Websites:
http://www.lifesciencesite.com
http://www.sciencepub.net

Emails:
editor@sciencepub.net
sciencepub@gmail.com

Life Science Journal

MARSLAND PRESS
Multidisciplinary Academic Journal Publisher

# Effect of Reinforced Replacement Soil on Behavior of Soft Clay

Abd EL Samee W. Nashaat and Ahmed S. Rabei

Soil Mechanics and Foundation Civil Engineering Dep., Faculty of Engineering, Beni- Suef University, Beni- Suef, Egypt.
Waelnashat@eng.bsu.edu.eg, Ahmed011285@eng.bsu.edu.eg

**Abstract:** In the present study, the analysis is performed using finite element analysis to investigate the effect of geogrid reinforcement layers number on bearing capacity of soft clay, settlement and contact pressure as well as location and shape of failure surface at contact surface. The soil replacement used in this study is taken granular soil over soft clay. The soft clay material model used is Hardening Soil Model. The analysis program consists of sandy soil replacement with different thicknesses without and with different number of reinforcement layers at different vertical spacing between reinforcement layers. The parameters investigated included replacement layer thickness, number of geogrid reinforcement layers, vertical spacing between layers, and footing width. It was concluded that, the ultimate bearing capacity of soft clay at contact surface with replaced layers increases with increasing geogrid reinforcement layers number. However, increasing thickness of replaced reinforcement layer increases ultimate bearing capacity of soft clay. In addition, the ratio between settlement and total thicknesses of replaced layers at contact surface decreases with increasing replaced of reinforcement thickness and increasing geogrid reinforcement layers number. However, the stresses in soft clay soil at contact surface between soft clay and replacement soil decreases with increasing replacement thicknesses and increasing geogrid reinforcement layers number. In addition, the contact pressure values at contact surface with replacement layer decrease with increasing geogrid reinforcement layers number. In addition, the failure wedge angle of soft clay increases with increasing replacement thicknesses and increasing different number of geogrid reinforcement layers. In addition, the contact pressure values at contact surface with replacement soil layer has been determined.
[Abd EL Samee W. Nashaat and Ahmed S. Rabei. **Effect of Reinforced Replacement Soil on Behavior of Soft Clay.** *Life Sci J* 2019;16(10):17-35]. ISSN: 1097-8135 (Print) / ISSN: 2372-613X (Online). http://www.lifesciencesite.com. 3. doi:10.7537/marslsj161019.03.

**Keywords:** Bearing, capacity, reinforced, replacement, soft clay

## 1. Introduction

Removed and replacement soil is widely used in construction practices and proved to be an effective technique.

Alamshahi and Hataf (2009) presented the effect of a new type of geogrid inclusion on the bearing capacity of a rigid strip footing constructed on a sand slope. A finite element analyses was carried out on a soil slope. It was concluded that the bearing capacity of footings on slope increased by additional grid-anchor layers. It is also included that the load-settlement behavior and bearing capacity of the rigid footing considerably improved by the inclusion of a reinforcing layer at the appropriate location in the fill slope [1].

Ornek et al. (2012) presented the use of the multi-linear regression model and artificial neural networks to predict the bearing capacity of circular footings on compacted granular fill over clay soil. The data used have been obtained from a series of field tests. Seven footing diameters over three different granular fill layer thicknesses were used in the field tests. It was concluded that, the bearing capacity of clay soil has been affected by using the granular fill layers [2].

Abu-Farsakh et al. (2013) investigated the behavior of reinforced sandy soil foundations - geosynthetic. The reinforcement layers number and the vertical spacing between them as well as type of geosynthetic reinforcement have been investigated. The effect of reinforcement geosynthetic on the distribution of vertical stress in the sand and the strain distribution along the reinforcement were observed. It was concluded that the reinforcement affects the behavior of reinforced sand foundation. [3].

Kolay et al. (2013) investigated by placing geogrids at different depths the improvement of bearing capacity of silty clay soil. Rectangular footing resting on the soil was used in the tests. It was concluded that increasing number of geogrid layers increases the bearing capacity of soft clay soil [4].

Altalhe et al. (2015) investigated the bearing capacity of strip footing on a sand slope using one, two and three reinforcing layers.

It was concluded that, increasing number of reinforced layers increases the bearing capacity of sandy soil [5].

Hasanzadeh and Choobbasti (2016) investigated the use of clay stabilized with different granular compacted fill depths on the bearing capacity of clay soil. It was concluded that the use of granular fill over clayey soils has a great effect on the bearing capacity [6].

Hussein et al. (2017) investigated the behavior of footings resting on geosynthetic reinforced replacement soil overlying loose sand. The number of reinforcement layers (N = 1, 2, 3), length of reinforcement relative to footing width (L/B = 6, 4, 2), and thickness of the replacement soil relative to footing width (d/B = 1.2, 1.5, 1.8) were considered. It was concluded that the bearing capacity increases by increasing the number of reinforcement layers and thickness of replacement soil [7].

Mahallawy (2019) investigated the use of unreinforced and geogrid-reinforced sand bed resting on stone columns. The investigations included the effect of thickness of unreinforced and geogrid-reinforced sand bed as well as the number of geogrid reinforcement. It was concluded that the use of geogrid reinforcement increases the bearing capacity and decreases the settlement of sandy soil [8].

In the present study, a reinforced sand soil is used in the analysis with a different geogrid (Tensar Ux 1500) layers number. The main purpose of the present study is to investigate the effect of geogrid reinforcement layers number on the following parameters:

i. Bearing capacity of soft clay with reinforced replaced soil.
ii. Settlement (vertical displacements) of soft clay with reinforced replaced soil.
iii. Contact pressure of soft clay with reinforced replaced soil at contact surface.
iv. Location and shape of failure surface of soft clay with reinforced replaced soil.

## 2. Research Methodology

### 2.1 Material

In the present study, the analysis is performed using finite element program to investigate the effect of geogrid reinforcement layers number on bearing capacity of soft clay, settlement (vertical displacements) and contact pressure of soft clay as well as location and shape of failure surface at contact surface. The soil replacement over soft clay used in this study is taken of sandy soil.

### 2.2 Soil Behavior

In this study the soft clay soil has been selected in the analysis. The Poisson's ratio is taken $\nu_s$ = 0. 35 and the value of elasticity modulus is taken $E_s$=1200 $KN/m^2$. The soil is simulated by a semi-infinite element isotropic homogeneous elastic material simulates the soil and the material model used is Hardening Soil Model. The used material properties are listed in Tables (1) to (3).

Table (1): Geogrid reinforcement parameters

| | |
|---|---|
| EA | 1560 kN/m |
| $T_{ult.}$ | 114 kN/m |

Table (2) Hardening soil model input parameters (soft clay).

| **Parameter** | **Name** | **Value** | **Unit** |
|---|---|---|---|
| Material model | Model | Hardening Soil Model | ------- |
| Type of material behavior | Type | Drained | ------- |
| Dry soil weight | $\gamma_{dry}$ | 15.0 | $KN/m^3$ |
| Wet soil weight | $\gamma_{wet}$ | 18.00 | $KN/m^3$ |
| Permeability in hor. direction | $K_x$ | $1.1 \times 10^{-4}$ | m/day |
| Permeability in ver. direction | $K_y$ | $1.1 \times 10^{-4}$ | m/day |
| Reference secant stiffness from drained triaxial test | $E_{50}^{ref}$ | 9700 | $KN/m^2$ |
| Reference tangent stiffness for oedometer primary loading | $E_{od}^{ref}$ | 9700 | $KN/m^2$ |
| Reference unloading/reloading stiffness | $E_{ur}^{ref}$ | 29100 | $KN/m^2$ |
| Power for stress | m | 1.0 | |
| Young's modulus | $E_{ref}$ | 1200 | $KN/m^2$ |
| Poisson ratio | $\nu_s$ | 0.35 | ------- |
| Cohesion | $C_{ref}$ | 0.59 | $KN/m^2$ |
| Friction angle | Ø | 5.50 | ------- |
| Dilatancy angle | ψ | 0 | ------- |
| Interface Strength reduction | $R_{inter}$ | 0.001 | ------- |

Table (3): The sand replaced soil properties

| Parameter | Name | Value | Unit |
|---|---|---|---|
| Material model | Model | Mohr-Coulomb | ------- |
| Type of material behavior | Type | Drained | ------- |
| Dry soil weight | $\gamma_{dry}$ | 18.00 | $KN/m^3$ |
| Wet soil weight | $\gamma_{wet}$ | 19.00 | $KN/m^3$ |
| Permeability in hor. direction | $K_x$ | 1 | m/day |
| Permeability in ver. direction | $K_y$ | 1 | m/day |
| Young's modulus | $E_{ref}$ | 8500 | $KN/m^2$ |
| Poisson ratio | $\nu_s$ | 0.25 | ------- |
| Cohesion | $C_{ref}$ | 0 | $KN/m^2$ |
| Friction angle | Ø | 38 | ------- |
| Dilatancy angle | $\psi$ | 10 | ------- |
| Interface Strength reduction | $R_{inter}$ | 0.67 | ------- |

**2.3 Dimensions of the numerical model:**

Investigated model were performed for a square footing resting on sandy soil replacement over soft clay to establish the load versus settlement curves of unreinforced and reinforced soil system. Dimensions of model cross section refer to the width of footing (B) and thickness of sandy soil replacement (h). Fig (1) shows the proposed numerical model dimensions. The footing width of model (B) and the width of replacement soil L=3.0 B and the total height of replacement soil (h) are shown in Fig (1).

**3. Numerical Analysis**

**3.1 Research Program**

In the present study, PLAXIS program was used to determine the effect of geogrid reinforcement layers number on bearing capacity of soft clay, settlement and contact pressure as well as location and shape of failure surface at contact surface. The parameters investigated included replacement layer thickness, number of geogrid reinforcement layers, vertical spacing between layers and footing width. The analysis program is shown in Table (4).

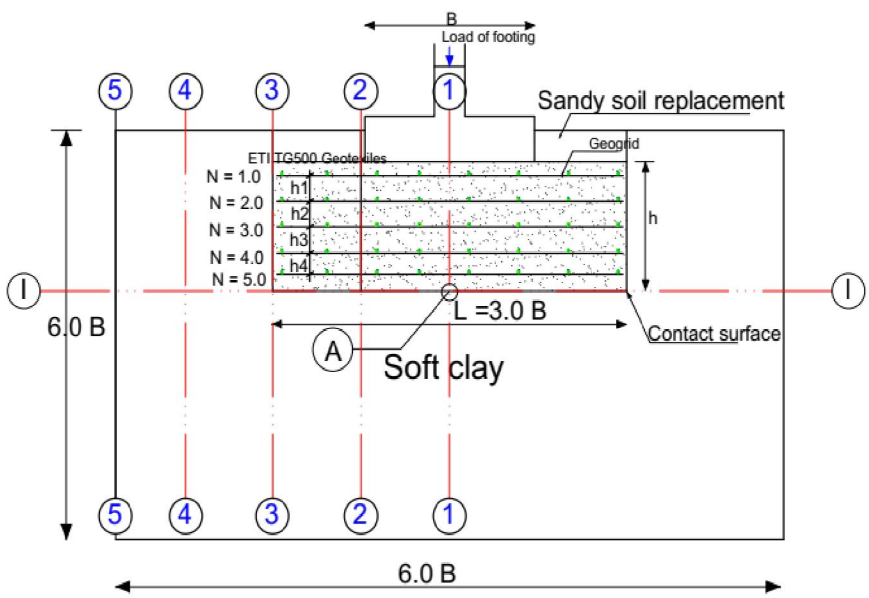



Fig (1). Dimensions of the numerical model.

