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STABILIZATION OF LOOSE FINE SAND DEPOSITS AS A FOUNDATION LAYER-NUMERICAL MODELING

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ملخص البحث:

يتم إجراء البحث عدديًا باستخدام حزمة العناصر المحدودة PLAXIS ، الإصدار 8.2. تمت مقارنة الحد الأقصى للحمل التي تم الحصول عليها من اختبار النموذج العددي باختبارات النموذج المعملى لأغراض التحقق من الصحة. أجريت دراسة حدية ووجدت أن كفاءة نظام إبر البولي بروبيلين- الشبكات البلاستيكية- والرمل أكبر مع زيادة عمق وجود الشبكة البلاستيكية تحت القاعدة u / B ، وبمحتوى الإبر (0.125٪ ، 0.150٪ ، 0.175٪ و 0.2٪) بالوزن من التربة الرملية المعالجة. من خلال تحليل بيانات المخرجات بما في ذلك الخرائط الكنتورية المظللةلكل من ؛ الإزاحات الرأسية والأفقية والإجهادات ، يمكن استخلاص النتائج لجميع الحالات المدروسة .

ABSTRACT:

The research is carried out numerically using finite element package PLAXIS version 8.2. The ultimate bearing capacity obtained from the numerical model test program is compared with the experimental model tests for the validation purposes. A parametric study were carried out and it was found that the efficiency of the sand-polypropylene needles -geogrid system increased with increasing geogrid embedment depth u/B, the tensional distributed needles content of (0.125%, 0.150%, 0.175% and 0.2%) by weight. Through the analysis of the output data, including the shaded contour maps of; vertical displacement, horizontal displacements and effective horizontal stresses, the conclusions could be derived for all the studied cases; unreinforced sand, reinforced with needle elements and reinforced with (geogrid-needles)

Keywords: Polypropylene needles, Geogrids, Soil reinforcement , Numerical modeling, Model validation

INTRODUCTION

The use of inextensible reinforcements to stabilize earth structures has grown rapidly in the past two decades. They can be laid continuously along the width of the reinforced soil system (grid type) or laid at intervals (strip type). Both grid and strip reinforcements are widely used around the world. Recently, Horpibulsuk and Niramitkornburee; 2010 [1] have introduced a new cost-effective inextensible reinforcement type, which is designated as “Bearing reinforcement”. The advantages of the bearing reinforcement are available raw material, simple and fast installation, convenient transportation, and high pullout and rupture resistances with less steel volume.

Needle polypropylene content of 0.25%, 0.5%, 0.75% and 1% by weight of raw soil with their lengths of 10, 15, 20 and 25 mm by Prabakara J and Sridhar R.; 2002 [2] to reinforce a local problematic soil. The increase in the needles length and needles content also reduces the dry density of the soil. As well it was found that the shear stress is increased non-linearly with increase in length of needles up to 20 mm and beyond, where an increase in length reduces the shear stress. The percentage of needles content also improves the shear strength. But beyond 0.75% needles content, the shear stress reduces with increase in needles content. Sisal needles reinforced soils stabilized with cement were used as a building material.

Ahmad F, Bateni F, and Azmi M.; 2010 [3] mixed palm needless with silty sand soil to investigate the increase of shear strength during tri-axial compression. The specimens were tested with 0.25% and 0.5% content of palm needless of different lengths (15 mm, 30 mm and 45 mm). Reinforced silty sand containing 0.5% coated needless of 30 mm length exhibited approximately 25% increase in friction angle and 35% in cohesion compared to those of unreinforced silty sand. In addition, palm needless coated with acrylic butadiene styrene thermoplastic increased the shear strength of silty sand much more compared to uncoated needless.

The use of discrete flexible needle elements mimics the behavior of plant roots and gives the possibility of improving the strength and the stability of near surface soil layers (Al Refeai, T.O.; 1991 [4]). This technique for the stabilization of thin layers of soil, repairing failed slopes, soil strengthening around footings and earth retaining structures. Direct shear tests, unconfined compression tests and conventional triaxial compression tests have demonstrated that shear strength is increased and post-peak strength loss is reduced when discrete needless are mixed with the soil among others.

Tri-axial compression tests were carried by Consoli C, Casagrande T, Prietto M, and Thome A.; 2003 [5]. They added the tensionly distributed needless to cemented soil, conducted on the mixture, and concluded that the needles reinforcement increased both the peak and residual strength, and changed the cemented soil's brittle behavior to a more ductile one. The inclusion of needless significantly changed the failure mechanism by preventing the formation of tension cracks.

The use of tension ibers can improve the strength behavior, and significantly enhance the ductility and fracture toughness of soil matrix. It has been proved that discrete needless can be considered as good earth reinforcement material. Miller J. and Rifai S.; 2004 [6] reported that the shrinkage crack reduction and hydraulic conductivity of compacted clay soil increased with an increase in needles content. All these investigations show that

The main purpose of this research is to describe the engineering behavior of reinforced soil formations and how to characterize a specific reinforcement type and how the use of a combination of two reinforcement methods influence that behavior.

MATERIALS

Flixable Polypropelyene Needle Elements

The polypropylene needles were produced from long needless of polypropylene materials by cutting into required lengths. These needles were 65 mm in length (shown in **Figure-1)** and act predominately in tension and their properties as provided by the manufacturer are shown in **Table- 1**.

