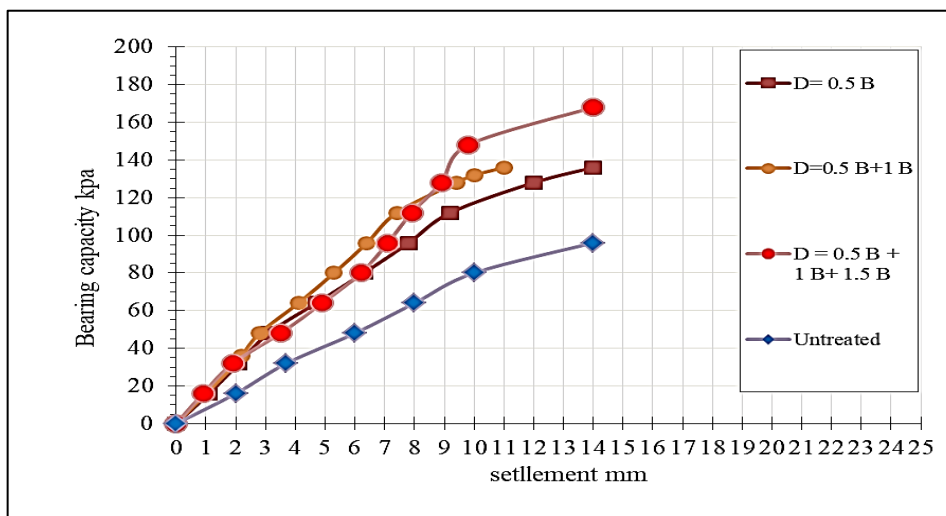


Figure 9: The Relation between the stress and the settlement for Gypseous Soil in a wet State experimental Results at RD 30% [ the best treated with single, double, and triple geotextile]

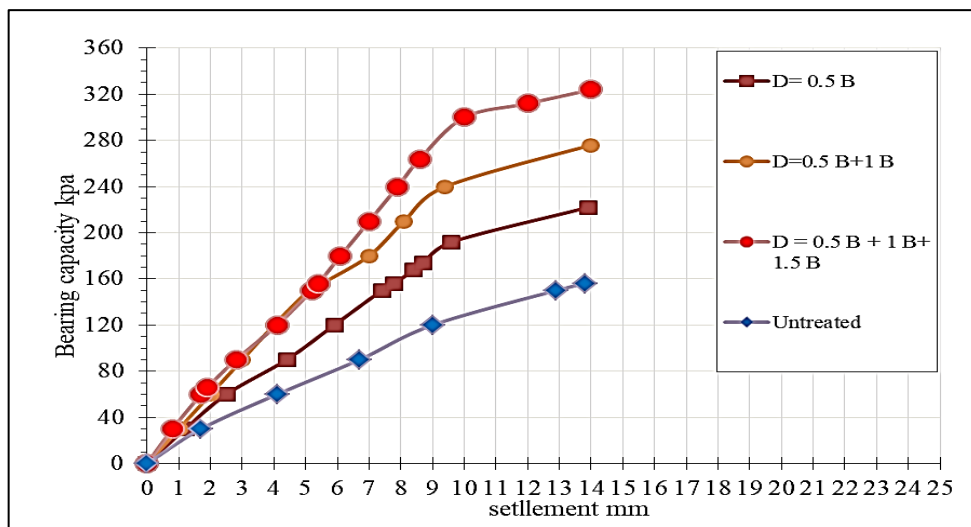


Figure 10: The Relation between the stress and the settlement for Gypseous Soil in a wet State experimental results at RD 60% [the best treated with single, double, and triple geotextile]

### 3.2 Effect Number of Geotextile Reinforcement Layers on Improvement Bearing Capacity Ratio (Bcr) % of Gypseous Soil Models

#### 3.2.1 The results at dry state with relative density (30%) and (60%)

Figure (11) provides experimental work for dry gypseous soil models. It explains how geotextile reinforcement at relative densities of 30% and 60% improved the bearing capacity ratio on the (BCR) of gypseous soil for varied patterns. Furthermore, it explains that increasing the number of geotextile reinforcement layers increases the improvement ratio of Bearing Capacity (BCR) for dry gypseous soil models. In addition, it also explains that the pattern with a single layer at depth (0.5B), double layer at depth (0.5 B+1B), and triple-layer at depth (0.5B+1B+1.5B) was the best improvement.