Where:

B : Footing width.

h : Total thickness of sandy soil replacement.

h1, h2, h3 and h4: Spacings between center lines of Geogrid reinforcement.

L : Width of sandy soil replacement = 3.0 B.

N : Layers number of geogrid reinforcement.

Table (4): Investigated cases of study by numerical analysis program.

| Model # | Reinforcement Stiffness, kN/m | Sandy soil replacement thickness (m) | Geogrid reinforcement layers number | Vertical spacing between reinforcement layers (S) |
|---|---|---|---|---|
| 1 | | 0.50 | | |
| 2 | | 0.75 | Without reinforcement layers | |
| 3 | | 1.00 | | 0.00 |
| 4 | | 1.25 | | |
| 5 | | 1.50 | | |
| 6 | | 0.50 | | |
| 7 | | 0.75 | | |
| 8 | | 1.00 | 1.0 | 0.5 h |
| 9 | | 1.25 | | |
| 10 | | 1.50 | | |
| 11 | | 0.50 | | |
| 12 | | 0.75 | | |
| 13 | | 1.00 | 2.0 | 0.333 h |
| 14 | | 1.25 | | |
| 15 | | 1.50 | | |
| 16 | 52 | 0.50 | | |
| 17 | | 0.75 | | |
| 18 | | 1.00 | 3.0 | 0.25 h |
| 19 | | 1.25 | | |
| 20 | | 1.50 | | |
| 21 | | 0.50 | | |
| 22 | | 0.75 | | |
| 23 | | 1.00 | 4.0 | 0.20 h |
| 24 | | 1.25 | | |
| 25 | | 1.50 | | |
| 26 | | 0.50 | | |
| 27 | | 0.75 | | |
| 28 | | 1.00 | 5.0 | 0.167 h |
| 29 | | 1.25 | | |
| 30 | | 1.50 | | |

### 3.2 Typical Numerical Model Results

In the present study, PLAXIS program was used to the effect of geogrid reinforcement layers number on bearing capacity of soft clay, settlement and contact pressure as well as location and shape of failure surface at contact surface. The settlement (vertical displacement) in soil due to change of the thicknesses of sand replacement layer without and with different geogrid reinforcement layers number. The vertical displacements (settlement) in surrounding soil as vectors, contour lines, shading and total stresses in surrounding soil of soft clay with reinforced replaced soil have been presented. The obtained results are shown in Figs. (2) to (11).

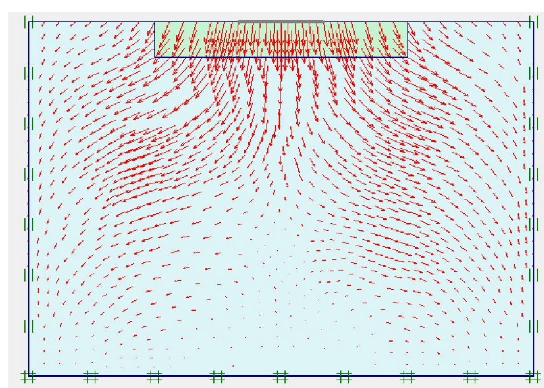


Fig. (2) Vertical displacements in surrounding soil as vectors of soft clay without geogrid reinforcement layers number (Hardening Soil Model).

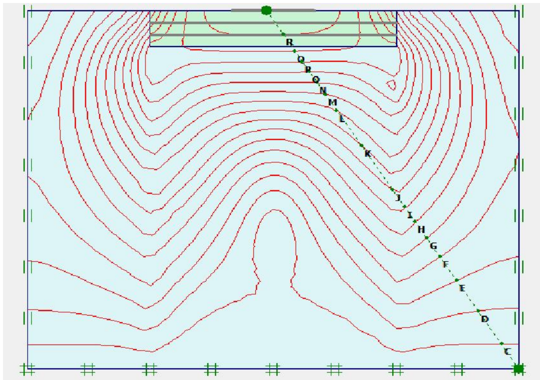


Fig. (3) Vertical displacements in surrounding soil as contour lines of soft clay with different geogrid reinforcement layers number = 2.0(Hardening Soil Model).

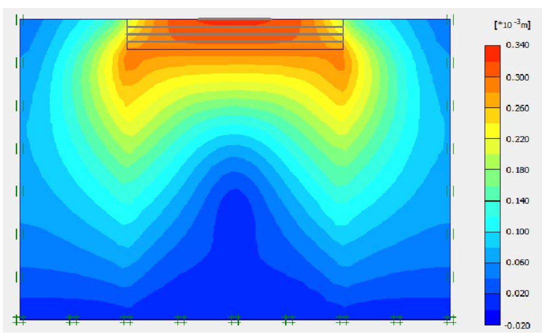



Fig. (4) Vertical displacements in surrounding soil as shading of soft clay with different geogrid reinforcement layers number = 3.0(Hardening Soil Model).

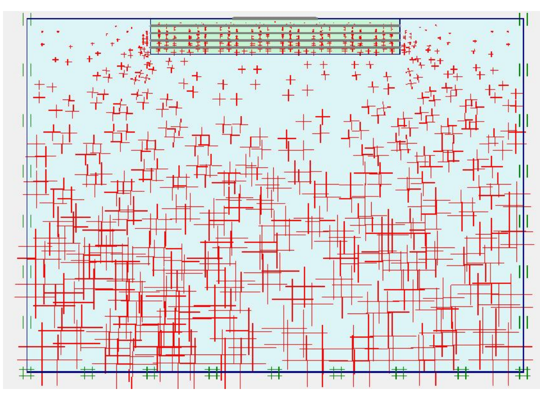


Fig. (5) Total stresses in surrounding soil as vectors of soft clay with different geogrid reinforcement layers number = 4.0(Hardening Soil Model).

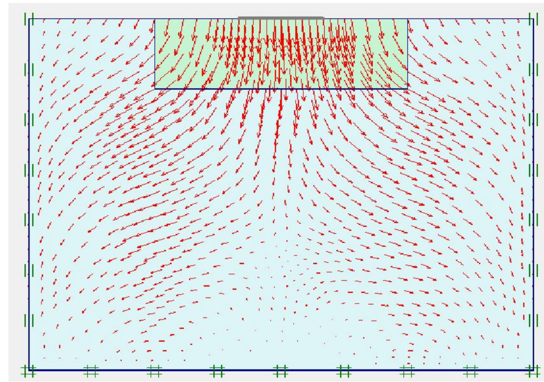


Fig. (6) Total displacements in surrounding soil as vectors of soft clay without geogrid reinforcement layers number (Hardening Soil Model).

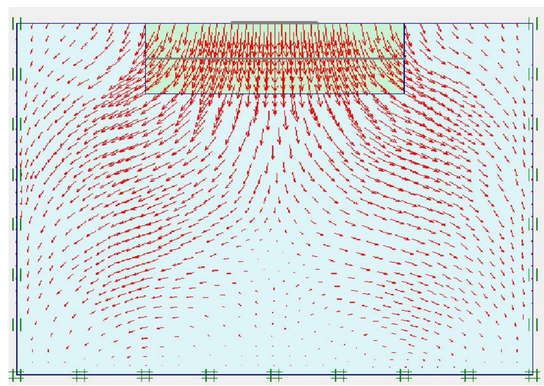


Fig. (7) Total displacements in surrounding soil as vectors of soft clay with different geogrid reinforcement layers number = 1.0. (Hardening Soil Model).

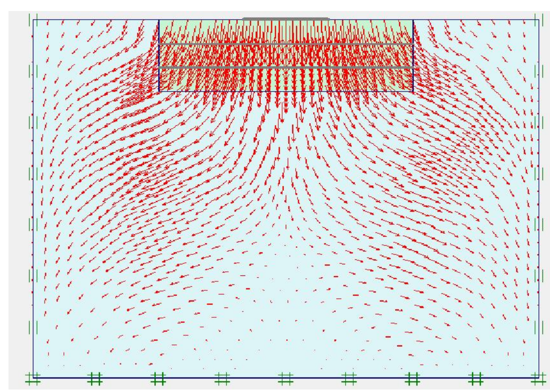


Fig. (8) Total displacements in surrounding soil as vectors of soft clay with different geogrid reinforcement layers number = 2.0. (Hardening Soil Model).

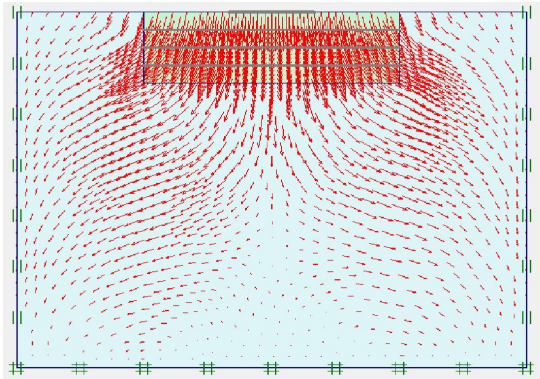


Fig. (9) Total displacements in surrounding soil as vectors of soft clay with different geogrid reinforcement layers number = 3.0. (Hardening Soil Model).

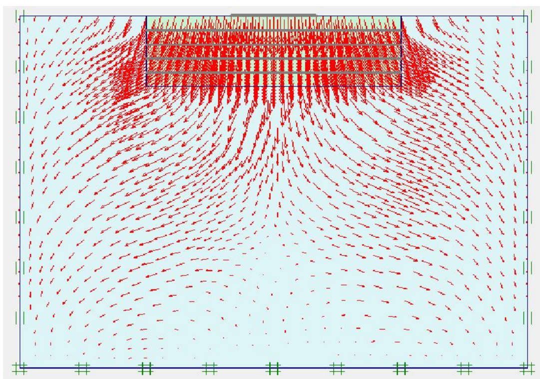


Fig. (10) Total displacements in surrounding soil as vectors of soft clay with different geogrid reinforcement layers number = 4.0. (Hardening Soil Model).

