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THE BEARING CAPACITY OF A CIRCULAR FOOTING ON GYPSEOUS SOIL BEFORE AND AFTER IMPROVEMENT

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Abstract

Bearing capacity of soil is an important factor in designing circular footing. It is directly related to foundation dimensions and consequently its performance. The calculations for obtaining the bearing capacity of a soil needs many varying parameters, for example soil type, depth of foundation, unit weight of soil, etc. In this work, the comparison between the values of bearing capacity of circular footing on gypseous soil before and after improvement determined by two different methods, the first method using compacted cement dust (Case1). The improvement were performed by making trench under the footing filled with compacted cement dust (at its optimum moisture content) at three depths [(Depth of trench, D =Width of trench, B =2 * the radius of footing R); (D=2B=4R) ; (D=3B=6R)], the trench had the same footing Dimensions, The second method is reinforcing gypseous soil with biaxial geogrids (Case2) have been shown to be an effective method for improving the ultimate bearing capacity of granular soils.

The ultimate bearing capacity of footing is estimated in terms vertical load and the generated settlement curves by using PLAXIS 2D Professional v.8.2. The computer program uses a finite element technique to solve the two dimensional problems of soil improvement. The improvement ratio in bearing capacity (BCR) was calculated by comparing the ultimate bearing capacity value when testing gypseous soil alone with its value of gypseous soil improvement. The ultimate bearing capacity obtained from the using compacted cement dust tests has been analyzed and compared with the value developed by reinforcing soil.

From the results, it was found that the compacted cement dust in case1 has BCR at D=2R larger than BCR values occurred from single–layer reinforced soil but multi-layer reinforced soil N=2 and 3, indicated more larger than case1 improvement with dust cement. The optimum geometry of the geogrid layes is [N=3; depth of the first layer, u=0.3; distance between geogrid layers S=0.3; and width of geogrid layer b=4], which it gives ultimate bearing capacity more than when used compaction layers of cement dust with depth, [D=4R or D=6R].

Keywords: Bearing Capacity, Improvement of Gypseous Soil, Cement Dust, Soil Reinforcement, Circular Footing, Plaxis Program.

ايجاد قابلية تحمل الاساس الدائري المنشأ فوق تربة جبسية قبل وبعد تحسينها

الخلاصة

قابلية تحمل التربة هي عامل مهم في تصميم الاسس الدائرية و التي لها علاقة مباشرة بابعاد الاساس و اداءه. حسابات قابلية التحمل تتطلب معرفة عدة عوامل منها نوع التربة، عمق الاساس، كثافة التربة، .... الخ. في هذا العمل،

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المقارنة بين قيم قابلية تحمل الاساس الدائري الجالس على تربة جبسية قبل وبعد التحسين تم ايجادها باستخدام طريقتين مختلفتين، الطريقة الاولى كانت باستخدام غبار الاسمنت و ذلك بعمل خندق بداخل التربة يملى بغبار الاسمنت المحدول برطوبة مناظرة الى نسبة الرطوبة المثلى و عند اعماق مختلفة للخندق و عندما تكون ابعاد الخندق تكون مساوية الى ابعاد الاساس [(D = B = 2 R); (D = 2B = 4R) ; (D = 3B = 6R)] . الطريقة الثانية تكون بتسليح التربة الجبسية باستخدام الجيوكرد و التي تبين بانها طريقة فعالة في تحسين قابلية التربة الحبيبية الجبسية.

قابلية التحمل لاساس دائري تم تخمينها بدلال منحني الحمل العمودي – الهبوط و باستخدام برنامج بلاكسز. برنامج الحاسبة استخدم تقنية العناصر المحددة لحل مسألة تحسين التربة. نسبة التحسين في قابلية التحمل للتربة تم حسابها من نسبة قيمة قابلية التحمل للتربة الجبسية بدون معالجة (تحسين) الى قابلية التحمل للتربة الجبسية بعد تحسينها. كذلك تم مقارنة قيم قابلية تحمل التربة باستخدام غبار الاسمنت مع قيم قابلية التحمل المتولدة من تسليح التربة بالجيوكرد.

من النتائج التي تم الحصول عليها، وجد بان نسبة قابلية التحمل في الحالة الاولى (غبار الاسمنت المحدول) عند عمق (D = B = 2 R) تكون اكبر من قابلية التحمل لطبقة واحدة من الجيوكرد و لكن عندما تزداد طبقات الجيوكرد الى اثنان او ثلاثة للتربة المسلحة فان قيم قابلية التحمل تصبح اكبر من الحالة الاولى. الشكل الهندسي الامثل لتحسين التربة اسفل الاساس الدائري باستخدام الجيوكرد تكون عندما [N = 3, u = 0.3, S = 0.3, and b = 4] بحيث تعطي قابلية تحمل قصوى اكبر من المستخدمة في حالة حدل غبار الاسمنت عند عمق [D = 4R or D = 6R] .

1. Introduction

Gypsies Soils are disturbed in many regions in the world including Iraq, which cover about (30 %) of the surface area of the country **[Al-Dulaimi, 2004]**. 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 **[Albusoda and Hessain, 2013].**

Generally, gypsiferous soils usually stiff when they are dry, but these soils may be affected greatly when subjected to changes in water content due to water table fluctuation, or due to water infiltration which may dissolve gypsum causing pores, crack and producing cavities that lead to increase the permeability in gypseous soils. Therefore, the safety and good performance of the foundation of structures and earth structures such as embankments and dams will be governed by the changes in the properties of these soils.

The bearing capacity and settlement for circular footings have already been one of the most highly interesting areas in geotechnical engineering for researchers and practical engineers. Defining the correct bearing capacity of the footing is a very important factor in economical terms. In general, the bearing capacity problem of footings has been extensively studied for many decades. The bearing capacity equation expresses the unit load that would cause a footing to plunge into the ground as a function of the cohesive intercept **c**, the surcharge **q** at the level of the footing base, and the unit weight **γ**. A variety of factors, all functions of **φ**, appear in each term; in particular, factors **Nc, Nq, and N γ** appear multiplying **c, q, and γ**, respectively **[Lee and Salgado, 2005].**

Many observations have been made in the literature in order to calculate bearing capacity of circular footings using the limit equilibrium method. In recent years, numerical methods, such as finite element method (FEM), have been widely used to compute the bearing capacity of circular footings. Nowadays, more and more ring footings are used for axi-symmetric structures such as silos, chimneys, and storage tanks and so on. The use of circular footings decrease the amount of material used and is more economical. This has lead to an increasing use of circular footing in countries which construction material on more expensive. Proposed different relations for prediction of the bearing capacity and settlement of strip, circular and square footings are not suitable for circular footings. Therefore, the theoretical prediction of

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ultimate bearing capacity and settlement for circular footings is a requirement in the design. **Kumar and Ghosh (2005**) investigated the bearing capacity factor Nγ for both smooth and rough ring footings by using the method of characteristics assuming that the interface friction angle between the footing base and the underlying soil mass increases gradually from zero along the footing centerline to along the footing base. **Boushehrian and Hataf (2003) and (2009)** performed a series of laboratory tests on model ring footings and found that for a ratio of internal to external radius of the ring (n) equal to 0.4 the bearing capacity reaches its maximum for sand. **Hataf and Razavi (2003)** found that n value for maximum bearing capacity of sand is not a unique value but is in the range of 0.2–0.4. **Zhao and Wang (2009)** utilize a finite difference code FLAC to study bearing capacity factor Nγ for ring footings in cohesionless soil. The value of Nγ is found to decrease significantly with an increase in radius ratio (n), which is the ratio of internal radius to external radius of the ring. The value of Nγ for a rough ring footing, especially for lager values of friction angle, is obviously higher than that for a smooth footing. In this paper the settlement and bearing capacity of ring footings are observed, Centralization on the ring footings of the cooling tower in Kazeroon cooling towers.