Table- 1 Flixable Polypropelyene Needle Properties

Property	Unit	Value
Density	g/cm^3	0.91-0.94
Tensile strength	Psi (Pound/sq. in.)	3200-5000
Water absorption, 24hr	%	0.01
Elongation	%	3-700
Softening point, T_g	°C	140-150
Melting point, T_m	°C	160-166
Thermal expansion	10-5 in./in. °C	5.8-10
Specific volume	cm^3/Ib	30.4-30.8

Figure-1: Descrete Flexible Polypropylene Needle Element

Sand

The tested sand sample is poorly graded loose fine sand with grain size distribution shown in **Figure-2**

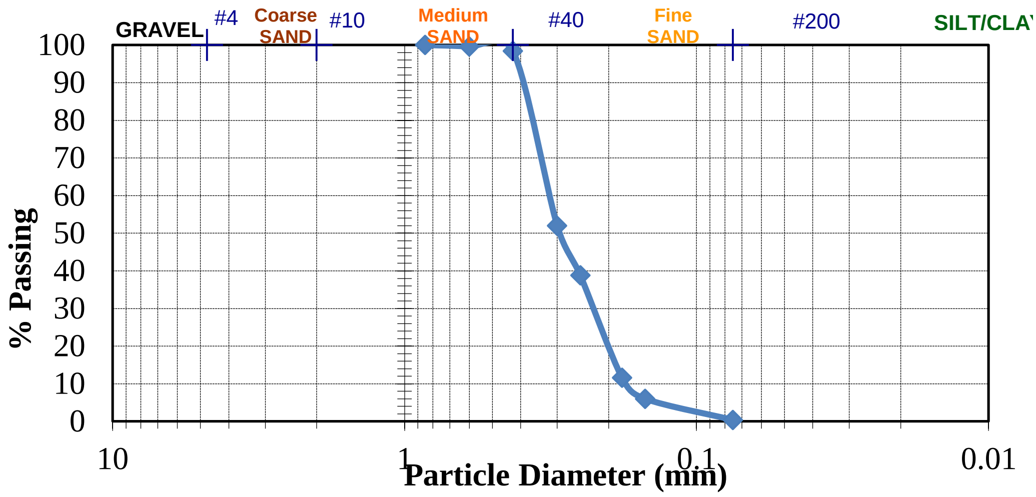

Figure-2: Tested Sand Grain Size Distribution Curve

Geogrid

TENAX TT GS type 045 mono-oriented geogrids as in **Figure-3** are designed especially for soil reinforcement and are manufactured by extruding and mono-directional drawing of high-density polyethylene (HDPE) grids. This technology produces products having important technical properties that permit their usage in structural applications and being chemically inert and having a high tensile strength and modulus are specifically produced for the reinforcement of soil. Soil and aggregate interlock within the geogrid openings, which, confine the soil and limit its relative displacements and increase the soil's shear stress resistance.

Soil compaction produces an interlock between the soil and both faces of the geogrid layer, thus it's necessary to reach a higher level of tension in order to overcome such an interlock and give rise to movement.

Figure-3: Uniaxial Geogrid- TENAX TT GS type 045

The numerical model testing program evaluates the design parameters related to the geogrid including; u, h_1 to h_n, L as shown in **Figure-4.**

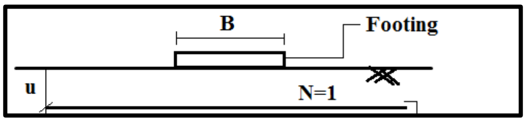

Figure-4: Geogrid Layout in Testing Program

MATERIAL MODELING

Sand

The sandy soil is represented by Mohr-coulomb constitutive law with the input parameters shown in Table-2 for pure sandy soil and Table-3 for the sandy soil mixed with different percentages of needle elements ranging between 0.125% to 0.2%.

Table- 2 Soil Parameters Used in FEM without Tensile Needle Elements

Soil Parameters	Soil Parameters without Tensile Needle Elements	
	Parameters name	**Value**
1	Unit Weight	16 kN/m^3
2	Young's modulus [E_{ref}]	20000 kN/m^2
3	Poisson ratio [v(nu)]	0.3
4	Cohesion [C_{ref}]	10 kN/m^2
5	Friction angle [φ]	33°
6	Dilatancy angle [ψ]	1°

Table-3 Sand Mixed with Tensile Needle Elements in Percentage of Sand by Weight

Soil Parameters	Added Tensile Needle Elements in Percentage of Sand by Weight			
	0.125	0.150	0.175	0.2
Unit Weight [kN/m3]	16	16	16	15.9
Young's modulus [Eref] [kN/m2]	26000	22000	20500	18700
Poisson ratio [v(nu)]	0.32	0.32	0.34	0.35
Cohesion [Cref] [kN/m2]	9	8	6	6
Friction angle [φ]	35°	37°	37°	38°
Dilatancy angle [ψ]	1	1	1	1

Geogrid Modeling

Geogrids are elastic flexible elements with a normal stiffness but no bending stiffness. Geogrids can only sustain tensile forces and no compression. These objects are generally used to model soil reinforcements. [Plaxis Version 8 manual 2002]. The geogrid was modeled using elasto-plastic constitutive model with the parameters as in Table- 4.

Table- 4 Geogrid parameters used in FEM

Geogrid Parameters	Geogrid Parameters Values	
	Parameter	Value
1	EA	500 kN/m
2	N_p	45 kN/m

Where: EA: Axial/Normal Stiffness

N_p: Ultimate tensile strength of the geogrid

Strip Footing Modeling

Footings (A, B, and C) are modeled as a plate with steel parameters shown in Table- 5.

Table-5 Steel Plate Footing Parameters Used in the FEM

Plate Properties	Plate Properties Values			
	Parameters Name	Values		
1	ϒ Steel	78.4 kN/m^3		
2	Young's modulus[E_{ref}]	2E+08 kN/m^2		
3	Thickness (cm)	1	1	1
4	Width (cm)	7.5	10	12.5
5	EA – Axial Stiffness (kN/m)	150000	200000	250000
6	EI – Bending Stiffness (kN.m^2/m)	1.25	1.6667	2.0833

NUMERICAL MODEL VALIDATION

Unreinforced Soil Bed

Figure-5 shows the results of the experimental model previously tested for the unreinforced soil bed for Footing (A, B, and C). It is noticed that as the width of the footing increases the stress at failure increases which agrees with Terzagi ultimate bearing capacity criteria