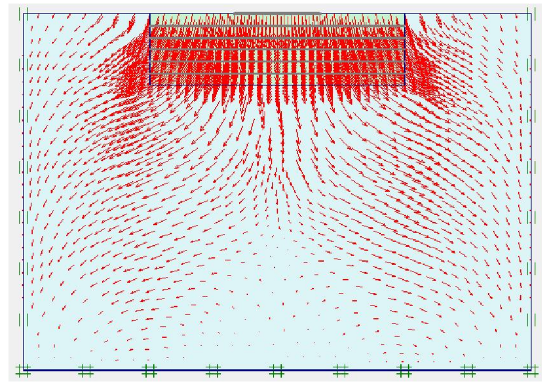


Fig. (11) Total displacements in surrounding soil as vectors of soft clay with different geogrid reinforcement layers number = 5.0. (Hardening Soil Model).

## 4. Analysis Of Results

The target of this research is to investigate the effect of geogrid reinforcement layers number on bearing capacity of soft clay, settlement and contact pressure as well as location and shape of failure surface at contact surface.

### 4.1 Determination Of The Ultimate Bearing Capacities

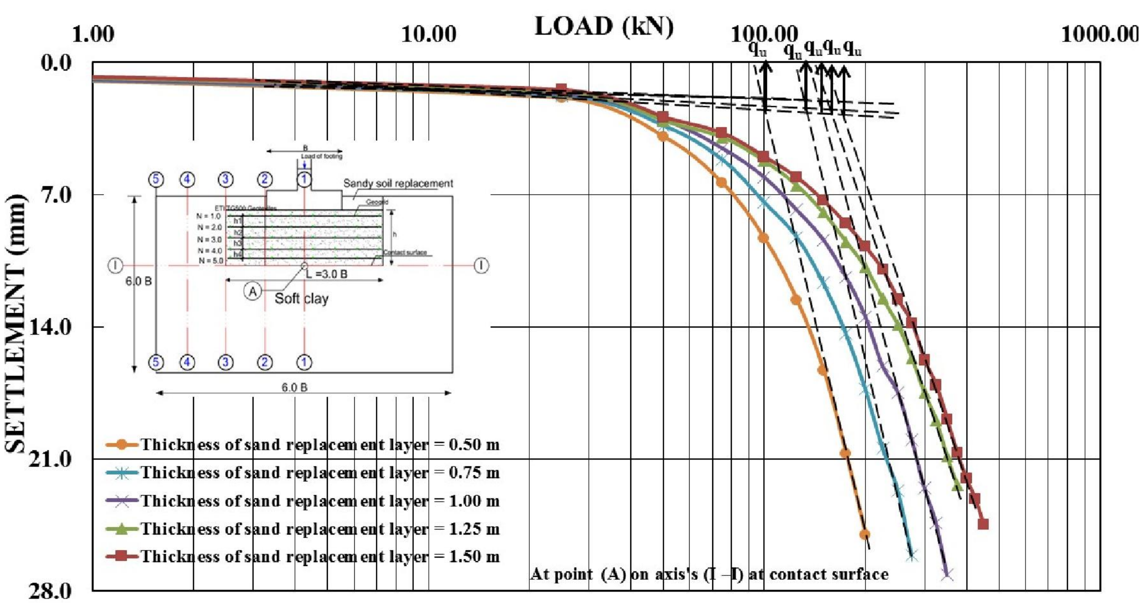



Fig. (12) Relationship between Load and settlement for soft clay at point (A) on axis (I-I) at different sand replaced thicknesses without geogrid reinforcement layers (determination of the ultimate bearing capacity by tangent method).

The ultimate bearing capacity was determined by the tangent-tangent and the modified chin methods for the different thicknesses of sand replaced layer without and with different geogrid reinforcement layers number are presented at point (A) on axis's (I – I) at contact surface between soft clay and replacement soil. Figs (12) and (13) show examples of determination of the ultimate bearing capacity by tangent and modified chin methods, for soft clay at contact surface with replaced soil layer without geogrid reinforcement layers. However, the values of ultimate bearing capacities for soft clay at contact surface with sand replaced layer without and with different geogrid reinforcement layers number from different methods are listed in Tables (5) and (6).

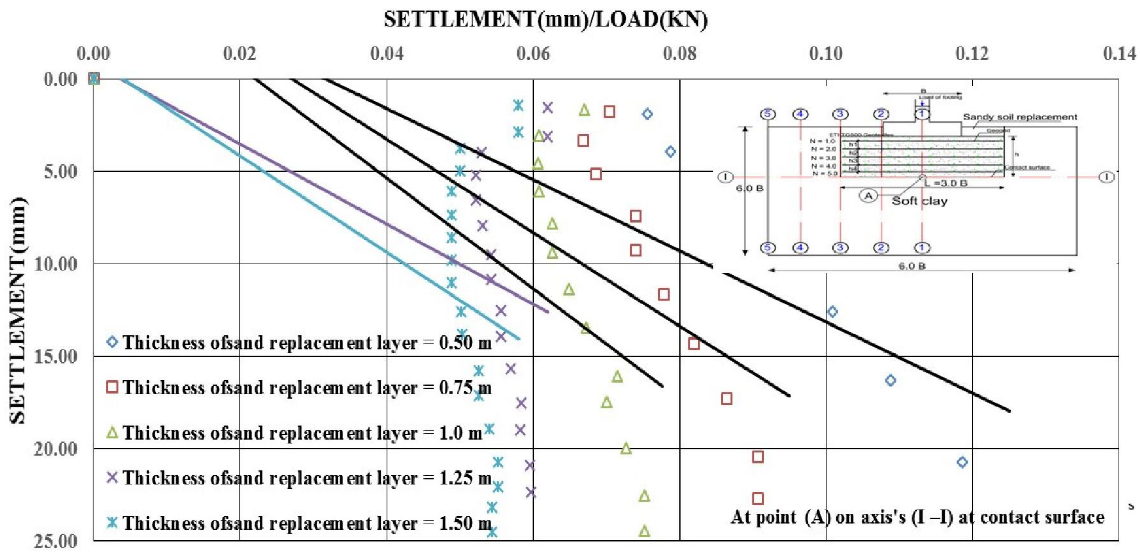



Fig. (13) Relationship between settlement and settlement /load for soft clay at point (A) on axis (I-I) at different sand replaced thicknesses without geogrid reinforcement layers (determination of the ultimate bearing capacity by modified chin).

Table (5) Ultimate Bearing capacities of soft clay at point (A) on axis's (I –I) at contact surface with replacement soil with reinforced replaced soil by using tangent method.

| No. | Sandy soil replacement thickness (m) | Ultimate Bearing capacities of soft clay at point (A) on axis's (I –I) at contact surface with replacement soil (KN/m$^2$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Geogrid reinforcement layers number | | | | | |
| | | Without reinforcement layers | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
| 1 | 0.50 | 100.00 | 107.00 | 113.96 | 122.27 | 130.22 | 139.34 |
| 2 | 0.75 | 152.00 | 163.40 | 174.84 | 186.73 | 199.80 | 214.78 |
| 3 | 1.00 | 189.00 | 204.12 | 219.43 | 234.57 | 252.16 | 272.34 |
| 4 | 1.25 | 202.00 | 215.74 | 229.33 | 245.38 | 260.84 | 278.58 |
| 5 | 1.50 | 218.00 | 232.17 | 246.10 | 262.10 | 277.82 | 295.88 |

Table (6) Ultimate Bearing capacities of soft clay at point (A) on axis's (I –I) at contact surface with replacement soil with reinforced replaced soil by using modified chin.

| No. | Sandy soil replacement thickness (m) | Ultimate Bearing capacities of soft clay at point (A) on axis's (I –I) at contact surface with replacement soil (KN/m$^2$) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Geogrid reinforcement layers number | | | | | |
| | | Without reinforcement layers | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 |
| 1 | 0.50 | 148.00 | 156.22 | 167.52 | 179.13 | 189.73 | 204.27 |
| 2 | 0.75 | 224.96 | 238.56 | 257.01 | 273.56 | 291.11 | 314.87 |
| 3 | 1.00 | 279.72 | 298.02 | 322.56 | 343.65 | 367.40 | 399.25 |
| 4 | 1.25 | 298.96 | 314.98 | 337.12 | 359.48 | 380.04 | 408.40 |
| 5 | 1.50 | 322.64 | 338.97 | 361.77 | 383.98 | 404.78 | 433.76 |

### 4.2 Effect Of Geogrid Reinforcement Layers Number On Ultimate Bearing Capacity Of Soft Clay At Contact Surface With Reinforced Replaced Soil

The ultimate bearing capacities of soft clay at point (A) on axis's (I–I) at contact surface with replacement soil obtained from the numerical analysis at different of geogrid reinforcement layers number are listed in Tables (7) and (8). Figs (14) and (15) show the relationship between geogrid reinforcement layers number and the values of ultimate bearing capacities of soft clay at point (A) on axis's (I–I) at contact surface with replacement soil layers at different thicknesses of replaced layers.

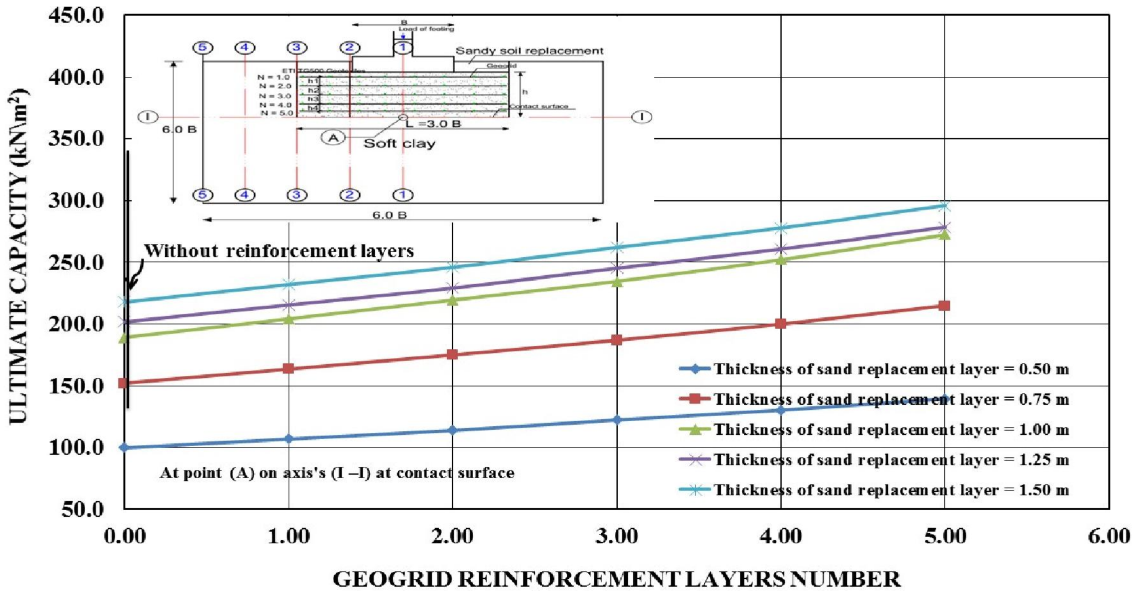



Fig. (14) The relationship between geogrid reinforcement layers number and the ultimate bearing capacities of soft clay at point (A) on axis's (I –I) at contact surface with replacement soil layers at different replaced thicknesses (by tangent method).