At a relative density of 30%, the best improvement (BCR) in the geotextile reinforcement single-layer phase pattern was 50% at a depth equivalent to 0.5 B. In comparison, the best improvement (BCR) in the double layer phase pattern of geotextile reinforcement was 75% at depth (0.5B+1B), and the best improvement (BCR) at depth (0.5B+1B+1.5B) was 93 %percent in the triple-layer phase pattern.

At a relative density of 60% in the single-layer phase pattern of geotextile reinforcement, the best improvement (BCR) at a depth equal to 0.5 B was 32%. The best improvement (BCR) at depth (0.5B+1B) was 56% in the double-layer phase pattern of geotextile reinforcement. While in the triple-layer phase pattern of geotextile reinforcement, the best improvement (BCR) at depth (0.5B+1B+1.5 B) was 96%.

#### 3.2.2 The results at wet ( soaking) state with relative density (30%) and (60%)

Figure (12) shows experimental work for wet gypseous soil models. It explains the improvement bearing capacity ratio (BCR ) of gypseous soil using geotextile reinforcement at relative density 30% and 60% for different patterns. It explains an increase in the improvement bearing capacity ratio (BCR ) for dry gypseous soil model with an increase of several geotextile reinforcement layers. In addition, it was the best improvement in the pattern with a single layer at depth (0.5B), a double layer at depth (0.5 B+1B), and a triple-layer at depth (0.5B+1B+1.5B).

At a relative density of 30% in the single-layer phase pattern of geotextile reinforcement, the best improvement bearing capacity ratio (BCR )at depth equal to 0.5 B was 69.2%. On the other hand, in the Double layer phase pattern of geotextile reinforcement, the best improvement (BCR )at depth (0.5B+1B) was 84.6%. Finally, in the triple-layer phase pattern of geotextile reinforcement, the best improvement bearing capacity ratio (BCR )at depth (0.5B+1B+1.5B) was 107.69%.

At a relative density of 60% in the single-layer phase pattern of geotextile reinforcement, the best improvement (BCR ) at a depth equal to 0.5 B was 56.5%. The best improvement (BCR )at depth (0.5B+1B) was 106.9% in the double-layer phase pattern of geotextile reinforcement. While in the triple-layer phase pattern of geotextile reinforcement, the best improvement (BCR ) at depth (0.5B+1B+1.5B) was 143.4%.

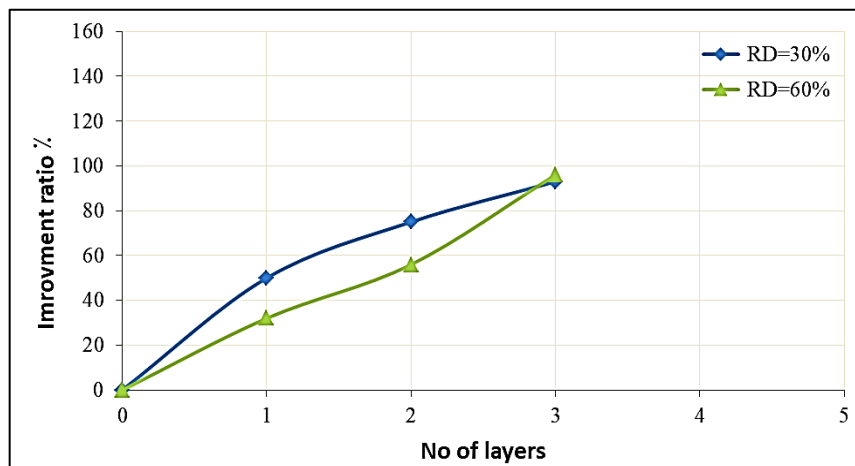


Figure 11: The relationship between improvement bearing capacity ratio (BCR) % and the numbers of geotextile reinforcement layers at the dry case