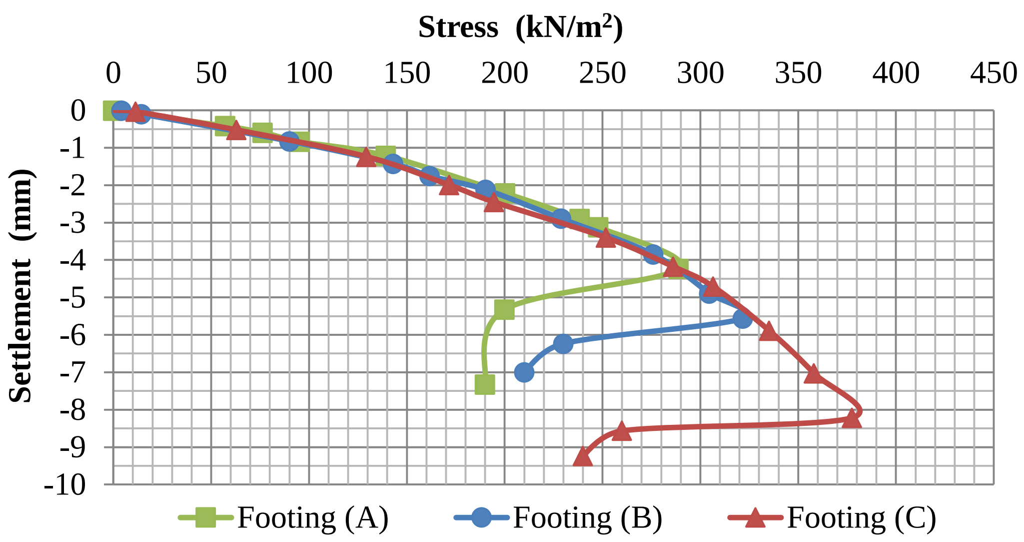

Figure-5: Stress-Settlement Characteristics of Unreinforced Soil Bed-Experimental Model Results for Footing (A, B, and C)

Unreinforced soil bed finite element model (FEM) vs. experimental model

Figure-6 a, b and c illustrate the comparison between FEM and the experimental model results for footing (A, B, and C) respectively. TABLE VIII summarizes the ultimate Stress (kN/m^2) applied and the corresponding settlement (mm) under Footing (A, B, and C), with the Stress and settlement values extracted are shown in Table- 6 below.

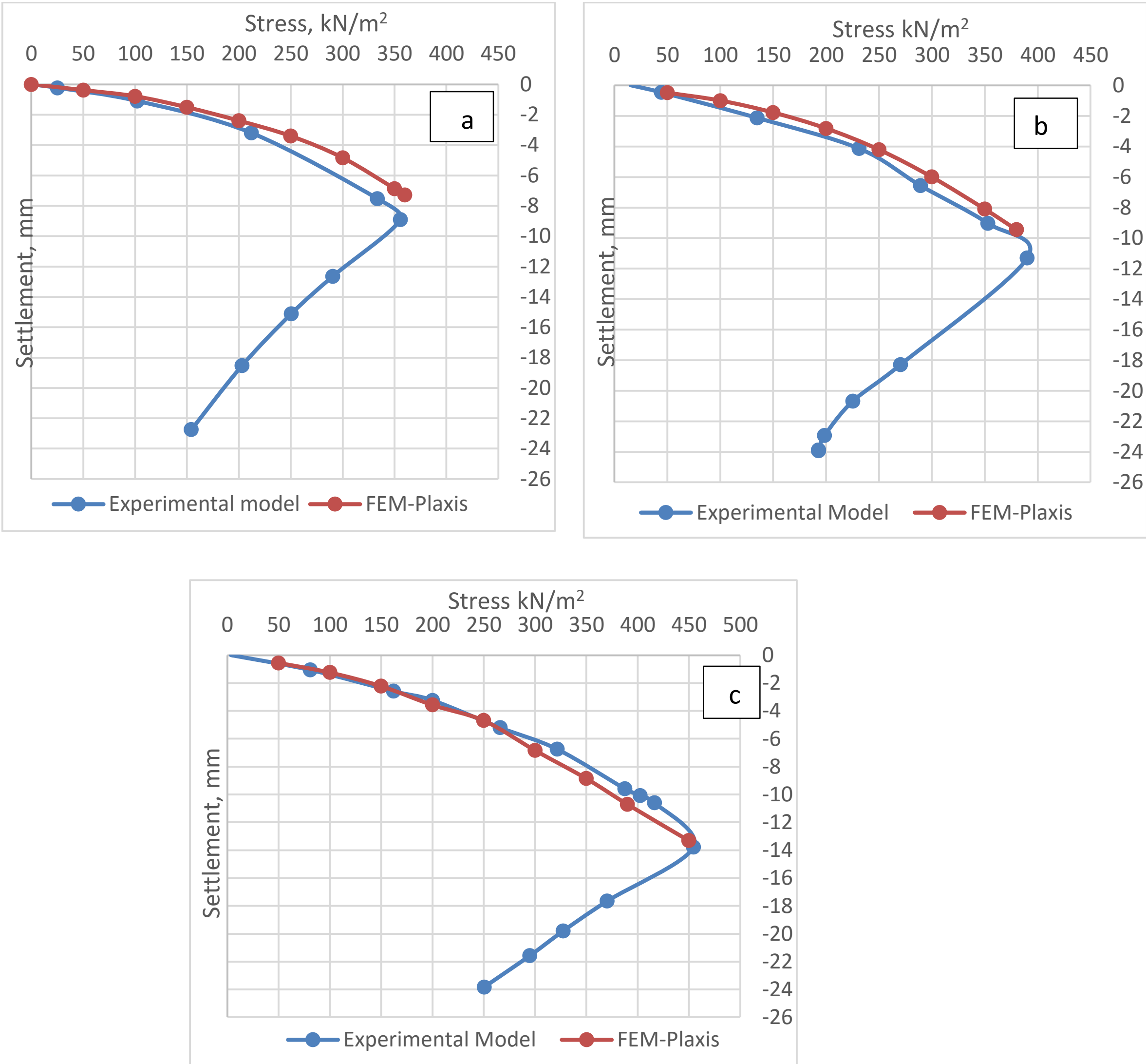

Figure-6: Stress-Settlement Characteristics of Unreinforced Soil Bed FEM Vs. Experimental Results for; a) Footing (A), b) Footing B And c) Footing C

Table-6 Unreinforced Soil Bed FEM vs. Experimental Results Footing (A, B, and C).