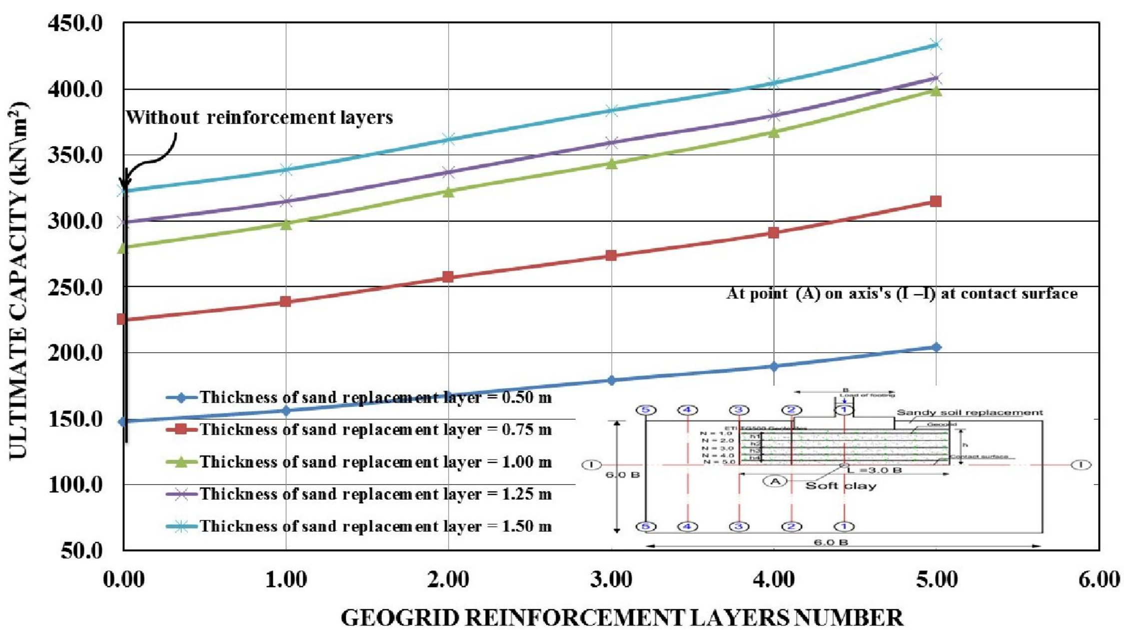



Fig. (15) The relationship between geogrid reinforcement layers number and the ultimate bearing capacities of soft clay at point (A) on axis's (I –I) at contact surface with replacement soil layers at different replaced thicknesses (modified chin).

From these figures, it can be concluded that the ultimate bearing capacity of soft clay at contact surface with replacement soil layers increases with increasing geogrid reinforcement layers number at different replaced thicknesses. In addition, increasing replaced reinforcement soil layer thickness increases ultimate bearing capacity at different geogrid reinforcement layers number.

**4.3 Effect Of Geogrid Reinforcement Layers Number On Settlement Of Soft Clay At Contact Surface With Reinforced Replaced Soil**

The settlement (vertical displacement) of soft clay at point (A) on axis's (I –I) at contact surface with replacement soil from numerical analysis at different geogrid reinforcement layers number are listed in Tables (7) and (8). Fig (16) shows the relationship between geogrid reinforcement layers number and the ratio between settlement and total thicknesses of replaced layers (ΔS\h) of soft clay at contact surface with replaced soil layer at different thicknesses of replaced layers.

Table (7) Settlement of soft clay at contact surface with replacement soil at geogrid reinforcement layers number.

| No. | Granular soil replacement thickness (m) | Settlement of soft clay at contact surface with replaced layer at geogrid reinforcement layers number (mm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Geogrid reinforcement layers number | | | | | |
| | | Without reinforcement layers | 1 | 2 | 3 | 4 | 5 |
| 1 | 0.50 | 9.41 | 8.83 | 8.27 | 7.80 | 7.33 | 6.88 |
| 2 | 0.75 | 10.30 | 9.67 | 9.06 | 8.49 | 8.03 | 7.56 |
| 3 | 1.00 | 11.47 | 10.77 | 10.09 | 9.47 | 8.96 | 8.42 |
| 4 | 1.25 | 12.75 | 11.97 | 11.21 | 10.53 | 9.95 | 9.34 |
| 5 | 1.50 | 14.24 | 13.37 | 12.52 | 11.78 | 11.13 | 10.47 |

Table (8) The ratio between settlement and total thicknesses of replaced layers (ΔS\h) of soft clay at contact surface with replaced layer at geogrid reinforcement layers number.

| No. | (ΔS\h) | The ratio between settlement and total thicknesses of replaced layers (ΔS\h) of soft clay at contact surface with replaced layer | | | | | |
|---|---|---|---|---|---|---|---|
| | | Geogrid reinforcement layers number | | | | | |
| | | Without reinforcement layers | 1 | 2 | 3 | 4 | 5 |
| 1 | ΔS\h | 0.19 | 0.18 | 0.17 | 0.16 | 0.15 | 0.14 |
| 2 | ΔS\h | 0.14 | 0.13 | 0.12 | 0.11 | 0.11 | 0.10 |
| 3 | ΔS\h | 0.11 | 0.11 | 0.10 | 0.09 | 0.09 | 0.08 |
| 4 | ΔS\h | 0.10 | 0.10 | 0.09 | 0.08 | 0.08 | 0.07 |
| 5 | ΔS\h | 0.09 | 0.09 | 0.08 | 0.08 | 0.07 | 0.07 |

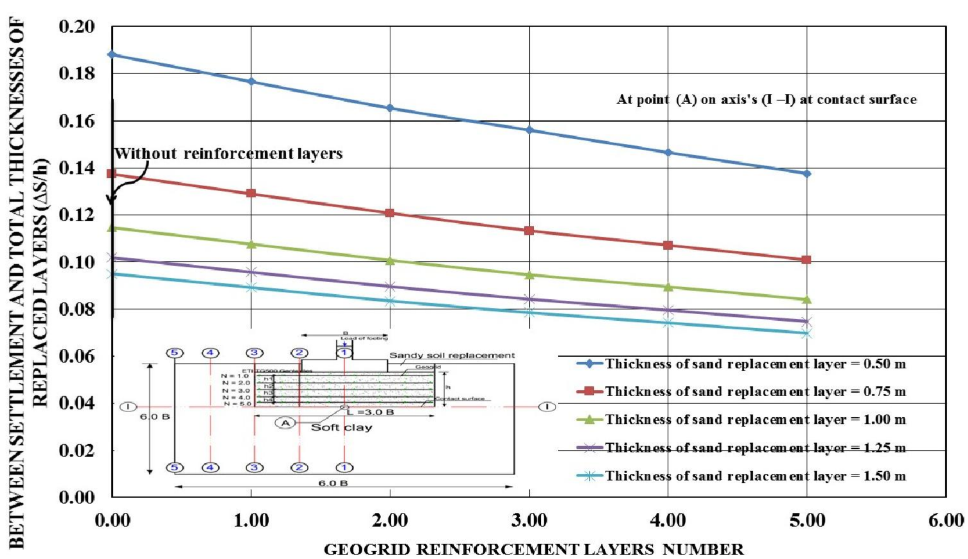



Fig. (16) The relationship between geogrid reinforcement layers number and the ratio between settlement and total thicknesses of replaced layers (ΔS\h) of soft clay at contact surface with replaced layer.

From the above, it can be concluded that increasing replaced reinforcement soil thickness decreases the ratio between settlement and total thicknesses of replaced layers (ΔS\h) at contact surface with replaced layer. In addition, the ratio between settlement and total thicknesses of replaced layers (ΔS\h) decreases with increasing geogrid reinforcement layers number. However, increasing geogrid reinforcement layers number, the settlement can be reduced by 14 % at all replacement thicknesses.

### 4.4 Effect Of Geogrid Reinforcement Layers Number On Stress In Surrounding Soft Clay Soil With Reinforced Replaced Soil

The stresses of soft clay at point (A) on axis's (I–I) at contact surface with reinforcement replacement soil at different geogrid reinforcement layers number are presented. Fig (17) shows the effect of the geogrid reinforcement layers number on stresses of soft clay at contact surface with replacement reinforcement soil.

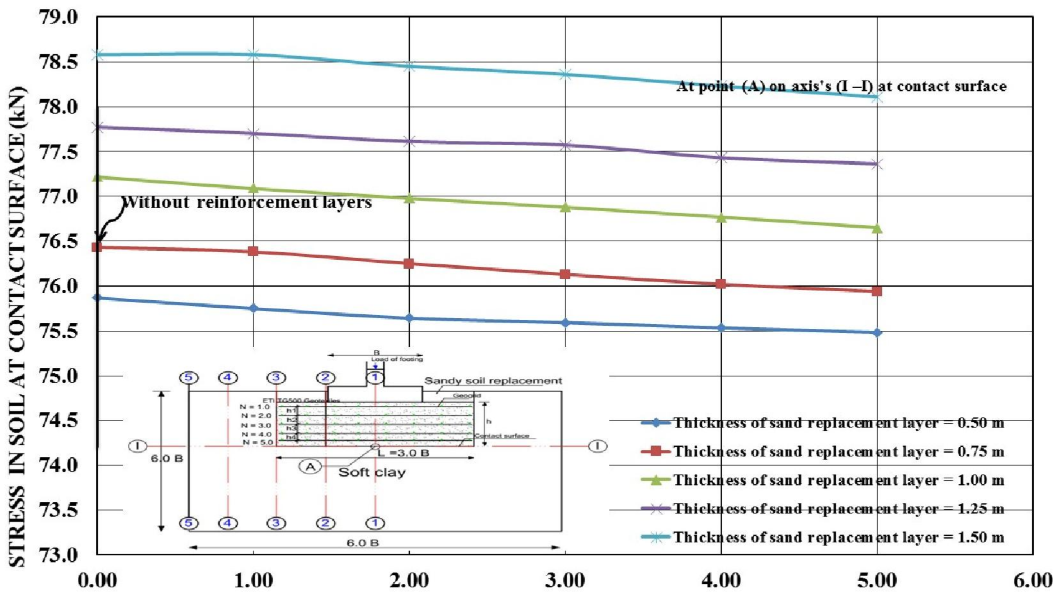
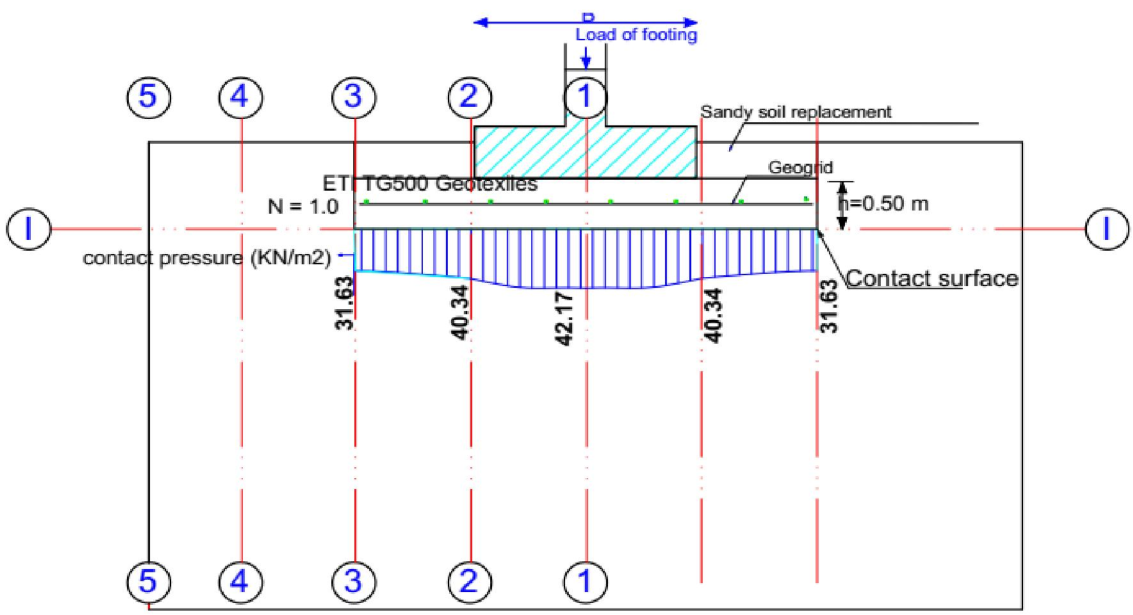



