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# PARAMETRIC STUDY OF GEOSYNTHETIC ENCASED STONE COLUMNS IN COLLAPSIBLE SOILS BENEATH AN EMBANKMENT DAM

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## *ABSTRACT*

*This paper examines the substantial parameters that influence the performance of geosynthetic encased stone columns (GESC) beneath an embankment dam. It is an extension of the previous research work of [1] (which examines the basic assumptions, procedures and results of the numerical analysis in simulating the behavior of GESC for collapsible soils to support an embankment dam).The consolidation end time, excess pore water versus time and settlement versus time; at different points were evaluated under consolidation analysis using a finite element (FE) software PLAXIS 3D. The results have shown that increasing the column diameter & height and decreasing the spacing between the column; has a considerable impact on dissipating pore water pressure and decrease the settlement. The GESC model with a diameter of 1.2m speeds up the consolidation time in comparison to model with 0.8m from 724 days to 574 days. It also decreases the settlement from 313mm to 223mm. Reducing the spacing of the GESC from 3.0m to 2.0m reduces the consolidation end time from 734 days to 576 days. It also decreases the settlement from 231mm to 282mm. The GESC model with a height 12.5m speeds up the consolidation end time in comparison to model with 7.5m from 751 days to 604 days. It also decreases the settlement from 292mm to 230mm.*

***KEYWORDS***: *Finite Element Method, Geosynthetic Encased Stone Column, Collapsible Soil, Consolidation Analysis, PLAXIS 3D*

## 1. INTRODUCTION

Suitable construction area is not always available; thus, a geotechnical engineers desires to alter the ground based on the technical necessities of each project.

If proper ground improvement is not carried out, foundations on collapsible soils can motive immoderate settlement and initiates undrained failure of the infrastructure [2]. Therefore, to prevent these unacceptable excessive and differential settlement, appropriate ground improvement techniques must be applied to the existing soil and increase the bearing capacity of foundation before construction.

Among the wide range of ground improvement techniques stone column is one of the new, and becoming more popular due to its simple construction and economic consideration.

Stone columns have been proved an effective ground improvement technique. However, stone columns are failed in strengthening a collapsible soil (because when a vertical load is applied on the top of the column, it bulges outward to failure) [3]. Further development in the stone column like encasing it with geogrid will be expected to overcome this problem.

The research conducted by [1] have been proved that geosynthetic encased stone columns are effective ground improvement technique for collapsible soils. Thus, this paper is an extension of the previous study which is conducted by [1]. The main impacts of varying the main influential parameters, such as diameter, height and spacing of the stone column will be assessed.

## 2. LITERATURE REVIEW

### 2.1 Related Laboratory and Field Studies

Different scholars conducted laboratory studies the performance of GESC in stabilizing different soil types. Among those scholars [4], [5], [6] and [7] have studied on collapsible soil, kaolin clay, soft clay and clay soil types respectively. Full scale field tests on stone columns also conducted by [8] and [10].

### 2.2 Related Numerical Studies

The research conducted by [10] studied the behavior of ordinary and encased stone columns by FEM analysis. [11]had also examined the influence of various parameters on the performance of geosynthetic encased stone columns through 3D numerical modeling. A numerical study was undertaken by [12]to examine the reinforcing role of stone columns in soft clay.

Parametric study on stone columns based on experimental and FEM analysis was also carried out by [13], [14] and [15].

### 2.3Particular Features of this Study

Under this paper, the analysis of FEM conception was contended with PLAXIS 3D software and different points were imposed to assess the amount of excess pore water pressure. The study adjoins the other uses of GESC with its findings. It argues that GESCs are not only act as reinforcing material for increasing the overall strength and stiffness of soft soil, but it also promotes consolidation through effective drainage. This is because the materials which are used in the stone column have high permeability in comparison to the host soil.

## 3. Material, Model Parameters and Model Validation

The properties of the soil were taken from the previous work of [1]. The properties of the stone column, embankment fill and geosynthetic encasement were adopted from the study of [9] (as it is taken in the work of [1]). The geosynthetic encasement was assumed to be isotropic elastic material with tensile stiffness $J_{enc}$=1750kN/m. These parameters are revised in the following table.

Table 3.1 Parameters for soil strata, embankment fill and stone column.

| Material | Embankment | Layer 1 (0-4.5m) | Layer 2 (4.5-10.5m) | Layer 3 (10.5-13.5m) | Layer 4 (13.5-18.0m) | Stone Column |
|---|---|---|---|---|---|---|
| Model Type | Mohr-Coulomb (drained) | Mohr-Coulomb (undrained) | Mohr-Coulomb(undrained) | Mohr-Coulomb (undrained) | Mohr-Coulomb (undrained) | Mohr-Coulomb (drained) |
| $\gamma_{unSat}$(kN/m$^2$) | 24.0 | 12.14 | 13.12 | 12.98 | 12.21 | 18 |
| $\gamma_{Sat}$(kN/m$^2$) | 28.0 | 17.24 | 17.74 | 17.70 | 17.27 | 20 |
| E'(kPa) | 50000 | 3700 | 6000 | 6900 | 7575 | 80000 |
| c'(kPa) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| ϕ'($^0$) | 38 | 32.54 | 38.28 | 43.10 | 43.15 | 38 |
| υ'(-) | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| ψ($^0$) | 8 | 2.54 | 8.28 | 13.10 | 13.15 | 8 |

To validate the FEM approach PLAXIS 3D (three-dimensional FEM software), a full-scale load test reported by [9] was used. The amount of excess pore water pressures was evaluated at the location where the piezometer installed (at depths of z = 3m, 6m, and 8m).

