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Modeling of Strip Footing on Loose Sandy Soil Using Composite of Geogrid – Bentonite

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ملخص البحث

في بعض الحالات يتم تنفيذ الأساسات السطحية علي طبقات من تربة ذات قدرة تحمل ضعيفة، من هذة الأنواع تربة الرمل السائب (Loose Sandy Soil)، مما ينتج عنها زيادة في قيم الهبوط. لذا فإننا نلجأ في هذة الحالات إلي عمل معالجة لهذه التربة الضعيفة بطرق مختلفة حتي تستطيع تحمل الأحمال الواقعة عليها بشكل آمن. وفي هذه الدراسة يتم بحث إستخدام أساليب مختلفة لمعالجة هذة التربة منها:-

1- إستخدام البنتونيت كمادة مخلوطة مع تربة الرمل السائب بنسب مختلفة هي 3 و6 و9 % بالوزن لرفع قدرة تحمل الرمل السائب.

2- إستخدام المنسوجات الصناعية مع خلط نسب مختلفة من البنتونيت مع تربة الرمل السائب.

وفي هذا البحث تم عمل دراسه تحليلية باستخدام برنامج التحليل العددي للتربة (PLAXIS) لتحليل الإجهادات الداخلية المتولدة بالتربة قبل وبعد خلط البنتونيت معها وتقدير الضغوط المتولدة بها . وتم مقارنة نتائج هذا النموذج قبل وبعد تطبيق أسلوب المعالجة عليه ومقارنة نتائج الدراسة العددية بنتائج النموذج المعملي الذي تم عمله لهذا الغرض. وقد تم إستنتناج المعادلات الرياضية التي تربط نسبة البنتونيت المستخدمة مع نسبة قدرة تحمل التربة المتوقعه. وأظهرت النتائج أن إستخدام البنتونيت كمادة مخلوطة مع الرمل السائب بنسب مختلفة هي 3 و6 و9 % ساعد بفاعلية في رفع قدرة تحمل التربة لمقاومة الأحمال الزائدة وتقليل الهبوط الناتج تحت تاثير أحمال التشغيل المختلفة. وأن إستخدام البنتونيت كمادة مخلوطة مع الرمل السائب بنسبة 3 % هي النسبة المثلي للخلط التي تعطي أقصي قدرة تحمل للتربة.

Abstract

A series of plain strain models using finite element analyses were performed by PLAXIS program to investigate the behavior of strip footings over reinforced loose sand - bentonite composite by geogrid under static loading. Soil was modeled using Mohr-Coulomb model and geogrid was modeled as an elastic element. Soils in the laboratory model were prepared use mixing ratio of 3, 6, and 9% of bentonite by weight with sand. The load – settlement curves were plotted for all numerical models. The numerical studies demonstrated that the presence of geogrid in sand makes the relationship between contact pressure and settlement of reinforced system nearly linear until reaching the failure stage. Also, it was found that a mixing bentonite percentage of (3%) enhanced the soil bearing capacity by 119%, Adding one and two geogrid layers to the same mixing proportion enhanced the soil bearing capacity up to 300 and 400% respectively,.

Keywords: Bearing Capacity, Bentonite Materials, Geogrid Reinforcement, Loose Sandy Soil, Numerical Model.

1. INTRODUCTION

The use of geogrid under static load to improve the bearing capacity and settlement behavior became an important topic in the last decade. Both experimental and numerical studies have been performed by several previous researchers to investigate the benefits of soil reinforcing studies have shown that geogrid reinforced foundations can increase the ultimate bearing capacity and reduce the settlement of shallow footings, compared to the conventional methods, such as to replacing natural soils or increasing footing dimensions (Boushehrian and Hataf [1], Patra et al. [2], Chung and Cascante [3], Mosallanezhad et al. [4] and Zidan [5]). This paper discusses the behavior of strip footing constructed on reinforced loose sand by geogrid and mixed with different bentonite ratios. Loose sand cannot be as foundations soil of structures, embankments construction, since it is susceptible to high compressibility. In order to use loose sand as the embankments base material, some other products have to be added to have adequate bearing capacity and reduce the settlement. Therefore, the increase of bearing capacity for loose sand by geogrid reinforcement was studied, the bentonite material also was selected as an important engineering material, because it has the advantage to absorb water to make sand plastic, and it is widely used for many purposes in relation to civil engineering materials. Bentonite is an effective material for plasticity properties, where it increases the liquid limit, plastic limit, the maximum dry density and hence the optimum moisture content (OMC). Agapitus and Kolawole [6] Concluded that the consistency limits, liquid limit, plasticity index and linear shrinkage increased linearly with bentonite content in lateritic soil mixed with bentonite. Also, the results showed that the geotechnical performance of compacted loose sandy soil - bentonite mixtures proposed as liner material in waste landfills showed that bentonite addition resulted in an increase in plasticity index, optimum moisture content and a reduction in dry unit weight. Expectedly, the hydraulic conductivity and unconfined compression strength of compacted mixtures decreased non-linearly while the volumetric shrinkage increased with increase in bentonite content. Wayal, et al. [7] investigated the use of bentonite and lime in stabilizing dune sands for possible uses in geotechnical engineering. The bentonite added to the mixture was helping in making cohesive bond in the mixture. The results showed substantial improvements in unconfined compression strength with addition of 15% bentonite and 3% lime. Further addition of bentonite and lime in dune sand causes compaction difficulties as the mixture becomes sticky. The minimum values of unconfined compressive strength were found in the mixture 5% bentonite and 1% lime. El.Mashad M. and Tetsuya H. [8],[9] concluded that the bentonite is the effective material for plasticity properties, where the increases in bentonite ratio led to increase the liquid limit, plastic limit and the OMC. On the other hand, the maximum dry density and the CBR ratio decrease as the bentonite ratio increases. Thus, the bentonite should have been used in a small amount to keep plasticity and CBR to achieve the economy. Hence 5% or less for the bentonite in the mixture is recommended through their experiments. Tetsuya H. and El.Mashad M. [10] Concluded that the bentonite should be used with a percent of 6% to keep enough plasticity and to contribute to the economy. Compacted bentonite is used as engineered barrier mainly for limiting migration of leachate from the wastes which may contain elements that are detrimental to the quality of groundwater for their designated uses. The use of compacted natural clayey soils due to very low hydraulic conductivity, self healing quality and a marked capacity to adsorb and retain contaminants for this purpose is well established by Rowe, et al. [11] and Gleason, et al. [12]. From the conducted previous works it is clear that mixing bentonite by ratio of 5 % gives the best ratio of enhancement the bearing capacity. Therefore, in this study it was decided to use ratios of bentonite (3, 6, and 9) % with and without geogrid layers.

