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# Numerical Evaluation of Bearing Capacity of Square Footing on Geosynthetic Reinforced Sand

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***Abstract***- Weak soils cannot sustain loads due to low bearing capacity. Different techniques are available to improve the bearing capacity. One of the used techniques is soil reinforcing. In this study, a numerical model has been built to investigate the performance of a square footing resting on Geosynthetic reinforced sand using the commercial finite element analysis package ANSYS. The effects of different parameters of the reinforcing layers on the bearing capacity of the sandy soil have been investigated. Nonlinear Drucker-Prager's model is used as a constitutive material model to simulate the soil behavior. Numerical model of dimensions 900mm x 900mm x 600mm and 150mm x 150mm x 25mm are used to simulate the soil and the square footing for experimental model simulation. Bearing capacity improving due to reinforcing layers is compared with experimental results. The comparison showed a good convergence between results which leads to successful model validation. Extensive parametric study has been undertaken in order to study the effects of different effective parameters, using six types of Geosynthetic reinforcing layers. Results showed that, the effective depth of the reinforced zone under the footing is twice the width of the footing, the optimum width of the reinforcing layers is about four times the width of the square footing, the optimum number of reinforcing layers is four layers within the effective reinforced zone and the effective depth of the first reinforcing layers measured from the bottom of the footing is about half the width of the square footing.

***Keywords*:** Geosynthetic reinforcement, Numerical modeling, Reinforced soil, Square footing

## 1. Introduction

The use of the soil reinforcing materials to improve the bearing capacity for weak soil has been studied. Several studies have been carried out by many researchers to understand the role of the reinforcing materials in improving the bearing capacity of soil [1–9]. Most of these studies are on strip or circular footings, however, the face that the rectangular and square footings are commonly used. The studies on square footings resting on reinforced soils are limited [10–17]. Study on the effect of geogrid reinforcement for both strip and square footings resting on sand was investigated [11]. From this study, it is found that the reinforced zone and the width of the reinforcement required for the strip footing are greater than the reinforced zone and reinforcement width required for the square footing. More studies are needed in this area to establish specific design procedures for geosynthetic reinforced soil supporting square footings.

In the present study, results from numerical simulations on square footing resting on sand with and without geosynthetic reinforcement are discussed. The main objective of this study is to predict the behavior of geosynthetic layers in improving the bearing capacity of the square footings and to study the influence of different reinforcement parameters, on the overall performance improvement of the system.

The parameters considered in the model tests are the type and tensile strength of the reinforcement, depth of reinforced zone, spacing of geosynthetic layers, spacing between the first layer and the bottom face of the footing, number of reinforcing layers and the width of reinforcing layers.

## 2. Experimental Set-Up and Measurements

As stated in [17], the sand beds were prepared in a steel tank with inner dimensions of 900 x 900 x 600 mm. A steel square plate is used to represent the footing of dimensions 150 x 150 x 25 mm. The base of the model footing was roughened by fixing a thin layer of sand with epoxy glue. A hydraulic jack welded against a reaction frame was used to push the footing into the bed for proper contact between the soil and the footing. A schematic diagram of the test set- up is shown in Fig.1.

The sand was placed in the test tank to achieve the desired relative density. The sand bed was of 600 mm depth. The side walls of the tank were made smooth by coating with a lubricating gel to reduce the boundary effects. In case of tests with reinforced sand beds, geosynthetic layers were placed at predetermined depths while preparing the sand bed. After preparing the bed, the surface was leveled, and the footing was placed exactly at the center of the loading jack to avoid eccentric loading. The footing was loaded by a hand-operated hydraulic jack supported against a reaction frame. A recess was made in the footing plate at its center to accommodate a ball bearing, through which vertical loads were applied to the footing. A recalibrated proving ring was used to measure the load transferred to the footing. The load was applied in small increments. Each load increment was maintained constant until the footing settlement was stabilized. Footing settlements and surface deformations were measured through dial gauges. In this study the numerical model has been built to simulate this physical model.

