Finite element analysis of embankments on gypsiferous subgrade soil - stone column strengthened with geogrid

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Abstract: Gypsum and anhydrite rocks are frequently found in numerous countries of the world in extensive deposits, the huge region in middle and west of Iraq is classified as a gypseous soil. Stone columns are a non-time dependent foundation technique used to increase the structural stability and to reduce the structural deformations of soil. In the present study, the finite element method is used as a tool to utilized the effect of using stone columns with geogrid as reinforcing material for treatment gypsiferous subgrade soil under embankment during both construction and consolidation conditions. The results show that decreasing the stone column spacing leads to a considerable decrease in the settlement beneath the embankment, especially below the center line, reduction in the settlement of about 60% and when using geosynthetic material the reduction about 75%. Also, increases the excess pore water pressure immediately after the construction of each lift of the embankment and then falls with and without using geosynthetic material. The vertical stress in the gypsiferous subgrade soil increases at a very small rate especially in the early stages and decreases as stone columns spacing decreases.

Key words: Gypsiferous soil, Stone columns, Embankment, Geogrid.

1. Introduction

Large areas of the earth’s surface area are covered with soils that are subjected to huge reduction in total volume when they become saturated. Such materials are termed collapsing soils; one of the significant collapsible soils is named gypseous soils. In Iraq, gypseous soil with a percentage of gypsum between (10-70%) is covered about 31.7% of the area [1].

Gypseous soils generally can be used for construction under dry and even under short term flow, however it become problematic, collapsible and undergo large settlement under long term flooding with water. Water will cause dissolution and softening of gypseous soils and being highly compressible that which leads to one or a combination of the processes which are collapsibility, consolidation and leaching processes [2,3].

Several problems related to construction on or by gypseous soils such as cracks, tilting, collapse, and leaching the soil will appear due to combination of collapsibility, consolidation and leaching processes. So any kind of structure resting on problematic soils such as gypseous soils, there are many available methods to improve the behaviour of soil [4,5,6].

Ayadat (1990) [7] was used a gap-graded mixture as a host collapsible ground consisting of concrete sand with 78%, Leighton Buzzard sand (less than 90 mm) 10%, and 12% speswhite kaolin clay for treating collapsible soil. Outcomes showed that the using geosynthetics with sand column causes to an increase in the qg of the sand column. Also observed a decrease in the settlement that was in proportion to the geosynthetic material stiffness.
AL-Numani, (2010) [8] carried out an experimental study on the impact of 3 type of additives with gypseous soil so as to enhance the gypsum soil compaction properties. In this study used cement, ceramic and a mix of cement and ceramic as the additives, the outcome show that the best improvement in characteristics of compaction test is accomplished when the sample is treated with adding mix of cement and ceramic, the MDD only increases with the increases in mixing content, while the opposite is true for the OMC, also the results show that the MDD of improvement gypsum soil with ceramic material increases with the increase in ceramic content up to 8% after which the density decreases.

Karim, et. al., (2013) [9] study the effect of adding two additives (kaolinite and bentonite) for improving collapsible gypseous soil in site of Al-Qarma which is located in Al-Anbar Governorate. It was found higher cohesion values and lower frictional strength has been obtained in soil-bentonite mixture samples than that of soil-kaolinite mixture.

Aldaoood et. al., (2013) [not listed in the references] evaluation of the lime stabilized gypseous soil stability behavior under different conditions (erosion, leaching and soaking). The outcome showed that the weight loss increased for samples subjected to the flowing water and further increment in weight losses with flow duration increases. Also, the UCS decreased during the soaking process and a further reduction in strength with increasing soaking duration.

Fattah, et. al., (2014) [10] examined collapse potential of gypseous soil improve by grouting acrylate liquid, study showed that the liquid of acrylate was able to reduce the gypseous soil compressibility by more than 60–70%.

Al-Obaidy (2017) [11] analyzed by methods of geotechnical laboratory work the mechanism of failure and stress-settlement behavior of a footing resting on untreated soil, soil treated with an OSC, and soil treated with an ESC into loess deposits subjected to soaking. The results of the three physical models exhibited the benefit of using an ESC over the OSC and the untreated collapsible soil. Both the qo and the reduction in compressibility increased when using the ESC. This may be related to the saturation degree of the host soil; the higher saturation degree, the greater the improvement achieved.

Fakhraldin and Ali (2017) [12] studying the effect of using geogrid type Netlon CE121as reinforcing CBR material. The results show that increased the CBR value when using of geogrid reinforcement, also large influence on CBR when placed geogrid reinforcement as the first layer under the surface, the reliable depth is 0.15D where D is the diameter of CBR mold.

The objective of the present study utilized the possibility of using crushed stone columns to improve gypsiiferous soil under embankment load. The study was carried out by means of an analytical solution using PLAXIS 2D Professional v8.6 computer program.