2. MATERIALS

In the current research, air-dried clean siliceous yellow sand was used. The used sand was obtained from El-menia governorate, Desert Road, Egypt. Grain size analysis was performed on several sand samples according to ASTM D421 [13]. Figure (1) shows the grain size distribution of used sand. The plot shows that a medium to fine sand was selected. The tested sand was classified as poorly graded sand (SP) according to the unified soil classification system [USCS] [14]. Physical properties of the sand were determined as shown in table (1).

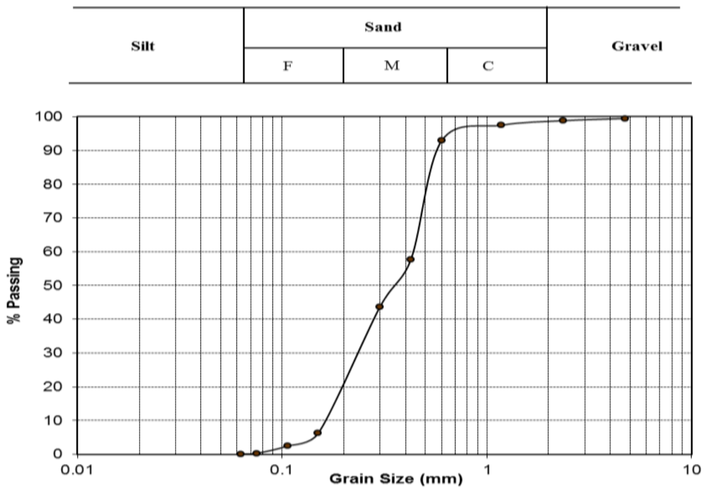

Figure (1) Grain Size Distribution of Used Sand

Table (1) Summary of the Physical Properties of Sand

Property	***Value***	***Property***	***Value***
Specific gravity (Gs)	2.64	Maximum dry unit weight (γ_{dmax})(kN/m^3)	16.80
Void ratio (e)	0.70	Minimum dry unit weight (γ_{dmin})(kN/m^3)	13.90
% of fine Sand	18.55	Maximum void ratio (e_{max})	0.907
% of medium Sand	79.17	Minimum void ratio (e_{min})	0.52
% of coarse Sand	1.27	Angel of internal friction ϕ°	30.0
% of fine Gravel	1.0	Effective diameter (D_{10}) mm	0.362
Unit weight (γ_b)(kN/m^3)	16.41	Coefficient of uniformity(C_u)	1.450

Calcium bentonite produced in Egypt was used in this research. Physical and chemical analysis was done. The Atterberg limits of bentonite are 576.8% (LL), 46.1% (PL), 30% (SL) and 530.7 % (PI). The clay content was about 82% with Activity 4.88 and Free Swelling 380 %. The total dissolved salts (TDS ppm) was 3328, and it is composed mainly of Calcium (CL ppm) 568, (SO3 ppm) 40, with PH 7.3. The reinforcing material used in this study was Tenax from type Bi-Axial geogrid (LBO - 440 SAMP) with high-density polypropylene (pp) with peak tensile strength of 40 kN/m, The tensile strength at 2 and 5% strain is 14 kN/m and 28 kN/m, respectively. The width of reinforcement is taken as 5 times the foundation width ($5b_f$) in all analysis cases.

3. NUMERICAL MODEL

The experimental and numerical studies can complement each other in leading to a much better understanding of the true behavior of strip footing on top of sand only and sandy soil mixed with different ratios of bentonite in addition to using one or two geogrid layers. Therefore, a plane-strain finite element analysis was conducted using the widely known software PLAXIS code, professional version 8.2 [15] for soil and rock analysis. The analysis was carried out by considering strip shaped footing on loose sand and treated layer with depth ranging from (0.50 to 1.0) b_f mixed with different bentonite ratios.

3.1 Numerical Model Description

The soil was modeled using an elasto-plastic constitutive law incorporated with Mohr-Coulomb model. The footing was modeled using beam element of linear elastic material behavior. The interaction between the footing and the underlying soil was simulated by employing 15-node interface elements. Interface strength reduction factor of 0.8 of the effective soil shear strength was adopted in the analysis. The required shear strength parameters were inferred from a series of laboratory tests on soil samples, and their values are given in table (2). The strip footing parameters values were calculated as shown in table (3).