Footing	Experimental Model		FEM-Plaxis	
	Ultimate Stress (kN/m^2)	Settlement (mm)	Ultimate Stress (kN/m^2)	Settlement (mm)
A	355.6	8.9	360	7.28
B	390	11.3	380	9.4
C	454.6	13.7	450	13.3

The comparison results of the unreinforced soil bed case between the FEM results and the experimental model shows reasonable agreement.

Tensile Needle Elements percentage – Case of footing (B)

Figure-7 shows the experimental model results in the form of stress-settlement plot for needles percentage range of (0.125%, 0.15%, 0.175% and 0.2%) for footing B

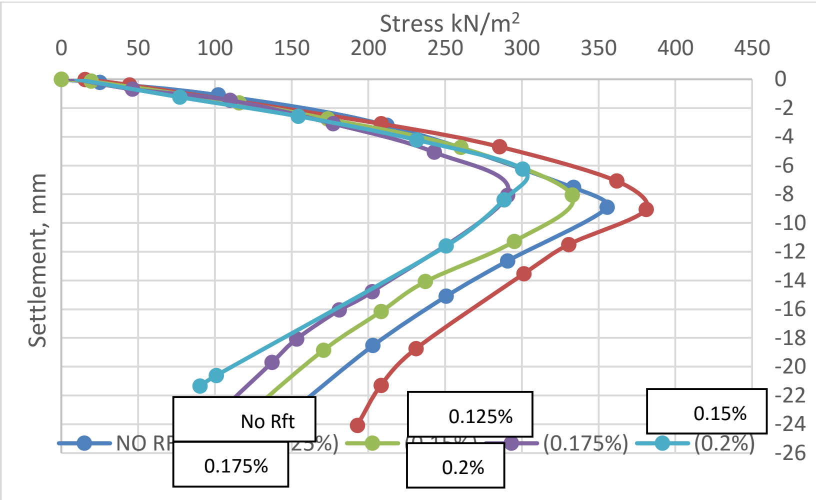

Figure-7: Stress-Settlement Characteristics for the Effect of Percentage of Needles by Total Weight of Treated Sand for Footing (B)- Experimental Results

It is observed that, the maximum mobilized stress of the composite is corresponding to the needles content of 0.125%.

Figure-8a, b, c and d representing the comparison between FEM and the experimental model results in form of stresses-settlement relationship for needles content of (0.125%, 0.15%, 0.175% and 0.2%) respectively. Table-7 summarizes the extracted readings of mobilized ultimate stress (kN/m^2) with the corresponding settlements (mm) under Footing B.

