Numerical Analysis of Geogrid and Deep Mixing Column Supported Embankment

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Abstract. Embankment is an essential component of civil engineering constructions. It is required for the implementation of many projects such as roads, railways, and dams. However, large deformations and lateral movements may occur due to the poor mechanical properties of the weak soils. To avoid that, the subgrade must be improved. One of the efficient and economic techniques that solve these problems is the column-supported embankment system. In this paper, a numerical model of the embankment was established using (ABAQUS) software program. Three different modes were studied to explain the behavior of these embankments. A parametric study was conducted to examine the various influencing factors, such as elastic modulus of columns, the effect of the geogrid layer on the performance of embankment, the settlements, the lateral movement, the shear strength of the soil, the stress concentration ratio, the soil arching ratio, and the tension force in geogrid layer were determined and analyzed for various embankment modes. The results show that the effect of the elastic modulus of columns plays a vital role in the performance of the embankment. Similarly, the geogrid layer also has significant effects on the lateral displacement, and the shear strength of the embankment. In general, for all modes, the decrease in the elastic modulus of the columns leads to an increase in the embankment loads that carried out by the soil between the columns. While, the absence of the geogrid layer leads to an increase in the embankment loads carried by columns.

Keywords: Embankment, Column-Supported Embankment, Geogrid, Settlement, and Soil Arching.

1. Introduction
The column supported embankments (CSE) with the geogrid layers have been confirmed to be one of the most effective and economic techniques for soft soils that may undergo large deformations and lateral movements [1]. In this system, the geogrid layer is acted as reinforcement with horizontal direction while the columns are acted as a vertical reinforcement. Many publications during the last years focused on using supporting embankments by geogrid column-supported technique. The designing of CSE with the geogrid reinforcement must include two determination steps. Step one evaluates the behavior of the arching of the column in the fill. Step two the behavior of the load-deflection of the geogrid reinforcement. Many researchers studying the analyses of the CSE and proposed a model for step one (the arching step). They proposed a limited state equilibrium model.

The arching is concentric in this model. This model is an extension of many models, such as these developed by Hewlett and Randolph, 1988 and Zaeske, 2001. The developed model represents the behavior obtains the arching for the relatively thin fill. The geogrid reinforcement in the column embankment obtains a more efficient method to transfer the load to the columns in a mechanism of arching. Many loading cases may be exerted on the model such as that affects the columns and geogrid reinforcement strips located between the columns. In the second case, the load is distributed as an inverse
tributions are presented with behavior of as center to center spacing, two ratios of forced materials [6]. In the present work, e case histories, numerical taken by soil to columns, the mechanism of load transfer called soil arching [8]. Practically restrained by shear stresses of embankment fill, the shear conveys the embankment loads concentration engendered on columns and the reduct height with time, the stress increment on columns is more than on the soil, and as a result of the stress T 2.2.

The tests involved the following parameters (s/d = 2.5, 3 and 4), (L/d= 5 and 8), (height of embankment H=200, 250, and 300 mm), (testing were conducted on both ordinary stone column (OSC), and encased stone columns (ESC)). The vertical effective stress at the top, middle under the centerline, and the lower edge between two columns were measured by using three load cells. The results had shown that the key parameter ratio (h/s-d) of the height of embankment to the clear spacing between two columns less than 1.2 and about 1.4 for the two cases of OSC and ESC, respectively. (where d is the stone column diameter, s is the spacing between columns). Also, the researchers had founded that there is no effect of arching observed, very large settlement at the embankment surface, and virtually unmodified stress acting on the soil when the ratio of (h/s-d) grater than or equal to 2.2 for two cases of OSC and ESC, respectively [4].

2. Plane Strain Supposition
It is always used in geotechnical analysis when soil structures are very long with the same uniform cross-section area and with finite dimensions such as soil embankment, which have a uniform cross-section with limited dimensions in the x-y plane whilst having a very large dimension in the z-direction. In this analysis, the strains along z-direction are nil (i.e., $\varepsilon_{zz} = \varepsilon_{13} = \varepsilon_{23} = 0$). Therefore, the 3-D embankment problem can be converted to a 2-D plane strain problem, by which, the x-y plane is assumed as the cross-section of the embankment, which can represent the whole embankment [5].

