Numerical Modeling of Geogrid Reinforced Soil Bed under Strip Footings using Finite Element Analysis


Many experimental, numerical, and analytical studies have been performed to investigate the behavior of reinforced soil foundation (RSF) for different soil types. However, the behavior of reinforced soil under the foundation has not been established yet.

2. FINITE ELEMENT MODELLING

Full modeling of soil, reinforcing elements, footing and loading are performed using commercial FEM package PLAXIS Version 8.2.

2.1 Material modeling

2.1.1 Soil constitutive law

The well-known Mohr-coulomb model has been considered as a first order approximation of real soil behavior. This elasto-plastic model requires the parameters shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit weight</td>
<td>17.78 kN/m²</td>
</tr>
<tr>
<td>Young’s modulus [Eref]</td>
<td>25000 kN/m²</td>
</tr>
<tr>
<td>Poisson ratio [ν(nu)]</td>
<td>0.35</td>
</tr>
<tr>
<td>Cohesion [Cref]</td>
<td>15 kN/m²</td>
</tr>
<tr>
<td>Friction angle [f]</td>
<td>30°</td>
</tr>
<tr>
<td>Dilatancy angle [Ψ]</td>
<td>0°</td>
</tr>
</tbody>
</table>

Table 1: Soil parameters

2.1.2 Geogrid modeling

Geogrids are elastic flexible elements with a normal stiffness and no bending stiffness. These objects are generally used to model soil reinforcements. The geogrid was modeled using elasto-plastic constitutive model with the parameters shown in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EA</td>
<td>500 kN/m</td>
</tr>
<tr>
<td>Np</td>
<td>45 kN/m</td>
</tr>
</tbody>
</table>

Table 2: Geogrid parameters

Where: EA: Axial/Normal Stiffness
Np: Ultimate tensile strength of the geogrid

2.1.3 Strip footing modeling

Six strip footings (A), (B), (C), (D), (H) & (L) with different dimensions are used as shown in Table3.

<table>
<thead>
<tr>
<th>Model Footings (m)</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.075</td>
<td>0.1</td>
<td>0.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Full Scale Footings (m)</th>
<th>D</th>
<th>H</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3: Strip footings model and real full scale dimensions
The steel strip footings (A), (B) & (C) are modeled as a plate with steel parameters shown in Table 4.

<table>
<thead>
<tr>
<th>Plate Properties</th>
<th>ϒ Steel</th>
<th>kN/m²</th>
<th>Modulus of Elasticity E</th>
<th>2E+08</th>
<th>kN/m²</th>
<th>Thickness (cm)</th>
<th>1</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width (cm)</td>
<td>7.5</td>
<td>10</td>
<td>12.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EA – Axial Stiffness (kN/m)</td>
<td>150000</td>
<td>200000</td>
<td>250000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EI – Bending Stiffness</td>
<td>1.25</td>
<td></td>
<td>1.6667</td>
<td></td>
<td></td>
<td>2.0833</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Own Weight (kN/m/m)</td>
<td>0.0588</td>
<td>0.0784</td>
<td>0.098</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Steel plate footing parameters used in the FEM

The concrete strip footings (D), (H), (L) are modeled as a RC element with an interface elements with parameters shown in Table 5.

<table>
<thead>
<tr>
<th>Material Model</th>
<th>Linear Elastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit weight</td>
<td>23.563 kN/m³</td>
</tr>
<tr>
<td>Young’s modulus [Eref]</td>
<td>2.482E+07 kN/m²</td>
</tr>
<tr>
<td>Poisson ratio [ν(nu)]</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 5: Concrete footing parameters used in the FEM

2.1.4 Interface elements
The roughness of the interaction modeled by choosing a suitable value for the strength reduction factor in the interface (Rinner). This Factor relates the interface strength to the soil strength (friction angle and cohesion). An interface element between the soil and the geogrid had the typical value of Rinner =0.85 is used. This factor relates the interface strength to the soil strength. The value of the Rinner was chosen based on previous experience with the interaction between soils and geogrids which develop bearing and friction stresses. [M.A Sayed 2012]. The interface element between the soil and the steel plate was chosen rigid (Rinner =1) and between the concrete footing and the soil was chosen with the typical value of Rinner =0.6.

2.1.5 Boundary conditions
The modeled boundary conditions are assumed such that the vertical boundaries are free vertically and constrained horizontally while the bottom horizontal boundary is fully fixed as shown in Figure 1.

2.1.6 Mesh Generation and initial conditions
Once the model geometry is defined and the material properties are assigned to all clusters and structural objects, the geometry inputs has to be divided into finite elements in order to perform finite element calculations. A refined mesh was adopted to minimize the effect of mesh dependency on the finite element modeling of cases involving changes in the number, length, and the location of geogrid layers. Figure 2 shows the mesh generation of the FEM. The sand layer in this study was dry, so there was no need to enter ground water condition. The analysis does, however, require the generation of initial effective stresses by means of $K_0 = (1-\sin\phi)$ procedure. Figure 3 shows the initial conditions for the FEM.

