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THE EFFECT OF USING LAYERED GEOGRID REINFORCEMENT ON THE COLLAPSIBILITY OF GYPSEOUS SOILS

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Abstract: The geotechnical engineering considers the gypseous soils as collapsible soils. The existence of these soils causes problems for the structures, because of the dissolution and filtration of the gypsum from soil texture by the flow of water through the soil mass, this problem was the focus of attention of many researchers over the years to improve the properties of these soils. This research aims to study the effect of using geogrid reinforcement to reduce the collapse of gypseous soils upon soaking. A series of laboratory models tests in addition to routine laboratory tests carried out on three soils with different gypsum contents. The soils were brought from AL-Najaf district, the first soil S1 was taken from 0.5 meter below the ground surface with high gypsum content (26%). The second soil S2 was taken from 4 meter below the ground surface, with Slight gypsum content (6.9%), the third soil S3 was artificially prepared, by mixing the first soil S1 with the second soil S2 to get the required moderate gypsum content. A new technique manufactured locally for this work and a series of tests including dry and soak tests carried out using steel container (280×280×250) mm. The soils were placed in steel container at their field densities. The single layer geogrid reinforcement test was conducted by placing the geogrid layer at three different depths for all soils [(Depth of the reinforcement layer, D = 0.25 width of foundation, B), (D = 0.5B) and (D = 0.75B)]. The study includes also the effect of number of reinforcing layers (N) on the collapse behavior of gypseous soils. The models were reinforced with N=1, N=2 and N=3 (the vertical distance between geogrid layers, Z=0.25B). The study includes the observation of collapsibility of soaked gypseous soils at stress level of 100 kPa. A strip footing of (270×40×30) mm dimensions was taken as a testing model. This footing was placed at the center of the top surface of the bed soil. For all testing models, the footing was loaded gradually up to 100 kPa, after 24 hours, the corresponding settlement was recorded. Then, the soil is soaked for 24 hours and the generated settlement recorded under the same stress level 100 kPa. The results showed that the most effective depth for single layer reinforcement is at (D=0.25B) for the three soils, which gives a collapse reduction factor (CRF) of about (28.5%, 29.41%, 30.43%) for soils (S1, S2, S3) respectively. The effective number of reinforcement layers was (N=3: D=0.25B: Z=0.25B), which gives (CRF) of about (54.08%, 82.35%, 69.56%) for (S1, S2, S3) respectively compared with unreinforced model.

Keywords: *Improvement of Gypseous Soils, Geogrid Reinforcement, Strip Footing, Collapsibility.*

تأثير استعمال طبقات من مشبكات التسليح البلاستيكية على انهيارية الترب الجبسية

الخلاصة: ان هندسة تقنية التربة تعتبر التربة الجبسية من الترب القابلة للانهيار مما تسبب أضرار جسيمة للمباني المشيدة عليها بسبب تفكك وترشيح الجبس من نسيج التربة نتيجة لتدفق المياه خلال كتلة التربة، وهذه المشكلة أصبحت محط اهتمام العديد من الباحثين على مر السنين لتحسين خصائص هذه التربة. في هذا البحث تم دراسة تأثير استعمال مشبكات التسليح البلاستيكية على انهيارية الترب الجبسية عند الغمر بالماء بتنفيذ سلسلة من الفحوصات المختبرية لنماذج (جافة واخرى مغمورة بالماء) قبل وبعد التسليح على ثلاث انواع من الترب من محافظة النجف ذات محتوى جبسي مختلف (التربة الاولى S1 من عمق 0.5 متر ذات محتوى جبسي عالي 26%، والتربة

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الثانية S2 من عمق 4 متر ذات محتوى جبسي قليل 6.9% وتم تحضير التربة الثالثة S3 ذات المحتوى الجبسي المتوسط من خلطهما معا) في جهاز خاص اعد لهذا البحث يتألف من صندوق حديدي بأبعاد mm (250×280×280) مع اساس شريطي ابعاده (30×40×270) mm تم وضعه في مركز نموذج التربة المرصوصة في صندوق جهاز الفحص (جميع النماذج المستخدمة تم رصها عند كثافتها الحقلية) وتم اعتماد اجهاد 100 kPa في جميع الفحوصات. عند التسليح بطبقة واحدة، تم استخدام ثلاث اعماق: (B، عرض الاساس D=0.25 ، عمق الطبقة الاولى من التسليح)) و (D=0.5B) و (D=0.75B)). تضمن البحث ايضا دراسة تأثير عدد طبقات التسليح (N=1, N=2, N=3) وكانت المسافة الرأسية بين طبقات التسليح (Z=0.25B). من نتائج التسليح بطبقة واحدة تم الحصول على اعلى مقدار لمعامل تخفيض الانهيارية (CRF) عند العمق (D=0.25B) حيث حققت (28.5%, 29.41%, 30.43%) للترب الثلاثة (S1, S2, S3)على التوالي، و من نتائج التسليح بعدة طبقات تم الحصول على اعلى مقدار لمعامل تخفيض الانهيارية عند N=3 و (Z=0.25B) ، حيث حققت (54.08%, 82.35%, 69.56%) للترب الثلاثة (S1, S2, S3)على التوالي.

1. Introduction

Gypseous soil is that contains a sufficient percentage of gypsum ($CaSO_4.2H_2O$) so that it impacts the behavior of soil. The specific gravity of Gypsum is (2.32) and its solubility in water is (2gm/liter) at 20^oC , but this amount of dissolving may increase if the water contains some salts [1] , [2] and [3] .

In the natural state, the presence of gypsum in the soil considers as a binder between the soil particles.

However, the soil is classified collapsible because when the water acts, the gypsum will start dissolving leaving voids leading to a significant change in the soil structure, great losses in strength, sudden increase in compressibility and continuation in deformation [4], [5] and [6] .

Many problems have appeared in the various structures that have been constructed in gypseous soils in Iraq. For example, Samara tourist hotel, Karbala elevated water tank [6], [7], and [8], Mosul Dam, where the soil beneath the dam suffers from the continuity of cavities generating due to the continuous dissolution of gypsum under the dam [9]. For this reason and because gypseous soils cover about (30%) of Iraq area [10], this research is a try to study the improvement of the characteristics of these soils.

2. Previous Studies

Many efforts have been done to improve the properties of gypseous soils by using physical or chemical methods, which are almost of high cost. Therefore, the use of natural materials and residual of industrial materials to improve the properties of gypseous soil becomes of more benefit [11].

The earth reinforcement is one of the important economic methods is used to improve the soil in terms of low cost and ease of construction compared with other techniques. Geogrids is one of the materials that used in the reinforcement, and is distinguished from other materials, as it is having high tensile modulus, with a long service life, lightweight and open structure [12].

This open structure increases the interlock between the soil and the reinforcement, which is very important to increase the tensile and shear strength [13].

The advanced resistance of friction in the surface of the interlock between the soil and the reinforcement is highly significant.

3. Experimental Works

3.1. *Materials Used*

3.1.1. *Soil*

A series of laboratory models tests in addition to routine laboratory tests were carried out on three soils with different gypsum contents. The first soil S1 was brought from AL-Najaf district from 0.5m below the ground surface with gypsum content of (26%) which represents high gypsum content [14].