Table (2): Properties of Sand Mixed with Bentonite ratio in Model

PARAMETERS	***Sand + 0% Bentonite***	***Sand + 3% Bentonite***	***Sand + 6% Bentonite***	***Sand + 9% Bentonite***
Unsaturated Unit Weight (□unsat) kN/m3	13.90	17.1	19.30	20.1
Saturated Unit Weight (□sat) kN/m3	16.41	18.2	20.0	21.0
Permeability (K) (m/sec.)	2.84E-05	1.30E-07	1.19E-07	1.71E-07
Reference Young's Modulus (Eref) kN/m2	14000	13000	12500	12000
Poisson's Ratio (υ)	0.30	0.30	0.30	0.350
Cohesion (c) kN/m2	0.0	1.50	2.02	3
Friction Angle (ϕ) ∘	30.0	28.0	25.13	22.79
Dilatancy Angle (ψ) ∘	0	0	0	0
Interface Strength (Rinter)	0.80	0.80	0.80	0.80

Table (3): Properties of Strip Footing

PARAMETERS	VALUES
Axial Stiffness (EA) (kN/m)	400000
Flexural Rigidity (EI) (kN.m2/m)	13.30
Equivalent Plate Thickness (m)	0.020
Poisson's Ratio (υ)	0.30
Specific Weight (kN/m/m)	1.56

The boundary conditions were chosen and the mesh was generated by the program and refined in the area around the footing. The geometry model of specified dimensions was done as the experimental tests in [16], i.e. a model of 1.80 m. long, 0.90 m. width and 1.0 m. height was created using line option in the plaxis window. Figures (2 and 3) show the geometry of used model and finite element mesh of geometry model, respectively.

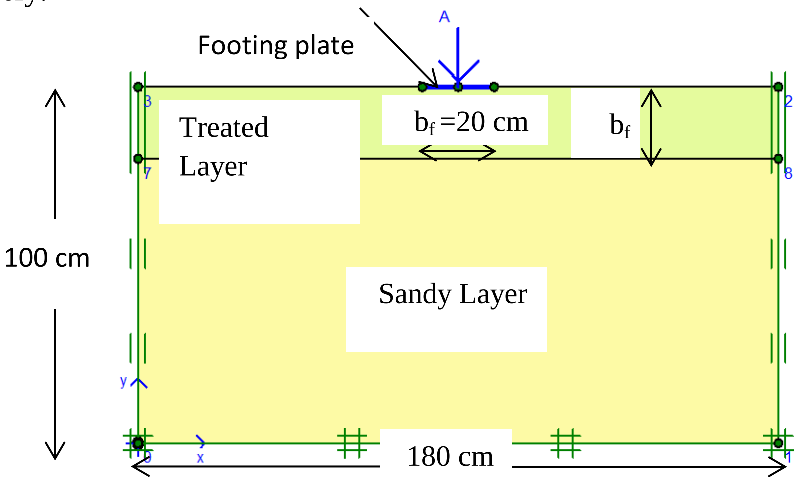

Figure (2): Numerical Model Geometry without Geogrid Reinforcement.

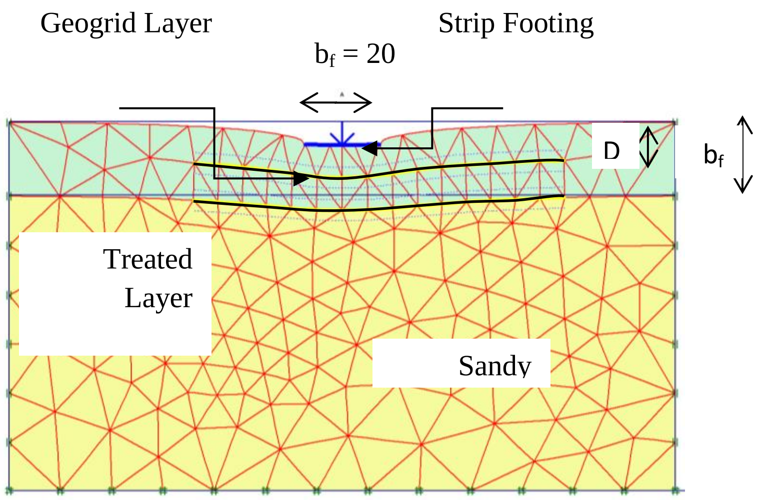

Figure (3): Deformed Mesh after Analysis with Two Geogrid Layer.

The main modeling program consisted of 12 model divided into three series, S1, S2 and S3. Table (4) shows the numerical model configuration.

Table (4) Numerical Model Configurations

Test Code	***Purpose of study***	***Number of Geogrid Layers***	***Depth of Geogrid Layers***
Sandy soil only	Effect of Bentonite ratio on loose sand (S1)	0	0
S+3%B			
S+6%B			
S+9%B			
Sandy soil only	Effect of Bentonite ratio with one geogrid layer on loose sand (S2)	1	0
S+3%B+1G			D = 0.50 bf
S+6%B+1G			D = 0.50 bf
S+9%B+1G			D = 0.50 bf
Sandy soil only	Effect of Bentonite ratio with two geogrid layer on loose sand (S3)	2	0
S+3%B+2G			D = 0.50 bf ,1.0 bf
S+6%B+2G			D = 0.50 bf ,1.0 bf
S+9%B+2G			D = 0.50 bf ,1.0 bf

S: Loose Sand B: Bentonite G: Geogrid layer Sn: Series number (S1, S2 & S3)
D: Depth of geogrid layer bf: footing width

1. RESULTS AND DISCUSSIONS FOR NUMERICAL MODEL

Four methods are available to estimate the failure of a shallow foundation, based on results of load settlement curves, however if there is no distinct failure pattern of the foundation/soil system available, the values can be obtained as recommended by Cerato [17], Lutenegger and Adams [18].

1- log-log Method
2- Tangent Intersection Method (TIM)
3- 0.1 B_f Method
4- Hyperbolic Method.

The 0.1 B_f method is found to be the most enclose from other methods. So, it was used to find the ultimate bearing capacity value for each case in the current numerical study.