2.1. Composite Foundations
When the natural ground is reinforced or replaced partially by other materials, the new system which composed of ground soil and the reinforcement materials is called composite foundation; the types and stiffness of composite foundations depend on the reinforced materials [6]. In the present work, a composite foundation system with deep mixing columns is studied. The system was analyzed before and after loading by using two dimensions (ABAQUS) software program [7].

2.2. Load Transfer and Soil Arching Phenomena
The vertical stresses on columns and the soil between columns are increased with increase embankment height with time, the stress increment on columns is more than on the soil, and as a result of the stress concentration engendered on columns and the reduction engendered on the soil. The soil arching practically restrained by shear stresses of embankment fill, the shear conveys the embankment loads taken by soil to columns, the mechanism of load transfer called soil arching [8, 9].
Two global indexes describe the mechanism of soil arching phenomena; the first index is the degree of soil arching ($\rho$), and it can be expressed as the following in Eq. (1):

$$\rho = \frac{P_b}{\gamma h + q}$$

where ($\rho$) is soil arching ratio, ($P_b$) is applied vertical stress on soil, ($\gamma$) density of filling, ($h$) height of filling, and ($q$) is surcharge loading. Another factor is the stress concentration ($n$); which can explain by the difference of elastic modulus of soil and columns which lead to transfer the loads from soil to columns. It is defined as the ratio of the vertical stress on the columns to the vertical stress on the soil between the columns; which can be expressed as the following in Eq. (2):

$$n = \frac{\sigma_p}{\sigma_s}$$

where: ($n$) is stress concentration ratio, ($\sigma_p$) is stress on column and ($\sigma_s$) is stress on soil between columns. Stresses concentration ($n$) and soil arching ratio ($\rho$) are used to evaluate the effect of the reinforced-column supported embankment technique in embankment performance [9].

3. Material Properties

Three modes were used to simulate the behavior of geogrid column-supported embankment by using the finite element software (ABAQUS). For comparison purposes, three modes are used with different elastic modulus of the column. The first mode is an embankment with reinforcement, it is modulus (Mode1), and the second mode is an embankment with reinforcement with different elastic modulus of the column that in mode 1, it is termed (Mode 2). These modes are compared with the third mode that includes the embankment without reinforcement, it is termed (Mode3). The details and the dimensions of the embankment are shown in Fig. 1. The material properties of the embankment, soil layers are presented in Table 1, while the column, and the geogrid layer are presented in Table 2. The geogrid layer is used as a horizontal reinforcement, which is embedded in the platform layer at 0.25m above the top of deep mixing columns.

![Embankment cross-section](image)

**Figure 1.** Embankment cross-section.

| Embankment layers | Depth (m) | Density $\rho$ (kg/m$^3$) | Elasticity E (MPa) | Internal friction $\varphi'$ | Cohesion $C'$ (kPa) | Dilatancy angle, $\Psi$ | Poisson ratio, $\mu$ |
|-------------------|-----------|---------------------------|--------------------|----------------------------|-------------------|----------------------|------------------|
| Fill soil         | 5         | 1939                      | 20                 | 24.6                       | 16.8              | 0.1                  | 0.3              |
| Soft soil (silt)  | 12        | 1816                      | 7.6                | 19.7                       | 7.6               | 0.1                  | 0.33             |
| Clay              | 8         | 1867                      | 22.1               | 21                         | 15.7              | 0                    | 0.3              |
Table 2. Deep mixing column properties.

| Mode | Type   | Length (m) | Diameter (m) | Density ρ (kg/m³) | Elasticity E (MPa) | Poisson ratio μ |
|------|--------|------------|--------------|-------------------|-------------------|-----------------|
| 1    | Deep mixing | 12         | 0.4          | 2040              | 5000              | 0.2             |
| 2    | Deep mixing | 12         | 0.4          | 1837              | 30                | 0.3             |
| Geogrid | -     | 42         | 0.02         | 2040              | 135               | 0.3             |

All embankment fills and the soil layers are modeled as a linear-elastic, and perfectly plastic model (Mohr-Coulomb failure criterion). The columns are modeled as linear elastic isotropic material embedded in the region under the embankment. The geogrid layer is modeled as a truss element embedded in the platform layer. After establishing the model, the soil properties, the surface interactions, and defining boundary conditions in the numerical model are assigned. For embankment filling and soil layers, the model is meshed by CPE4R elements type as shown in (Figure 2). While, the CPE3 is used to mesh the columns. The CPE4R and CPE3 are plane strain elements. The geogrid layer is meshed by T2D2. T2D2 is defined as a 2D stress-displacement truss elements. The T2D2 element have 2 linear nodes [7]. Then, the analysis results are carried out for all models during loading. The verification problem is applied to the software, where the value of the program is close to the field data.