The second soil S2 was brought from AL-Najaf district from 4m below the ground surface with gypsum content of (6.9%) which represents slightly gypsum content [14]. The third soil S3 was artificially prepared by mixing the first soil S1 with the second soil S2 to get the required moderate gypsum content of (16.15%) [14].

3.1.2. *Reinforcement*

The reinforcement used is geogrid made of polyethylene. Geogrid properties as tested by Material Engineering Department in Mustansiriyah University are listed in Table (1).

Table (1). Geogrid properties

Roll Dimensions, (m)	30*2
Grid Dimension, (mm)	8*6
Thickness, (mm)	3.3
Grid Weight, (kg/m^2)	0.72
Tensile Strength (kN/m)	7.66
Stress–strain modulus kN/m^2	4399

3.2. *Soil Testing*

3.2.1. *Chemical and physical tests*

The two soils (S1 & S2) were oven dried at (45-50) ^{o}C, (Note: all the physical tests were conducted on this dry temperature due to the presence of gypsum in the soils to avoid losing of crystal water if the temperature increased higher than 50^{o}C), [3].

Then, the soils were crushed by the grindery and sieved through No. 4 sieve (4.75 mm). Soil S3 was prepared by mixing S1 & S2 to get the required moderate gypsum content.

A series of chemical and physical tests were conducted to obtain the soils properties, see Figures (1), (2), (3), (4) and Tables (2) and (3). In Table (2), data were conducted by The Environmental Engineering Department in Mustansiriyah University.