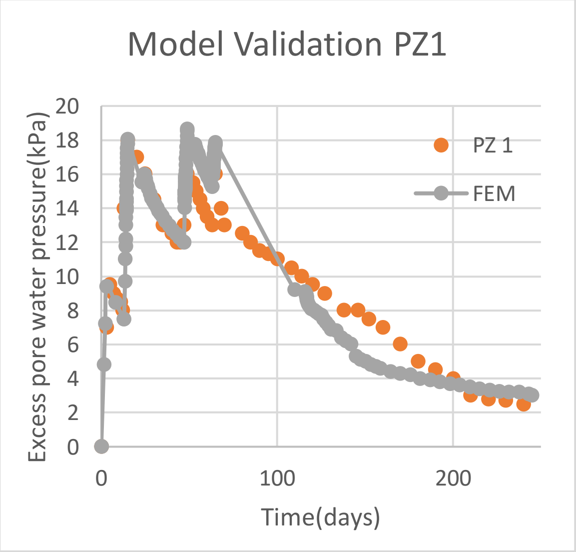

Figure 3.1Measured and FEM computed excess pore water pressure at 3m depth.

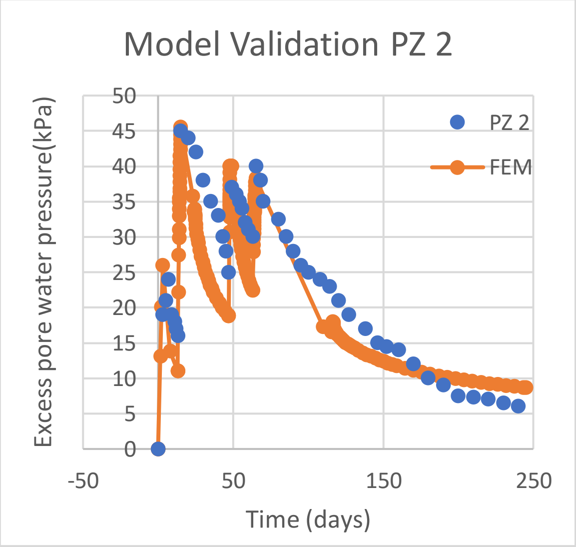

Figure 3.2Measured and FEM computed excess pore water pressure at 6m depth.

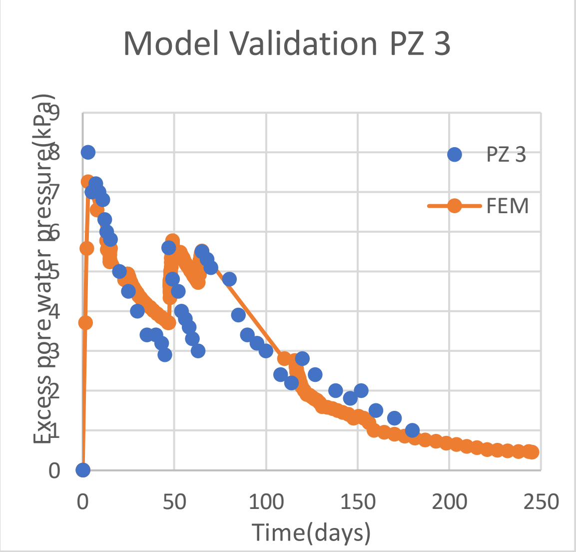

Figure3.3 Measured and FEM computed excess porewater pressure at 8m depth.

As it can be seen from that 3D model numerical analysis, it can fully simulate the measured excess pore pressure. The model reasonably predicted the expected maximum excess pore pressure during construction phase and the dissipation of excess pore pressure during consolidation period.

The numerical procedure for the construction of the embankment fill is also as its discussed in [1]. The position of the points of locations for FEM analysis is shown below.

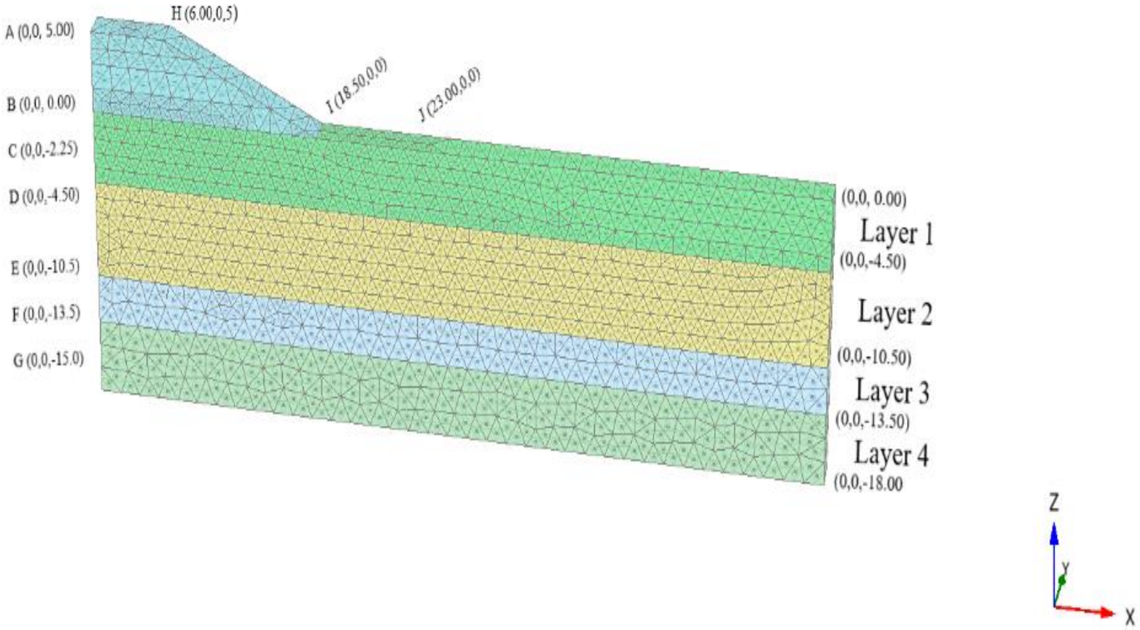

Figure 3.4 Mesh Connectivity and Points of location for FEM analysis.