4.1 Effect of Bentonite Ratio Mixture with Loose Sand (S1)

Four models of finite element analysis were performed to study the effectiveness of the behaviour of strip footing in sandy soil with and without bentonite mixture. Figure (4) presents the stress v/s settlement curves for strip footing resting on loose sand beds with and without mixing bentonite ratio for layer with depth (b_f) equal width of the footing as shown in previous figure (2). In order to estimate the improvement of the soil produced by the inclusion of bentonit, the (Bearing Capacity Ratio) B.C.R was calculated for each model. The B.C.R was defined as the ratio of the bearing capacity of treated soil with bentonite and that without bentonite. This value is calculated for each model and is defined as the equation (1):

$$(BCR) = q_T / q_{UT} \qquad (1)$$

Where q_T and q_{UT} are the bearing capacity for treated and untreated soil respectively, Table (5) shows the stress at failure load and rate of B.C.R for each test model.

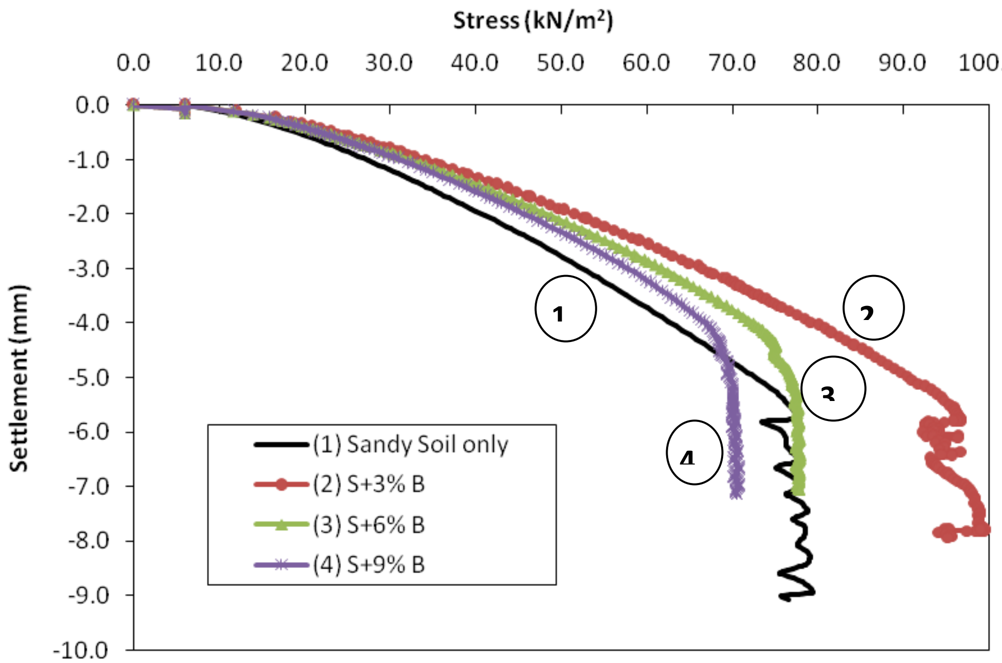

Figure (4): Cumulative Curve for the Stress- Settlement of Different Bentonite Ratio.

(Table 5) Ultimate Stress Value (kN / m^2) and rate of B.C.R for series (S1)

Series (S1)	***Failure Stress (kN / m2)***	***(B.C.R)***	***Settlement (mm)***
Sand without Bentonite	76.67	1.0	9.50
Sand with 3 % Bentonite	91.107	1.19	8.70
Sand with 6 % Bentonite	77.86	1.02	7.39
Sand with 9 % Bentonite	70.59	0.92	7.50

From figure (4) and table (5), it can be concluded that the improvement ratio in bearing capacity for sand occurred when mixed with 3% bentonite by 19% compared with case of sand only. But when using 6% bentonite, the bearing capacity was almost as the case of without mixing bentonite. The ultimate bearing capacity decreased by 8% when mixed with 9% bentonite compared with case of without using bentonite with lower value of settlement. So, the maximum improvement ratio in bearing capacity occured in mixture of sand with 3% bentonite ratio. The results from numerical model compared with the results of experimental model which were obtained by Tarek et al. 2016, [16] as shown in figure (5).

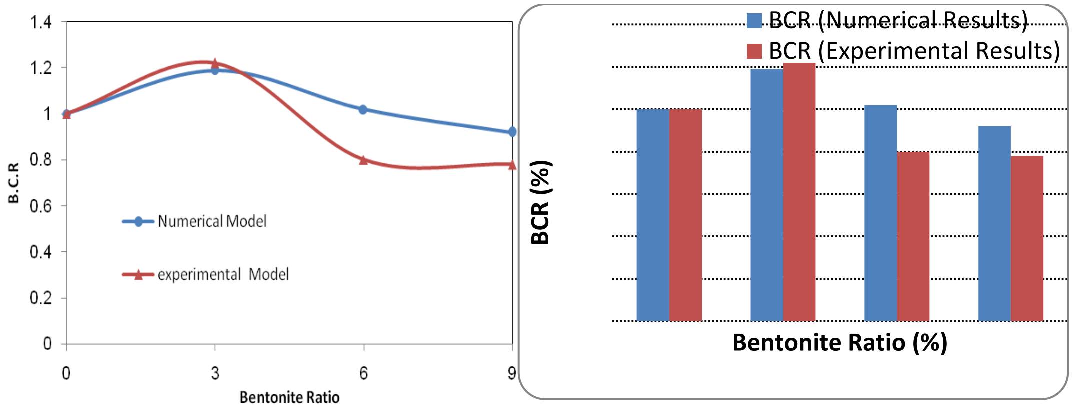

Figure (5): Comparison between present numerical results and experimental results reported by Tarek et al. [16].

From figure (5), it can be seen that the bearing capacity for mixing soil with bentonite ratio increases till ratio of 3 % bentonite, then the increase in bentonite ratios more than 3%, lead to decrease in ultimate bearing capacity. This result indicates that the best ratio for improving the bearing capacity was 3%. The reason of this result is due to the bentonite particles act a lubricant for loose sand and decreased the void ratio in sand.