2. Bearing Capacity Improvement of the Soil

In geotechnical engineering, bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil. Ultimate bearing capacity is the theoretical maximum pressure which can be supported without failure; allowable bearing capacity is the ultimate bearing capacity divided by a factor of safety. Sometimes, on soft soil sites, large settlements may occur under loaded foundations without actual shear failure occurring; in such cases, the allowable bearing capacity is based on the maximum allowable settlement. There are three modes of failure that limit bearing capacity: general shear failure, local shear failure, and punching shear failure. The bearing capacity problem of footings has been extensively studied for many decades. The bearing capacity equation expresses the unit load that would cause a footing to plunge into the ground as a function of the cohesive intercept c, the surcharge q at the level of the footing base, and the unit weight **γ**. A variety of factors, all functions of **φ**, appear in each term; in particular, factors N_c, N_q, and N_γ appear multiplying **c, q**, and **γ**, respectively.

In this research in order to calculate the bearing capacity, the rigid footing was chosen and the settlement under the rigid footing is assumed as uniform one. A uniform vertical displacement was prescribed to the model until failure was accrued. Applying the vertical displacement, it is assumed that when the vertical displacement is applied to the footing, the soil could not move horizontally.

3. Chemical Treatment of Gypseous Soils

The treatment of gypseous soils means decreasing or eliminating the effect of water on the gypseous soils to ensure the safety and stability of the engineering structures.This treatment can be achieved chemically or physically. The chemical treatment means that the soil properties are improved with some chemical additive used to improve the engineering properties of the gypseous soil and decrease the effect of water percolating on this type of soil. Cement treatment is a way of chemical treatment, which is widely used to improve the engineering properties of the gypseous soil. Cement may be added for all types of soil expect those containing organic matters.

4. Reinforcing Treatment of Gypseous Soils

The use of geosynthetics in civil engineering has flourished in recent years due to its ability to improve soil properties in some manner. Specific to this study, the use of geogrid to improve the bearing capacity and settlement performance of foundations has proven to be a cost effective foundation system. In this application geogrid has allowed the use of shallow foundations where traditionally more expensive deep foundations such as piles have been used. Soil reinforcement including geosyntetics, galvanised steel mesh and anchoreed steel cable are used to improve the bearing capacity, and decrease the settlement in soil structures such as embankments, retaining walls, bridge abutments and foundations. The settlement and bearing capacity characteristics of foundations are dependent on many varied and interconnected parameters and conditions and predicting these relationships has been the subject of many studies.

The circular foundation, which is predominantly used in axi -symmetric structures and has economic advantages over boxed foundations has received little research attention. Over the last two decades, considerable advances have been made into the understanding of the behavior of reinforced soil foundations and on the applications and limitations of using geosynthetics to improve the performance of shallow foundations. Detailed investigations have been performed using small scale laboratory test models and a (limited) number of in-situ tests. These studies (among others) have demonstrated that; a geosynthetic reinforcement placed below a foundation can increase both, the ultimate bearing capacity, and allowable bearing stress at a given settlement. However, due to the numerous parameters effecting the bearing capacity of shallow foundations and, limited literary records that predict the global effects of the physical and strength specifications of reinforced sand embankments, strength parameters of geogrid reinforcement, consider found action conditions and lack of research into geogrid reinforced circular foundations, more research is required to understand this emerging technology.

The main objective of the work was to undertake numerical investigation into the strength and settlement characteristics of circular pad foundations strengthened by using underlying geogrid reinforced granular soil. The paper investigated the various areas such as : the effect of reinforcement placement and determination of optimum placement depth and number of reinforcement layers; the effects of reinforcement strength and identification of the optimal strength; the effects of using granular soils and their benefits to shallow foundations; and the geometric properties and advantages of circular foundations.
The results are presented and analyzed with the aim of increasing the bearing capacity of circular foundations.

The bearing capacity of foundation soil comes from cohesion factor, c and frictional factor, Φ. in granular soil (dry sand), load taking factor is only the frictional one. Safe bearing capacity is defined as the maximum pressure, which the soil can carry safely without the risk of shear failure. Shear failure may result from the foundation failure as well as from excessive settlement. Before the application of load, the soil below the base of the footing is in elastic equilibrium and after the load is applied, the soil passes from elastic to plastic equilibrium with failure.

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Due to the concentric loading; the ultimate bearing capacity of the foundation (qu) was calculated based on Terzaghi laboratory and practical observations for vertical loads on unreinforced circular foundations as follows: **[Bowles, 1996].**

$$qu = 1.3CN_c + \gamma D_f N_q + 0.3\gamma BN\gamma \ldots\ldots\ldots\ldots\ldots eq.(1)$$

Where:
γ= unit weight of soil
B = foundation diameter,
D_f = foundation embedment depth,
C = cohesion of sand. Nc, N_q and Nγ = coefficients of bearing capacity.

5. Testing Material

The soil samples used in this study were brought from one location at Al-Nda'a region west of Al-Najaf city. The soil samples are obtained from a depth of (3-4) m below the natural ground surface, the physical and chemical properties of the soils are summarized in **Table 1.**The cement dust provided from cement factory of Al-Kufa, Najaf Governorate, Iraq. Specific gravity test, standard Proctor and direct shear test were conducted on cement dust. The results are shown in **Table 2.**

Table1 : Physical and Chemical Properties of Soil.

Type of test	Property	Value
Atterberg limits	L.L	23%
	PI	NP
Specific Gravity of Soil	Gs	2.69
Maximum Unit Weights	γ_{sat}	19.1 kN/m^3
Standard Compaction	γ_{dmax}	1910 kg/m^3
	ω_{opt}	13%
Consolidation Test	e	0.906
	C_c	2.51
Direct Shear Tests	c	2
	φ	32
Water Content	Water Content (%)	33.68
Nashat and Al-Mufty method	Gypsum Content (%)	32
	υ_s	0.35
CBR	E_s	20 Mpa
Permeability Test	k	1.6 × 10^{-4} cm/s
	SO_3%	6.9

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Table 2 : Results of Physical, Standard Proctor and Direct Shear Test for Cement Dust.

Type of test	Property	Value
Atterberg limits	L.L	23%
	PI	NP
Specific Gravity of Soil	Gs	2.66
Standard Compaction	γ_{dmax}	18.5 kN/m^3
	ω_{opt}	21%
Direct shear test	C at ω_{opt}.	48 kPa
	Φ at ω_{opt}	29^o

6. Physical Tests

6.1 Specific Gravity:

The specific gravity of the soil is determined according to the British standards (BS 1377: 1975, Test No.6 (B), Head 1980) which is equal to **2.69**.

6.2 Atterberg Limits:

Liquid limit test is carried out in accordance with (BS 1377: 1975, Test 2 (A)). The liquid limits are carried out on soil passing sieve (No.40) and the temperature used for drying is maintained at (45–50)°C due to the presence of gypsum in the soil, (ASTM 2216- 80).

6.3 Water Content

This is performed in accordance with (BS 1377: 1975, Test (A), Head 1980). The water content is determined at drying temperature of (45) °C because the soil contains a significant amount of gypsum, to avoid the loss of crystal water is required, So the magnitude of **Water Content** =**33.68**%.