## 4. DISCUSSION

Three different categories with nine models, by varying one parameter while keeping others constant, have been considered to analyse the effect of each parameters as listed below.

A. **Model D**(varying the geosynthetic encased stone column diameters)

- MD1: 9 GESC at 2.5m spacing with 10m height and 0.8m diameter.
- MD2: 9 GESC at 2.5m spacing with 10m height and 1.0m diameter.
- MD3: 9 GESC at 2.5m spacing with 10m height and 1.2m diameter.

B. **Model H**(varying the geosynthetic stone column heights)

- MH1: 9 GESC at 2.5m spacing with 1.0m diameter and 7.5m height.
- MH2: 9 GESC at 2.5m spacing with 1.0m diameter and 10m height.
- MH3: 9 GESC at 2.5m spacing with 1.0m diameter and 12.5m height.

C. **Model S**(varying the geosynthetic stone column spacing)

- MS1: 9 GESC with 1.0m diameter and 10m height at 2.0 spacing.
- MS2: 9 GESC with 1.0m diameter and 10m height at 2.5 spacing.
- MS3: 9 GESC with 1.0m diameter and 10m height at 3.0 spacing.

The following table summarizes these categories.

Table 4.1 Different models of stone column for finite element analysis.

| Model Type | Model Categories | Diameter of SC (m) | Height of SC (m) | Spacing (m) | Number of SC |
|---|---|---|---|---|---|
| D | MD1 | 0.8 | 10 | 2.5 | 9 |
| | MD2 | 1.0 | | | |
| | MD3 | 1.2 | | | |
| H | MH1 | 1.0 | 7.5 | 2.5 | 9 |
| | MH2 | | 10 | | |
| | MH3 | | 12.5 | | |
| S | MS1 | 1.0 | 10 | 2.0 | 9 |
| | MS2 | | | 2.5 | |
| | MS3 | | | 3.0 | |

### 4.1 Consolidation End Time Analyses

The results of consolidation end time for different models is illustrated below.

#### A. Model D

GESC with different diameters (0.8m, 1.0m and 1.2m) were assumed. Figure 4.1 ascertain, the change of the column has an influence on consolidation end time. The model with a diameter of 1.2m speeds up the consolidation time in comparison to the model with diameter 0.8m from 724 days to 524days.

### B. Model H

Figure 4.2 shows the consolidation end time of different height models (7.5m, 10.0m and 12.5m).The GESC with height 12.5m speeds up the consolidation end time in comparison to the model with height 7.5m from 751 days to 604 days.

### C. Model S

GESC with 2.0m, 2.5m and 3.0m were modelled as shown in Figure 4.3. Hence, reducing the spacing of the GESC from 3.0m to 2.0m has a significant impact on reducing the consolidation end time from 734 days to 576 days.

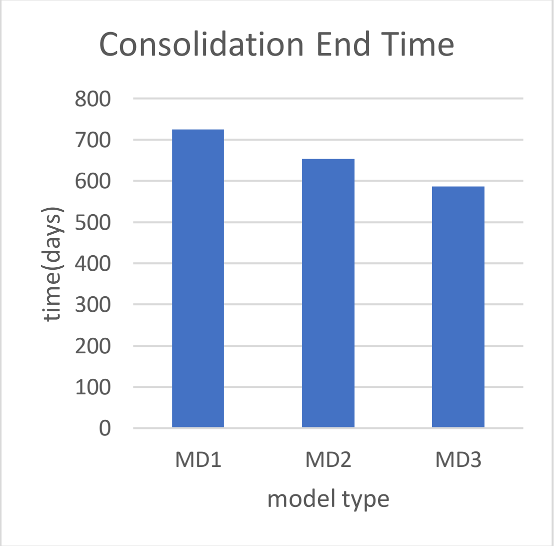

Figure 4.1 Consolidation end time of Model D.

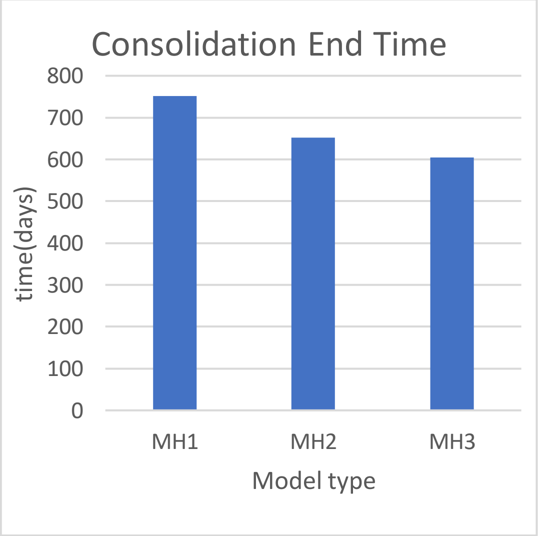

Figure 4.2 Consolidation end time of Model H.

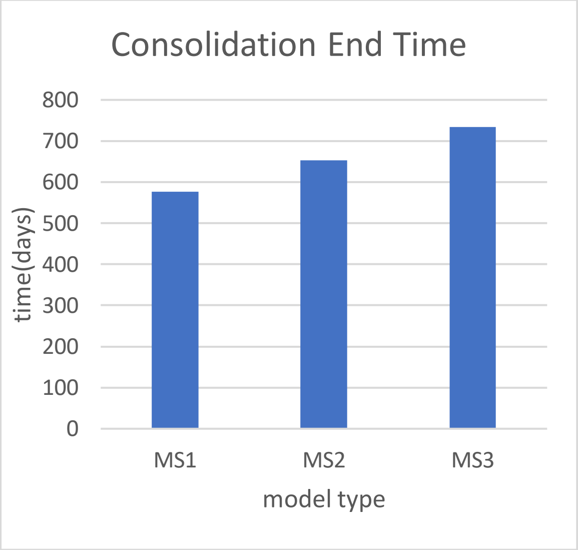

Figure 4.3 Consolidation end time of Model S.