4.2 Effect of Combinations of One Geogrid Layer with Different Bentonite ratios (S2).

Four models were performed to investigate the effect of inserting one geogrid layer on the bearing capacity, settlement of the footing on reinforced sand mixed with 3, 6 and 9% bentonite ratio. Figure (6) shows section elevation of the model configuration.

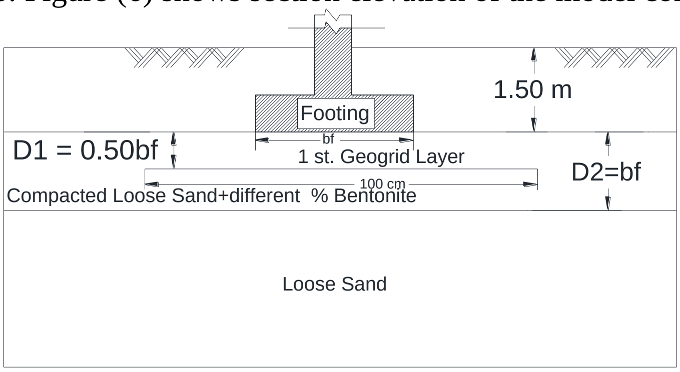

Figure (6) Section Elevation of the Model Configuration for Group Series (S2)

The results of four models are presented in figure (7), to clarify the influence of inserting one geogrid layer mixed with different bentonite ratio on the behavior of loose sand.

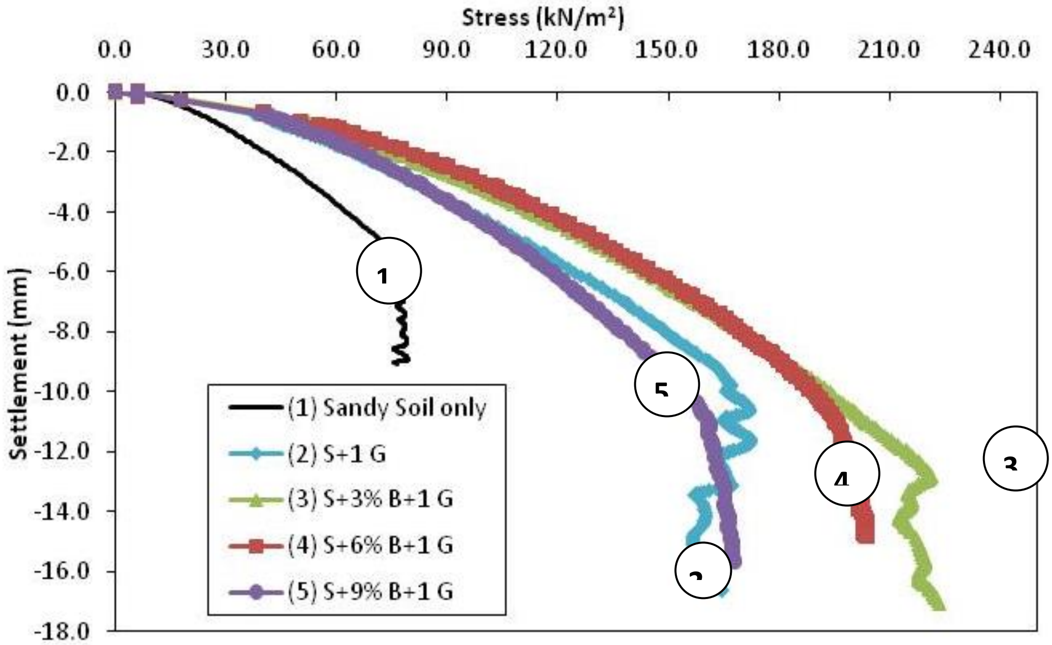

Figure (7): Relationship between Stress (kN / m^2) and Settlement (mm) of series (S2).

Table (6) show the stress at failure load and rate of increase in B.C.R for series (S2) reinforced by one geogrid layer with 3, 6 and 9 % bentonite.
(Table 6) Ultimate Stress Value (kN / m^2) and Rate of B.C.R for Series (S2).

Series (S2)	***Failure Stress (kN / m2)***	***(B.C.R)***	***Settlement (mm)***
Sandy Soil only	76.67	1.0	9.50
S+ 1G	164.58	2.27	8.36
S+3% B+1G	223.75	2.92	7.67
S+6% B+1G	204.17	2.66	7.45
S+9% B+1G	167.86	2.19	6.66

From figure (7) and table (6), it can be concluded that:-

- The improvement ratio in ultimate bearing capacity for loose sand when reinforced by one geogrid layer only were 127 % compared with case of without reinforcement.
- The improvement ratio in ultimate bearing capacity for loose sand when reinforced by one geogrid layer and mixed with 3,6,9 % bentonite were 292, 266, 219 % respectively, compared with the case of without improvement. So, the maximum improvement ratio occurs in case of mixing 3% bentonite when using one geogrid layers.
- The vertical settlement decreases when reinforced by one geogrid layer and mixed with 3, 6, 9 % bentonite by 8.3, 10.9, 20.3 % respectively, compared with case of without improvement at failure stress by 0.1 B_f method.
- The increase in footing ultimate stress can be attributed to reinforcement mechanism which derived in the passive zone, interlocking in sand/bentonite particles and adhesion between the longitudinal / transverse geogrid members and the sand. The mobilized passive resistance of soil column confined in the

geogrid apertures along with the interlocking limit the vertical deformations of sand particles. The mobilized tension in the reinforcement enables the geogrid to resist the imposed vertical shear stresses built up in the soil mass beneath the loaded area and transfer them to under layers of soils leading to a wider failure zone as shown in figure (8).

