BEHAVIOURAL STUDY OF ORDINARY AND ENCASED FLY ASH COLUMNS

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ABSTRACT

Constructing on soft ground is now a necessity due to the world's growing population and limited land availability. Several different methods have been utilized to enhance the bearing capacity and control settlements in the ground. This work focuses on the behavior of stone columns with the emphasis on the substitution of the conventional filler materials with fly ash. The analysis carried out through PLAXIS 3D also evaluates the performance of geosynthetic encasement on the behavior of the column. The findings indicate that fly ash fill reduces settlement to a very great extent, and encasement increases it even more when compared to the non-encased columns. Validation of the numerical model against experimental data demonstrated the accuracy of the numerical model.

Keywords: Stone Column, Encasement, Geogrid, Fly Ash, Finite Element Analysis, PLAXIS 3D

1. Introduction

The increase of urbanization, coupled with a scarcity of land, has led to the development of soft soils. Soil improvement techniques such as dewatering, granular column installation, or pre-loading, are applied to change such soils into constructible land. Out of the various, stone column method is most popular as it enhances the bearing capacity of soil, aids in pore pressure dissipation through increased drainage and decreases consolidation time [1], [2]. Heretofore, stone aggregates (20-75 mm) were employed; however, newer researches have suggested the usage of sustainable filler fly ash, a by-product of coal combustion [2], [3]. Moreover, the columns can be further laterally confined in extremely soft soils by surrounding them with geosynthetics, such as geogrids [1], [4].

2. Literature Review

Nonetheless, literature contains some studies about the performance of stone columns and the relevant effect of possible geosynthetic encasement. Jayapal and Karpurapu [5] performed a 3D numerical validation of embankments supported by ordinary and encased columns, and noted that closer spacing and stiffer encasements improved the factor of safety. The load–

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settlement behavior of stone column backfill with fly ash was studied by Anand and Sarkar [6] who found it effectively improved it. Geosynthetic encasement is also reported to be effective in transferring the stress efficiently and enhance lateral confinement [7]–[9]. Previous research has also focused on the optimal encasement length, as well as the role of axial stiffness in mitigation of settlement [10], [11].

3. Methodology

3.1. **Model Setup**

A three-dimensional numerical model was created in PLAXIS 3D that involves a system of layered soil 40 m in length and 6 m in width, and double by stone columns installed 2 m from center to center in a 6 × 3 pattern. A strip of 2 m width was extracted out of the overall area that was divided evenly, thus only half of the strip was used for analysis.

3.2. **Soil and Material Properties**

The soil parameters were modeled using the Soft Soil and Mohr–Coulomb models. Both coarse aggregates and fly ash were used to simulate the stone columns by attachment of material properties. The geosynthetic encasement used geogrid elements with an axial stiffness of 1750 kN/m.

3.3. **Boundary Conditions and Loading**

The model was restrained at the base in all the directions, whereas the lateral boundaries permitted the vertical degree of freedom but prevented the horizontal degree of freedom. The embankment was 5.3 m tall, 6 m wide, and 18 m long.

3.4. **Parametric Studies and Validation**

Parametric studies examined how::

- Substituting stone aggregates with fly ash,
- Using simple stone columns as opposed to geosynthetic encasement
- Different encasement length (l/d ratio),
- Modifying the axial rigidity of the encasement material.

The PLAXIS 3D model settlement and stress results were validated with the experimental data in [1] and [5].

4. Validation Study

The settlement and total stress characteristics from the journal and numerical analysis on PLAXIS 3D are compared using their respective graphs and tables for the same model.