## 4.2Analysis of Excess Pore Water Pressure

The amount of excess pore water pressure was evaluated at four points (points C, D, E And F) for each model. These points are indicated on chapter 3, Figure 3.1.It can be considered that the extent of excess pore pressure reaches maximum value after completion of every step of the construction of the embankment. Moreover, it decreased gradually with time until it reaches consolidation end time.

The most remarkable quit end result to emerge from information from Point C to Point F is that, in comparison to the ground level there exist a higher amount of excess pore water pressure at lower levels. It can beregarded from Point C that, there is no appreciable amount of change in excess pore waterpressure, and as the depth increases, these differences also increase. Thus, in deeper layers, the height of stone pillars plays an important role in reducing excess porewater pressure.

### A. Model D

GESC with three different diameters (0.8m, 1.0m and 1.2m) were modelled to evaluate the effect of column diameter excess pore water pressure dissipation at different points (shown in figures 4.4 to 4.7). Thus, among these three models the column that has a larger diameter speeds up the consolidation time.

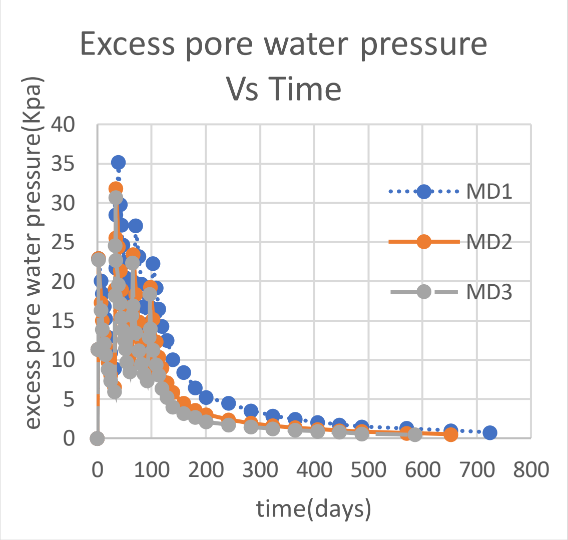

Figure 4.4 Model D: Excess pore water pressure versus Time at point C (0,0,-2.25)

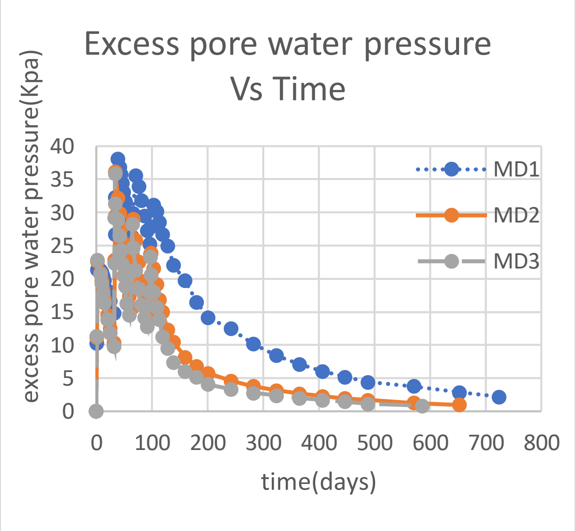

Figure 4.5 Model D: Excess pore water pressure versus Time at point D (0,0, -4.50)

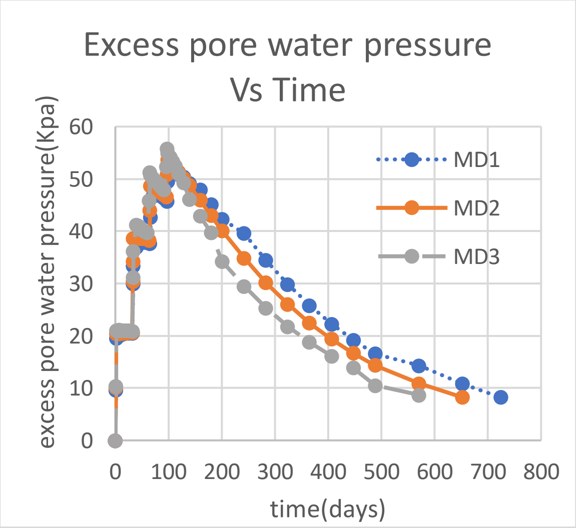

Figure 4.6 Model D: Excess pore water pressure versus Time at point E (0,0,-10.50)

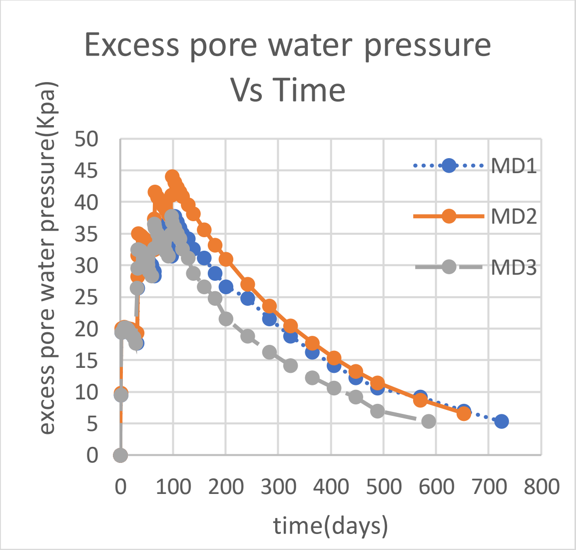

Figure 4.7 Model D: Excess pore water pressure versus Time at point F (0,0,-13.5)

### B. Model H

Stone columns with varying heights have been analyzed to assess the excess pore water pressure at different points. As shown in the following figures Model MH3 has the best performance in dissipating the excess pore pressure and accelerating the consolidation time because of long height of the column.