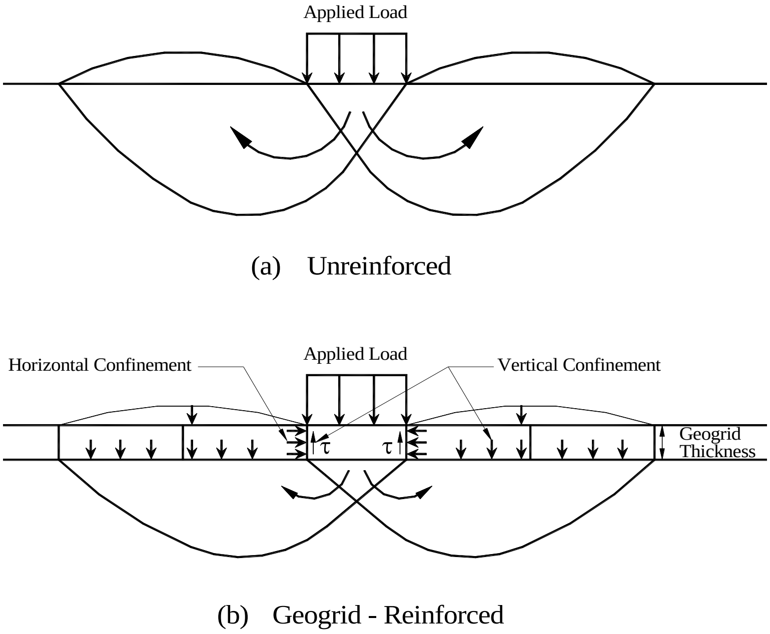

Figure (8): Unreinforced and reinforced soil by geogrid behavior.

- When using one geogrid layer, increasing bentonite ratio more than 6% has no effect in enhancing the bearing capacity.

Therefore, the results from numerical model compared with the results of experimental model which were done by authors as shown in figure (9).

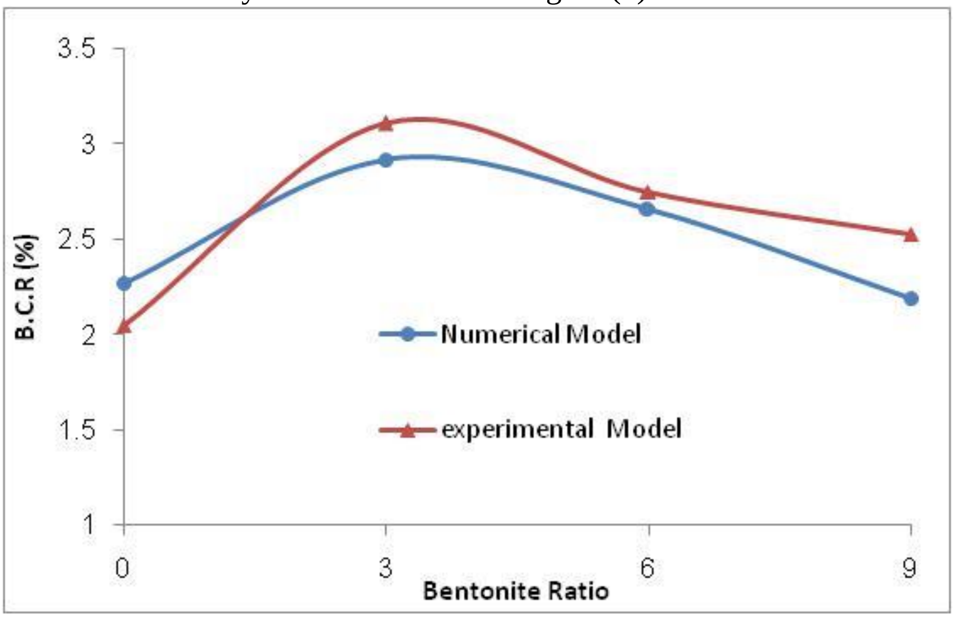

Figure (9): Comparison between present numerical results and experimental results for mixed soil reinforced with one geogrid layer. Tarek et al. [private communication].

4.3 Effect of Combinations of Two Geogrid layers with Different Bentonite ratios (S3).

Four models were performed to investigate the effect of inserting two geogrid layers on the bearing capacity, settlement of the footing on reinforced mass mixed with 3, 6 and 9% bentonite. Figure (10) shows section elevation of test configuration.

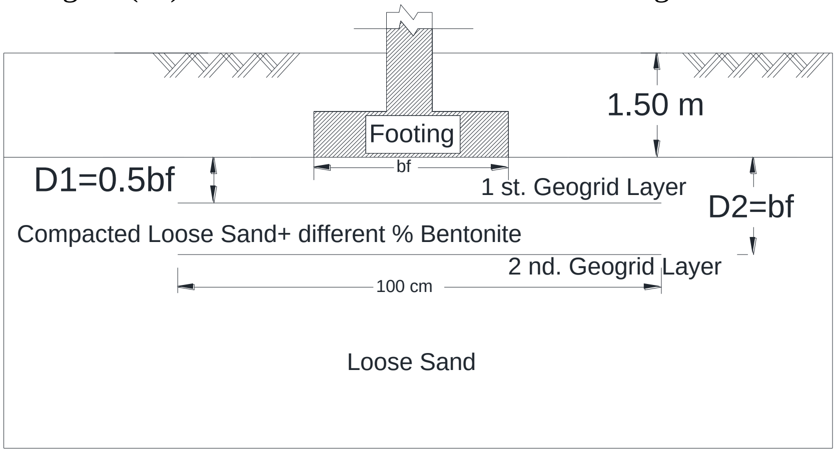

Figure (10) Section Elevation of Model Configuration for Series (S3)

The results of four models are presented in figure (11), to clarify the influence of inserting two geogrid layers mixed with different bentonite ratio on the behavior of loose sand.