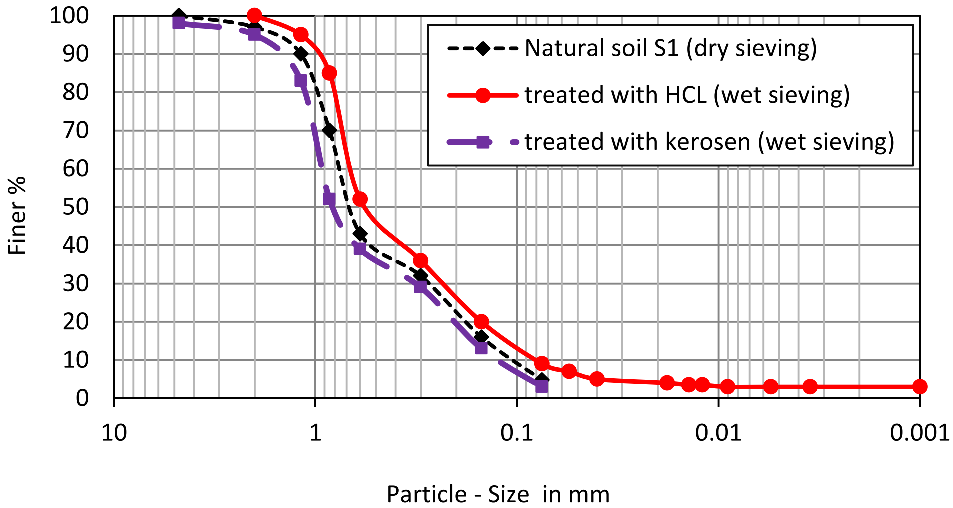


Figure (1). Grain size distribution for S1

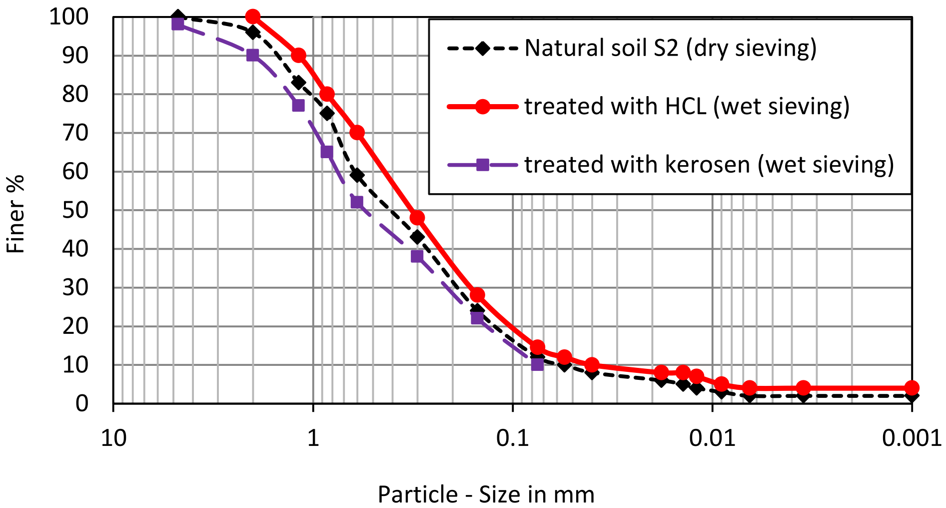


Figure (2). Grain size distribution for S2

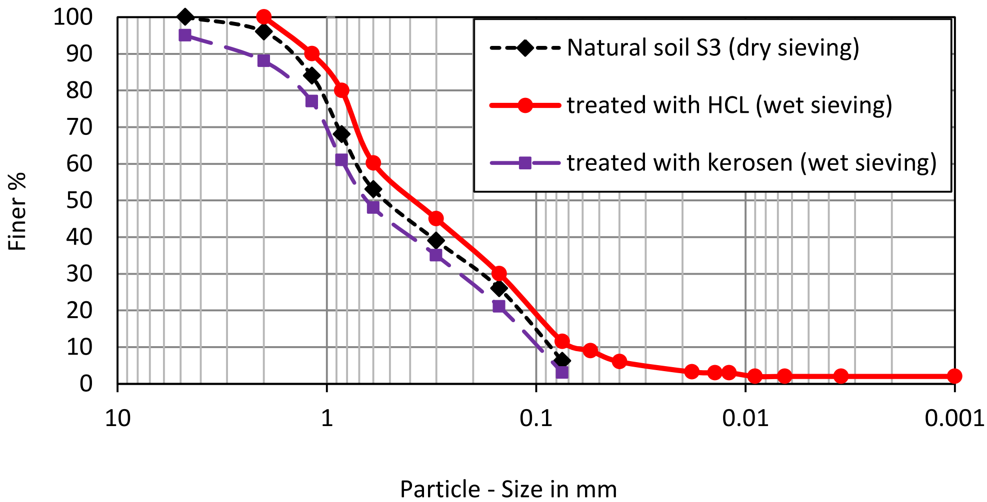


Figure (3). Grain size distribution for S3

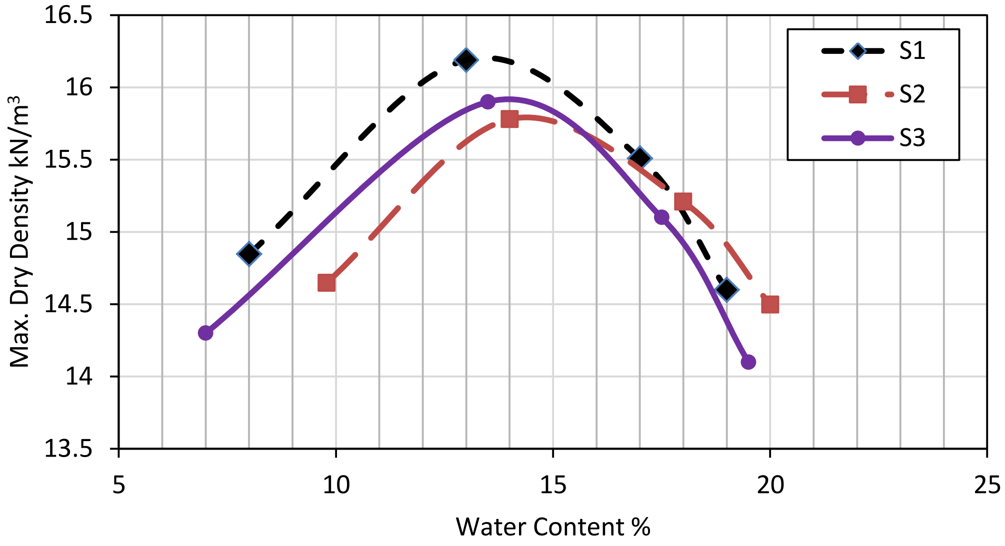


Figure (4). Compaction Curves for Soils S1, S2 and S3

Table (2). Chemical Properties of soils

Chemical Composition	Type of Soil		
	S1	S2	S3
Gypsum Content (%)	26	6.9	16.15
T.S.S. (%)	28.48	8.36	18.55
SO_3 (%)	12.05	3.15	7.45
PH	7.87	7.21	7.43

Table (3). Results of physical tests

Soil Property	Type of Soil			Specification of Test
	S1	S2	S3	
Depth (m)	0.5	4	Mix of S1&S2	--------------------------
Specific Gravity (Gs) (Kerosene method)	2.44	2.51	2.48	BS 1377:1975, Test No.6(B), Head,1980
Field unit weight(γ_{field}) (kN/m^3)	14.42	15.33	Mix of S1&S2 used 14.87	BS 1377, Test No. 15 (E)
Initial Void Ratio (e_o)	0.839	0.801	0.824	--------------------------
Moisture content (W_C)%	8.7	10	9.4	ASTM (D2216-80)
Liquid Limit (L.L) %	26	38	33	(ASTM 2216-80) BS 1377: 1975, Test No. 2 (A)
Plastic Limit (P.L)%	19	24	22	(ASTM 2216-80) BS 1377: 1975, Test No.3
Plasticity Index (P.I)%	7	14	11	--------------------------

Table 3. Continued

Soil Property		Type of Soil			Specification of Test
		S1	S2	S3	
Soil Classification (*)		SP-SC	SC	SP-SC	ASTM 422-79 (wet sieving) by HCL ASTM 422-63 hydrometer method
Fine soil Percent (%)		9	25	11.5	------------------------
Uniformly Coefficient (C_u)		9.37	--------	8.8	-------------------------
Coefficient of Curvature (C_Z)		0.88	--------	0.55	-------------------------
Compaction Characteristics Maximum Dry Unit Weight (γ_{dmax}) (kN/m^3)		16.19	15.78	15.9	(Proctor Test) (ASTM D698 -78).
Optimum Moisture Content (O.M.C.) %		13	15	14	
Direct Shear Tests	C	2.5	5	3.7	ASTM D3080 -72
	Φ	31.7	31	31.3	

(*) According to Unified Soil Classification System.

3.2. 2. *Collapsibility test (CT)*

In the Double Oedometer Test suggested by Jennings and Knight [15], two similar specimens are placed in consolidometer cells, one of which is flooded with water, while the other is kept in its natural water content.

Both specimens are stressed beginning from (25 kPa) and left for (24 hrs). Then, the test is continued following the standard procedure of doubling the applied loads every (24 hrs) .After that, the collapse potential (CP) was calculated by using Eq. (1) given by Kezdi [16].

$$CP = \Delta e / (1+e_o) \quad (1)$$

CP = Collapse Potential

Δe= change in voids ratio upon wetting

e_o= Initial voids ratio

Figure (5) and (6) show the results of this test for the soils S1 & S2 at their field densities.

The collapse potential of soil S3 (which is prepared by mixing S1 & S2 to get the required moderate gypsum content of 16.15%) is determined on samples compacted statically to the chosen density of 14.87 kN/m3 using a loading machine operating at a very slow speed.

However, [17] stated that the method of compaction has only a minor influence on the collapse behavior.

Figure (7) shows the result of collapsibility test for the soil S3 at chosen density of 14.87 kN/m^3.