6.4 Particle Size Characteristics:

The grain size distribution is determined by sieve analysis test, which is conducted in accordance with (ASTM D922-72) with dry sieving. The grain size distribution curves of the soil sample are shown in **Figure 1**, The median grain size $\mathbf{D_{50}}$ from the curve was 0.365 mm. The $\mathbf{D_{60}}$ and $\mathbf{D_{10}}$ sizes were 0.4 mm and 0.185 mm, and the uniformity coefficient ($\mathbf{D_{60}}$ to $\mathbf{D_{10}}$) was 2.16, so the soil specimens can be classified according to the Unified Soil Classification System as well graded sand (SW).

6.5 Coefficient of Permeability

The constant head permeability tests were performed on the soil. **Table 3** shows the result of this test. It can be clear that the soil may be classified as low permeability soil.

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Table 3: Coefficient of Permeability

Time (sec)	Head difference	Flow (ml)	Flow rate (m^3/s)	Permeability k (cm/s)
85	0.855	35.5	$6.96*10^{-9}$	1.6×10^{-4}

6.6 Standard Proctor Compaction Test

Standard Proctor compaction tests were conducted on stabilized soil. **Figure 2** shows the moisture-unit weight relationship for stabilized soil. From the laboratory results, the optimum moisture content and the maximum dry density of the sample are **13%** and **1910** kg/m^3 respectively**.**

6.7 Strength properties

Series of direct shear tests were carried out to study the shear strength parameters (c and φ). **Figure 3** shows the results of this test. Cement dust caused an increase in φ and (C). Higher cohesion was reached with higher percentage of CD.

7. Chemical Tests

The gypsum content is found according to the method presented by Al-Mufty and Nashat (2000). This method consists of oven drying the soil at (45°C) until the weight of the sample becomes constant. The weight of sample at (45°C) is recorded. Then, the same sample is dried at (110°C) until the weight becomes constant and recorded. The gypsum content is calculated according to the following equation:

$$G\% = \left[\left(W45^{\circ}C - W110^{\circ}C\right)/W45^{\circ}C\right] \times 4.778 \times 100 ....eq.(2)$$

Where:
G = Gypsum content (%)
$W_{45°C}$ = Weight of the sample at (45°C)
$W_{110°C}$ = Weight of the sample at (110°C)

So the Gypsum Content (%) for the soil sample is found equal to **32**%.

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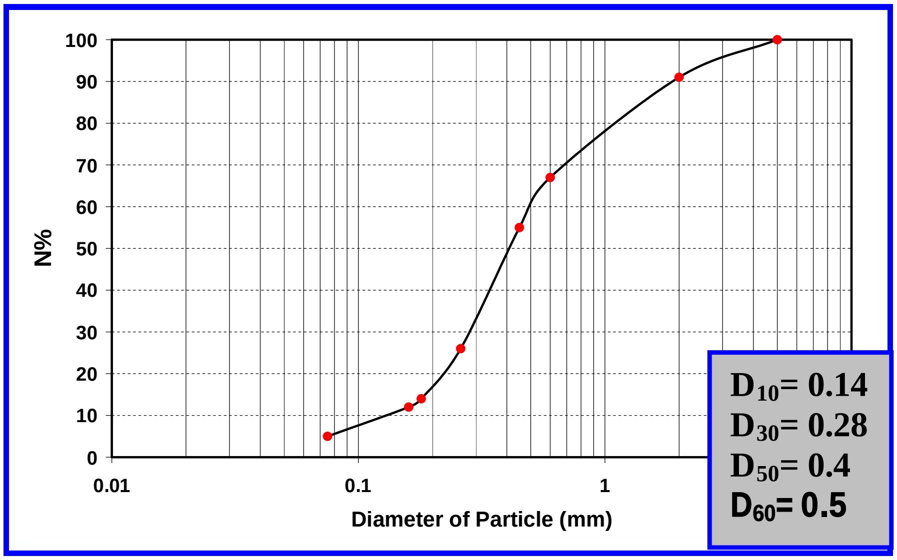

Fig.1 : Grain Size Distribution of the Soil.

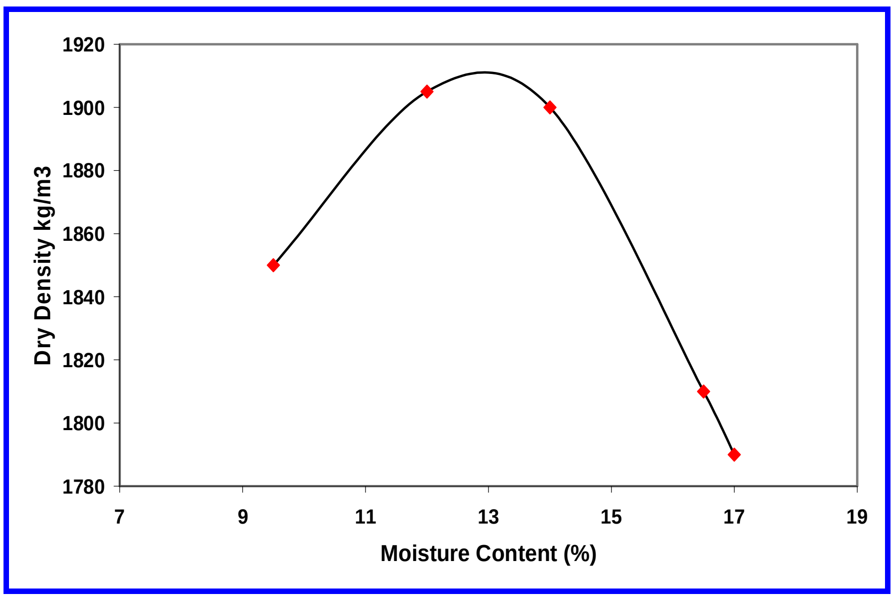

Fig.2 : Dry Density Against Moisture Content Relationship.

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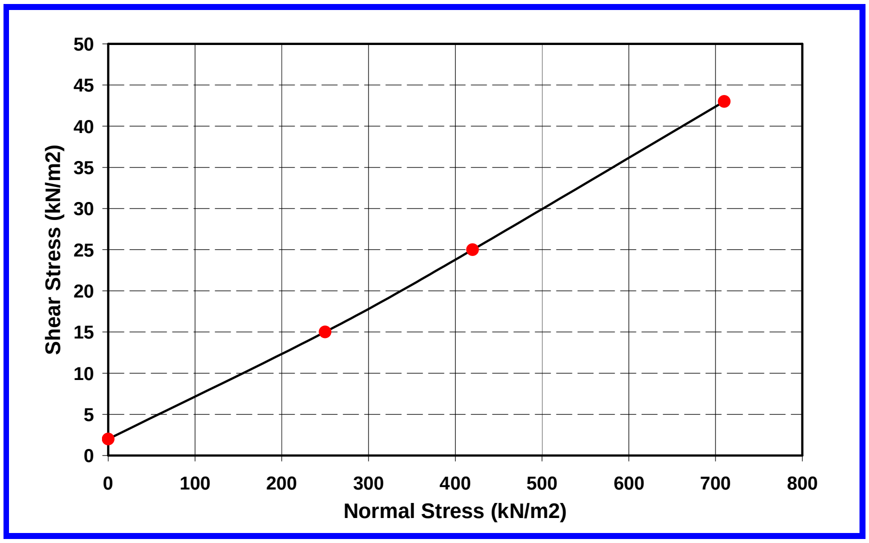

Fig.3 : Normal Stress and Shear Stress Curve.