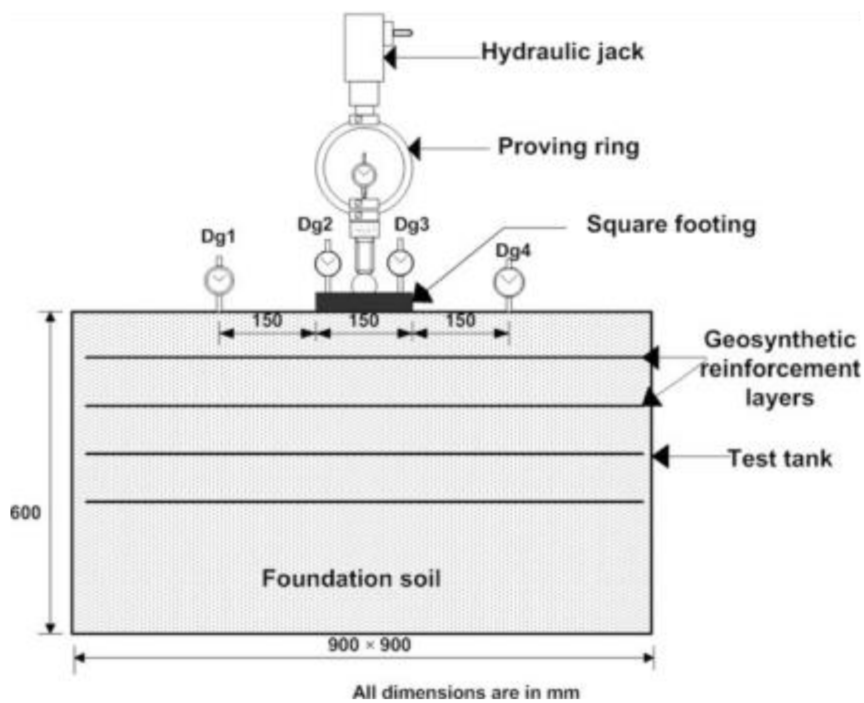


Fig. 1. Schematic diagram of the test set-up by [18]

## 3. Numerical Modelling

Loading tests were carried out on square footing rested on reinforced and unreinforced sand numerically, using ANSYS package. Drucker-Prager's model is used to simulate the sand [18]. Full 3D model of 900mm x 900mm x 600mm dimensions was used. The outer four sides of the model were restricted to move in direction normal to its plan and free to move in the other directions. The bottom of the model was restricted to move in all directions.

The model was divided into a regular grid pattern of 24216 elements (soil and footing without reinforcement). The initial geostatic stresses were calculated in the model. Fig.2 shows the layout of the multi-layer geosynthetic reinforced sand in the model. N layers of reinforcement, square in shape; of side width w are placed at specific depths. The depth of the first layer measured from the bottom face of the footing is defined as v and the vertical spacing between consecutive layers of the reinforcement is measured as h. The total depth of reinforced zone is measured as Z.

Table 1 describes the various parameters used in the model. All these parameters are expressed in non-dimensional form in terms of the footing width as $v/B_f$, $h/B_f$, $w/B_f$ and $Z/B_f$. In case 1, 2, 3 and 4 the value $v/B_f$ and $h/B_f$ were kept equal, but in case 5 $v/B_f$ varies from $h/B_f$. The square footing dimension is measured as $B_f$ x $B_f$.

In order to validate not only the material models and corresponding properties but also the analysis procedures; a validation stage is initially conducted by comparing the results of a series of physical tests undertaken by [17] with those obtained from a detailed numerical modeling of the same physical problem. This validation stage has been done successfully prior to undertake a parametric study stage. This enabled a model calibration and material parameters