2.2 Finite Element Modeling Matrix
Figures 4 and 5 show the FEM matrix for the single and multi-reinforcement case which is the same matrix for the experimental study. In the Multi-layered case the FEM is created on footing (B) with h/B=0.75. Figure 6 shows the geogrid layout in the FEM, where (N) is the Number of reinforcement layers, (L) is the geogrid length, (u) the depth of the first layer measured from the bottom face of the footing, (h) the vertical spacing between consecutive layers of the reinforcement, and the footing width (B).
Figure 4: FEM Matrix (Single Layer Reinforced soil bed)

Effect of \( u/B \)
- \( u/B = 0.25 \)
  - L/B = 7.5
- \( u/B = 0.5 \)
  - L/B = 7.5
- \( u/B = 0.75 \)
  - L/B = 7.5

Effect of \( L/B \)
- \( L/B = 2.5 \)
  - u/B = 0.25
- \( L/B = 7.5 \)
  - u/B = 0.25
- \( L/B = 12 \)
  - u/B = 0.25

Figure 5: Experimental model Matrix (Multi-Reinforced soil bed)

Multi-Reinforced soil bed
- Footing (A), (B), (C), (D), (H) & (L)
  - N = 2
    - u/B = 0.25
      - h1/B = 0.75
      - L/B = 7.5
  - N = 3
    - u/B = 0.25
      - h1/B = 0.75
      - h2/B = 0.75
      - L/B = 7.5
  - N = 4
    - u/B = 0.25
      - h1/B = 0.75
      - h2/B = 0.75
      - h3/B = 0.75
      - L/B = 7.5

Figure 6: Geogrid Layout

2.3 FEM results Validation

The results are presented on the relation between the stresses under the footing in \( \text{(kN/m}^2 \) versus its associated settlement in (mm).

Plaxis Calculations identifies the stress at failure with (X) sign and reports that the soil body collapsed.

Figures from 7 to 12 illustrate the comparison between the FEM and the experimental results for Unreinforced soil bed for footing (B) & N = 1, L/B = 7.5 and \( u/B = 0.25 \) & N = 1, \( u/B = 0.25 \) and L/B = 5 & N = 1, L/B = 5 & \( u/B = 0.25 \) & N = 2, \( u/B = 0.25 \), h1/B = 0.75, & L/B = 7.5 & N = 3, \( u/B = 0.25 \), h1/B = h2/B = 0.75, & L/B = 7.5 & N = 3, \( u/B = 0.25 \), h1/B = h2/B = h3/B = 0.75 & L/B = 7.5

Figure 7: Unreinforced soil bed FEM vs. Experimental model results for footing (B)

Figure 8: Footing (B) FEM vs. Experimental Model results with N = 1, \( u/B = 0.25 \) & L/B = 7.5

Figure 9: Footing (B) FEM vs. Experimental model results with N = 1, L/B = 5 & \( u/B = 0.25 \)
It can be noticed from the comparison of the FEM and the experimental model results in the unreinforced, single reinforced and multi-reinforced soil bed that there is a medium agreement between the FEM and the experimental model results. Therefore the FEM is validated and ready for parametric study.

2.4 PLAXIS outputs

Other than stress (kN/m²) and Settlement (mm) curves, there are other outputs like the deformation mesh, Cartesian effective stresses, plastic points, horizontal and vertical displacements, Cartesian strains, Geogrid displacement and the tension in Geogrid. Figures 13 to 17 show the outputs for N=1, u/B=0.25 & L/B=7.5 with footing (B) at the ultimate stress value.
3. RESULTS, ANALYSIS AND DISCUSSION

Result analysis and comparison will be carried out and presented through the bearing capacity ratio (BCR). The improvement in the bearing capacity is represented using a non-dimensional factor, called bearing capacity ratio BCR. This factor is defined as the ratio of the footing ultimate pressure with reinforced bed ($q_{\text{reinforced}}$) to the footing ultimate pressure with the unreinforced bed ($q_{\text{unreinforced}}$).

3.1 Effect of first reinforcing layer depth ($u/B$):

The depth of the first reinforcing layer has been changed in terms of $u/B=0.25$, 0.5 & 0.75 for $L/B=7.5$ for footings (A), (B), (C), (D), (H) and (L) to get the optimum depth. Figure 18 illustrates the BCR of the soil versus variable values of $u/B$ for different footings. It is noticed that the values of (BCR) for $u/B=0.25$, and $L/B=7.5$ are 1.67, 1.67, 1.63, 1.18, 1.10 & 1.07 respectively, therefore 7%-70% improvement. That means as the width of the footing increase the improvement of the BCR decrease.

3.2 Effect of reinforcing layers width ($L/B$):

The width of the first reinforcing layer has been changed in terms of $L/B=2.5, 5, 7.5 & 12$ for $u/B=0.25$ for footings (B), (D), (H) & (L) to get the optimum width. Figure 19 illustrates the BCR of the soil versus variable values of $L/B$ for footings (B), (D), (H) & (L).

It is shown that from the finite element models, the effect of using $L/B = 7.5$ and 12 is almost the same therefore effect of using $L/B=7.5$ is the optimum for footing (B), (D), (H) & (L).