8. Results of Parametric Study

In general, settlement is the governing criterion for designing a footing resting on weak granular soil (gypseous soil) **[kumar et al., 2008]**, therefore the nonlinear behavior of soil was modeled using 2D PLAXIS program to simulate the behavior of circular footing on gypseous soil (Weak granular soil). Interface elements have been used to model both the interaction between the footing base and the soil. The simple graphical input procedure enables a quick generation of complex finite element models, and the enhanced output facilities provide a detailed presentation of the computational results. The calculation itself is fully automated and based on robust numerical procedures.

In this study used two methods to improve bearing capacity of gypseous soil under circular footing with diameter of 5m and thickness of 0.5m is used, first by used cement dust and second by reinforcing soils with geogrids.

Automatic generation of (15 node) triangle plane strain elements for the soil, (5 node) beam elements for the footing. The footing pressures are applied in increments. This is specified by applying vertical pressure in the y-direction along the wide footing load at each time step in the program. The load in load-settlement behavior is sum of the Y-Boundary forces and settlement is the maximum vertical Y-displacement at the node 923 at the center of the footing load. The soil has the tendency to a nonlinear behavior. The soil's nonlinear stress-strain behavior in different levels can be model. The Mohr- Coulomb model is one of the first soil behavior models which is elasto-plastic model. This model uses four parameters, which consist of elasticity modulus (E), Poisson's ratio (ν), internal friction angle of soil (φ), cohesion (C). **Table 4** shows parameters used for the calculations of bearing capacity.

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9. Parametric Study for case1 (improvement by dust cement).

The cement dust, was compacted at maximum dry density with optimum moisture content (ω_{opt} = 13%), it puts under circular footing to depth D = 2R, D = 4R, D = 6R when R= 5 m, D=10, 20 and 30 m. **Figure 4 to Figure 12** shows the model configuration and finite element of model for D = 2R, D=4R, D=6R, and **Table 4** shows soil parameters used for the calculations of bearing capacity in this case, while Table 5 shows footing and geogrid parameters.

Table 4: Soil Parameters used in the Calculations of Bearing Capacity.

γ_{dmax} (kg/m^3)	c (Kpa)	φ (˚)	ν	E(Mpa)
1910	2	32	0.35	20

Table (5): Footing and Geogrid Parameters.

Parmeter	Footing	Geogrid
EI (kN.m /m ^{2})	4500000	-
EA (kN/m)	8000	2000

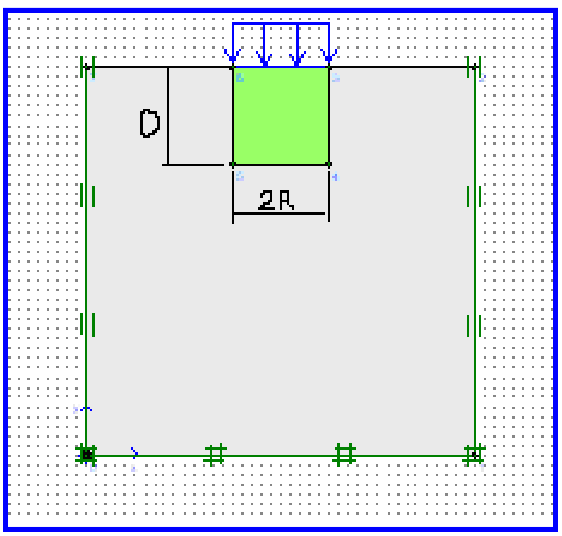

Fig.4: Model Configuration for (D=2R).

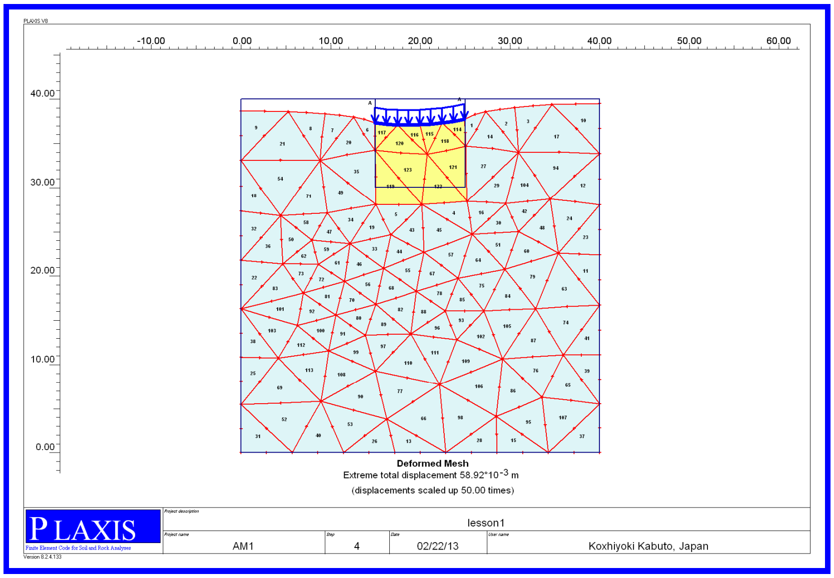

Fig.5: Finite Element of Model (for D = 2R).

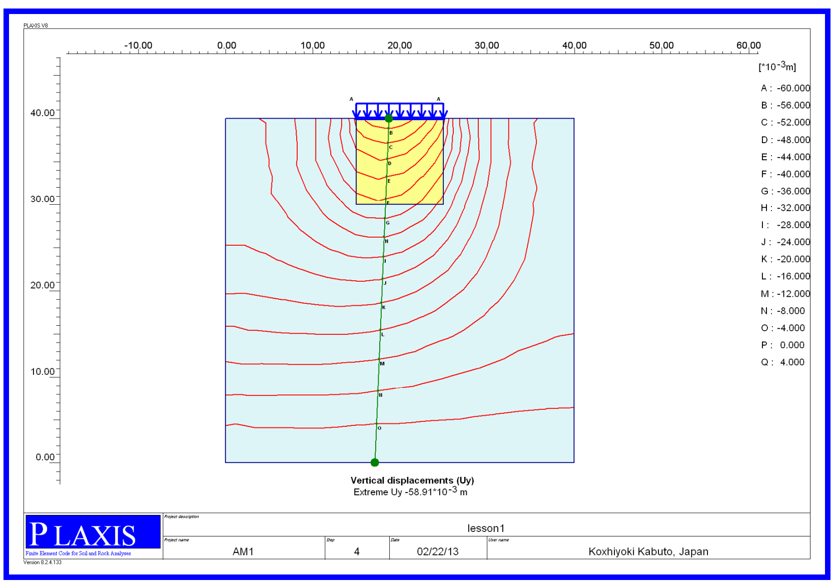

Fig.6: Control Lines to Vertical Displacement (for D = 2R).