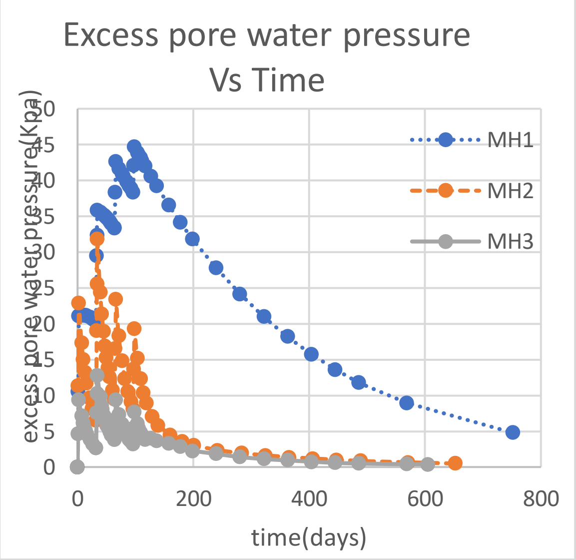

Figure 4.8 Model H: Excess pore water pressure versus Time at point C (0,0,-2.25)

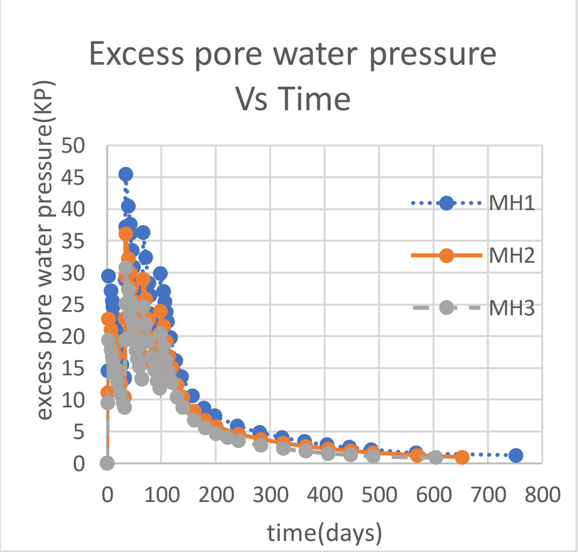

Figure 4.9 Model H: Excess pore water pressure versus Time at point D (0,0,-4.50).

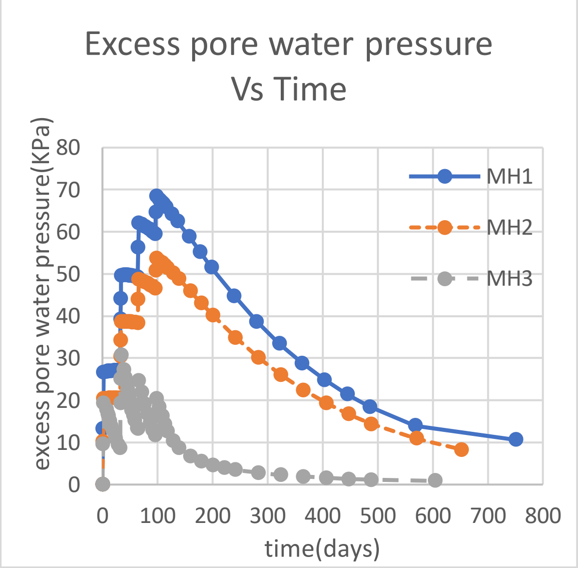

Figure 4.10 Model H: Excess pore water pressure versus Time at point E (0,0,-10.5)

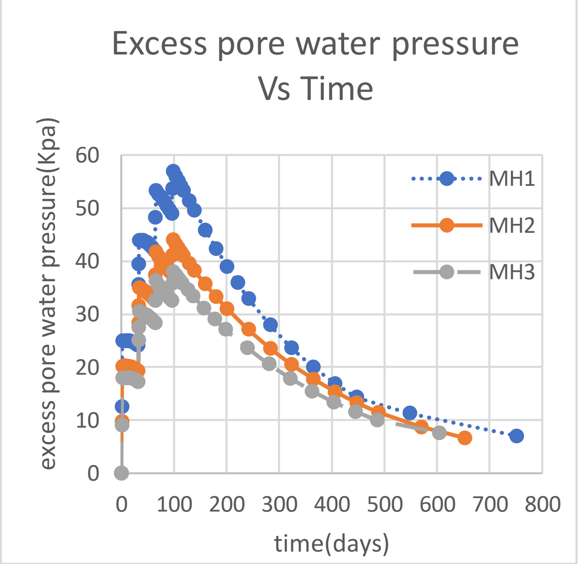

Figure 4.11 Model H: Excess pore water pressure versus Time at point F (0,0,-13.5).

### C. Model S

Excess pore water dissipation was also analyzed by varying the spacing of the geosynthetic encased stone column. Thus, as it is illustrated in the following figures, stone column with smaller spacing has substantial impact influence in dissipating the excess pore water pressure. Hence, reducing the spacing of the columns decreases the amount of consolidation end time considerably.