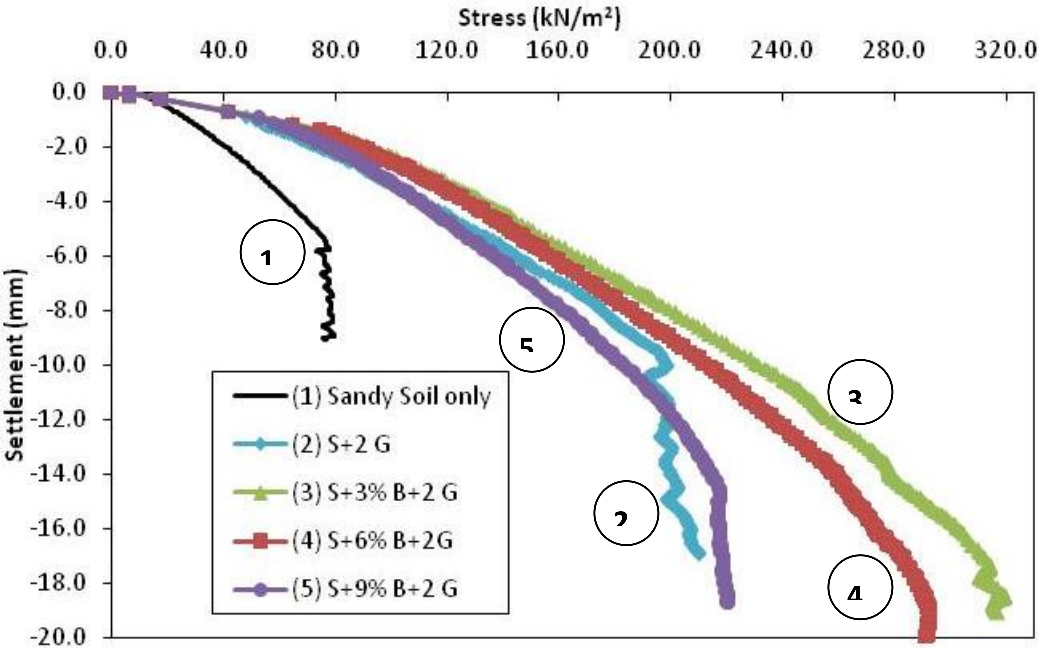

Figure (11): Relationship between Stress (kN/m^2) and Settlement (mm) of Series (S3).

Table (7) shows the stress at failure load and rate of increase in BCR for series (S3) reinforcement by two geogrid layer with different bentonite ratios.

(Table 7) Ultimate Stress Value (kN /m^2) and rate of increase in B.C.R for series (S3).

Series (S3)	***Failure Stress (kN / m2)***	***(B.C.R)***	***Settlement (mm)***
Sandy Soil only	76.67	1.0	9.50
S+ 2G	209.05	2.72	9.37
S+3% B+2G	317.68	4.14	8.72
S+6% B+2G	293.81	3.83	7.90
S+9% B+2G	220.24	2.87	6.77

From figure (11) and table (7), it can be concluded that:-

- The improvement ratio in bearing capacity for loose sand when reinforced by two geogrid layers only were 141 % compared with case of no using of reinforcement.
- The improvement ratio in bearing capacity for loose sand when reinforced by two geogrid layers mixed with 3,6,9 % bentonite were 414, 383, 287 % respectively, compared with case of without improvement. So, the maximum improvement ratio occurs in case of mixing 6% bentonite when using two geogrid layers.
- The vertical settlement decreases when reinforced by two geogrid layers mixed with 3, 6 and 9 % bentonite by 8.2, 16.8, 28.7 % respectively, compared with case of without improvement.
- The mode of soil failure is close to a punching shear failure in case of without using bentonite, whereas using two geogrid layers without bentonite is local shear failure, But when using bentonite ratio with two geogrid layers, the mode of failure changed to general shear failure.
- When using two geogrid layers, increasing bentonite ratio more than 6% has no effect in enhancing the bearing capacity.
- Therefore, the results from numerical model compared with the results of experimental model which were done by authors as shown in figure (12).

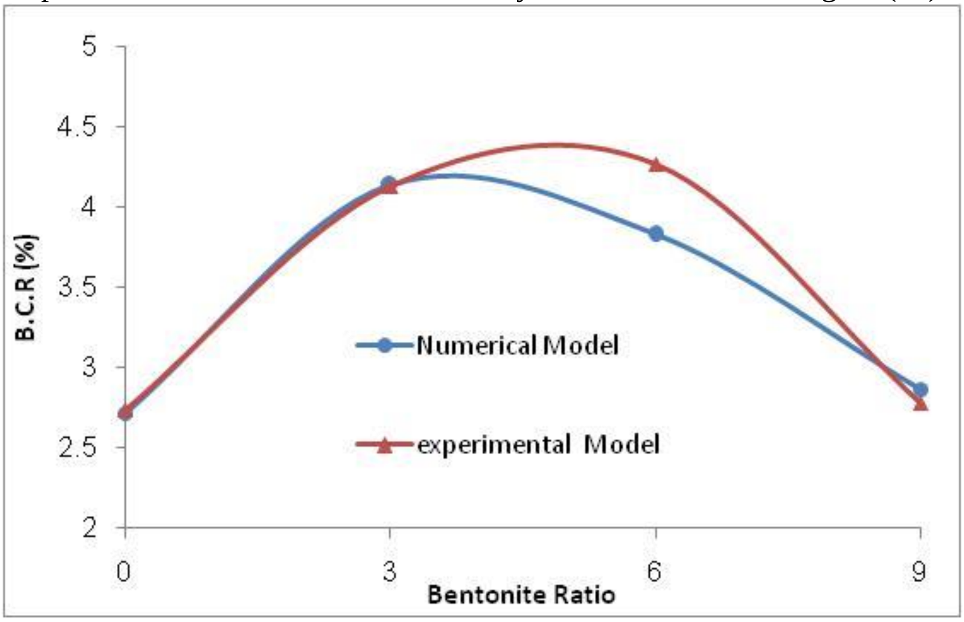

Figure (12): Comparison between present numerical results with experimental results for mixed soil reinforced with two geogrid layer, Tarek et al. [private communication].