Fig. (17) Stresses in soft clay at contact surface with reinforcement replacement soil versus geogrid reinforcement layers number at different replaced thicknesses.

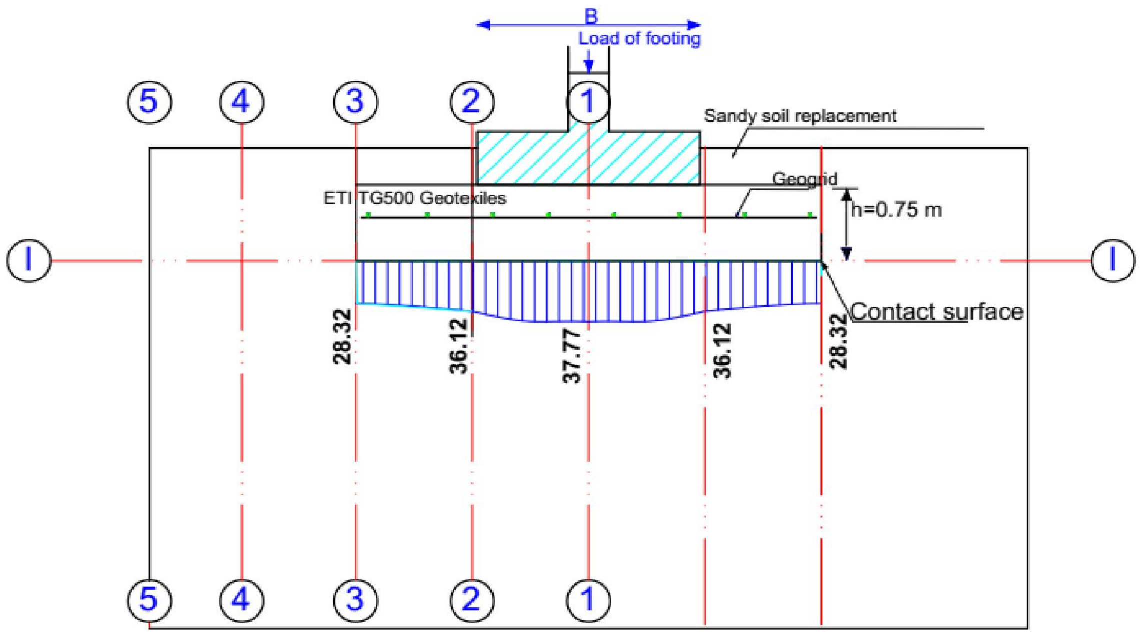



a) thicknesses of replaced layers h =0.50 m

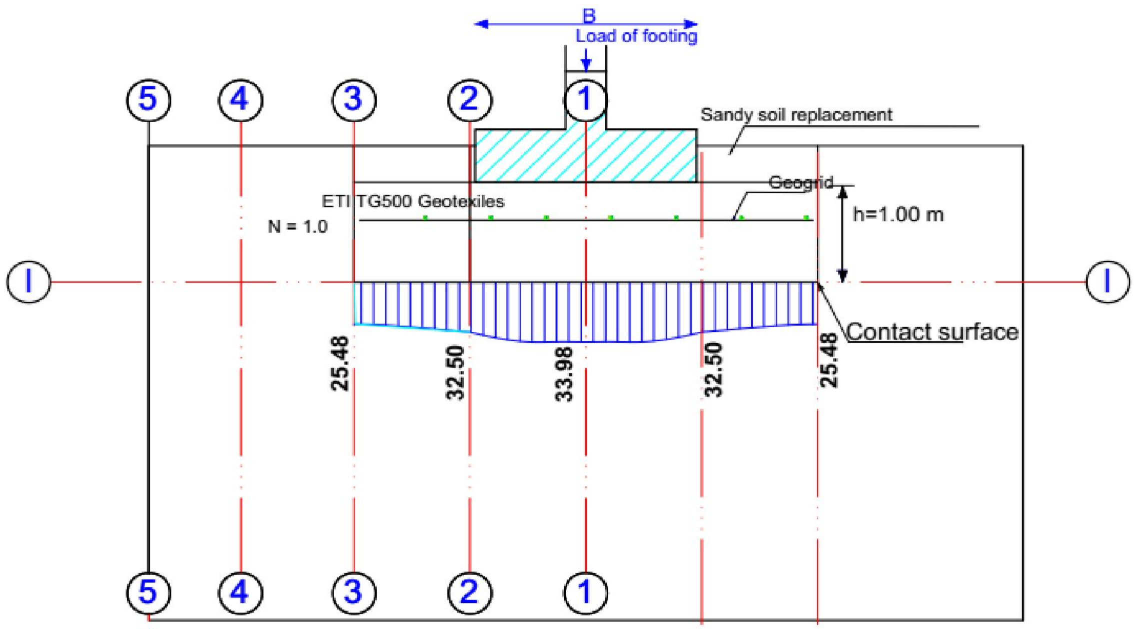
From these figures, it can be concluded that, the stresses in soft clay soil at contact surface with reinforcement replacement soil decreases with increasing replacement reinforcement soil thicknesses and increasing geogrid reinforcement layers number.

**4.5 Effect Of Geogrid Reinforcement Layers Number On Contact Pressure At Contact Surface With Reinforced Replaced Soil**

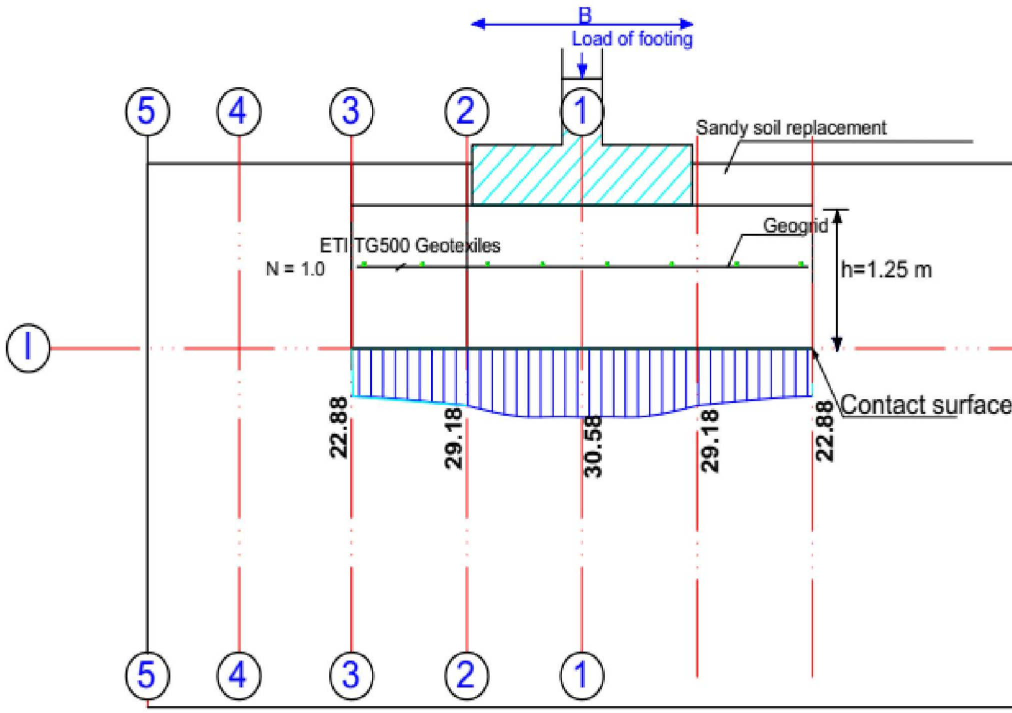
Fig. (18) show the effect of geogrid reinforcement layers number on contact pressure of soft clay along axis's (I –I) at contact surface with replacement reinforcement soil at different thicknesses of replaced soil layers. The relationship between the contact pressures at contact surface with replacement soil layer along axis's (I–I) and geogrid reinforcement layers number N=1.0 is presented in Fig. (19).