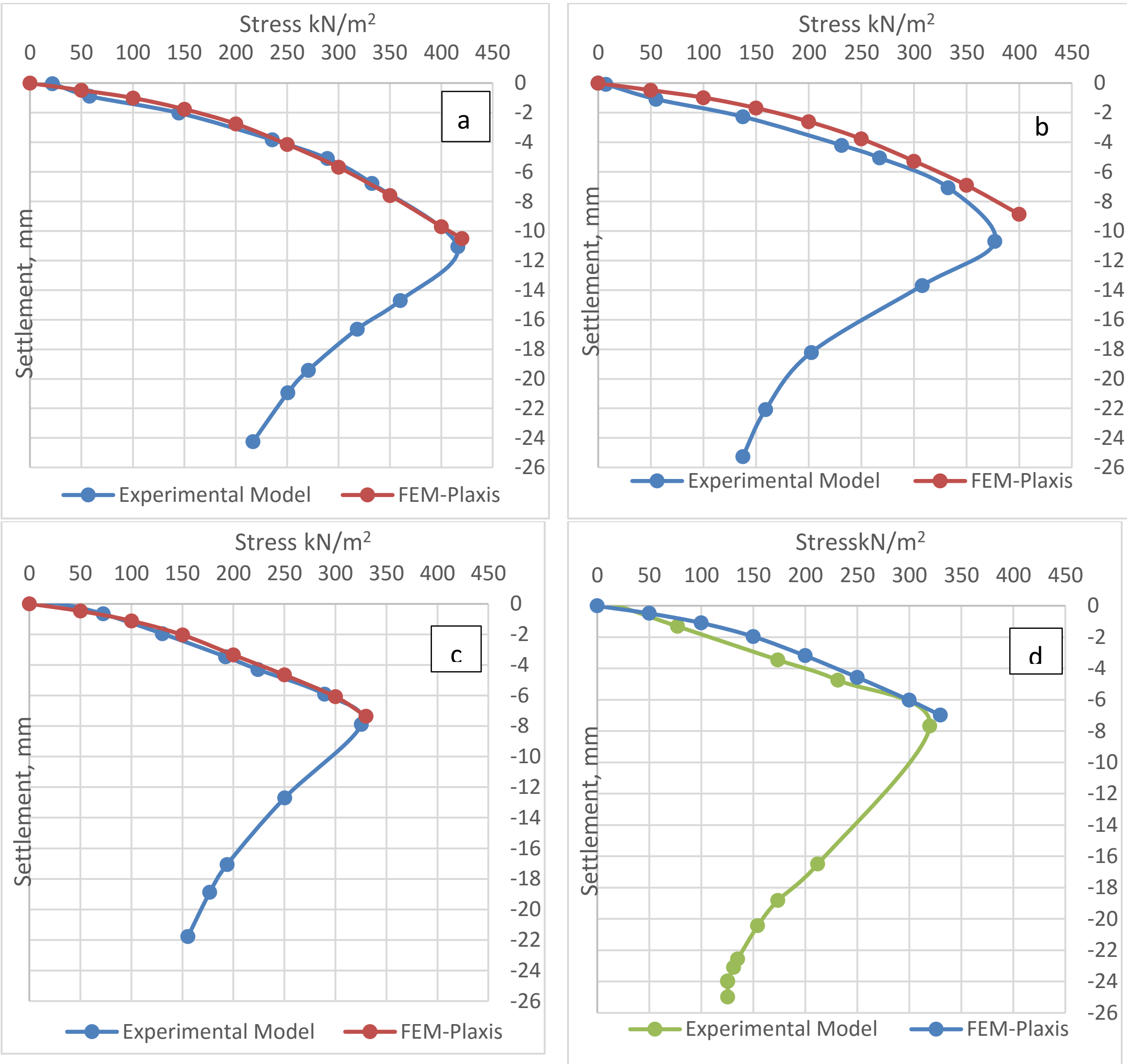

Figure-8: Stress-Settlement Characteristics for the Effect of Percentage of Needles by Total Weight of Treated Sand for Footing (B) for Needles Content of; a) 0.125%, b) 0.15%, c) 0.175% and d) 0.20 %

Table-7 Tension Needles Reinforced Soil Bed FEM vs. Experimental Model Results for Footing (B)

Tension Needles Percentage%	Experimental Model		FEM-Plaxis	
	Ultimate Stress (kN/m2)	Settlement (mm)	Ultimate Stress (kN/m2)	Settlement (mm)
NO RFT	390	11.3	380	9.4
0.125%	415.94	11.06	420	10.5
0.15%	376.94	10.7	375	8.01
0.175%	325.48	7.89	330	7.36
0.2%	319.6	7.67	330	6.99

The results indicating a decrease in the stresses with increasing the needles content more than 0.125% by the weight of treated soil **Figure-9** shows the tangle of the polypropylene needles as increasing their content during the experimental model tests.

Figure-9: The Tangle of Needless as Content Increased

Single Geogrid- Reinforced Soil Bed With Tension Needles

Effect of u/B for footing (B) for needles content of 0.125%

Figure-10 a, b and c illustrates the comparison between the FEM and the experimental results for Footing (B) with N=1, L/B=7.5 and u/B=0.25, 0.5 and 0.75 respectively. Table- 8 summarizes the ultimate stress applied on the footing with the corresponding settlement (mm) under footing B with N=1, L/B=7.5 and u/B=0.25, 0.5 and 0.75.

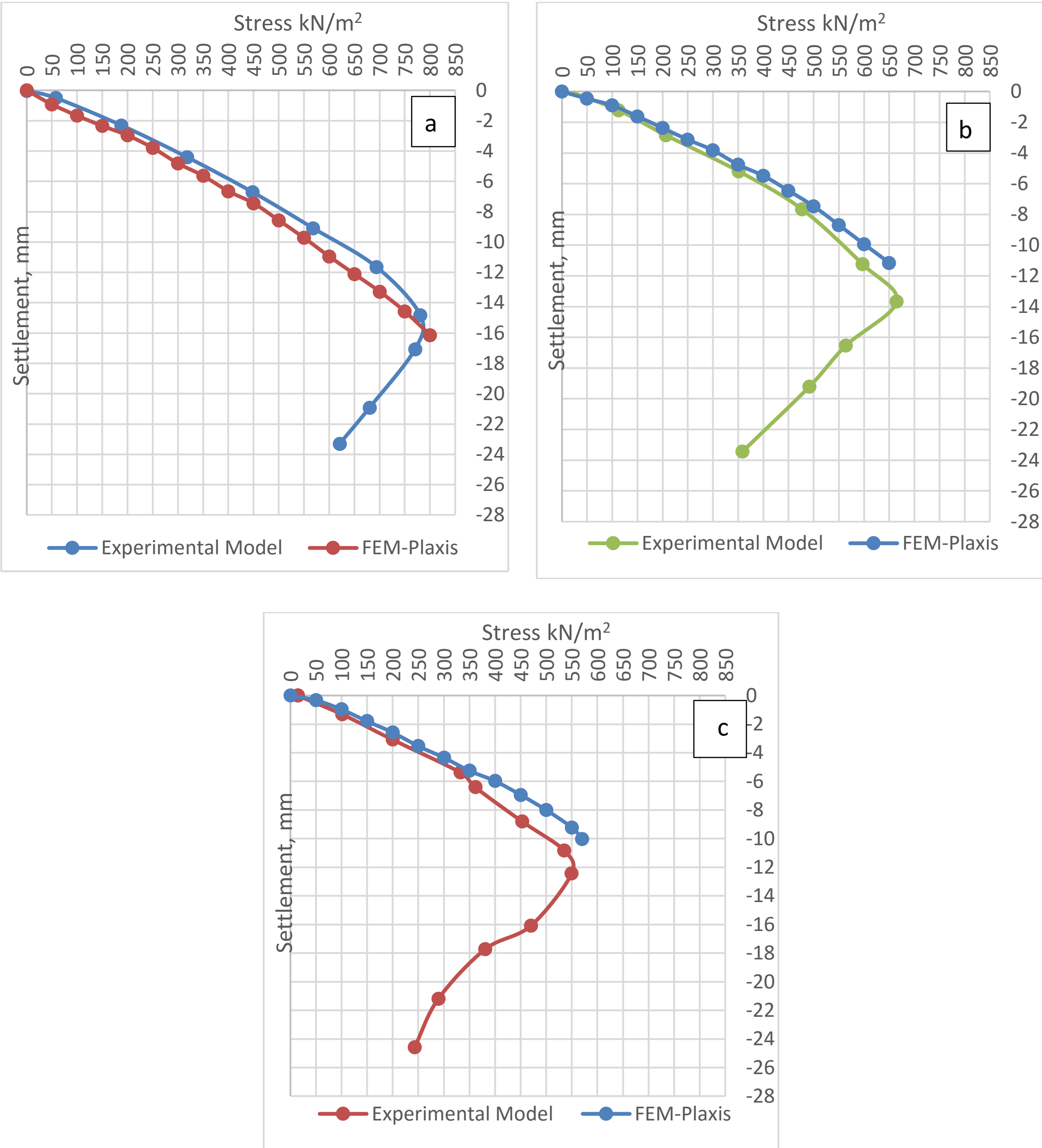

Figure-10: Effect of (U/B) on Stress-Settelment Relationship for (Tension Needles-Single Geogrid Layer) Reinforcement for Footing (B) [N=1, L/B=7.5]; a) U/B=0.25, b) U/B= 0.5 and c) U/B=0.75