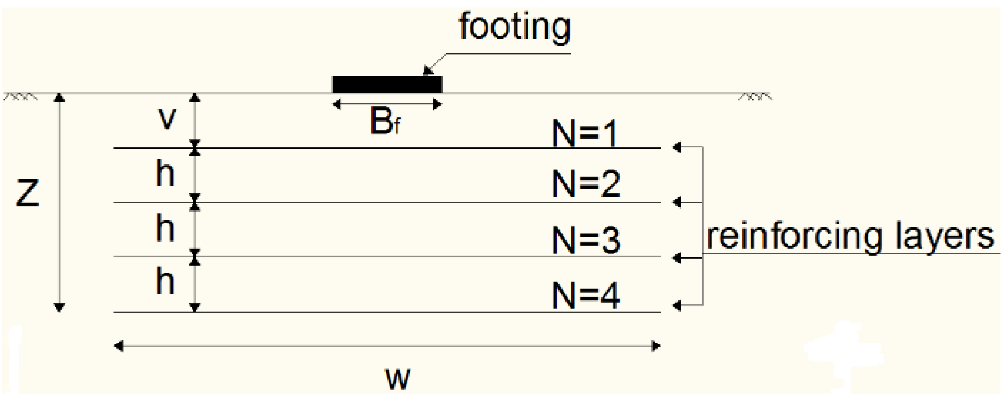


Fig. 2. Model configuration

Table 1. Model various parameters

| Case | $v/B_f$ | $h/B_f$ | $Z/B_f$ | $w/B_f$ | Type of Geosynthetic Material |
|---|---|---|---|---|---|
| **1** | 0.667 | 0.667 | 2.67 | 5.5 | ST.G-M.G-SO.G-ST.T-M.T-SO.T |
| **2** | 0.4-0.5-0.667-1 | 0.4-0.5-0.667-1 | 2.00 | 5.5 | M.G |
| **3** | 0.500 | 0.500 | 2.00 | 1-2-3-4-5-5.5 | M.G |
| **4** | 0.333 | 0.333 | 1.33 | 4.0 | M.G |
| | 0.500 | 0.500 | 2.00 | 4.0 | M.G |
| | 0.667 | 0.667 | 2.67 | 4.0 | M.G |
| | 0.833 | 0.833 | 3.33 | 4.0 | M.G |
| **5** | 0.333 | 0.333 | 1.83 | 4.0 | M.G |
| | 0.500 | 0.333 | 2.00 | 4.0 | M.G |
| | 0.667 | 0.333 | 2.17 | 4.0 | M.G |
| | 0.833 | 0.333 | 2.33 | 4.0 | M.G |
| | 1.000 | 0.333 | 2.50 | 4.0 | M.G |

1. Where :

ST.G: Stiff geogrid, E = 4230 MPa & M.G: Medium geogrid, E = 1970 MPa

SO.G: Soft geogrid, E = 35 MPa & ST.T: Stiff Geotextile, E = 3150 MPa
M.T: Medium geotextile, E = 1575 MPa & SO.T: Soft geotextile, E = 42 MPa

### 3. 1. Soil Modeling

The soil used in this study is considered sand of dimensions=900mm x 900mm x 600mm, modulus of elasticity=4x104KPa, Poisson's ratio=0.3, density=1900Kg/m3, cohesion=10KPa, friction angle=35° and flow angle=11° [19]. A 3D finite element model was used to simulate the sand using Drucker-Prager's as material model and Solid45 as element type [18]. The sand model consists of 24192 elements (only sand model), each of 33mm length, 25mm width and 25mm depth as shown in Figure.3.

### 3. 2. Geothynthetic Reinforcement Modeling

In this study, six different types of reinforcements are used [20]. The reinforcement is modeled using Linear Isotropic model as material model and Link8 as element type. Poisson's ratio of the used reinforcement=0.3, the aperture size of the reinforcement=33mmx25mm and the cross-section area of the reinforcement = 9mm x 2mm as shown in Figure.3.

### 3. 3. Square Footing Modeling

The square footing was modeled as steel footing of dimensions=150x150x25mm, modulus of elasticity=2.1x1011 GPa and Poisson's ratio=0.3.The square footing was modeled using Linear Isotropic model as material model and Solid 45 as element type. Its model consists of 24 elements, each of 33mm length, 25mm width and 25mm depth as shown in Figure.3

### 3. 4. Validation Stage

The validation model is undertaken to ensure the proper use of the numerical modeling. Figure.4 shows the experimental and numerical results of pressure-settlement relation for reinforced and unreinforced soil. It can be noticed that there is a good agreement between both results. This enabled a model calibration and material parameters.