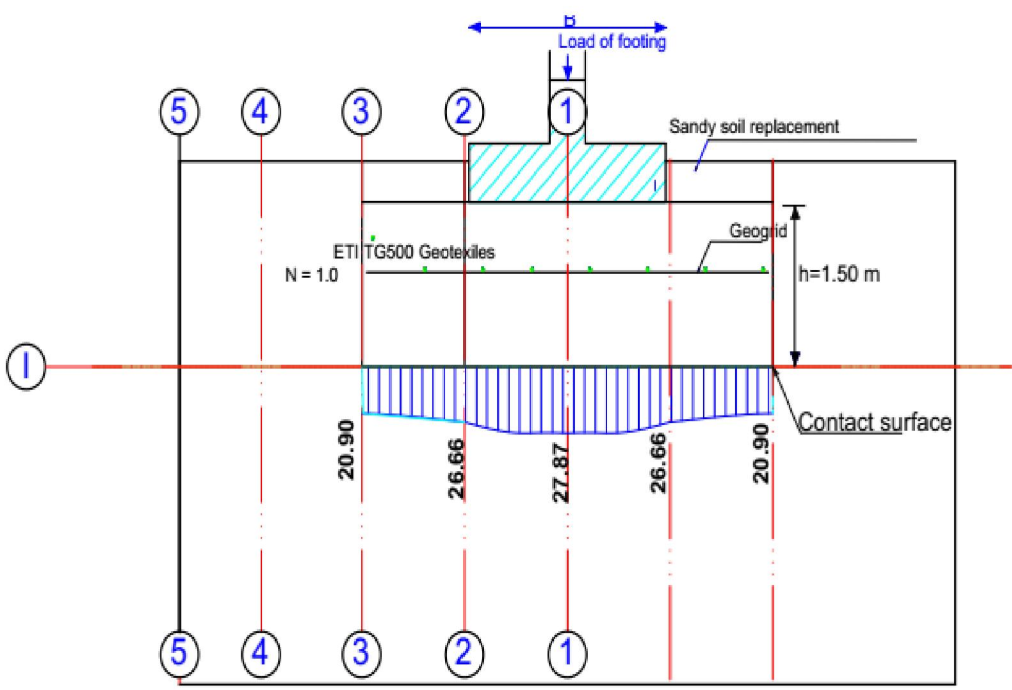

b) thicknesses of replaced layers h =0.75 m




c) thicknesses of replaced layers h =1.00 m




**d) thicknesses of replaced layers h =1.25 m**




**e) thicknesses of replaced layers h =1.50 m**

Fig. (18) Contact pressure at contact surface with replacement layer along axis's (I–I) at geogrid reinforcement layers number N=1.0 and at different thicknesses of replaced soil layers.

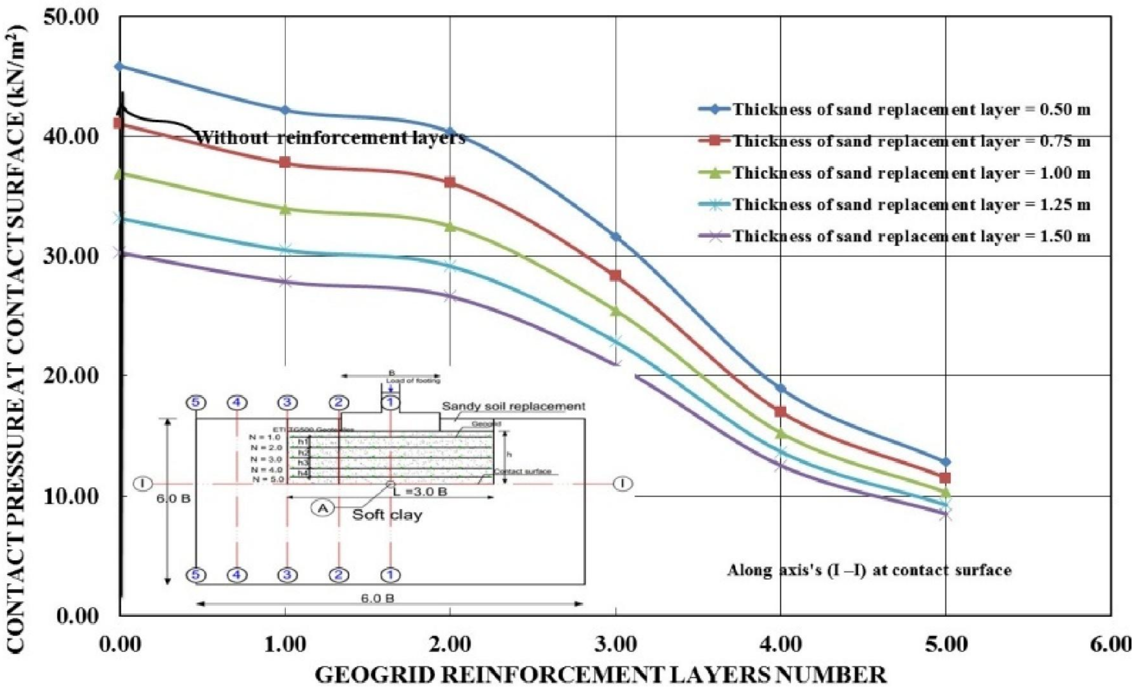



Fig. (19) The relationship between geogrid reinforcement layers number and the contact pressures at contact surface with replacement soil layer along axis's (I – I).

From these figures, it can be shown that the contact pressure values at contact surface with replacement layer along axis's (I–I) decrease with increasing geogrid reinforcement layers number and increasing thicknesses of replaced soil layers.

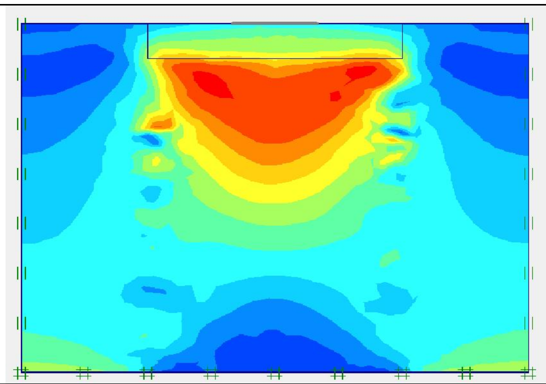
**4.6 Effect Of Geogrid Reinforcement Layers Number On Location And Shape Of Failure Surface**

Fig (20) shows the effect of replacement soil thicknesses without geogrid reinforcement layers on the shape and location of the failure mechanism. Fig (21) shows the effect of number of geogrid reinforcement layers with different replacement thicknesses on the shape and location of the failure mechanism.

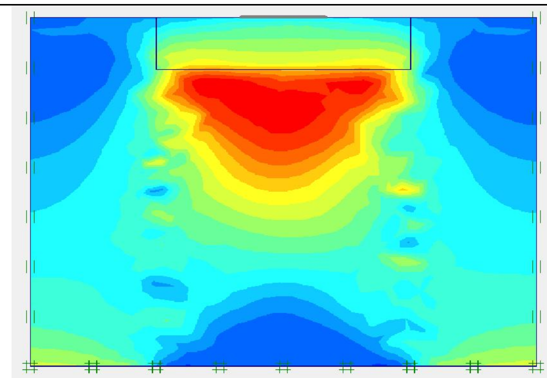
The failure mechanism in the soft clay at contact surface with replacement soil layer along axis's (I–I) has been presented. This mechanism is identical from what Terzaghi's failure surface. The failure wedge angles of soft clay at contact surface with replacement soil along axis's (I –I) at different geogrid reinforcement layers number are listed in Table (9). Fig (22) shows examples of failure mechanism for the soft clay at contact surface with replacement soil layer. The relationship between geogrid reinforcement layers number and failure wedge angles at contact surface with replacement soil layer along axis's (I–I) is presented in Fig. (23).

Table (9 The failure wedge angles of soft clay at contact surface with replacement soil at geogrid reinforcement layers number.

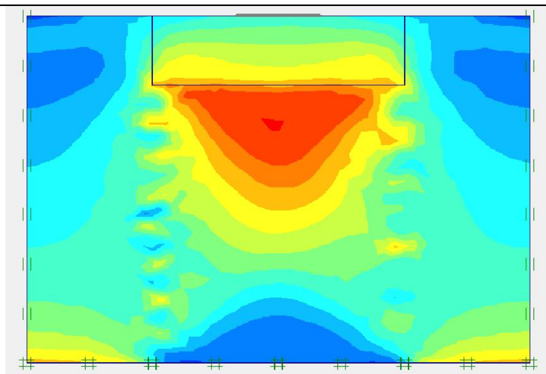
| No. | Granular soil replacement thickness (m) | The failure wedge angles of soft clay at contact surface with replaced layer at geogrid reinforcement layers number (deg) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Geogrid reinforcement layers number | | | | | |
| | | Without reinforcement layers | 1 | 2 | 3 | 4 | 5 |
| 1 | 0.50 | 24 | 27 | 29 | 31 | 33 | 36 |
| 2 | 0.75 | 27 | 29 | 32 | 35 | 39 | 43 |
| 3 | 1.00 | 29 | 32 | 35 | 38 | 42 | 46 |
| 4 | 1.25 | 32 | 35 | 38 | 41 | 45 | 49 |
| 5 | 1.50 | 34 | 38 | 41 | 44 | 48 | 52 |
| | | | | | | | |



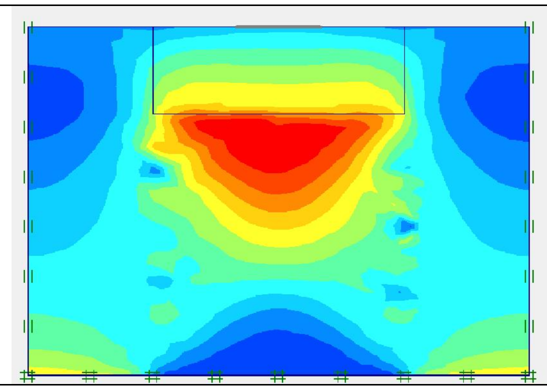
a) Sand replacement layer without geogrid reinforcement layers thickness = 0.50m



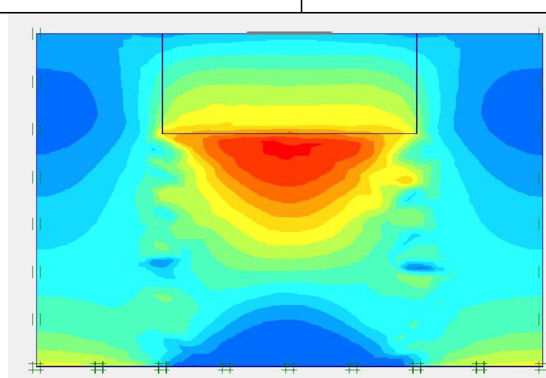
b) Sand replacement layer without geogrid reinforcement layers thickness = 0.75m



c) Sand replacement layer without geogrid reinforcement layers thickness = 1.00m

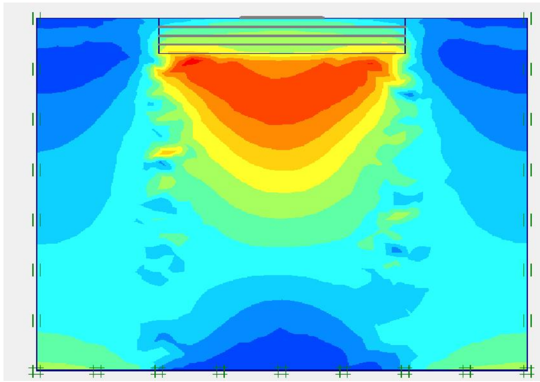


d) Sand replacement layer without geogrid reinforcement layers thickness = 1.25m

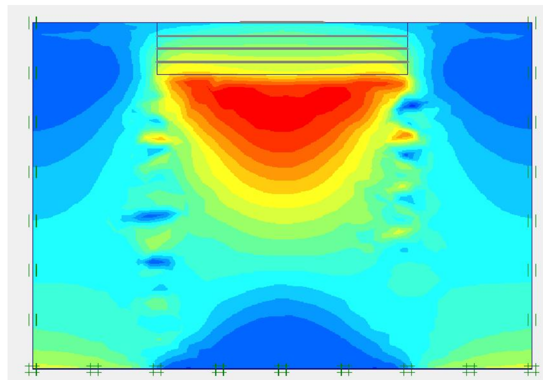


e) Sand replacement layer without geogrid reinforcement layers thickness = 1.50m

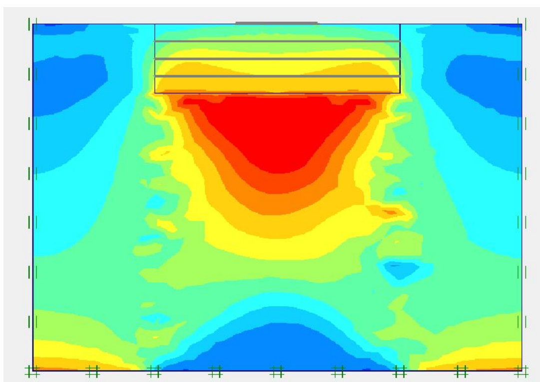
Fig. (20) Failure surface of granular replacement layer over soft clay without geogrid reinforcement soil layers thicknesses.