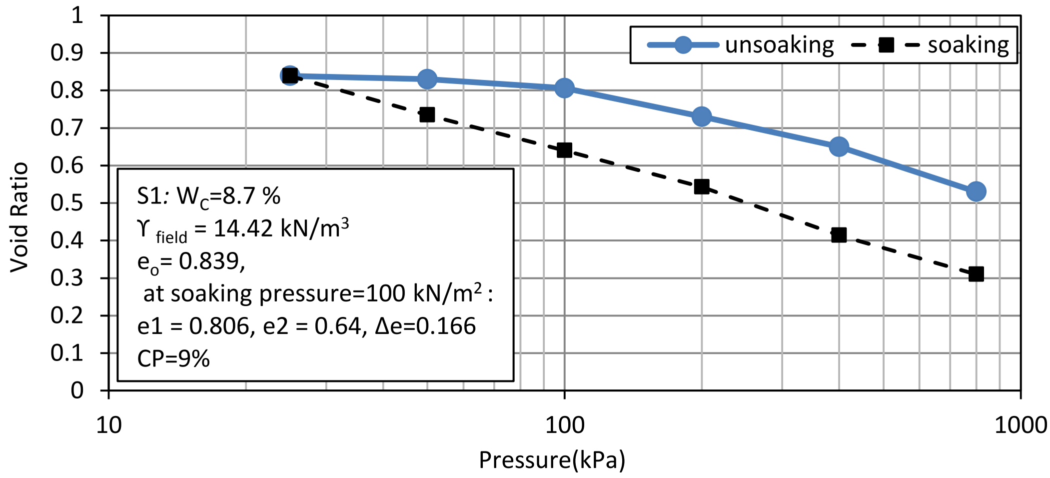


Figure (5). Typical results of collapse test (CT) for soil S1

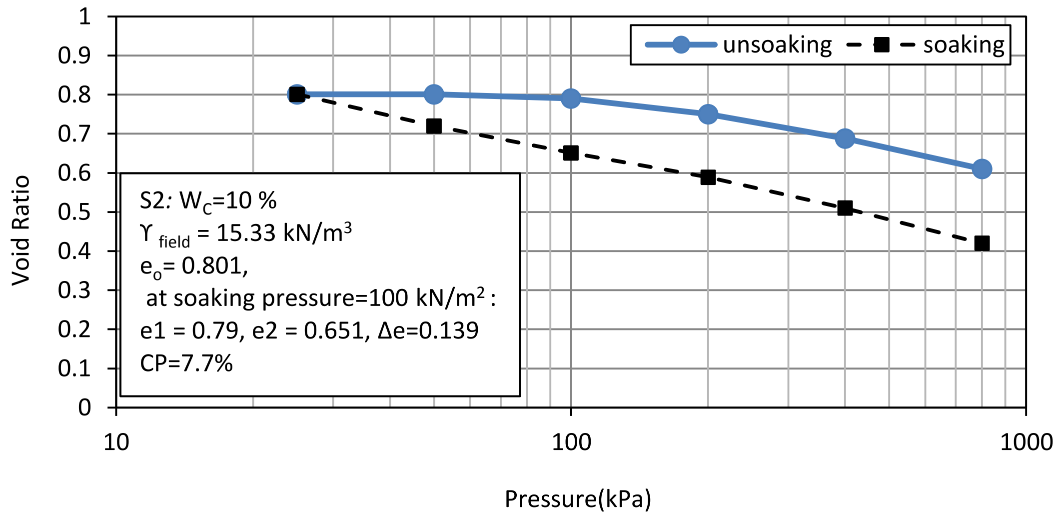


Figure (6). Typical results of collapse test (CT) for soil S2

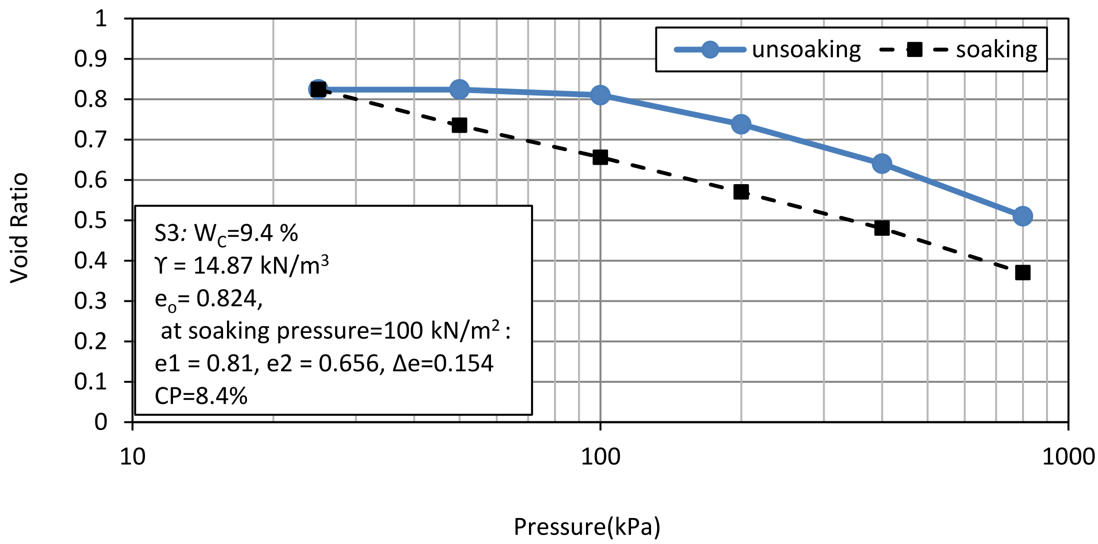


Figure (7). Typical results of collapse test (CT) for soil S3

3.3. *Description of the Engineering Box Test (EBT)*

The model box used in this research is made of steel plates of 3mm thickness, with internal dimensions of (250 x 270 x 250) mm. The front side of the box consists of glass plate of 10 mm thickness. The soil is placed inside the box at its natural moisture content. The box is placed on steel base mounted on steel foundation that should be maintained balanced to prevent any inclination of the system.

The footing is of dimensions (270 x 40 x 30) mm and made of rigid oak wood and polished. The upper face of the footing is covered with two thin steel plates, the upper plates have a suitable hole at the center of the footing used to convert the load to the footing by the use of footing ram, the footing model is placed on the center of the box, loads are converted to the footing by a loading ram with diameter of 30 mm, this loading ram is connected with balanced bar of (330 x 40 x 58) mm through a hole. The datum bar has a steel square plate fixed centrally at its top that used for setting of the loads and contains two holes.

Two vertical steel rods fixed through these holes to support the datum bar and maintain it's balanced during the loading. The lower parts of these rods are lubricated smooth surface having the datum bar attachment which moves vertically. The two rods are joined with the steel foundation, see Figure (8). The settlement of the footing at its both sides are measured by means of dial gauges (0.01) mm sensitivity**.**

Before soaking After soaking

Figure (8). Testing equipment

3.4. *Unreinforced and Reinforced Soil Placement*

The soils are first crushed with a hammer to small sizes and they were dried at (40-45) ^{o}C, then further crushing is carried out using a grinding machine. Next, the soil is mixed with water at its initial moisture content by the electrical mixer. The soil is compacted inside the box at its initial moisture content in (5) layers each of 40 mm height to satisfy its field density. In the case of reinforced soil, the soil is compacted at several layers depending on the position and the number of the reinforcement layers.

The positions of the first reinforcement layer are shown in Figure (9). The position and the number of the reinforcement layers are shown in Figure (10).