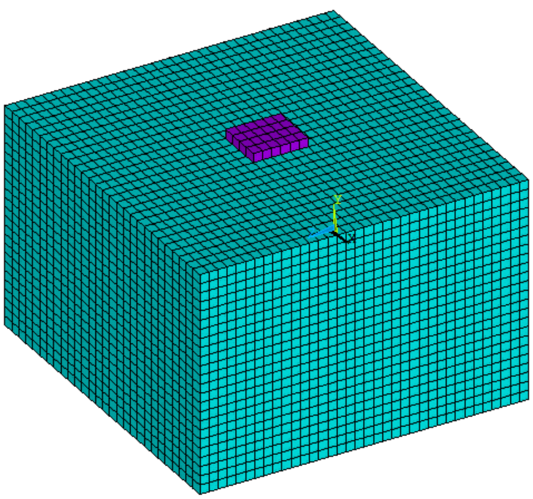

Fig. 3. Soil and footing modeling

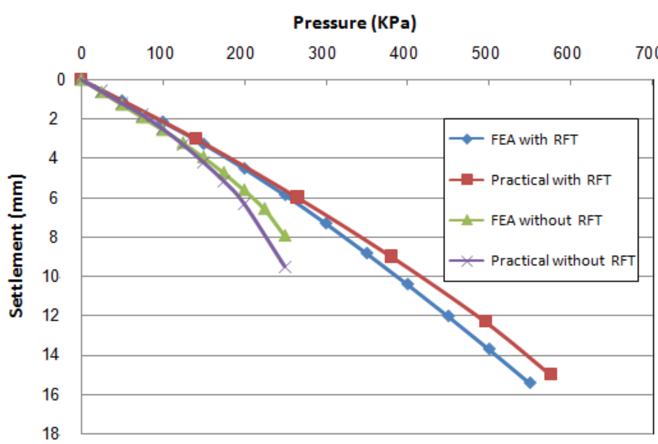


Fig. 4. Validation stage results

## 4. Results and Discussion

### 4. 1. Effect of Reinforcing Material Type

Six reinforcement types with different modulus of elasticity were used in this study. Along the investigation, some parameters were kept fused while others are changed. Table 2 shows the fused parameters. Figure.5 illustrates the square footing settlement corresponding to each reinforcing type. The more the reinforcement stiffness increase, the more the bearing capacity becomes. Increasing the stiffness of the reinforcement over the stiffness of the medium geogrid gives insignificant increase in the bearing capacity.

It is concluded that the effect of the stiff geogrid, medium geogrid, stiff geotextiles and medium geotextiles is almost the same, and then using medium geogrid (E = 1970 MPa) is considered the optimum choice.

Table 2. Constant parameters (Case 1)

| $Z/B_f$ | N | $h/B_f$ | $v/B_f$ | $w/B_f$ |
|---|---|---|---|---|
| 2.667 | 4 | 0.667 | 0.667 | 5.5 |