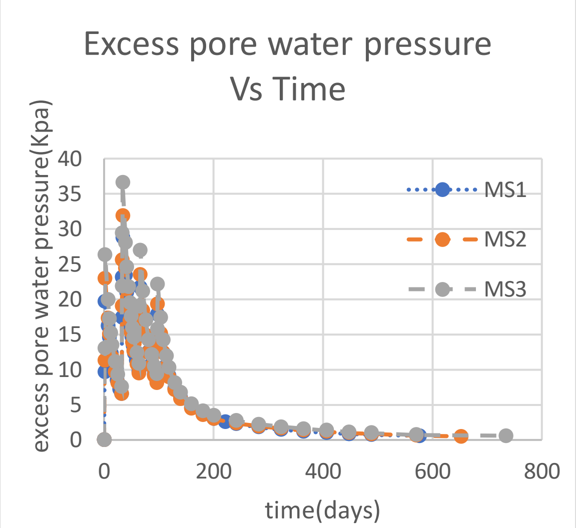

Figure 4.12 Model S: Excess pore water pressure versus Time at point C (0,0,-2.25)

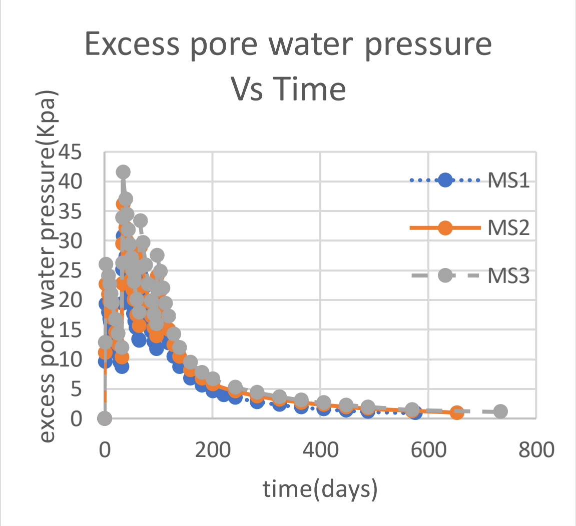

Figure 4.13 Model S: Excess pore water pressure versus Time at point D (0,0,-4.50)

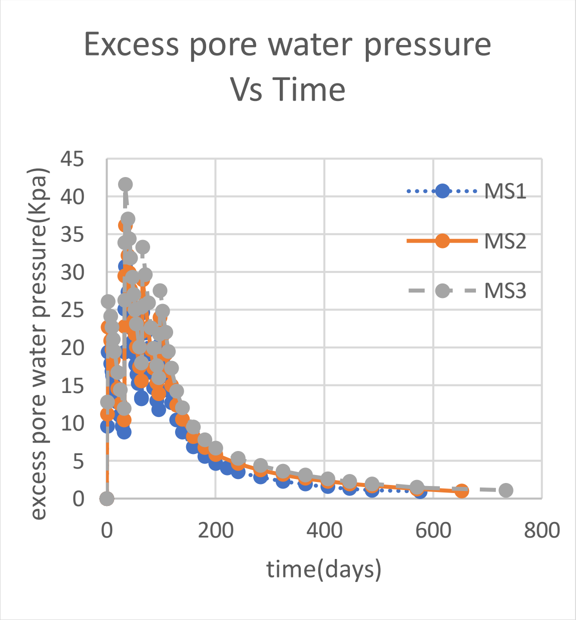

Figure 4.14 Model S: Excess pore water pressure versus Time at point E (0,0,-10.50)

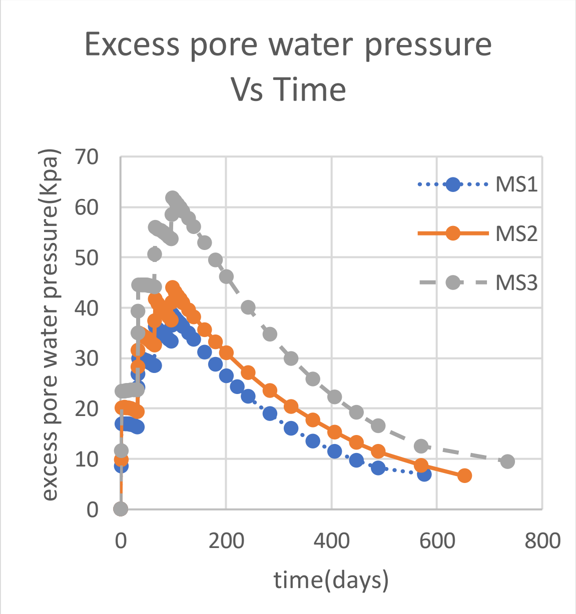

Figure 4.15 Model S: Excess pore water pressure versus Time at point F (0,0,-13.5)

### 4.3 Settlement Analysis with respect to Time

Settlement versus time relationships at three points (A, H and I) for each three conditions of the model were analyzed at the consolidation end time.Among the selected points the maximum settlement come about at a Point A, the middle of the embankment,while heaving(swelling) was observed at Point I.

#### A. Model D

As shown in figures 4.16 to 4.18(Models of GESC by varying diameters), the model with widest diameter (MD3) has the best performance in decreasing the settlement. Thus, increasing the column diameter will decrease the settlement and enhances the characteristics of the soil.