Table-8 FEM Vs. Experimental Model Ultimate Stress and the Corresponding Settlement for Footing (B) [N=1, L/B=7.5 and u/B=0.25, 0.5 and 0.75]

Variable Parameter u/B	Experimental Model		FEM-Plaxis	
	Ultimate Stress (kN/m²)	Settlement (mm)	Ultimate Stress (kN/m²)	Settlement (mm)
0.25	780.8	14.8	800	16.14
0.5	655.1	13.6	650	11.15
0.75	549.4	12.4	570	10.03

NUMERICAL MODEL OUTPUT

Reinforced Soil Below Footing Type (B)

Vertical displacement

a) **At Stress 250 kN/m^2**

Figure-11 a, b, and c shows the results which illustrate the vertical displacement contours under vertical stress 250 kN/m^2 for unreinforced sand, tension needles reinforced sand with content of 0.125% and (geogrid-tension needles) reinforced sand respectively.

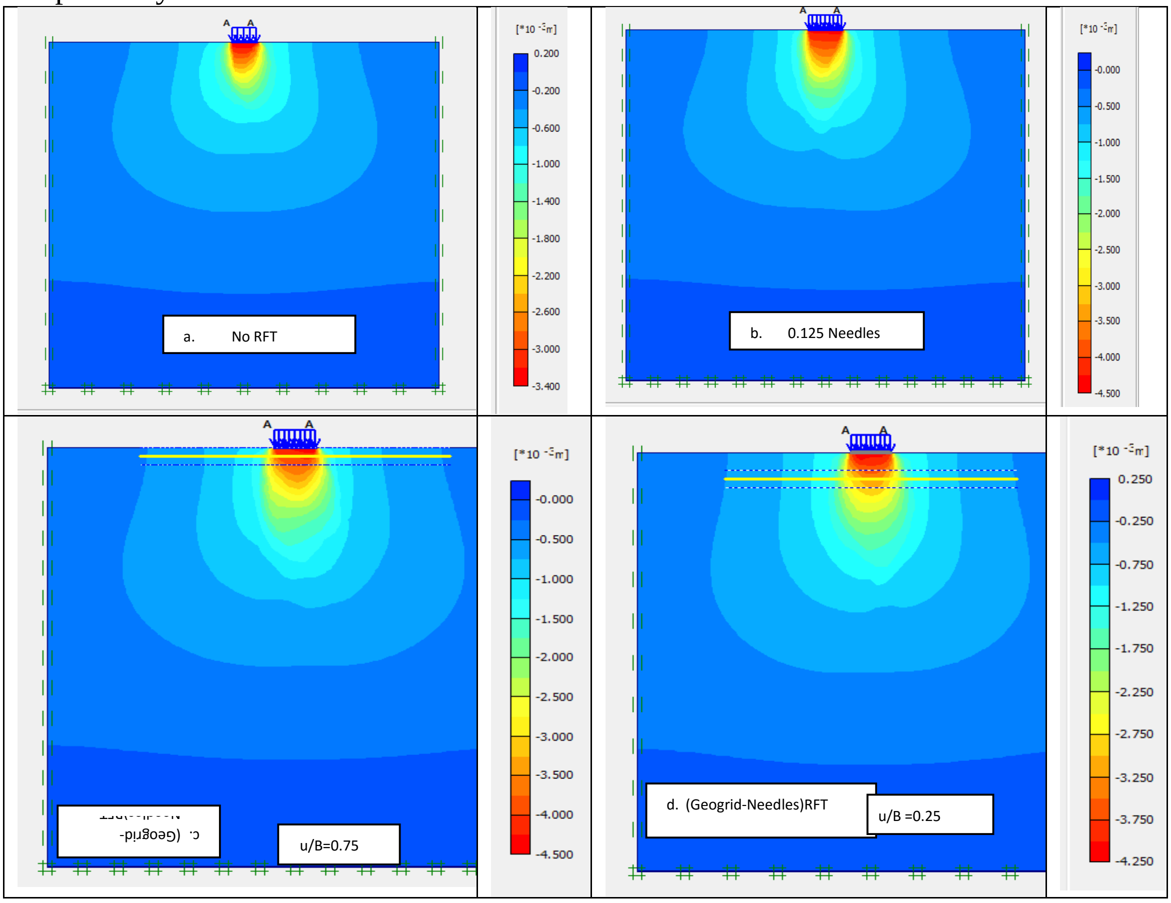

Figure-11: Vertical Displacement Shaded Contours at Vertical Stress of 250 kN/m^2 For The Case; a)No RFT, b) 0.125% Needles RFT , c) Geogrid(U/B=0.25) With 0.125% Needles RFT And d) Geogrid(U/B=0.75) With 0.125% Needles RFT

Figure-11 a shows the distribution extends for the affected zone till depth 0.58 m from the top of the soil layer. Whereas Fig. 10b shows that the distribution extends to 0.6 m depth from the top of the soil layer which indicated limited effect on the affect zone when adding 0.125% of needles.