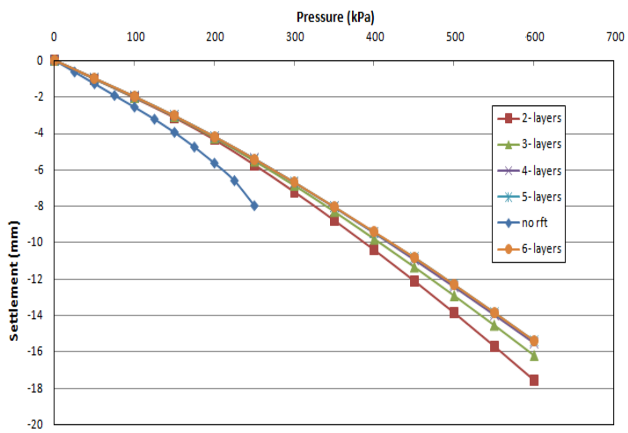


Fig. 5. Effect of reinforcement material type

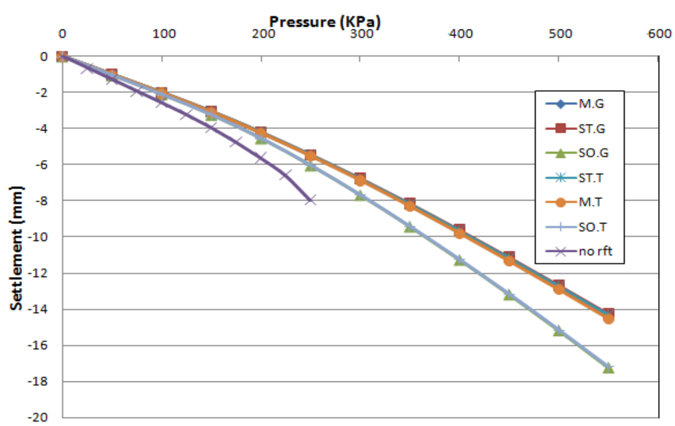


Fig. 6. Effect of layers number

### 4. 2. Effect of Number of Layers

In this study, two, three, four, five and six layers of the reinforcing material have been used.

Table 3 shows the fused parameters in this case 2. Figure.6 illustrates the square footing settlement corresponding to the difference in the number of layers. Increasing the number of the reinforcing layers increase the bearing capacity of the soil, until we reach four layers. It is clear that, using more than four layers of the reinforcing element gives insignificant increase in the bearing capacity.

It is concluded that the effect of using four, five and six layers of the reinforcing layers is almost the same, then using four layers is considered the optimum choice.

Table 3. Constant parameters (Case 2)

| $Z/B_f$ | $w/B_f$ | M.G | N |
|---|---|---|---|
| 2 | 5.5 | E = 1970 MPa | 2 – 3 – 4 – 5 – 6 |

Therefore,

| N | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| h=v | 150mm | 100mm | 75mm | 60mm | 50mm |
| $h/B_f$=$v/B_f$ | 1 | 0.667 | 0.5 | 0.4 | 0.333 |

## 4. 3. Effect of Reinforcing Layers Width

The width of used reinforcing layers has been changed to get the optimum width.

Table 4 shows the fused parameters in this case 3. Figure.7 shows the square footing settlement corresponding to the difference in the width of the reinforcing layers. Increasing the width of the reinforcing layers increase the bearing capacity of the soil, until reaching width equal four times the width of the footing. So, increasing the width of the reinforcement to be more than four times the width of the footing gives insignificant increase in the bearing capacity.

It can be concluded that the effect of using w/Bf = 3, 4, 5 and 5.5 is almost the same. Then, using w/Bf = 4 is considered the optimum choice.

Table 4. Constant parameters (Case 3)

| Z/Bf | N | h | $h/B_f$=$v/B_f$ | M.G |
|---|---|---|---|---|
| 2 | 4 | 75mm | 0.5 | E=1970 (MPa) |

Therefore,

| w (mm) | 150 | 300 | 450 | 600 | 750 | 825 (model limits) |
|---|---|---|---|---|---|---|
| $w/B_f$ | 1 | 2 | 3 | 4 | 5 | 5.5 |