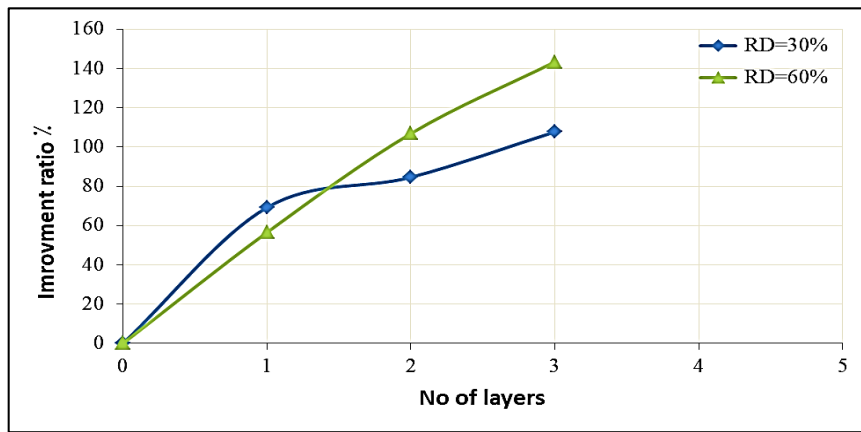


Figure 12: The relationship between the improvement bearing capacity ratio (BCR) % and the number of geotextile reinforcement layers at the wet case

Figure (13) compares the improvement ratio in bearing capacity (BCR%) values and the pattern in relative densities of 30% and 60% in dry conditions depending on the data obtained from models' tests in the dry state. It can be seen that the improvement ratio BCR% is better in the case of single and double reinforcement at a relative density of 30%. Still, the improvement ratio is better at the density relative to 60%. This value increases when using triple layers, which may be why the improvement in weak soil appears more clearly and better than in strong soil.

Figure (14) compares the improvement ratio in bearing capacity (BCR%) values and patterns in relative densities of 30% and 60% in wet conditions depending on the data obtained from the results of models' tests in the wet state. It can be seen that the improvement ratio BCR% is better in the case of single reinforcement at a relative density of 30%. Still, the increasing value when using double and triple layers, at which the improvement ratio is better at the density relative to 60%, maybe why weak soil improvement appears more clearly and better than in strong soil.