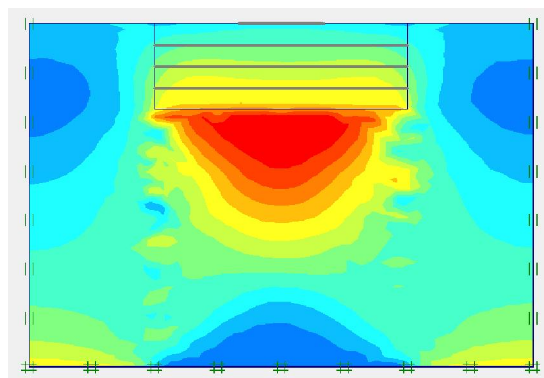
a) Sand replacement thickness = 0.50 m with number of geogrid reinforcement layers = 3.0



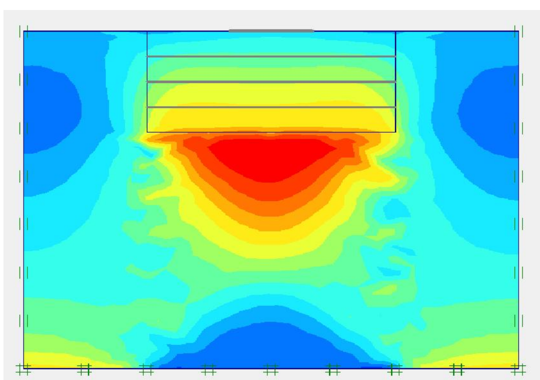
b) Sand replacement thickness = 0.75 m with number of geogrid reinforcement layers = 3.0



c) Sand replacement thickness = 1.00 m with number of geogrid reinforcement layers = 3.0

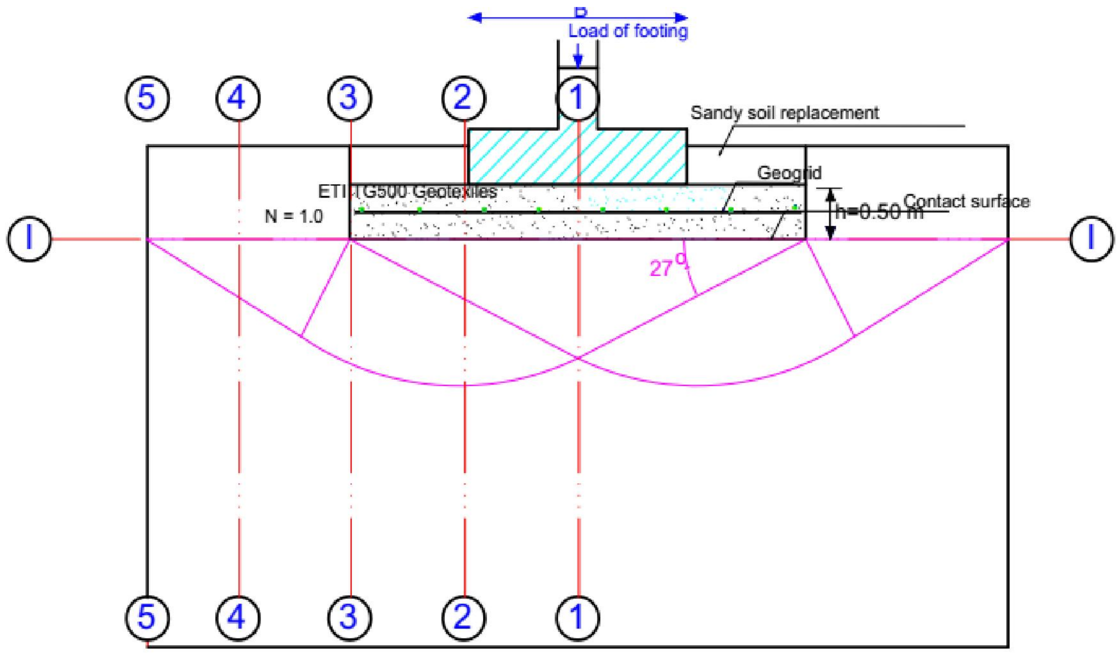


d) Sand replacement thickness = 1.25 m with number of geogrid reinforcement layers = 3.0

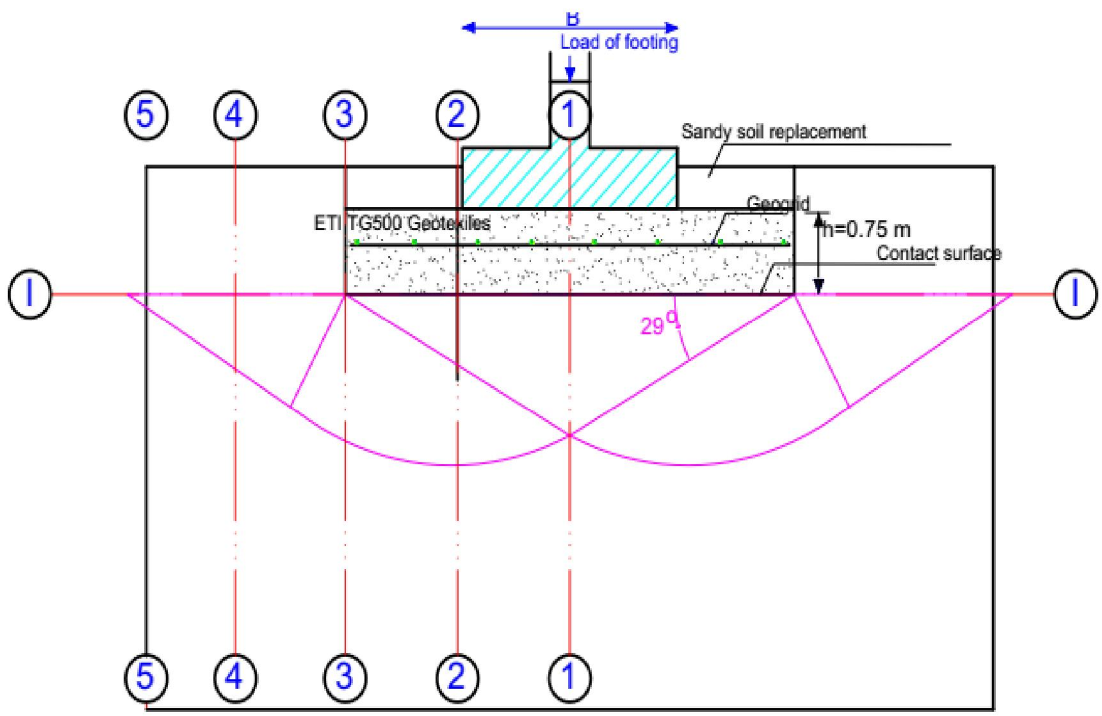


e) Sand replacement thickness = 1.50 m with number of geogrid reinforcement layers = 3.0

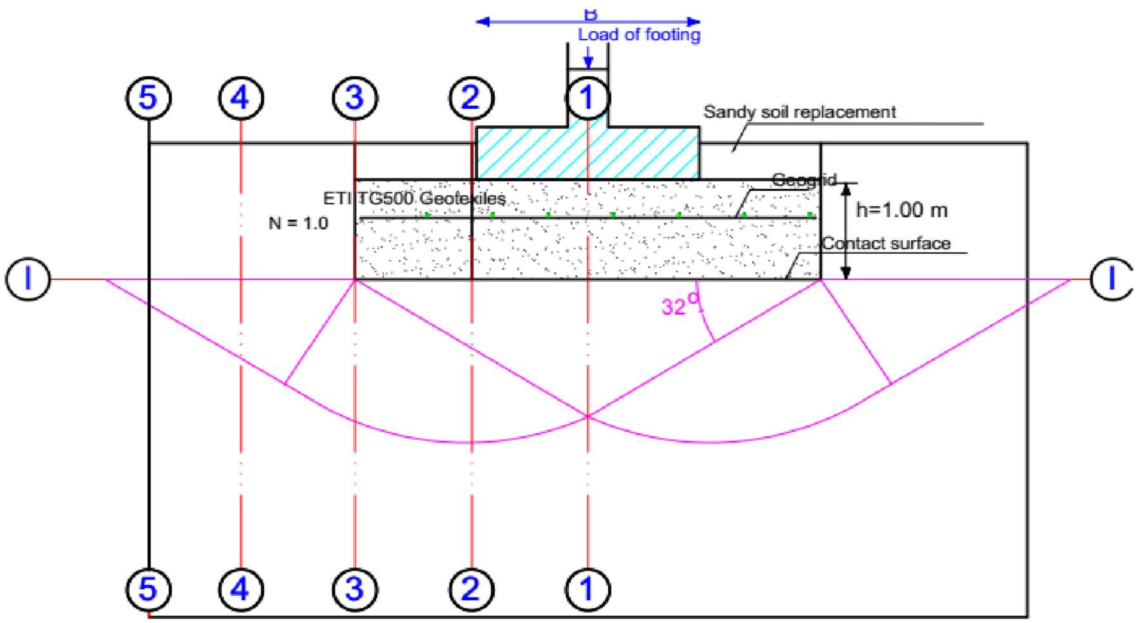
Fig. (21) Failure surface of number of geogrid reinforcement layers =3.0 with different granular replacement soil thicknesses over soft clay.