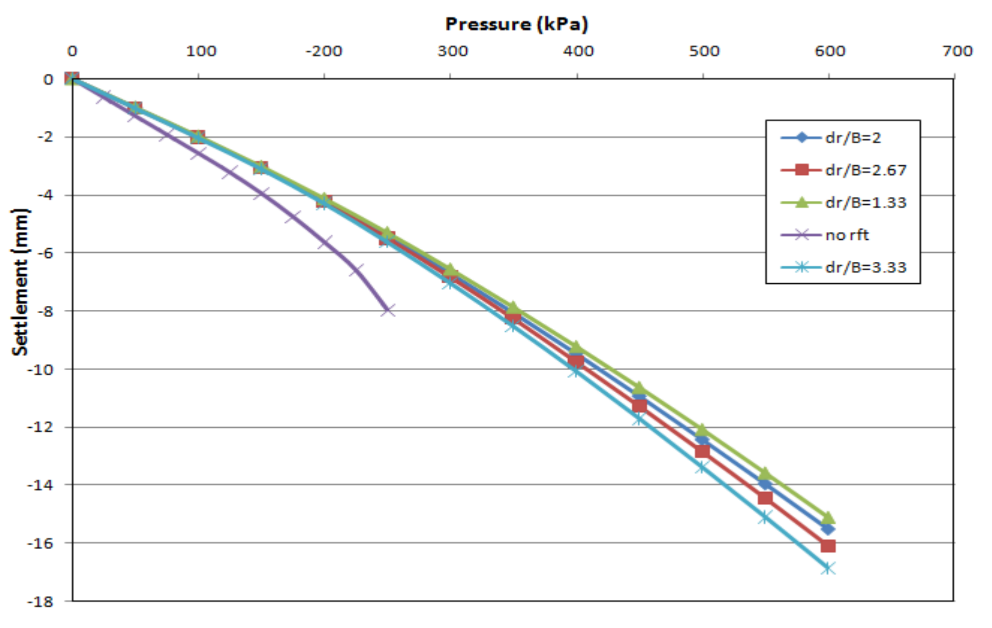


Fig. 7. Effect reinforcement layers width

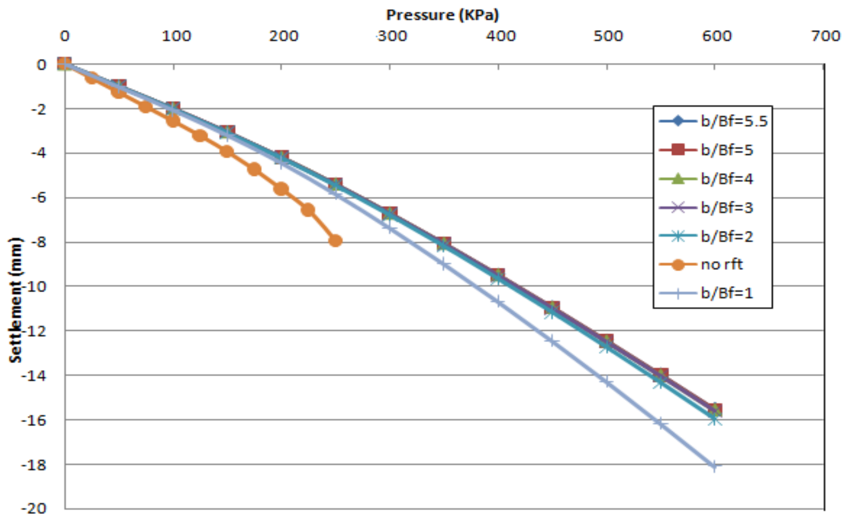


Fig. 8. Effect of the reinforced depth

### 4. 4. Effect of Reinforced Zone Depth

The depth of the reinforced zone has been changed to get the optimum depth. Table 5.a shows the constant parameters. Then, due to the change in the spacing between the reinforcing layers, the depth of the reinforced zone will be changed as shown in Table 5.b. Figure.8 shows the square footing settlement corresponding to the difference in the depth of the reinforced zone. The less the reinforced zone depth (small distance between reinforcing layers), the more the bearing capacity becomes until reinforced depth zone that gives Z/Bf = 2 (h/Bf = 0.5). When using Z/Bf more than 2, the increase in the bearing capacity becomes insignificant.

It can be noticed that the effect of using Z/Bf = 1.33 and 2 is almost the same. Then, using Z/Bf = 2 is considered the optimum choice.