Figure 2. mesh of embankment filling and soil layers.

4. Analysis Results

4.1. Maximum settlements

The settlement results are presented in Table 3 shown below. The settlement for mode 2 is larger than mode 1. Also, the settlement of mode 2, takes much longer time to stabilize than the corresponding settlement of mode 1, while the settlement magnitude for mode 3 is much closed with settlement magnitude for mode 1. Also, lateral displacement in the toe of the embankment for the three modes are presented in Table 3. The results show that the lateral displacement for mode 2 and mode 3 is larger than that in mode 1.

Table 3. Maximum settlements of surface soil for all modes.

| Loading stages | Mode 1 | Mode 2 | Mode 3 |
|----------------|--------|--------|--------|
| Layer 1        | 9      | 12.3   | 9      |
| Layer 2        | 15.4   | 21     | 15.6   |
| Layer 3        | 21.6   | 29.4   | 22.2   |
| Layer 4        | 27.7   | 37.8   | 28.7   |
| Layer 5 (all layer) | 33.6   | 47     | 35     |
| Layers with live load | 39.82 | 58.54  | 42.10  |
| Toe of embankment | 6.73  | 10.99  | 11.80  |

Maximum settlements (mm)
4.2. Soil Shear Strength and Load Transfer

The shear strength of embankment for the three modes are presented in Table 4. As shown, mode 1 is much closed to mode 2, while the magnitude for mode 3 is larger than that in mode 1. The stress concentration ratio (n) and soil arching ratio (ρ) are used to study the effect of elastic modulus of columns and geogrid layer on embankment behavior. The magnitude of the stress by the column and arching that are depending on the percentage of embankment loads which columns carried to the loads carried by the soil between columns. The stresses concentration ratio and the arching ratio for the three modes are presented in Table 4. The stress concentration ratio and the arching ratio decreases significantly in mode 2 compared with mode 1. This means that the decrease of elastic modulus of deep mixing column is leading to an increase in the load that carried out by the soil between the deep mixing columns. Absence the geogrid layer in mode 3 comparing with mode 1 leads to increasing the stress concentration ratio and arching ratio. This means that the increase in deep mixing column loading and decreasing the load carried by soil between the deep mixing columns. The deflected shape is presented in Fig. 3. As shown in the figure the displacement in the left figures and the settlement in the right figures.

![Deflected shape of the mode 1](image1)

![Deflected shape of the mode 2](image2)

![Deflected shape of the mode 3](image3)

Figure 3. Settlement and displacement of the three modes.

| Mode | Max. column stress (kPa) | Max. soil stress (kPa) | Stress concentration ratio | Arching ratio | Shear strength (kN) |
|------|-------------------------|-----------------------|---------------------------|---------------|-------------------|
| 1    | 860                     | 41.3                  | 20.8                      | 28            | 30                |
4.3. Tension in geogrid layer

The tension force in the geogrid layer is presented in (Table 5). The max tension for mode 2 is larger than that in mode 1. It means that the tension force in the geogrid layer is strongly influenced by the elastic modulus of deep mixing column. Also, the tension force in the geogrid layer is decreased with an increase of the elastic modulus of columns. The decrease in the elastic modulus of the columns leads to an increase in the loads carried out by the soil between the columns. A single layer of the geogrid reinforcement behaves as a tensioned member due to its flexibility.

| Mode  | 1   | 2   |
|-------|-----|-----|
| Shear strength (kN/m²) | 4.645 | 7.15 |

Table 5. Maximum tension force in the geogrid layer.

5. Conclusions

According to the results gained from the present work, several points may be concluded:

- The settlement values are influenced by the elastic modulus of the deep mixing column, but slightly influenced by the geogrid layer.
- The lateral displacement is mostly influenced by the elastic modulus of the deep mixing column and geogrid layer.
- The soil shear resistance is slightly influenced by the elastic modulus of columns, but strongly influenced by the geogrid layer.
- There are decreasing in the elastic modulus of the columns for all modes, that will increase the loads of the embankment that carried out by the soil between the columns. Reversely, the absence of the geogrid layer leads to an increase in the loads of the embankment that carried out by the columns.

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