Figure-11 a shows the vertical displacement under the footing is around $3*10^{-3}$ m to $3.4*10^{-3}$ m where, as shown in Fig. 9b; the vertical displacement under the load zone round from $4*10^{-3}$ m to $4.4*10^{-3}$ m that nearly is the same compared with Fig. 10c when adding geogrid layer from $4*10^{-3}$ m to $4.5*10^{-3}$ m. Fig. 10d shows the vertical displacement under footing increased with increasing the depth between geogrid layer and the soil top layer(u/B = 0.75).

Fig. 10a shows the lateral extend of the influence area is 0.36 m from the right and the left of footing whereas in **Figure-10** b the lateral extend of the influence area is 0.38 m from the right and the left and almost same in **Figure-10 c**.

b) At Stress 360 kN/m²

Figure-12 a, b, c and d shows the results which illustrate the vertical displacement shaded contours under vertical stress 360 kN/m^2 with different soil media on unreinforced sand, 0.125% tension needles reinforcement and geogrid layer with needles reinforcement.

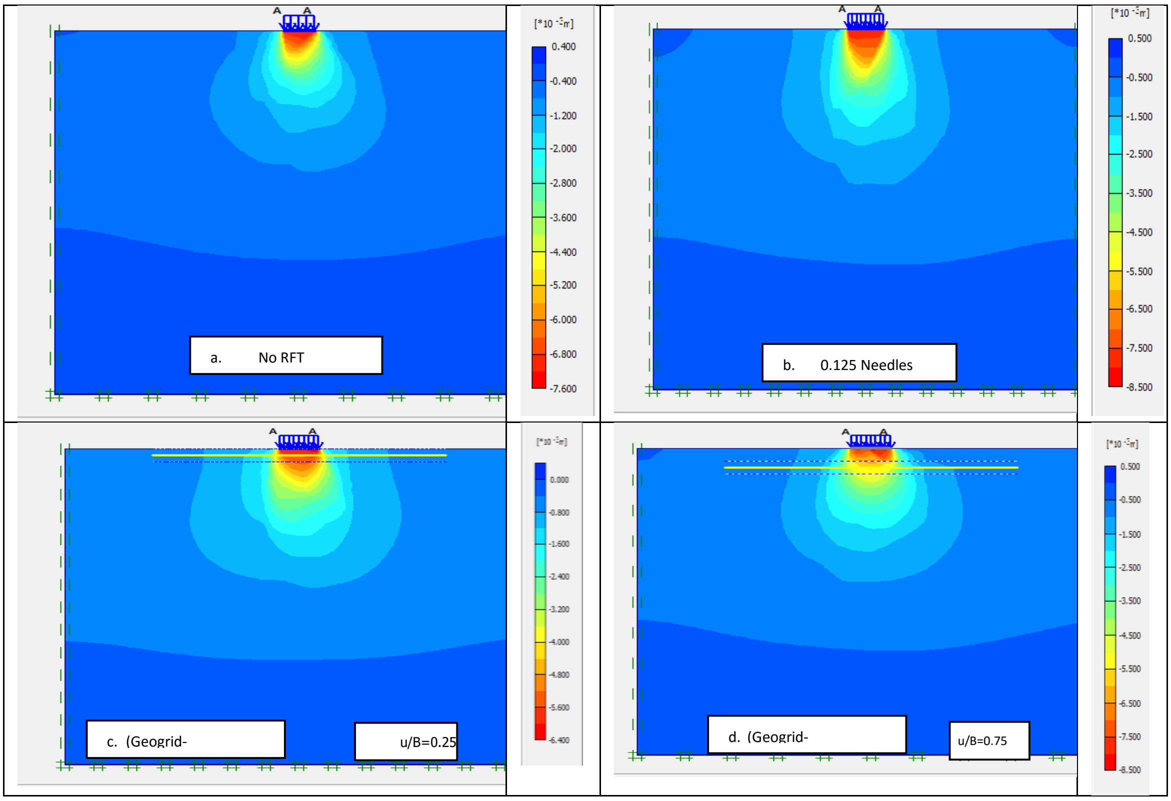

Figure-12: Vertical Displacement Shaded Contours at Vertical Stress of 360 kN/m² for The Case; A)No RFT, B) 0.125% Needles RFT, C) Geogrid(U/B=0.25) with 0.125% Needles RFT and D) Geogrid(U/B=0.75) with 0.125% Needles RFT

Figure-12 a shows the vertical displacement distribution for the affected zone till depth 0.46 m from the top of the soil layer. Whereas **Figure-12** b shows that the distribution extends to 0.52 m depth from the top of the soil layer which indicated limited effect on the affect zone when adding 0.125% of needles. Fig. 11c shows the distribution extends for the affected zone till depth 0.54 m from the soil top layer which indicated limited effect on the affected zone when adding the geogrid layer with 0.125% of polypropylene tension flexible needles.

Figure-12 a shows the vertical displacement under the footing is around 6.8*10^{-3} m to 7.28*10^{-3} m otherwise as shown in **Figure-11** b; the vertical displacement under footing around from 7.5*10^{-3} m to 8.11*10^{-3} m but increase more in **Figure-12** c when adding geogrid layer from 5.6*10^{-3} m to 6.18*10^{-3} m. Fig. 12d shows the vertical displacement under footing increased with increasing the depth between geogrid layer and the soil top layer.

Figure-12 a shows the lateral extend of the influence area is 0.16 m from the right and the left of footing whereas in **Figure-12** b the lateral extend of the influence area is 0.2 m from the right and the left otherwise **Figure-12** c shows the lateral extend of the influence area is 0.2 m to 0.38 m also from the right and the left of the footing.

Comparing the vertical displacement shaded contours for the two cases of vertical stresses 250 and 360 kN/m^{2,} it can be noticed that, reinforcement using single geogrid layer with tension needless, has a positive effect in reducing the vertical displacement value in case of higher applied stress. For both applied vertical stresses, using the tension needless alone as a reinforcement, has a slight effect on the width of the composite influence zone. Whereas using the single layer of geogrid with u/B=0.25 has an obvious effect on increasing of the composite influence zone width.