3.3 Effect of the spacing between the 1st & 2nd Geogrid ($h_1/B$):

From Figure 20, it is noticed that the values of (BCR) for using two reinforcing layers with $u/B=0.25$, $L/B=7.5$ & $h_1/B=0.75$ are 2.5, 2.12, 1.85, 1.32, 1.20 & 1.14. For footings (A), (B), (C), (D), (H) & (L) respectively, therefore 14%-150% improvement. That means as the width of the footing decrease the improvement of the BCR increase.

3.4 Effect of the spacing between the 2nd & 3rd Geogrid ($h_2/B$):

From Figure 21 It is noticed that the values of (BCR) for using three reinforcing layers with $u/B=0.25$, $L/B=7.5$ & $h_1/B=0.75$, $h_2/B=0.75$ are 2.5, 2.27, 2.14, 1.36, 1.3 & 1.25 for footings (A), (B), (C), (D), (H) & (L) respectively, therefore 25%-150% improvement. That means as the width of the footing decrease the improvement of the BCR increase.

3.5 Effect of the spacing between the 3rd & 4th Geogrid ($h_3/B$):

From Figure 22 it is noticed that the values of (BCR) for using four reinforcing layers with $u/B=0.25$, $L/B=7.5$ & $h_1/B=0.75$, $h_2/B=0.75$ & $h_3/B=0.75$ are 2.5, 2.27, 2.14, 1.36, 1.3 & 1.25 for footings (A), (B), (C), (D), (H) & (L) respectively, therefore 25%-150% improvement. That means as the width of the footing decrease the improvement of the BCR increase.
It can be concluded from the experimental and finite element models that the effect of using \( h_1/B = 0.75 \) is the optimum for footing (A), (B), (C), (D), (H) & (L).

It can be concluded from the experimental and finite element models that the effect of using \( h_2/B = 0.75 \) with \( h_1=0.75 \) is the optimum for footing (A), (B), (C), (D), (H) & (L).

It can be noticed that \( h_3/B=0.25, 0.5, 0.75 \) & 1 having the same BCR for footing (A), (B), (C), (D), (H) & (L). Figure 23 and 24 illustrates the settlement (mm) for footings (A), (B), (C), (D), (H) & (L) in order to conclude the optimum value for \( h_3/B \).

It can be concluded that \( h_3/B=0.75 \) is the least settlement, therefore it is the optimum.

### 3.6 Optimum No. of Reinforcement layers

Figure 25 & Figure 26 illustrates BCR and Settlement (mm) VS the no. of geogrids for footing (A), (B) & (C). It can be noticed that the BCR value increases with the increase of geogrids layer up to \( N=3 \). Figure 39 shows that the BCR value for \( N=3, 4, \) & 5 is the same for footing (A), (B) & (C), but the settlement (mm) for \( N=4 \) is less than the settlement for \( N=3 \), and for \( N=4 \) and 5 the is no significant change in settlement (mm) which can be concluded from Figure 27, therefore the optimum number of geogrids reinforcement is four for footing (A), (B) & (C).
Figure 27 & Figure 28 illustrates BCR and Settlement (mm) VS the no. of geogrids for footing (D), (H) & (L). It can be noticed that the BCR value increases with the increase of geogrids layer up to N=3, but the settlement (mm) for N=4 is less than the settlement for N=3, and for N=4 and 5 the is no significant change in settlement (mm) which can be concluded from Figure 29, therefore the optimum number of Geogrid reinforcement is four for footing (D), (H) & (L).

From footing (A), (B), (C), (D), (H) & (L) it can be concluded that the optimum number of Geogrid layers to be used is four for footing (D), (H) & (L). It can be noticed that the BCR value increases with the increase of geogrids for footing (D), (H) & (L). It can be seen that the number of geogrid reinforcement is four for footing (D), (H) & (L) but the BCR value increases with the increase of the number of geogrids for footing (D), (H) & (L). It can be concluded that the optimum number of reinforcement is four for footing (D), (H) & (L).

**4. CONCLUSIONS**

Based on the Experimental and numerical investigation results, the following conclusions may be drawn:

1. The results of numerical modeling have shown that the provision of a reinforcement layer at an appropriate location in the body of sand dunes has resulted in a significant increase in the bearing capacity of footings.
2. The optimum embedment depth (u/B) of the first reinforcement layer which resulted in the maximum ultimate bearing capacity of the geogrid-reinforced soil bed was about 0.25 times the width of the footing.
3. The optimum spacing (h/B) between each successive reinforcement layer which resulted in the maximum ultimate bearing capacity of the geogrid-reinforced soil bed was about 0.75 times the width of the footing.
4. The optimum Length (L/B) of the reinforcement layer which resulted in the maximum ultimate bearing capacity of the geogrid-reinforced soil bed was about 7.5 times the width of the footing.
5. The results of model tests and numerical analyses have shown that the optimum number of reinforcement is 4 layers.
6. A medium agreement between the experimental and numerical results on general trend of behavior and the critical values of the geogrid parameters is observed. The study showed a directly proportional relation between the number of reinforcement layer and the BCR, and an inversely proportional relation between the footing width and the BCR.

**REFERENCES**