5. PARAMETRIC CORRELATIONS OF OBSERVED TRENDS

From the current study, it can be clearly seen the effect of mixing bentonite to loose sandy soil. Also, the effect of inserting geogrid reinforcement on loose sandy soil mixed with 3, 6 and 9 % bentonite ratio. So, a parametric correlation of observed trends for each test series of models was obtained as can be seen in Fig.13.

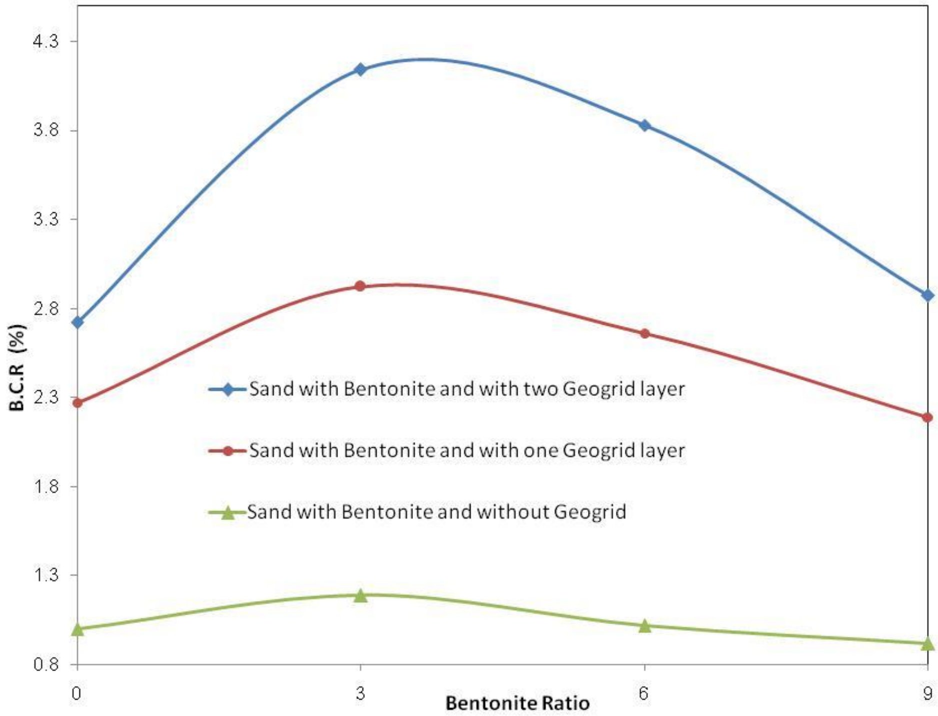

Figure (13) Relationship for improvement in BCR and bentonite ratios

From Fig. 13. It can be concluded that:
Based on the current numerical results, the improvement ratio in bearing capacity for loose sand mixed with different bentonite ratios can be defined by the following equation number (2).

$$BCR = 0.008\,B^2 + 0.06\,B + 1.0 \qquad (2)$$

Where (BCR) is the improvement ratio in bearing capacity and (B) the bentonite ratio.
Based on the current numerical results, the improvement ratio in the bearing capacity for loose sand mixed with different bentonite ratios and insert one geogrid layer can be defined by the following equation number (3)

$$BCR = 0.03B^2 + 0.263\,B + 2.31 \qquad (3)$$

Based on the current numerical results, the improvement ratio in bearing capacity for loose sand mixed with different bentonite ratios and insert two geogrid layer, can be defined by the following equation number (4) depend on figure (13).

$$BCR = 0.07B^2 + 0.6\,B + 2.77 \qquad (4)$$

CONCLUSIONS

The current research was carried out to clarify the effect of mixing sandy soil with 3, 6 and 9 % bentonite ratio and insert geogrid layers at different depths under shallow foundations. The following conclusions were drawn:-

1. The ultimate bearing capacity for loose sand increased when mixed with 3 % bentonite by 119 %. But when using 6% bentonite the bearing capacity was almost as the case of without mixing bentonite. The ultimate bearing capacity decreased by 8% when mixed with 9% bentonite compared with case of without using bentonite. Thus, the maximum improvement ratio occurred at 3 % bentonite.
2. To improve the ultimate bearing capacity by bentonite mixing, it should be used a small enough and economy ratio, hence 3% is recommended through the experiments and numerical study.
3. The improvement ratio in ultimate bearing capacity for loose sand when reinforced by one geogrid layer and mixed with 3,6,9 % bentonite were 292, 266, 219 % respectively, compared with case of without improvement. So, the maximum improvement ratio occurs in case of mixing 3% bentonite when using one geogrid layer.
4. The improvement ratio in ultimate bearing capacity for loose sand when reinforced by two geogrid layers and mixed with 3,6,9 % bentonite were 317, 293, 220 % respectively, compared with case of without improvement. So, the maximum improvement ratio occurs in case of mixing 3% bentonite when using two geogrid layers.
5. The increase in bentonite ratio more than 3 % was not of a great influence in enhancing the ultimate bearing capacity for sand mixed with bentonite.
6. The failure stress assessment of the study cases sheds the light on the importance of the computer programming for determination of the failure stress of soil. Moreover, the settlement of the critical failure stress distribution zones, also come out as a part of solution.

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