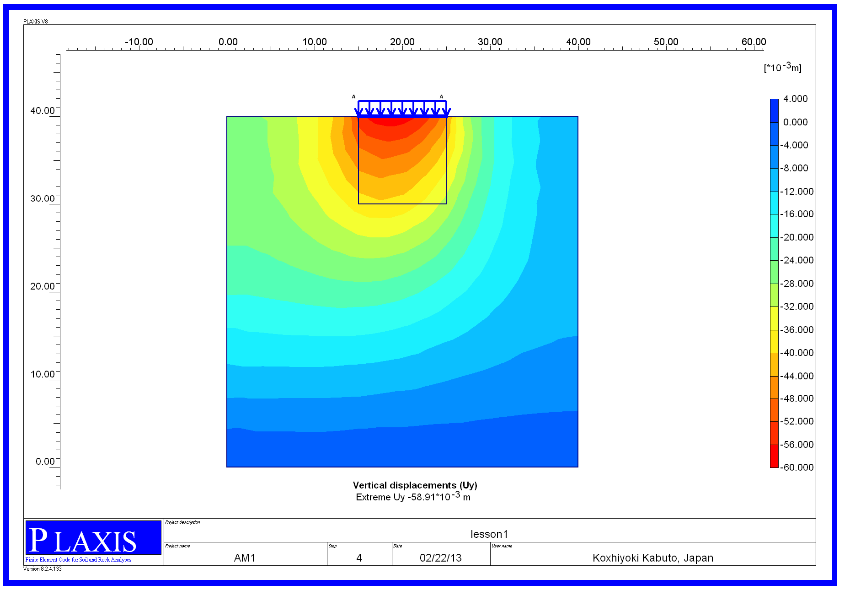

Fig.7 :Shadings to Vertical Displacement (for D = 2R).

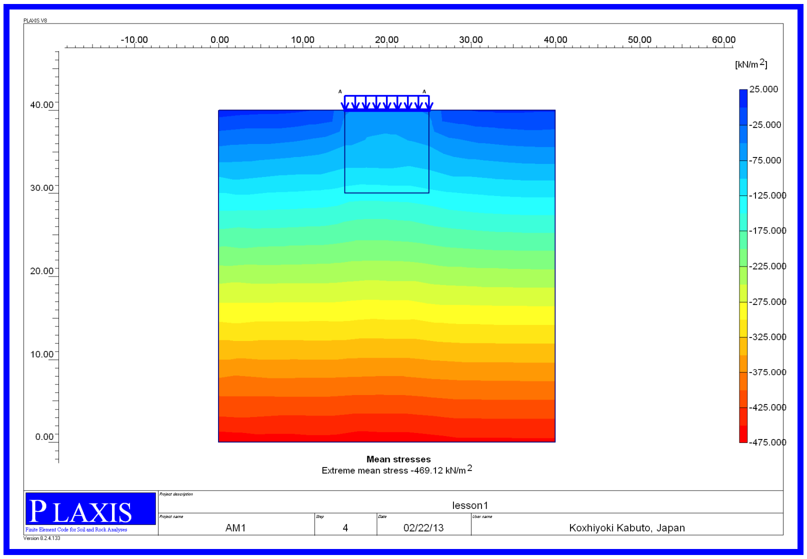

Fig.8: Shadings to Stress(for D = 2R).

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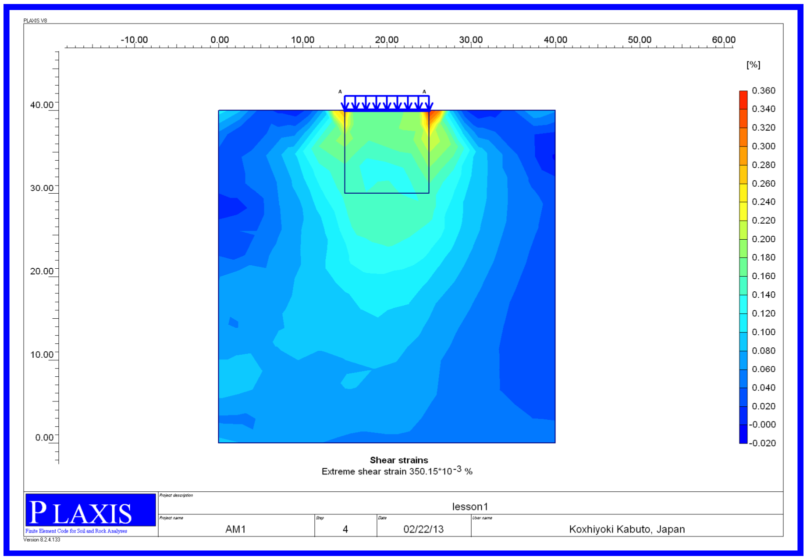

Fig.9 : Shadings to Shear Strain (for D = 2R).

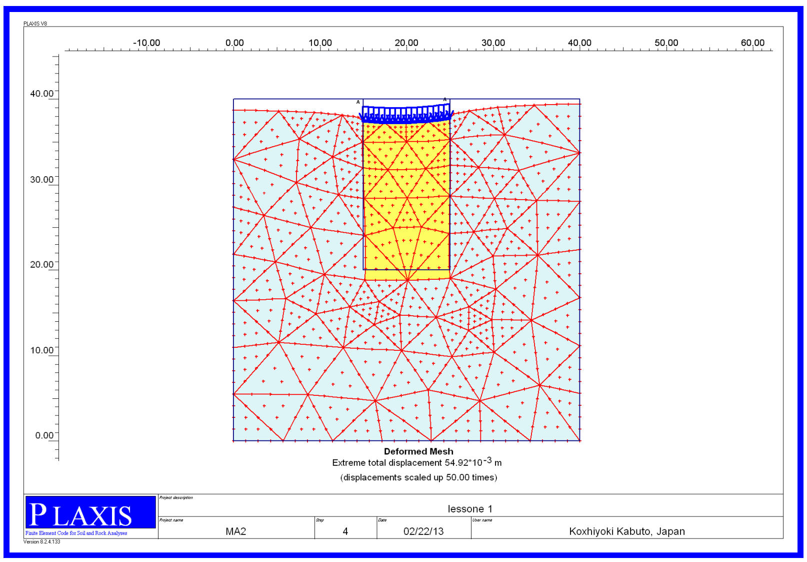

Fig.10 : Finite Element of Model (for D = 4R).

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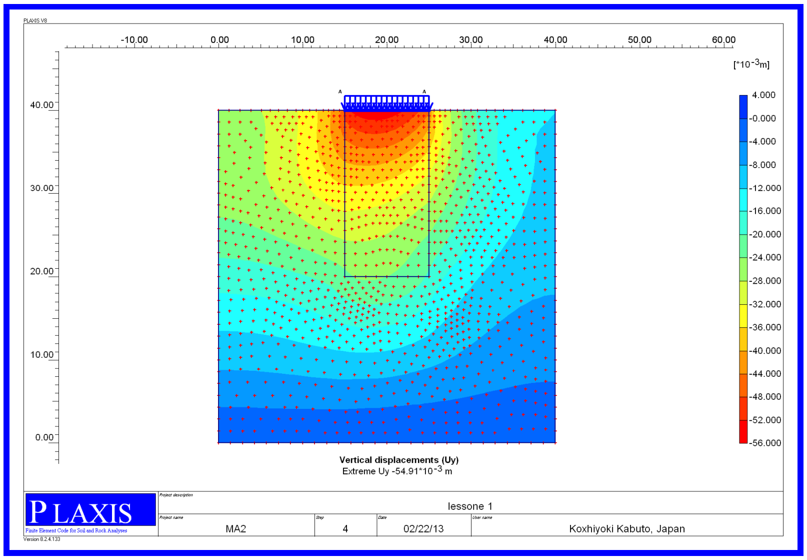

Fig.11: Shadings to Vertical Displacement (for D = 4R).