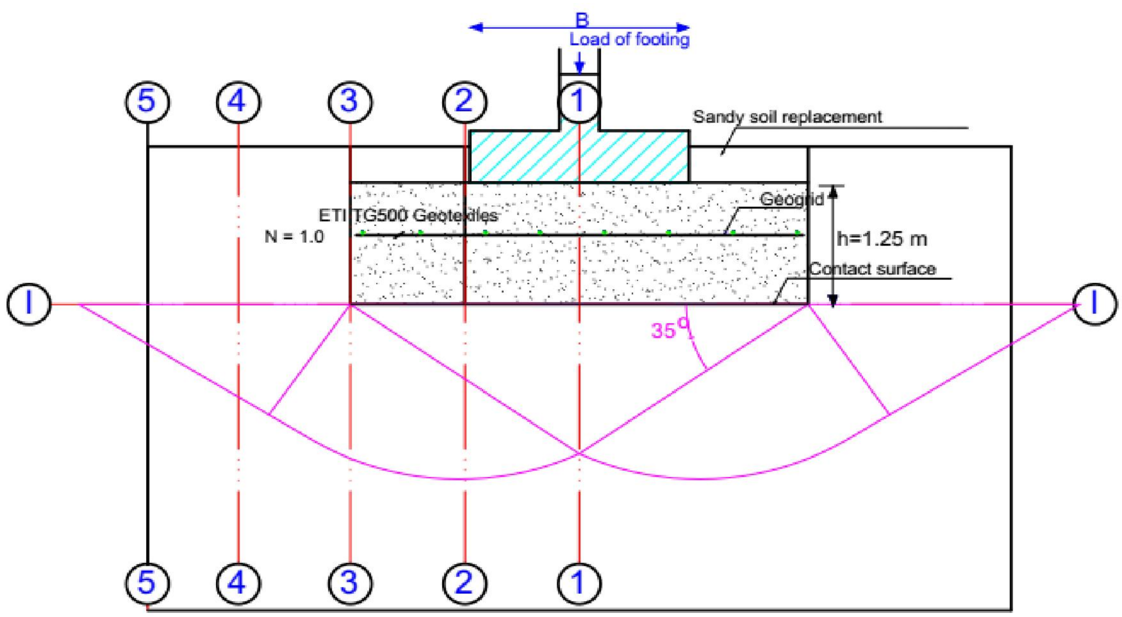

a) thicknesses of replaced layers h =0.50 m



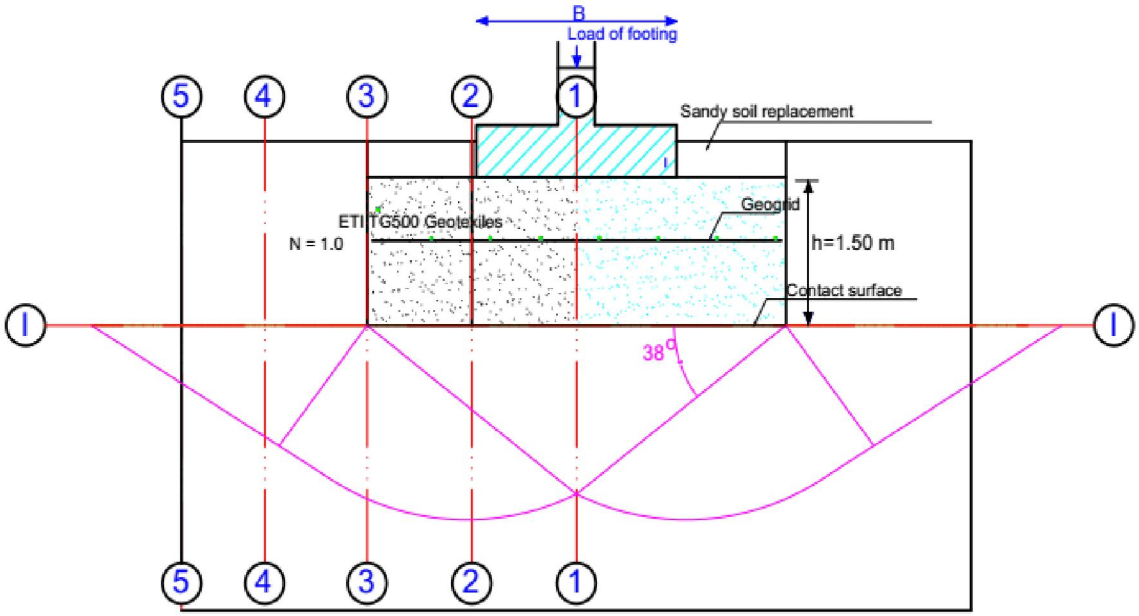

b) thicknesses of replaced layers h =0.75 m




c) thicknesses of replaced layers h =1.00 m




d) thicknesses of replaced layers h =1.25 m




e) thicknesses of replaced layers h =1.50 m

Fig. (22). Failure mechanism of soft clay at contact surface with replacement soil layer along axis's (I–I) at different thicknesses of replaced layers.

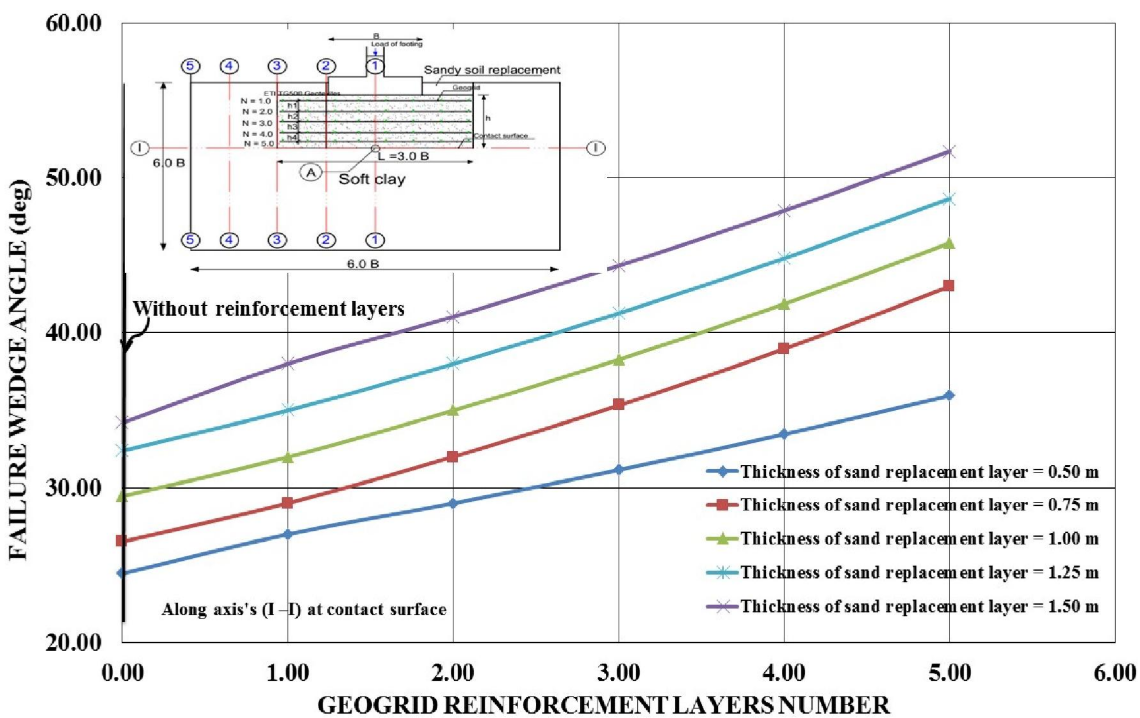



Fig. (23) The relationship between the failure wedge angle at contact surface with replacement layer along axis's (I–I) and geogrid reinforcement layers number.

From the above, it is clearly shown that the failure wedge angle increases with increasing replacement thicknesses and increasing different number of geogrid reinforcement layers.

## 5. Conclusions

Based on the obtained results the following conclusions are drawn:

i. The ultimate bearing capacity of soft clay at contact surface with replaced layer increases with increasing geogrid reinforcement layers number and increasing replaced of reinforcement soil layer thickness.

ii. The ratio between settlement and total thicknesses of replaced layers at contact surface decreases with increasing replaced of reinforcement thickness and increasing geogrid reinforcement layers number.

iii. The stresses at contact surface between soft clay and replacement soil decreases with increasing replacement thicknesses and increasing geogrid reinforcement layers number.

iv. The contact pressure values at contact surface with replacement soil layer has been determined.

v. The failure wedge angles of soft clay increases with increasing replacement thicknesses and increasing different number of geogrid reinforcement layers.

**References**


1 Saeed Alamshahi and Nader Hataf (2009) "Bearing capacity of strip footings on sand slopes reinforced with geogrid and grid-anchor" Geotextiles and Geomembranes 27 (2009) 217–226. journal homepage: www.elsevier.com/locate/geotexmem.

2 Murat Ornek, Mustafa Laman, Ahmet Demir and Abdulazim Yildiz (2012) "Prediction of bearing capacity of circular footings on soft clay stabilized with granular soil" Soils and Foundations 2012;52(1):69–80. The Japanese Geotechnical Society. www.sciencedirect.com.

3 Murad Abu-Farsakh, Qiming Chen and Radhey Sharma (2013) "An experimental evaluation of the behavior of footings on geosynthetic-reinforced sand" Soils and Foundations 2013;53(2):335–348. The Japanese Geotechnical Society. www.sciencedirect.com.

4 P. K. Kolay, S. Kumar, and D. Tiwari (2013) "Improvement of Bearing Capacity of Shallow Foundation on Geogrid Reinforced Silty Clay and Sand" Hindawi Publishing Corporation Journal of Construction Engineering Volume 2013, Article ID 293809, 10 pages http://dx.doi.org/10.1155/2013/293809.

5 Enas B. Alt Alh E, Mohd Raihan TAh Aa, and Fathi M. ABd RABBO (2015) "Behavior of Strip Footing on Reinforced Sand Slope" Journal of Civil Engineering and Management ISSN 1392-3730/e ISSN 1822-3605 2015 Volume 21(3): 376–383 doi:10.3846/13923730.2014.890646.

6 Ali Hasanzadeh and Asskar Janalizadeh Choobbasti (2016) "Estimation of Bearing Capacity of Circular Footings on Clay Stabilized with Granular Soil: Case Study" International Journal of Civil Engineering and Geo-Environmental. Vol. 50 (01). Pp.- 47-54. Journal homepage: http://ijceg.ump.edu.my ISSN:21802742.

7 Hussein, M.K., Hussein, M.K. and Amer, M. I. (2017) "Laboratory Model Tests on Shallow Footings Resting on Geosynthetic Reinforced Replacement Soil Overlying Loose Sand" eo Africa 2017 Conference Marraekech, Morocco 08 – 11 Octobre 2017.

8 Nagy Abdel Hamid El Mahallawy (2019) "Improvement of soft soils using reinforced sand over stone columns" Life Sci Journal 2012;9(2):269-276]. (ISSN: 1097-8135). http://www.lifesciencesite.com. 43.


9/29/2019