Effective Horizontal Stresses

a) At stress 250 kN/m^2

Figure-13 a, b and c shows the results which illustrate the horizontal effective stress under stress 250 kN/m^{2}and its distribution with different soil media on pure sand, 0.125% needles reinforcement and geogrid layer with needles.

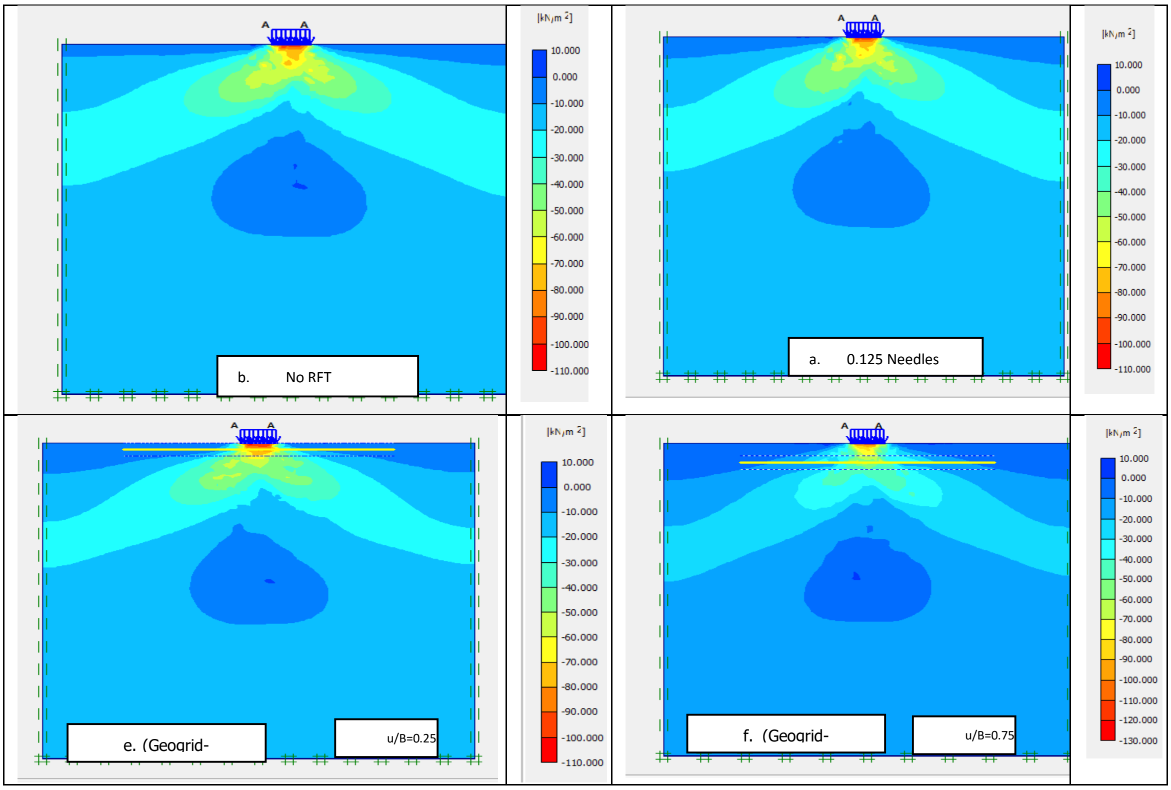

Figure-13: Horizontal Effective Stress shaded contours at vertical stress of 250 kN/m^2 for the case; a)No RFT, b) 0.125% Needles RFT, c) Geogrid(u/B=0.25) with 0.125% needles RFT and d) Geogrid(u/B=0.75) with 0.125% needles RFT

Figure-13 a, b, and c illustrates clearly changes and progress on the soil behavior by adding Needles and Geogrid reinforcement on the Horizontal Effective Stress. **Figure-13** a shows that the effective horizontal stresses are around 100 to 103.49 kN/m^2 indicating a punching shear pattern that is extend in the affected zone till 0.24 m from the right and the left side on the horizontal level. **Figure-13** c shows that the stressed affected zones with high stress values decrease and the absolute maximum stress show margin increase as result of the mechanical effect of the geogrid in joining the different stress zones. Geogrid is effective in two phenomena; increasing the affected zone and the other is the decreasing of the absolute value of stresses.

Figure-13 a, b, and c shows that the stressed zone on horizontal effective stress is decreased with adding needles and geogrid layer reinforcement. **Figure-13** d shows that the increasing of the depth between the top layer of soil and the geogrid (u/B) gives better effect on reducing the horizontal effective stresses under footing and under the geogrid layer itself, as the horizontal effective stresses on **Figure-13** c is approximately between 50 & 80 kN/m^2 but in **Figure-13** d the vertical displacement is approximately between 30 & 50 kN/m^2. Although the improvement under the geogrid layer, there is no effect above the geogrid layer, the values are 80 kN/m^2 & 100 kN/m^2 for both cases in **Figures-13** c and **Figure-13** d.

CONCLUSIONS

- The inadequate bearing capacity and the excessive settlement problems of shallow foundations due to weak soil conditions may be solved by employing the geo-synthetic reinforcing technique to strengthen the weak soil. .From the accomplished numerical model simulation, it can be proved that the use of (geogrid-tension needles) reinforcement is effective in the improvement of the bearing capacity of poorly graded fine sand.
- The stressed zones with high stress values decrease and the absolute maximum stress show margin increase as a result of the mechanical effect of the geogrid in joining the different stress zones.
- The depth between the top layer of the geogrid below the footing (u/B) gives better effect on reducing the horizontal effective stresses under footing and under the geogrid layer itself
- Reinforcement using single geogrid layer with tension needless, has a positive effect in reducing the vertical displacement value in case of higher applied stress. For the applied vertical stresses, using the tension needless alone as a reinforcement, has a slight effect on the width of the composite influence zone. Whereas using the single layer of geogrid with u/B=0.25 has an obvious effect on increasing of the composite influence zone width.

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