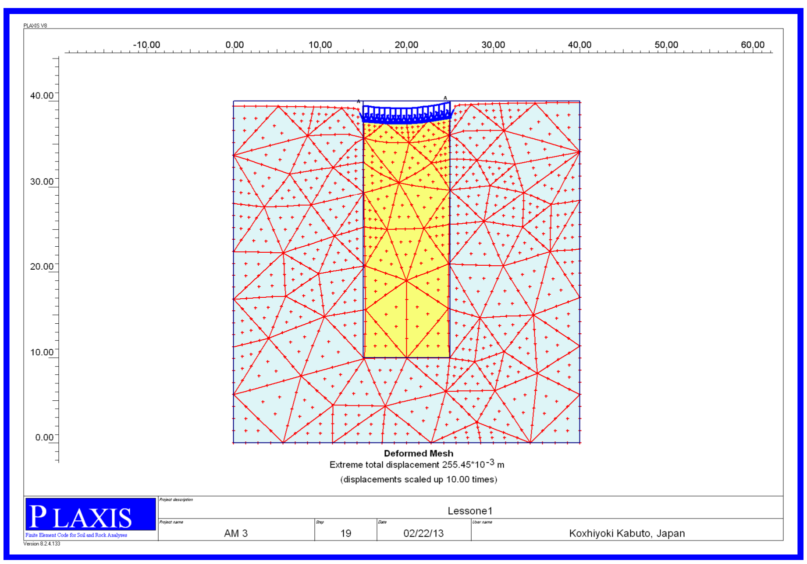

Fig.12: Finite Element of Model (for D = 6R).

10. Calculations of Bearing Capacity in Case 1

In this research in order to calculate the bearing capacity, the rigid footing was chosen and the settlement under the rigid footing is assumed as uniform one. A uniform vertical displacement was prescribed to the model until failure was accrued (displacement controlled method). Applying the vertical displacement, two different conditions can be presumed; in the first condition, it is assumed when vertical displacement is applied to the footing, the soil under the footing could move horizontally. In other words the friction between the soil and the footing is ignored (smooth footing).In the other condition, it is assumed that when the vertical displacement is applied to the footing, the soil could not move horizontally. In other words the friction between the soil and the footing is infinite (rough footing). In the PLAXIS software, the horizontal stress in static state is calculated using Jacky's formula.

11. Results of Load –Settlement tests for Case1

The loading tests were performed to determine typical load-settlement curves as shown **in Figure 13**. The ultimate bearing capacity of the footing was clearly determined by reading the peak point of the curve. So the ultimate bearing capacity is defined as the point where a maximum value of q_u is clearly arrived.

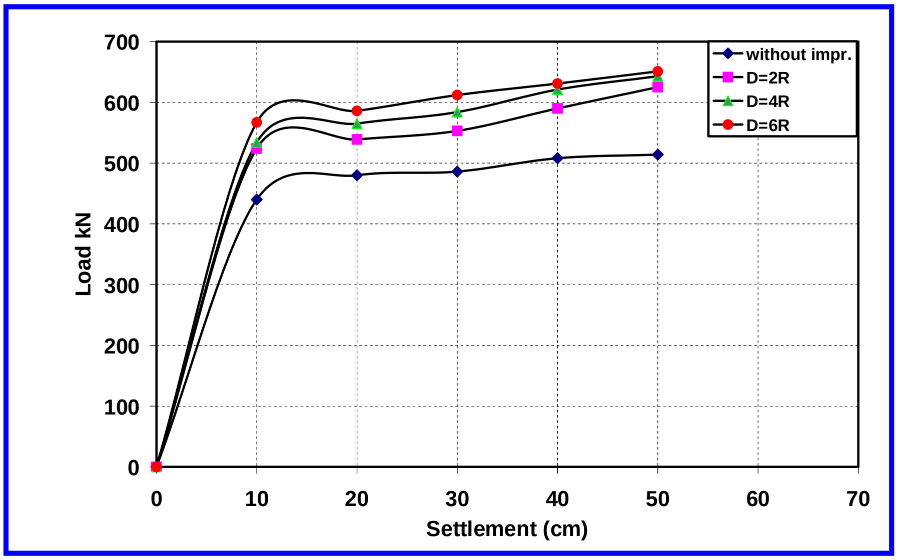

Fig.13: Load-Settlement Ratio Curve for Soil (Case 1).

12. Effect of D/2R Ratio on Bearing Capacity

In general, the ultimate bearing capacity increased as D/2R ratio increased. This behavior was expected due to the increase in strength of soil under the footing as the (D/2R) ratio, of the cement dust used for improvement, increased. In addition, the ratio of improvement increased as the (D/2R) ratio increased. The largest ratio of improvement gotten for soil improved by cement dust at D/2R = 3, **Figure 14**. This behavior may be explained according to the shear strength parameters, where the cohesion and angle of internal friction of cement dust were (48 kPa, 29^0) respectively.

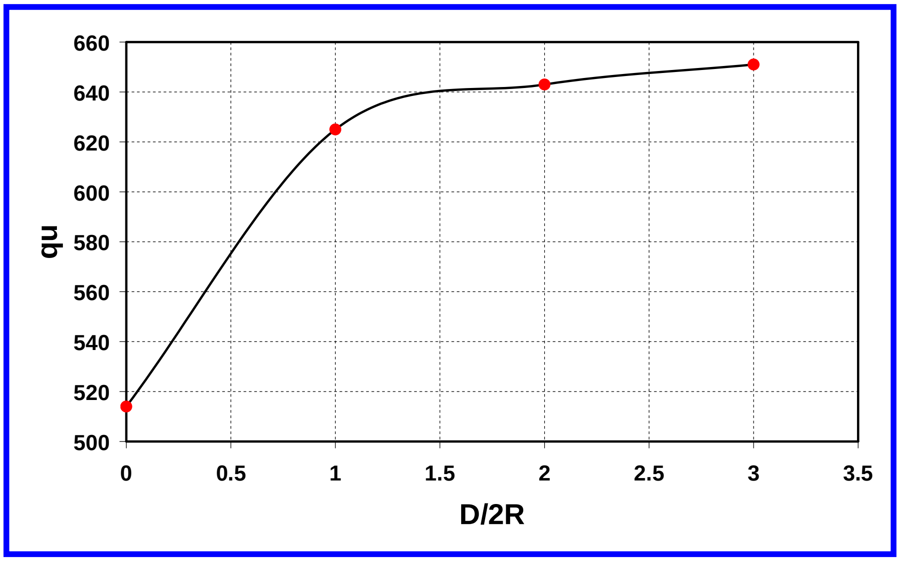

Fig.14: Ultimate Hearing Capacity-D/2R Ratio Relation.

13. Parametric Study for Case 2 (Improvement by Reinforcement).

The controlling parameters in foundation design are bearing capacity and settlement. Hence; it is important to evaluate the bearing capacity of circular foundations at various settlements in comparison to the settlement achieved at ultimate load. The **Figure 15** shows a circular foundation of diameter, **B** = 10 m supported on Geogrid reinforced on gypseous soil. The layers of geogrid having a width '**b**'. The top layer of geogrid is located at a depth u below the bottom of the foundation. The distance between consecutive layers of geogrid is '**S**', show **Figure 16.**

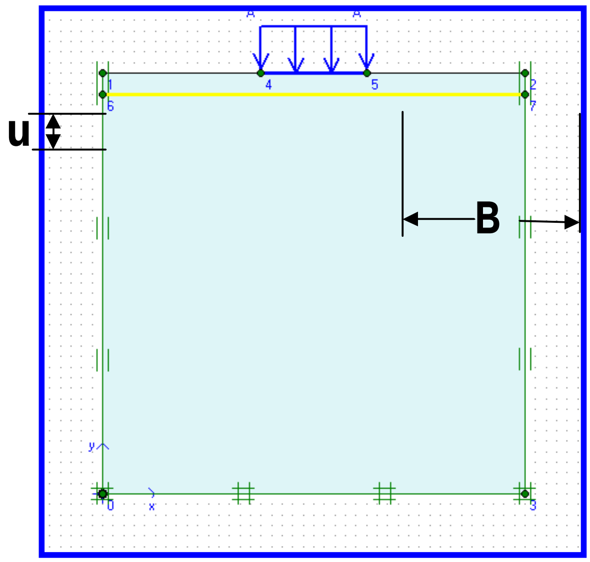

Fig.15: Schematic Model of the Circular Foundation on Reinforced Soil.