D=0.25B D=0.5B D=0.75B

Figure (9). The positions of the first reinforcement layer

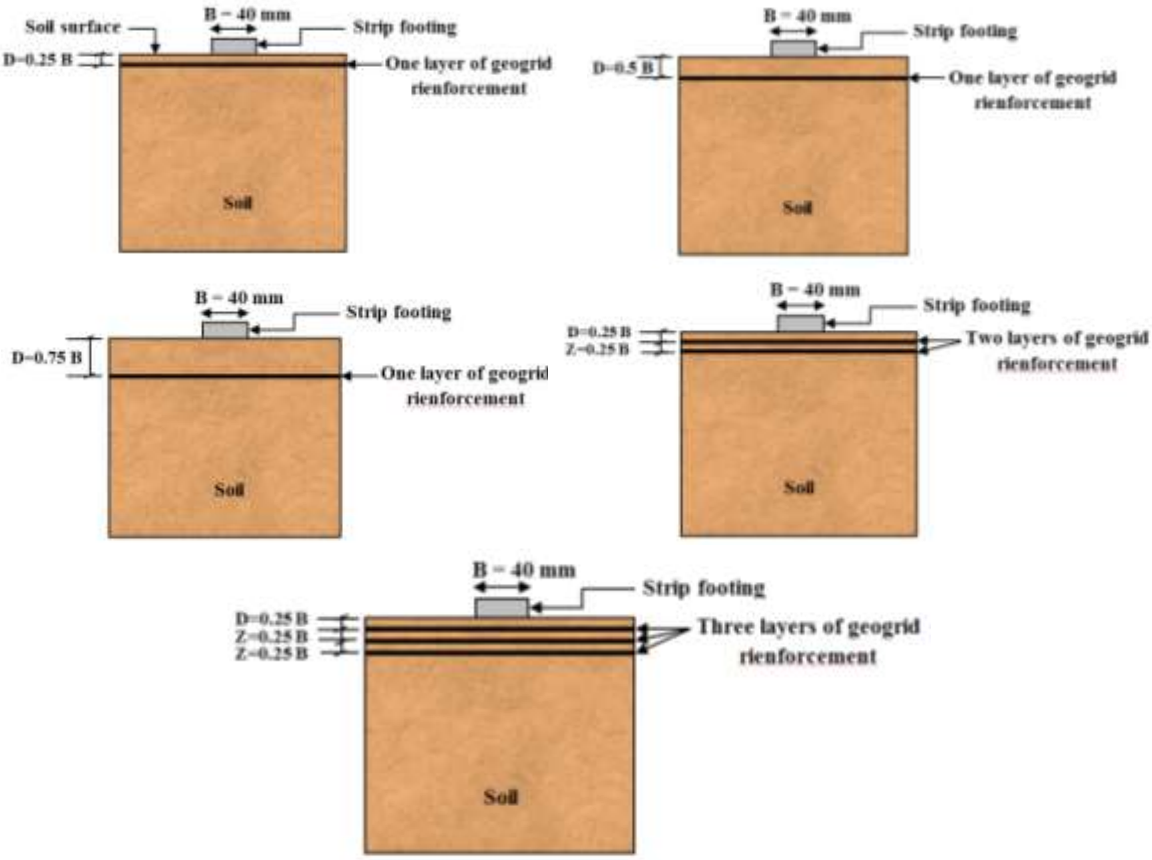


Figure (10). The position and the number of the reinforcement layers

4. Testing Procedure

In this test, the load is applied in regular increments. After the application of each incremental, enough time is allowed for settlement to occur. When the settlement becomes negligible (no change in the dial gauge reading is observed), another incremental load is applied. Similar procedure of plate load test by static load is shown in Lambe [18]. After applying the pressure of (100 kN/m^2), the soil is maintained for 24hrs and the settlement at this pressure was recorded. Then the soil is soaked for 24hrs by rising the water from the base of the box to the surface of the soil by using pipe connected to a cylindrical small tank with a proper head of (550 mm),The dial gauge reading at the end of the collapse is recorded and the collapse potential of the soil can be calculated.

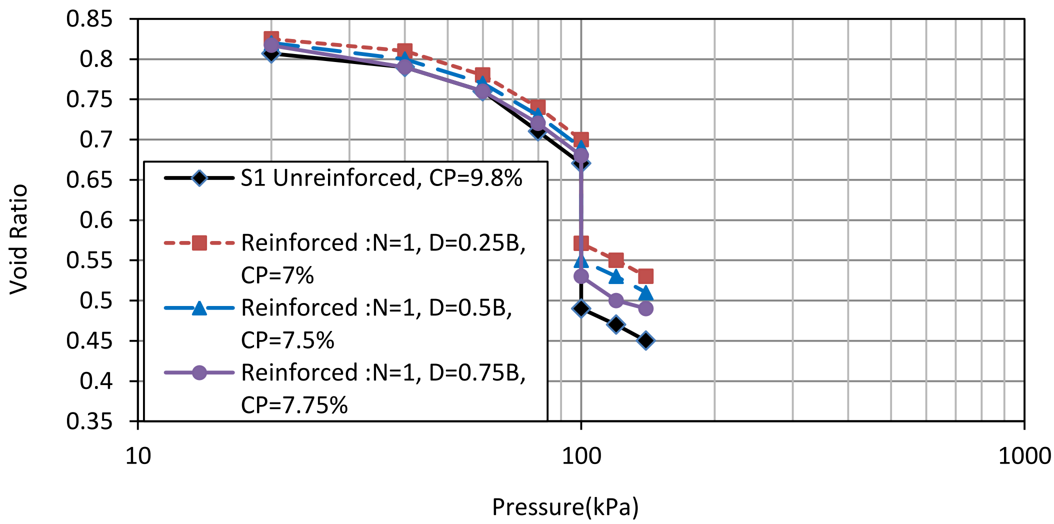
5. Results and Discussion

A series of collapse tests were carried out on the three gypseous soil improved by reinforcement with different number of layer and at the different depths. The soaked pressure for all cases is 100 kN/m^2.

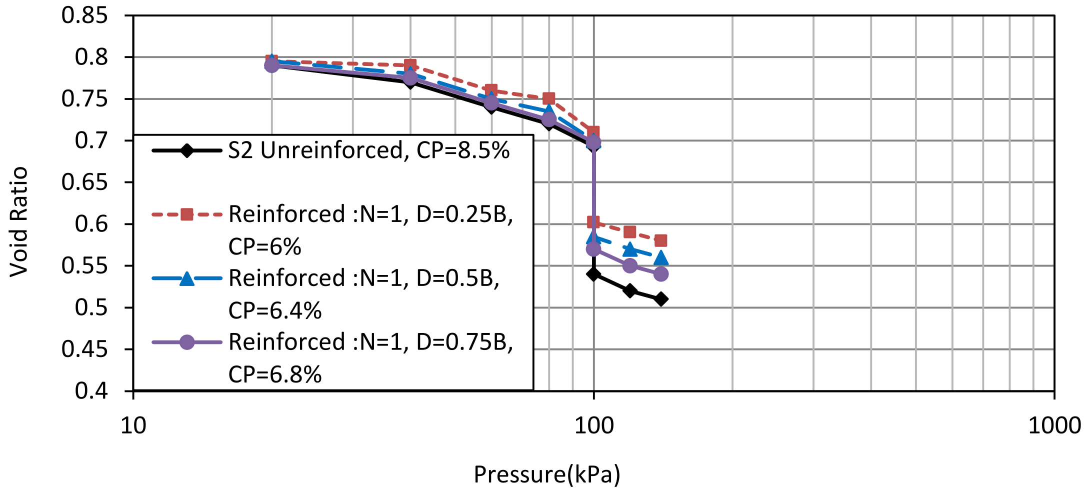
The Engineering Box Test (EBT) of soils at unreinforced state may be considered as a reference to measure the magnitude of improvement. When gypseous soils is loaded up to 100 kN/m^2 and soaked for (24) hours, the high values of collapse potential are observed in both tests :double oedometer and EBT .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 reduces the shear strength. In addition to the increasing of the ability of soil structure to roll slide, and deform to a new structure. This is also found by [13] and [19].

5.1. *Case One: The Effect of Depth of the Single Reinforcement Layer (D) on Collapse Potential Values*

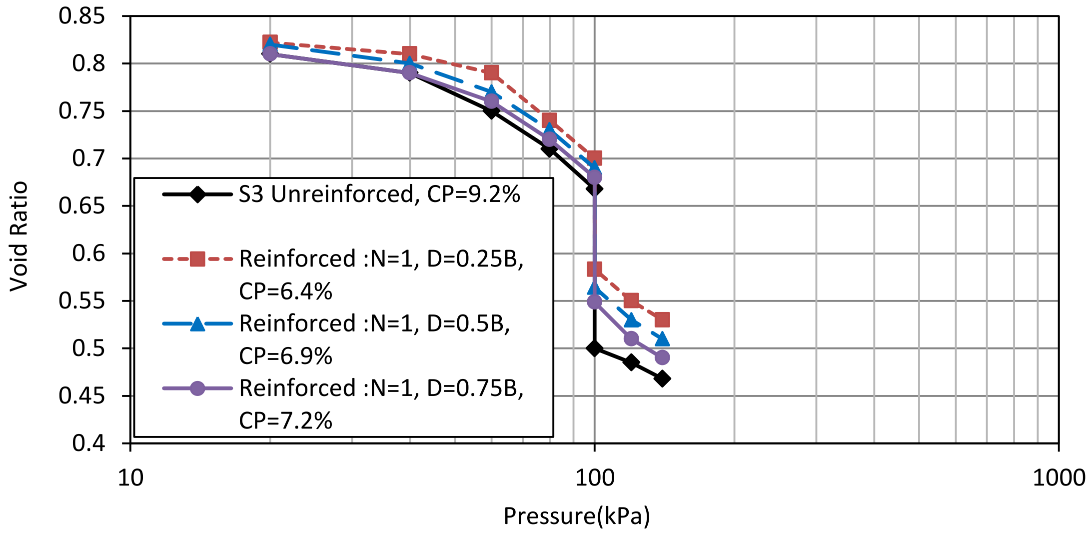
The relationship between the pressure and the void ratio was undertaken, by using log stress analysis for a strip foundation with single layer reinforcement. The results are shown in Figure (11), (12) and (13).