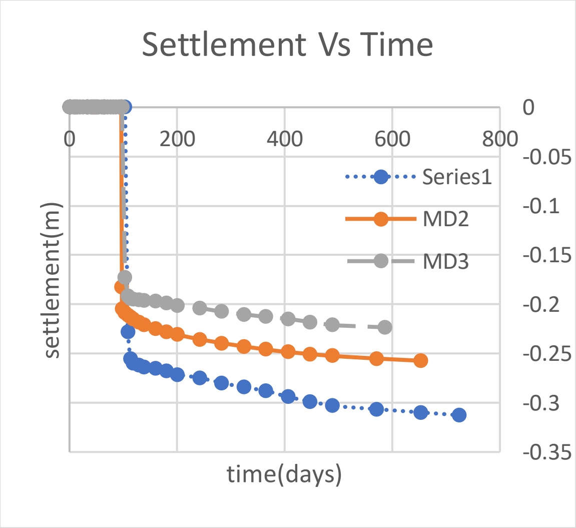

Figure 4.16 Model D: Settlement versus Time at point A (0,0,5)

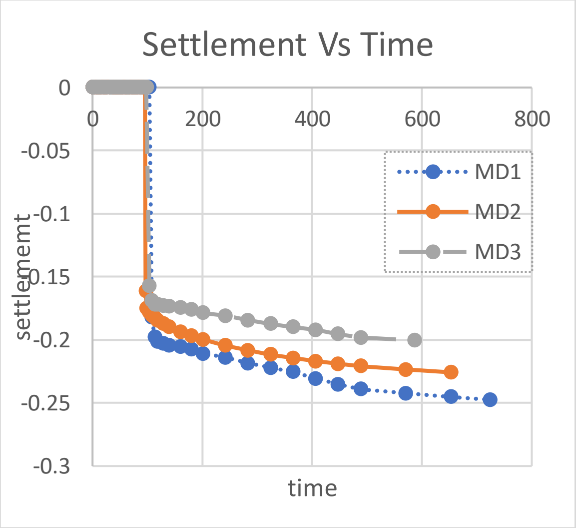

Figure 4.17 Model D: Settlement versus Time at point H (6,0,5)

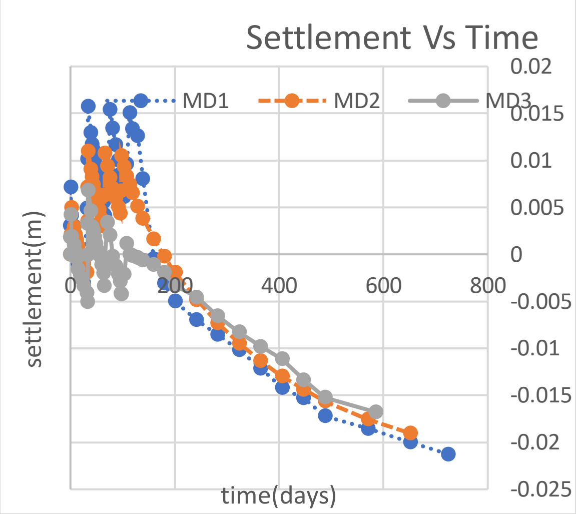

Figure 4.18 Model D: Settlement versus Time at point I (18.5,0,0)

## B. Model H

Figures 4.19 to 4.21 shows the results of settlement versus time for different GESC groups. Thus, these figures we can see that the settlement is largest for the shortest column (MH1), reducing with increasing the column height.

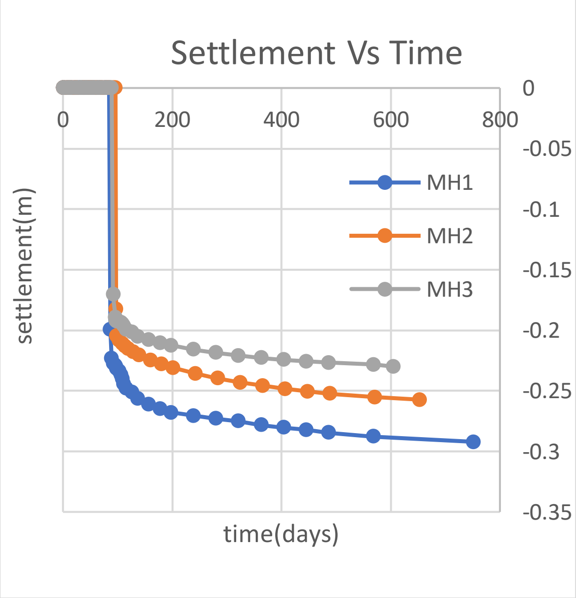

Figure 4.19 Model H: Settlement versus Time at point A (0,0,5)

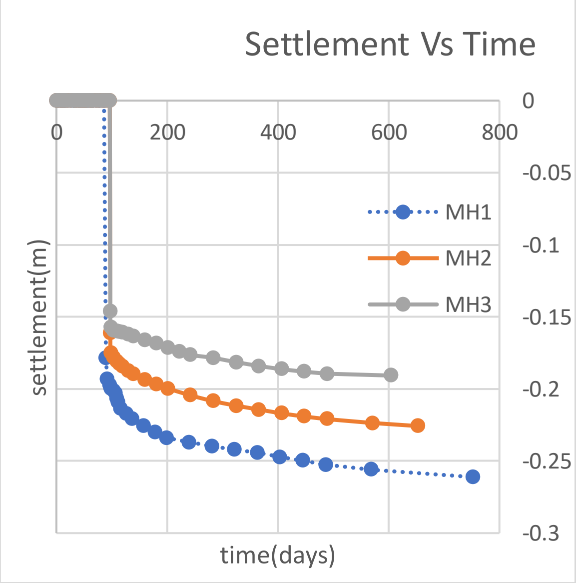

Figure 4.20 Model H: Settlement versus Time at point H (6,0,5)

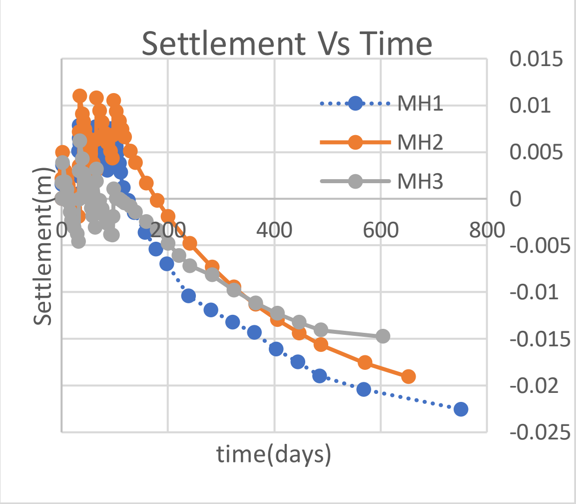

Figure 4.21 Model H: Settlement versus Time at point I (18.5,0,0)

### C. Model S

As can be observed from Figures 4.22 to 4.24, among the columns with different spacing, MS1 has the best performance in decreasing the settlement. Thus, there is a considerable decreasing in settlement by decreasing the spacing of the columns.