2. Computer Program and Constitutive Models

2.1 Description of the Problem

Gypseous soils with variable gypsum content are distributed in different zones but concentrated mainly in the Jazirah region, Pleistocene. In this paper, a trail is made to analyze embankments of 300 m length constructed on the foundation layers are composed of silty clay with 67% gypsum content which is located at Al-Anbar government west of Baghdad reinforced by stone columns. Another reinforcement type that suggested in this paper was placed layer of horizontal geogrid at the interface between soil foundation subgrade and embankment base with addition to use stone column. The water level was to be at 1 m from the ground surface as found in the location of subgrade soil that used in this analysis.

2.2 Finite Element Computer Program

Plaxis (2D, v8.6, 2011) is an application of finite element used for the analysis of deformation and stability in geotechnical engineering projects. It's make a possible comprehensive formulation to analyze both simple and highly complex problems. The construction of the embankment on gypseous soil was simulated by the sequential addition of the four horizontal layers with the period (1, 8, 15, 31, 49 days) between the stages in order to dissipate some pore water pressure that excess. Each layer is simulated as an ensemble of finite isoparametric 15-node quadrilateral elements.
2.3 Soil Parameters

An axisymmetric model was utilized in the analysis using the 15-noded structural solid element with medium refinement; the embankment of sandy soil to be analyzed was shown in Figure 1, Figure 2 and Figure 3. The height of the embankment is 4 m with 1:1.5 side slopes, the ratio of length to diameter is 9 so the stone column diameter is 1 m. Due to symmetry about the center, and only half of cross-section is modelled in the analysis. The bottom of the problem is fixed, while both vertical ends are allowed to move vertically but not horizontally. All the parameters needed in the analysis of this problem found by experimental work and tests were carried out in the "National Center for Construction Laboratories and Research" and shown in Table 1.

Table 1. The properties of foundation and embankment of problem

| Material                      | Model                          | Parameter         | Value       |
|-------------------------------|--------------------------------|-------------------|-------------|
| Embankment (sand)             | Linear-Elastic                 | Modulus of elasticity (E) | 50000 kPa   |
|                               |                                | Poisson’s ratio (ν) | 0.3         |
|                               |                                | Permeability (k)   | 0.5 m/sec   |
|                               |                                | Dry unit weight (γ₉ₐ) | 15 kN/m³    |
|                               |                                | Saturated unit weight (γₙₙₐ) | 18 kN/m³ |
| Gypseous Subgrade Soil        | Elastic–Plastic (Mohr-Coulomb) | Modulus of elasticity (E) | 20000 kPa   |
|                               |                                | Poisson’s ratio (ν) | 0.35        |
|                               |                                | Permeability (k)   | 8.6×10⁻⁶ m/sec |
|                               |                                | Dry unit weight (γ₉ₐ) | 16.7 kN/m³  |
|                               |                                | Saturated unit weight (γₙₙₐ) | 20.15 kN/m³ |
|                               |                                | Angle of friction (φ) | 34°         |
|                               |                                | Cohesion (c)       | 20 kPa      |
| Stone column (crushed stone)  | Elastic–Plastic (Mohr-Coulomb) | Modulus of elasticity (E) | 100000 kPa  |
|                               |                                | Poisson’s ratio (ν) | 0.30        |
|                               |                                | Permeability (k)   | 1×10⁻¹ m/sec |
|                               |                                | Dry unit weight (γ₉ₐ) | 16 kN/m³    |
|                               |                                | Saturated unit weight (γₙₙₐ) | 21 kN/m³   |
|                               |                                | Angle of friction (φ) | 41°         |
|                               |                                | Cohesion (c)       | 0.2 kPa     |
| Geogrid (type Tensar SS2)     | Elastic axial stiffens (EA)    | Elastic axial stiffens (EA) | 539 kN/m   |

Figure 1. The trail embankment with stone columns
3. Results and Discussion

3.1 Effect of Stone Column Spacing

Figure (4) shows the result of finite element analysis of settlement at point (A) on the center line for the untreated and treated foundation by stone columns (SC) with time during embankment construction. It can be noticed from this figure the settlement decreases when using the stone column with spacing (1.5d, 2d and 2.5d) by decreasing rate about (60, 54 and 46%), greater decrease in settlement was observed when using stone columns with spacing (1.5d).

The excess pore water pressure changes with time at point B (2 m) to the right of center line and (4 m) below the water table was shown in Figure(5). The pore water pressure starts to dissipate immediately after construction of each fill lift, then its value increases when the next fill is constructed and dissipation continues. This may be due to the drains function of the stone columns.
Figure 4. Settlement-time relationship at point A

The vertical displacement along the base of embankment sections (a-a) during the construction of embankment for untreated soil and soil with stone columns are presented in Figure (6). The maximum settlement occurs along the centerline. The vertical displacement reduced when using a stone column at different spacing. This behavior is due to the zone of higher effective horizontal stresses due to bulging of stone column, and then the vertical displacement decreases slightly towards the toe of the embankment and decreases significantly as the distance away from the toe become large.