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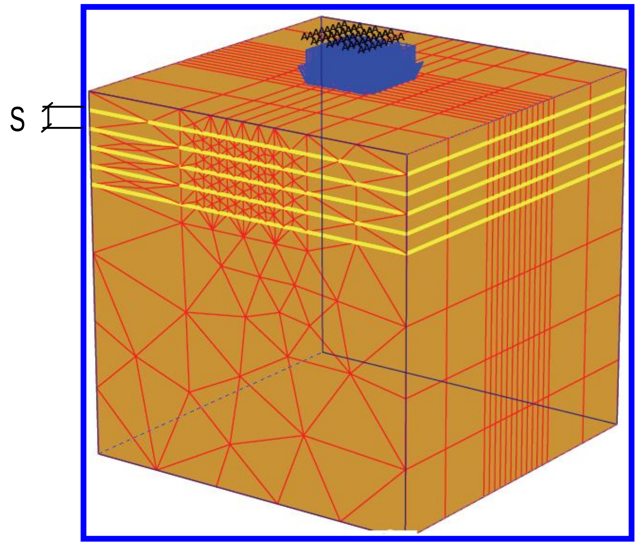

Fig. 16 : Finite Element Mesh Generation for 5 Layer Reinforcement with 4986 Elements.

The physical model for this investigation consists of a reinforced soil–foundation system with failure boundary radiating downward and outward from the foundation contact surface which shows dissipation of the stresses with depth. The parameters used in the model are: **B = 2R** = Circular foundation diameter, **N** = Number of geogrid layers, **b** = Geogrid width, and **D** = The foundation embedment depth. The reinforced depth is **d** and can be calculated as:

$$d = u + (N - 1).S .... eq.(3)$$

The increase in foundation bearing capacity can arise from two factors: stiffness increase due to the reinforcement, and friction strength In. finite element grids for geogrid-reinforced soil, the reinforced element is shown as a horizontal line.

The dimensions and boundary conditions of the geometric model are selected far enough from the foundation to diminish their effects on the analysis. Due to axisymetry of the model, only half of the model is used as any effects in this area are simply reflected into the other half of the model. Foundation and soil are mo deled with four nots isoperimetric finite element aid and for geogrid reinforcement; four nots one dimensional finite element model is used. The side boundaries of the model are denoted in the "x" direction and beneath the model in both directions of **x** and y are assumed fixed. The soil non linear behavior is as per modeled with a homogeneous uniform load imposed on foundation. To reach the required accuracy in calculations, uniform load is increased by increments until foundation failure.

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14. Results of Load –Settlement Tests for Case 2

14.1 Effect of Depth to the First Reinforcement Layer (u)

Analysis by the load-settlement curve was undertaken for a circular surface foundation with one layer of reinforcement. The results are shown in **Figure 17**. The results indicate that, the ultimate load increases as the ratio u/B increases. The results also show that; after the value of u/B, 0.3 the ultimate load be a relatively constant value.

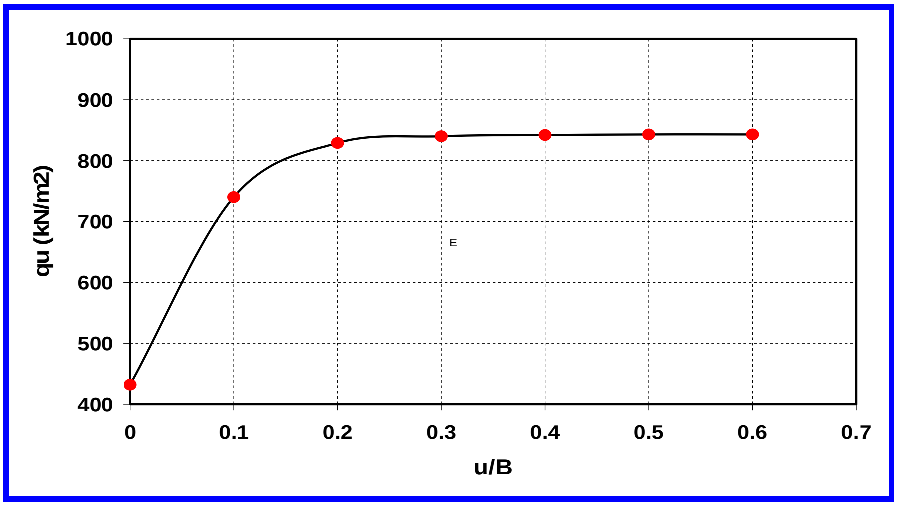

Fig.17: qu versus u/B for N=1 and b=4B.

14.2 Effect of Number of Reinforcement Layers (N) on Settlement

The load-settlement curve for the circular foundation supported by differing numbers of reinforcement layers with u/B = 0.3, S/B =0.3 and b/B = 4 is shown in **Figure 18**. The results show that; the curves for N= 3, 4 and 5 coincide with each other. This suggests that the optimum number of layers of reinforcement, N = 3.

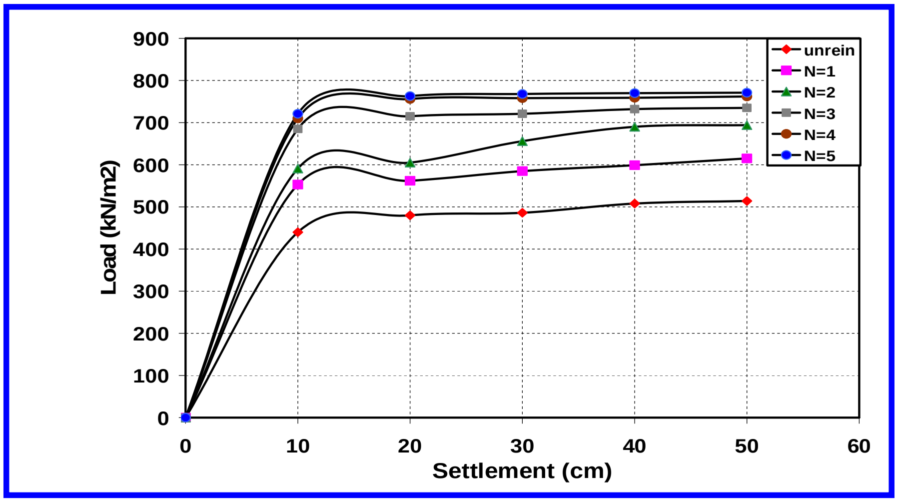

Fig.18: Load-Settlement Curves for Foundations with and without Reinforcement for u/B=0.3, S/B=0.3, b/B=4.

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14.3 Effect of Number of Reinforcement Layers (N) on BCR.