Figures (11). The relationship between the pressure and void ratio for soil (S1)



Figures (12). The relationship between the pressure and void ratio for soil (S2)

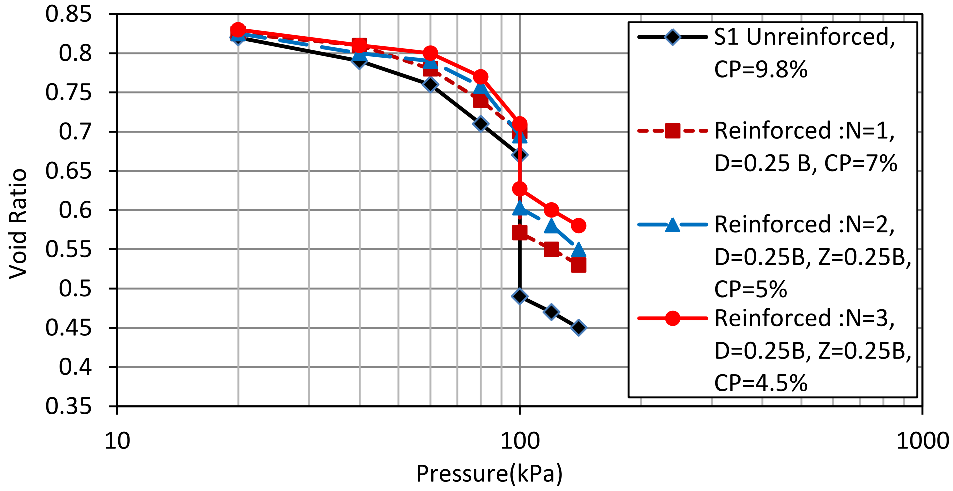


Figures (13). The relationship between the pressure and void ratio for soil (S3)

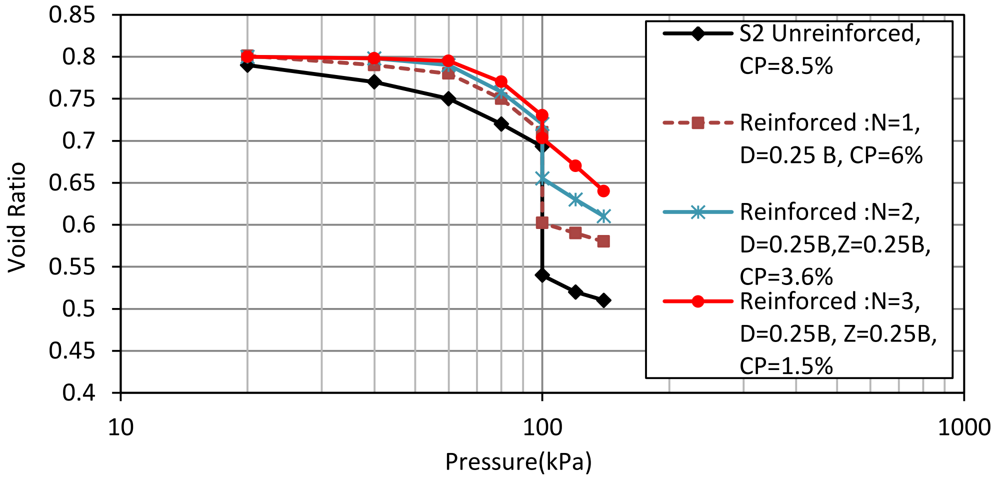
The results indicate that, the collapse potential decreases at all cases of reinforcement position. Also, it decreases as the ratio D/B decreases for all soil types. Perhaps the reason for this is that when the reinforcement approaching the loading surface, it will be within the zone of large stresses generated from loading. This makes the reinforcement takes much more of the stresses generated within the soil mass, which leads to further improvement in collapsibility. In other words, at the greater depth from loading surface, the stresses generated by the load will decrease so that, the reinforcement in a bigger depth will carry small part of the stresses subjected to the soil leading to a reduced improvement in collapsibility.

5.2. *Case Two: The Effect of Number of Reinforcement Layers (N) on Collapse Potential Values*

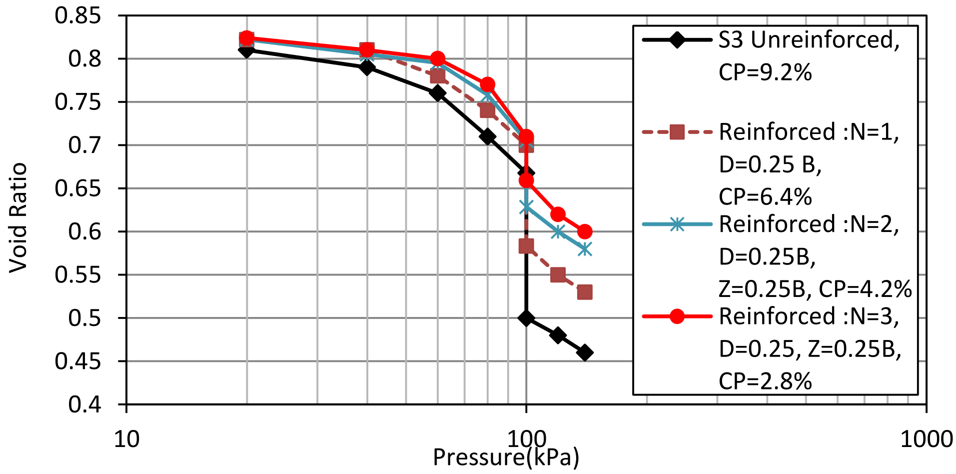
From the results of case one, the small distance between the reinforcement layers is selected as (Z/B=0.25). The Log Stress – Void Ratio Relation curve for the strip foundation supported by differing numbers of reinforcement layers with D/B = 0.25, Z/B =0.25 and N=1,2,3 is shown in Figure (14), (15) and (16).



Figures (14). The relationship between the pressure and void ratio for soil (S1)



Figures (15). The relationship between the pressure and void ratio soil (S2)



Figures (16). The relationship between the pressure and void ratio for soil (S3)

The results show that the collapse potential decreases at all cases of reinforcement layers number, but it decreases as the number of reinforcement layers increases for all soils types. This may be attributed to the same reason mentioned in the case one. Also, the presence of geogrid reinforcement in the spaces generated from the dissolution of gypsum plays a role in maintaining interdependence soil texture. Table (4) shows the collapse potential values of unreinforced and reinforced soils (EBT).