The stress settlement characteristics for the untreated subgrade soil, treated subgrade soil with the stone column at different spacing at point (C) are shown in Figure (7). It can be seen that the vertical stress increases at a high rate with increasing spacing between stone columns.

Figure 6. Settlement along the base of embankment

Figure 7. Stress-settlement relationship at point C

Figure (7) shows the stress time relations, the results show during the embankment construction stages the vertical stress in the subgrade soil increases at a very small rate especially in the early stages, and as stone columns spacing decreases, the vertical stress in the treated subgrade soil decreases and after 23 days from construction embankment the behavior of stress remains constant.
3.2 Effect of geogrid

The settlement time response at point (A) for different spacing between stone columns with geogrid material was shown in Figure (9). It can be noticed from the figure high decreased in settlement observed when using reinforcement material around the stone column and under the base of the embankment. The high rate decreased of settlement can be observed when using an encased stone column with horizontal reinforcement at spacing (1.5d).

The excess pore water pressure changes with time at point B (2 m) to the right of center line and (4 m) below the water table was demonstrated in Figure (10). It can be seen from this figure using geogrid material increased dissipation of pore water pressure and approached very little value when using geogrid material with the stone column at spacing 1.5d, while the closed value shown for 2d and 2.5d.

Figure (11) shows the relationship between vertical displacement along the base of embankment sections (a-a) during construction of embankment for different spacing of stone columns with geogrid. The maximum settlement along the centerline was reduced when using stone columns with geogrid materials. This may be attributed to the geogrid tensile strength in addition to stone columns, which causes a reduced in the stress transfer to the soil that causes reduction in the settlement. The relation between vertical stress and settlement under based of embankment reinforced with stone column at different spacing and geogrid at point (C) are shown in Figure (12). It can be observed that the vertical stress decreases at a small rate with decreasing spacing between stone columns and the value became closer for spacing 1.5d and 2d.
Figure 1. Settlement along the base of embankment

Figure 12. Stress-settlement relationship at point C

Figure (13) shows the stress time relation, the results show reinforcing the embankment by stone column and geogrid reduced the vertical stress in the subgrade soil at high rate as stone columns spacing decreases, the vertical stress in the treated subgrade at S=1.5d shows little change in stress during embankment construction and then became notice as spacing increase. Table (2) shows the results of analysis for both cases.

Table 2. Analysis results for both cases

| Spacing | Model with stone column | Model with stone column and geogrid |
|---------|-------------------------|-------------------------------------|
|         | Settlement (mm) | Excess pore water pressure (kPa) at end of consolidation | Vertical stress (kPa) | Settlement (mm) | Excess pore water pressure (kPa) at end of consolidation | Vertical stress (kPa) |
| Untreated soil | 396.98 | 0.3351 | 513.354 | 396.98 | 0.3351 | 513.354 |
| S=1.5d | 154.91 | 0.00159 | 95.114 | 100.83 | 0.00082 | 65.664 |
| S=2d | 181.17 | 0.01245 | 167.583 | 161.17 | 0.00605 | 140.599 |
| S=2.5d | 216.10 | 0.08652 | 216.401 | 186.10 | 0.05535 | 184.510 |

4. Conclusion

From the parametric study carried out by axisymmetric model finite elements on the problem of embankment constructed on gypsiferous soil reinforced with stone columns and geogrid, the following conclusions can be drawn:

1. Using stone columns to improve subgrade gypsiferous soil leads to significant effect in the behavior of the gypsiferous soil, both in undrained conditions and during consolidation stages with and without geogrid materials.
2. Decreasing the stone column’s spacing leads to a considerable decrease in the settlement beneath the embankment, especially below the center line. When the spacing of the stone
column (1.5d), reduction in the settlement of about 60% was obtained and when using geogrid material the reduction about 75%.

3. Increases the excess pore water pressure immediately after construction of each lift of the embankment and then falls. The excess pore water pressure dissipates suddenly when using stone columns, the rate of decreased about 79% of untreated soil, this is due to stone columns drain function.

4. The dissipation of excess pore water pressure increase at high rate about 95% as using geogrid material this is due to these work as filter material that prevent blocked the voids between stone columns particles.

5. The maximum vertical settlement below the centerline of the embankment decreases slightly as the distance away from the toe of the embankment is increases and upward movement of the surface far from the toe is not observed for both cases with and without geogrid material.

6. The vertical stress in the gypsiferous subgrade soil increases at a very small rate especially in the early stages, and decreases as stone columns spacing decreases. When using geogrid material, the vertical stress decreases at a small rate with decreasing spacing between stone columns and the value became closer for spacing 1.5d and 2d.

5. Data availability
The writers affirm that the information supporting the discoveries of this investigation are accessible inside the article or it's strengthening materials.

6. References
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