To evaluate the increase in bearing capacity, The bearing capacity is expressed in term of BCR (Bearing capacity ratio; Bearing capacity of reinforced soil to bearing capacity of unreinforced soil at same settlement). the bearing capacity ratio (BCR) is usually used for numerical simulation, the bearing capacity is introduced as a non-dimensional ultimate bearing capacity ratio, BCR, as follows:

$$CR = qu(R)/qu \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eq.(4)$$

where:
q_u = ultimate bearing capacity of soil without improvement.
$q_{u(R)}$ = ultimate bearing capacity of improvement soil by reinforcement.

Figure 19 shows a typical variation of BCR with the number of reinforcement layers for settlements 10,20,30,40 and 50 cm, when the vertical spacing (u), (S) and (b) were kept constant. The BCR increased with increasing the number of reinforcement layers within a depth of 1.5B and the rate of increase in BCR was less significant beyond this depth; in other words, placing geogrid reinforcement beyond a depth of 1.5B would not significantly increase the bearing capacity.

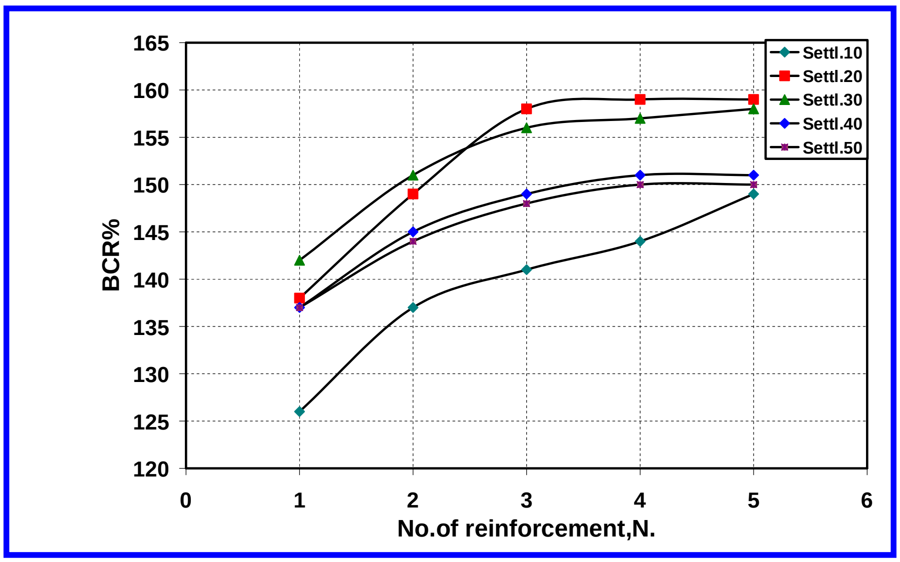

Fig.19 : BCR versus no. of Reinforcing Layers for Settlements 10,20,30,40 and 50 cm. (u/B=0.3, S/B=0.3, b/B=4).

15. Compression between Case1 and Case2 Results

When compression between Case1 and Case2 Results, it can be clear that the value of ultimate bearing capacity which obtained from case1 at D = 2R is larger the value of it is from case 2 when used one layer as reinforcement, but from the all result obtained from case

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1 and case 2 the optimum geometry used in this study to improve the gypseous soil is reinforce soil under foundation with number of reinforcement layers, N =3, u = 0.3, S = 0.3 and b = 4, which gives ultimate bearing capacity more than when used compaction layers of cement dust with depth, D = 4R or D = 6R, **Figure 20**.

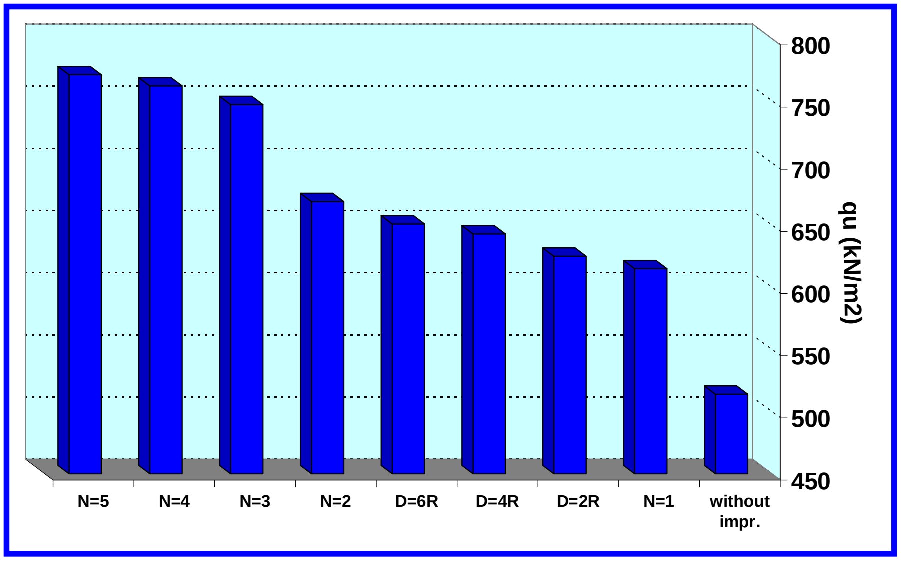

Fig.20: Ultimate Bearing Capacity from Case 1 and Case 2.

16. Conclusions

Low bearing capacity of gypseous soil under circular footings represents one of construction problems. This study was carried out to investigate and analyses bearing capacity of gypseous soil before and after improvement by two different methods, the first method using compacted cement dust (Case1), which can be defined as undesirable industrial waste material come from cement industry, was used to improve the bearing capacity of the soft soil considered in this research. The improvement were performed by making trench under the footing filled with compacted cement dust (at its optimum moisture content) at three depths (D = B = 2R, D = 2B = 4R, D = 3B = 6R), the trench had the same footing Dimensions, note that (B) represent the footing width. Pressure-settlement curves were used to predict the ultimate bearing capacity. The second method is reinforcing gypseous soil with biaxial geogrids (Case 2) have been shown to be an effective method for improving the ultimate bearing capacity of granular soils.

The ultimate bearing capacity obtained from the using compacted cement dust tests has been analyzed and compared with the value developed by reinforcing soil. The following conclusions are drawn from the tests conducted in the present study:-

1. In case1, the ultimate bearing capacity increased as D/2R ratio increased, The largest ratio of improvement gotten for soil improved by cement dust at D/2R=3.

2. For case 2, the result of used one layer of soil reinforcement indicate that, the ultimate load increases as the ratio u/B increases. The results also show that; after the value of u/B = 0.3 the ultimate load be a relatively constant value.

3. From load-settlement curve for the circular foundation supported by differing numbers of reinforcement layers suggests that the optimum number of layers of reinforcement, N = 3.

4. The BCR increased with increasing the number of reinforcement layers within a depth of 1.5B (15m) and the rate of increase in BCR was less significant beyond this depth.

5. The comparison between case1 and case2 results concluded that the compacted cement dust in case1 has BCR at D=2R larger than BCR values occurred from single–layer reinforced soil but multi-layer reinforced soil N=2 and 3, indicated more larger than case1 improvement with dust cement.

6. The final result from all this study is "the optimum geometry used to improve the gypseous soil is reinforce soil under circular foundation with number of reinforcement layers, N=3, u/B=0.3, S/B = 0.3 and b/B = 4, which gives ultimate bearing capacity more than when used compaction layers of cement dust with depth, D = 4R or D = 6R.

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