Table (4). Collapse potential values of unreinforced and reinforced soils (EBT)

Type of Soil	Unrein-forced Soil	Reinforced Soil				
		N=1, D=0.25B	N=1, D=0.25B	N=1, D=0.25B	N=2 D=0.25B Z =0.25B	N=3 D=0.25B Z =0.25B
S1	9.8 Trouble	7 Trouble	7.5 Trouble	7.75 Trouble	5 Trouble	4.5 Moderate trouble
S2	8.5 Trouble	6 Trouble	6.4 Trouble	6.8 Trouble	3.6 Moderate trouble	1.5 Moderate trouble
S3	9.2 Trouble	6.4 Trouble	6.9 Trouble	7.2 Trouble	4.2 Moderate trouble	2.8 Moderate trouble

It is noted that the rate of improvement in collapsibility using geogrid reinforcement was the best for the soil S2, which contains the largest proportion of fine grained soil (clay). Most probably, the using of geogrid reinforcement reduced the collapsibility that was caused by two reasons here, the first is the dissolution of gypsum and the second is the sliding of fine particles due to the dissolution of gypsum. This seems remarkable in the S3, which contains the proportion of fine grained soil less than the S2 and more than the S3.

5.3. *Final Analysis*

To make a comparison between the result obtained from collapse test before and after using geogrid reinforcement, a collapsibility reduction factor (CRF) is adopted as in the following formula**:**

$$CRF = \left(1 - \frac{\text{Collapse potential of natural soil}}{\text{Collapse potential of reinforced soil}}\right) x\ 100 \qquad (2)$$

The values of this factor are summarized in Table (5), (6) and (7) for soil S1, S2 and S3 respectively.

Table (5). Values of collapsibility reduction factor for soil (S1)

Test Type	Unrein-forced Soil (S1)	Reinforced Soil (S1)				
		N=1, D=0.25B	N=1, D=0.5B	N=1, D=0.75B	N=2 D=0.25B Z=0.25B	N=3 D=0.25B Z=0.25B
CT	0	22.2	16.6	13.8	44.4	50
EBT	0	28.5	23.4	20.9	48.9	54.08

Table (6). Values of collapsibility reduction factor for soil (S2)

Test Type	Unreinforced Soil (S2)	Reinforced Soil (S2)				
		N=1, D=0.25B	N=1, D=0.5B	N=1, D=0.75B	N=2 D=0.25B Z=0.25B	N=3 D=0.25B Z=0.25B
CT	0	22.07	16.88	11.68	53.2	80.5
EBT	0	29.41	24.7	20	57.64	82.35

Table (7). Values of collapsibility reduction factor for soil (S3)

Test Type	Unreinforced Soil (S3)	Reinforced Soil (S3)				
		N=1, D=0.25B	N=1, D=0.5B	N=1, D=0.75B	N=2 D=0.25B Z=0.25B	N=3 D=0.25B Z=0.25B
CT	0	23.8	17.85	14.28	50	66.66
EBT	0	30.43	25	21.73	54.34	69.56

Figures (17), (18) and (19) show the improvement as collapsibility reduction factor (CRF) in gypeuos soils (S1, S2 and S3) with respect to double oedometer (CT) and Engineering Box Test (EBT)

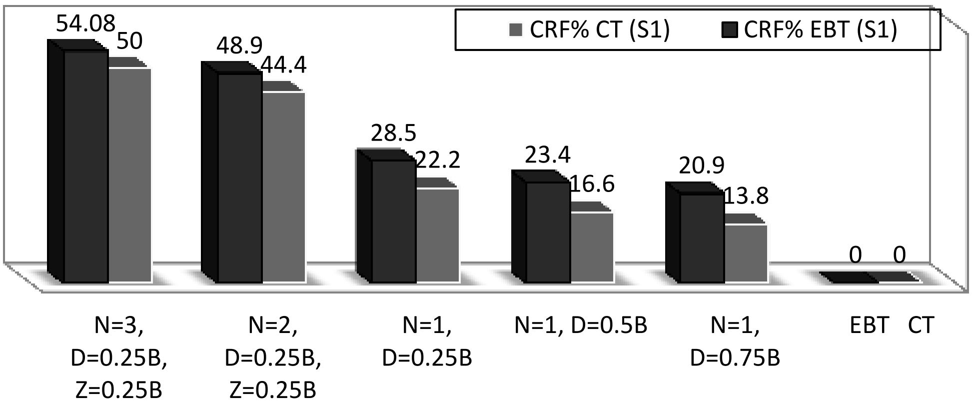


Figure (17). The improvement as (CRF) in soil (S1)

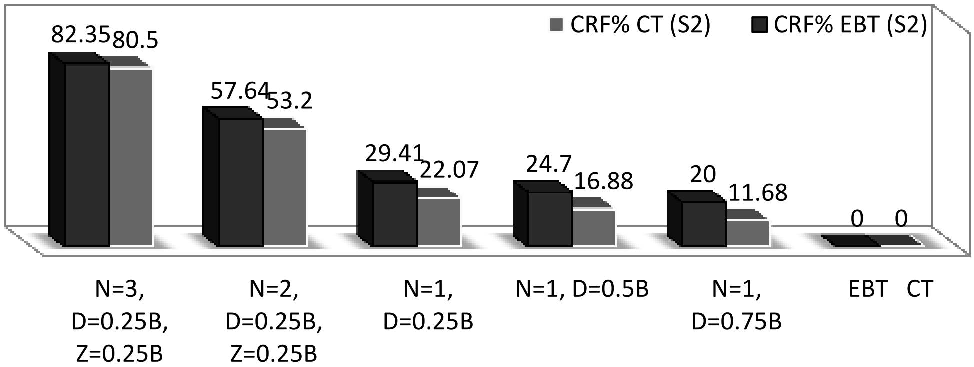


Figure (18). The improvement as (CRF) in soil (S2)

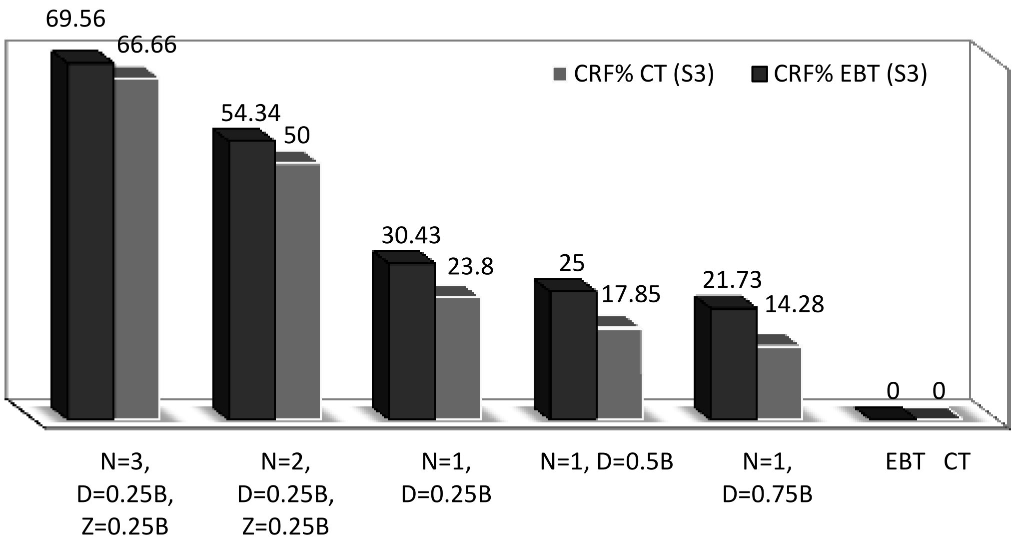


Figure (19). The improvement as (CRF) in soil (S3)

Figure (20) shows the improvement as (CRF) in gypeuos soils with respect to Engineering Box Test (EBT).