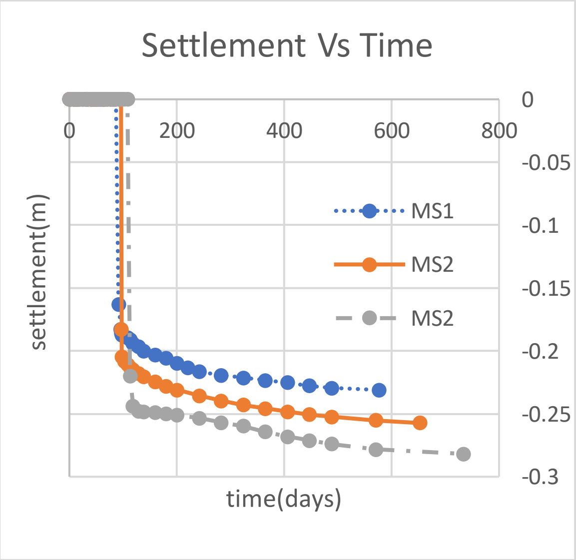

Figure 4.22 Model S: Settlement versus Time at point A (0,0,5)

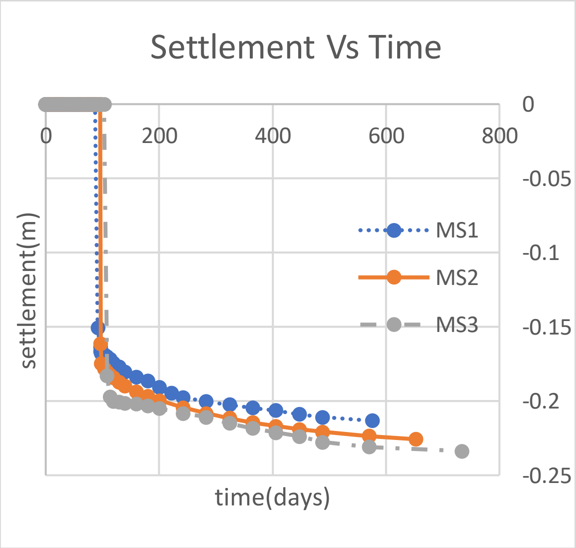

Figure 4.23 Model S: Settlement versus Time at point H (6,0,5)

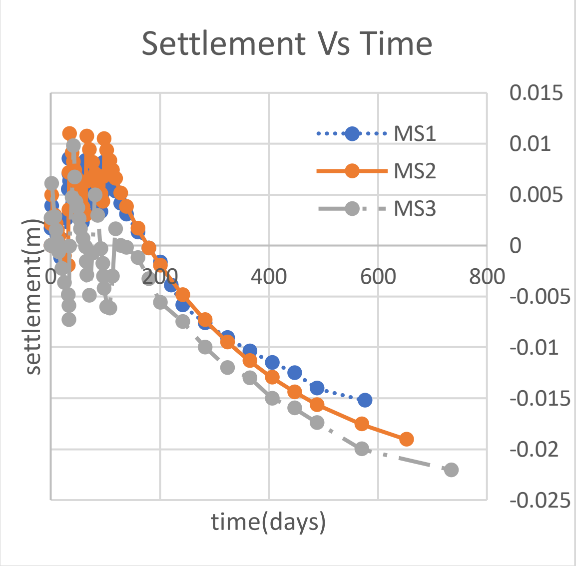

Figure 5.24 Model S: Settlement versus Time at point I (18.5,0,0)

## 5. Conclusion and Recommendation

This paper has examined the main influential factors on the performance of grouped stone columns that are used to stabilize a collapsible soil under an embankment dam. The diameter, height and spacing parameters are considered and the following conclusions are drawn.

- Keeping other parameters constant, and changing the diameter of the GESC has an influence in settlement and consolidation end time. Thus, increasing the diameter of the columns from 0.8m to 1.2m speeds up the consolidation end time by 20.72% and decreases settlement by 42.25%.
- Keeping other parameters constant, and changing the height of GESC from 7.5m to 12.5m speeds up the consolidation end time by 19.57% and decreases the settlement by 21.23%. Thus, it can be concluded that long columns can dissipate the excess pore water pressure and reduce settlement & consolidation end time.

- Keeping other parameters constant, and reducing the spacing between the column has also an important role in decreasing the consolidation end time and settlement. Reducing the spacing between the column from 3m to 2m speeds up the consolidation end time by 21.53% and decreases settlement by 18.09%.

The study also recommends to conduct further parametric study on the effect of variation of geosynthetic stiffness, stone column material, column length to diameter ratio and area replacement ratio; in order to attain the optimum design of GESC.

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**List of Symbols**

| | |
|---|---|
| E | Modulus elasticity |
| $\upsilon$ | Poisson’s ratio |
| $\gamma_{Sat}$ | Saturated unit weight |
| $\gamma_{Unsat}$ | Unsaturated unit weight |
| $\phi$ | Internal friction angle |
| $\psi$ | Dilatancy angle |
| c | Cohesion |
| J | Tensile stiffness of geotextile |
| GESC | Geosynthetic Encased Stone Column |
| FE | Finite Element |
| FEM | Finite Element Method |