Table. 5.a. Constant parameters (Case 4)

| **w/Bf** | **N** | **M.G** |
|---|---|---|
| 4 | 4 | E=1970 (MPa) |

Table. 5.b. Values of the reinforced zone depth

| **v=h (mm)** | **50** | **75** | **100** | **125** |
|---|---|---|---|---|
| Z (mm) | 200 | 300 | 400 | 500 |
| Z/Bf | 1.333 | 2 | 2.667 | 3.333 |

### 4. 5. Effect of the First Layer Depth

The depth of the first reinforcing layer is considered in this study. Table 6.a shows the constant parameters. Then, due to the change in depth of the reinforced zone, the depth of the first layer will be changed as shown in Table 6.b.

Figure.9 shows the square footing settlement corresponding to the difference in the depth of the first layer. The less the spacing between the first layer of the reinforcement and the bottom face of the footing, the more becomes the bearing capacity, until u/Bf = 0.5. It is clear that, increasing u/Bf more than 0.5 gives insignificant increase in the bearing capacity.

It is concluded that the effect of using v/Bf = 0.333 and 0.5 is almost the same. Then, using v/Bf = 0.5 is considered the optimum choice.

Table. 6.a. Constant parameters (Case 5)

| w/Bf | N | M.G | h/Bf |
|---|---|---|---|
| 4 | 4 | E=1970 (MPa) | 0.5 |

Table. 6.b. Depth of the first reinforcing layer

| Z (mm) | 275 | 300 | 325 | 350 | 375 |
|---|---|---|---|---|---|
| v (mm) | 50 | 75 | 100 | 125 | 150 |
| v/Bf | 0.333 | 0.5 | 0.667 | 0.833 | 1 |

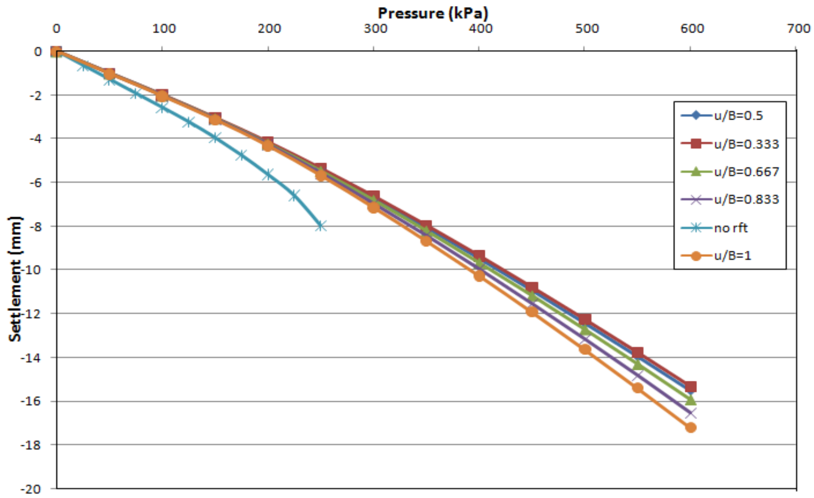


Fig. 9. Effect of the first reinforcing layer

## 5. Conclusion

According to the results obtained from the previous numerical studies, the following conclusions can be made on the behavior of square footing resting on sand reinforced with multiple layers of geosynthetic reinforcements:

- The tensile strength of the reinforcement and its modulus of elasticity play an important role in increasing the bearing capacity of the soil until certain limit. After this limit, the increase in the reinforcing material modulus of elasticity almost doesn't improve the bearing capacity of the soil. The medium geogrid is considered the optimum reinforcing material.
- Reducing the distance between the reinforcing layers, increase the bearing capacity of the reinforced soil. Within the effective reinforced zone, the optimum spacing between the reinforcing layers is about half the width of the footing, i.e. the optimum number of reinforcing material layers is four layers.
- Increasing the width of the reinforcing layers, increase the bearing capacity of the reinforced soil. The optimum width of the reinforcing material layers is about four times the width of the square footing.
- Increasing the depth of the reinforced zone, increase the bearing capacity of the reinforced soil. Effective depth of the reinforced zone under a square footing is twice the width of the footing.
- Reducing the distance between the first reinforcing layer and the bottom face of the footing, increase the bearing capacity of the reinforced soil. Effective depth of the first reinforcing layers measured from the bottom of the footing is about half the width of the square footing.

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