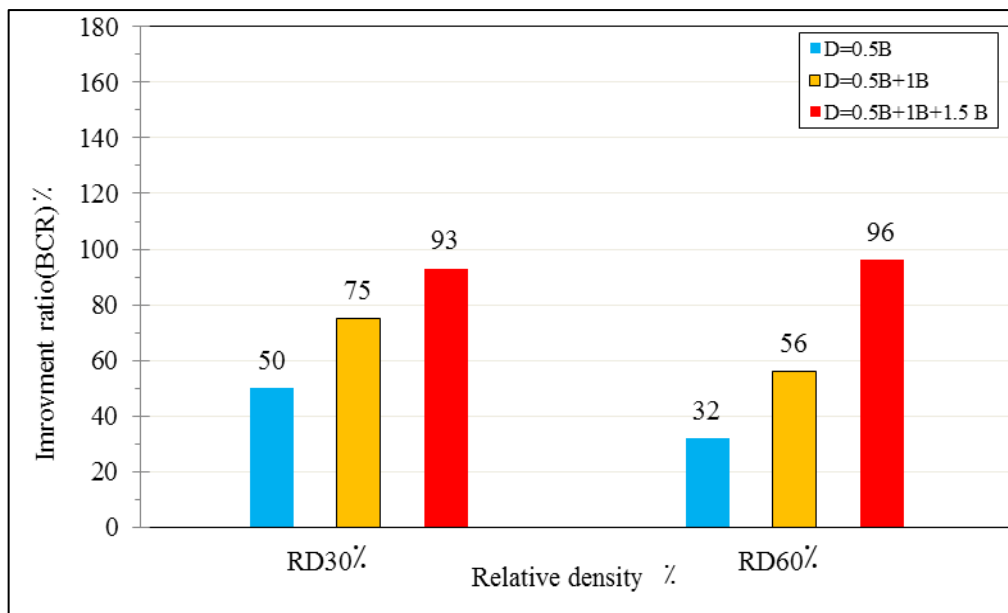
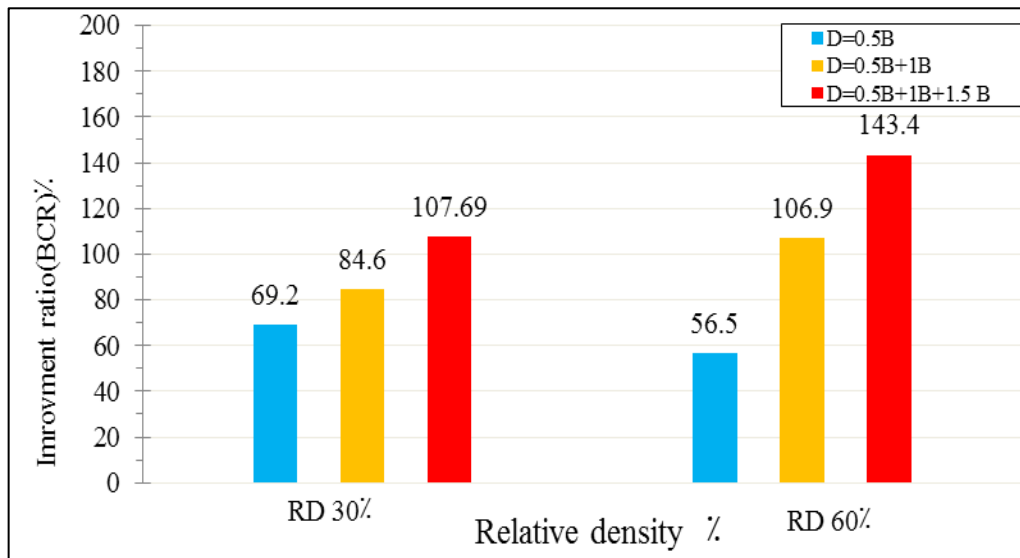


Figure 13: The improvement ratio in bearing capacity (BCR%) and relative density at 30%,60% relationship dry state (the best improvement for different patterns by single, double, triple-layer )





**Figure 14:** The improvement ratio in bearing capacity (BCR%) and relative density at 30%, 60% relationship wet state (the best improvement for different patterns by single, double, or triple-layer)

#### 4. Conclusion

- 1) The ultimate bearing capacity values of the Gypseous Soil model were achieved by the use Two Tangent Intersection Method in the dry case and are higher than in the wet case.
- 2) The bearing capacity Ratio (BCR) % of gypseous soil was improved using different geotextile reinforcement patterns.
- 3) The maximum degree of improvement of gypseous model soil was achieved when Using a triple layer at depth (0.5B+1B+1.5B) of geotextile reinforcement with the wet case was equal to 143 % at RD=60% while was equal to 96 % with a dry case at RD=60%.
- 4) Increasing the number of geotextile reinforcement layers increases the ultimate bearing capacity values of for Gypseous Soil model.
- 5) Increasing the number of geotextile reinforcement layers increases the improvement ratio of Bearing Capacity (BCR) for gypseous soil models.
- 6) The effective depth was at the pattern with a single layer at depth (0.5B), with double-layer at depth (0.5 B+1B), and a triple-layer at depth (0.5B+1B+1.5B) had the best improvement.

#### Author contribution

All authors contributed equally to this work.

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#### Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

#### Conflicts of interest

The authors declare that there is no conflict of interest.

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