Figure (21) shows the improvement as (CRF) in gypeuos soils with respect to double oedometer (CT).

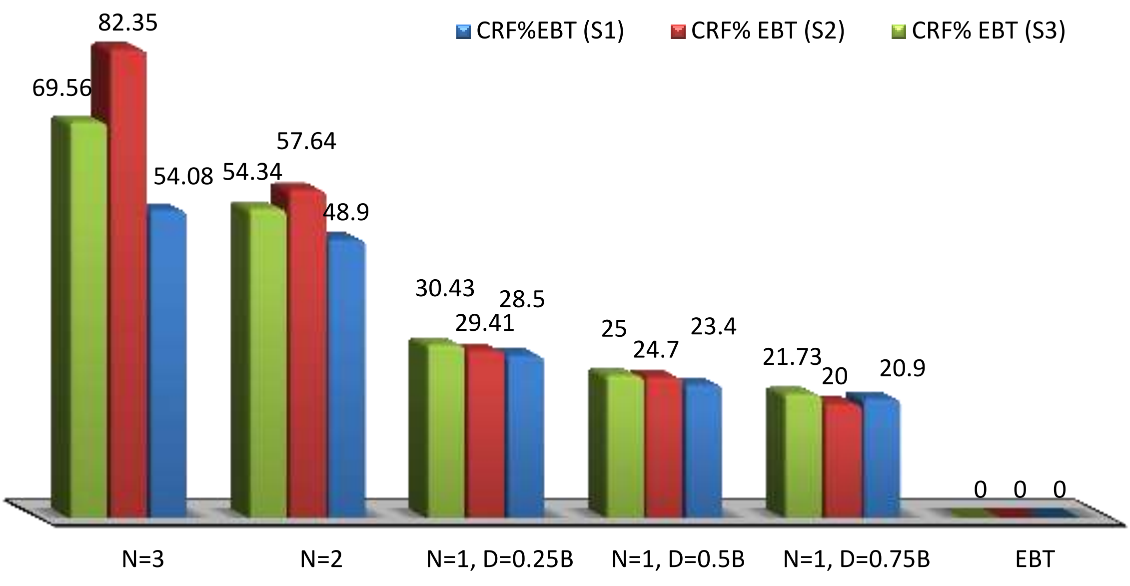


Figure (20). The improvement as (CRF) in gypeuos soils with respect to (EBT)

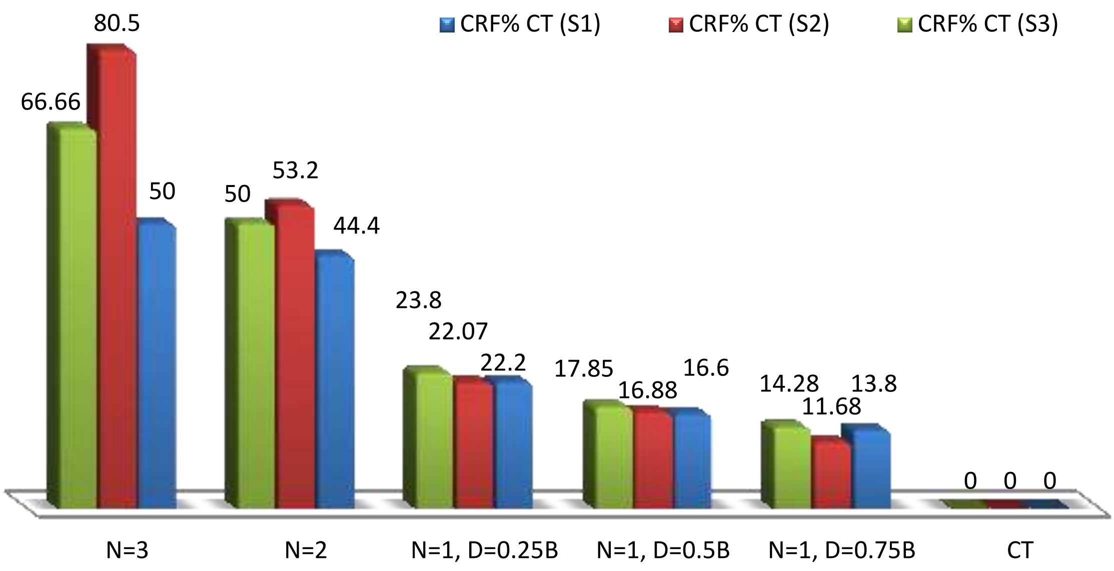


Figure (21). The improvement as (CRF) in gypeuos soils with respect to (CT)

6. Conclusions

1- The collapse potential is decreased at all cases of reinforcement layers number.

2- The collapse potential is decreased as the ratio D/B decreases for all soil types.
 Probably, the reason for this is that when the reinforcement is approaching the loading surface, it will be within the zone of large stresses generated from loading, making reinforcement carries much more of the stresses generated within the soil mass. This leads to further improvement in collapsibility.
 In other words, as the depth increases from loading surface, the stresses generated by the load will decrease. Therefore, the geogrid reinforcement will carry a small amount of stresses that subjected to the soil, leading to reduced improvement in collapsibility.

3- The collapse potential decreases as the number of reinforced layers increases for all soils types. This is may be attributed to the same reason mentioned in point (2) and perhaps the presence of geogrid reinforcement in the spaces generated from the dissolution of gypsum, plays a role in maintaining interdependence soil texture.

4- The most effective depth for single layer reinforcement is at (D=0.25B) for the three soils, which it achieves a collapse reduction factor (CRF) of about (28.5%, 29.41%, 30.43%) for soils (S1, S2, S3) respectively compared with unreinforced model.

5- The effective number of reinforcement layers was (N=3), which it achieves a (CRF) about (54.08%, 82.35%, 69.56%) for (S1, S2, S3) respectively compared with unreinforced model.

6- The rate of improvement in collapsibility using the layers of geogrid reinforcement was the best for the soil S2 and moderate for the soil S3 and the least rate was for the soil S1.

7- The rate of improvement in collapsibility using geogrid reinforcement was the best for the S2, which has the highest percentage of fine grained soil.
Most probably, the using of geogrid reinforcement reduced the collapsibility that was caused by two reasons here, the first is the dissolution of gypsum and the second is the sliding of fine particles due to the dissolution of gypsum. This seems remarkable in the S3, which contains the proportion of fine grained soil less than the S2 and more than the S3.

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