4.1. Vertical Stress Comparison

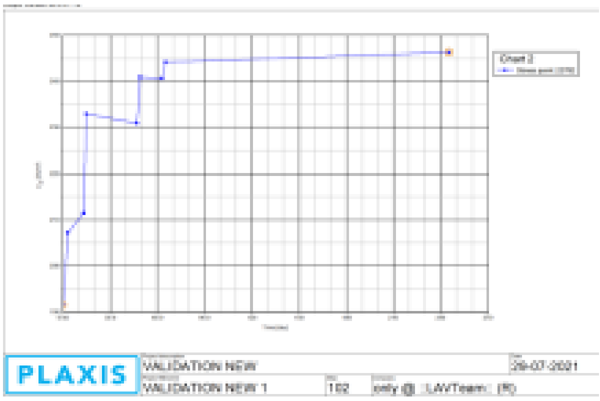

Figure 1: Vertical stresses on encased granular column from PLAXIS 3D

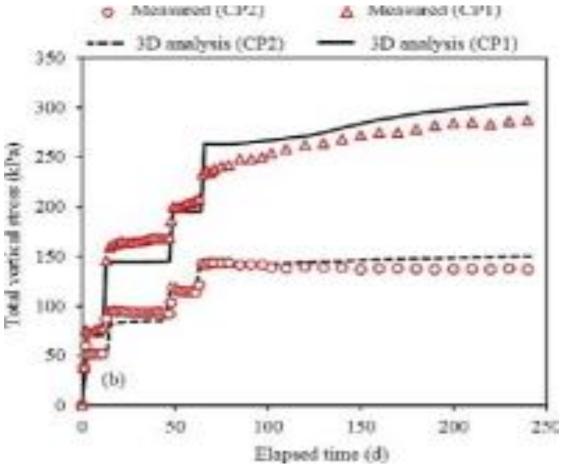

Figure 2: Vertical stresses on encased granular column in main journal

Figure 1 displays the vertical stresses on an encased granular column as calculated by PLAXIS 3D, whereas Figure 2 presents related data from the reference study. The strong correlation between the two validates the accuracy of the numerical model.

4.2. Settlement Comparison

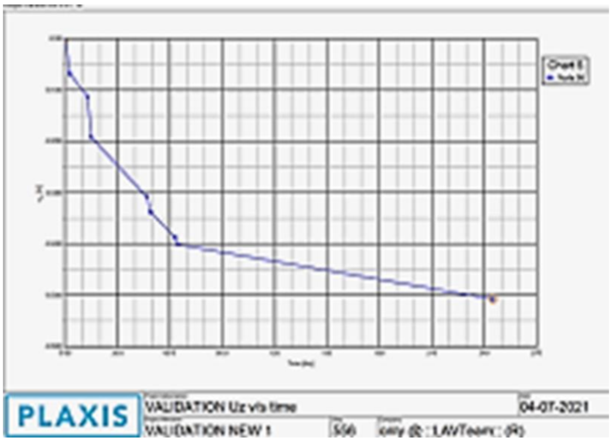

Figure 3: Settlement on encased granular column from PLAXIS 3D

Figure 3 gives the settlement profiles from PLAXIS 3D and reference study.

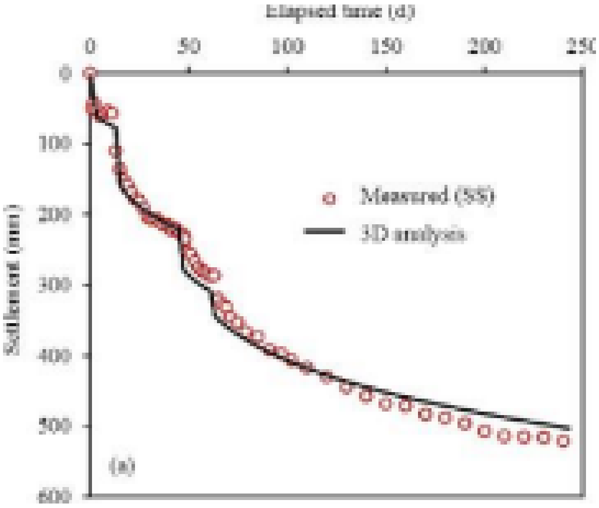

Figure 4: Vertical stresses on encased granular column in main journal

Table 1:Comparison of Settlement and Stress from Journal and PLAXIS 3D

Parameters	Value from journal	Value from PLAXIS 3D	Variation (%)
Settlement (mm)	510	502	1.56
Total stress(kN/m^2)	260	246	5.3

Table 1 presents the comparative results, indicating a maximum error variation of 5.3%, which is considered acceptable.

5. Numerical Investigation Using PLAXIS 3D

The study considers 7 layers of soil, extending 40 m in length and 6 m in width, which are stabilized with stone columns measuring 6 x 3 and spaced 2 m apart. For analysis, a 2 m wide strip of this layered soil is selected. Due to symmetry, only half of the strip is modeled. The embankment has a height of 5.3 m, a width of 6 m, and a breadth of 18 m. The stone columns are modeled to be 11 m long, with a diameter of 0.8 m and a center-to-center spacing of 2 m. Geogrids are used for encasement around the stone columns. In this study, the Soft Soil Model and Mohr-Coulomb model are applied to the soil layers, the embankment, and the stone columns. The geosynthetic encasements are represented as geogrid elements, with an axial stiffness of 1750 kN/m. The boundary conditions are set so that the bottom is fixed in all directions, while the vertical end sides are restricted in motion only in the x and y directions, allowing free movement in the vertical direction.

5.1. Settlement Comparison of Stone Columns

Stone columns were examined under four different conditions: standard stone columns, encased stone columns, standard fly ash columns, and encased fly ash columns. The findings indicate that substituting stone aggregates with fly ash leads to a reduction in settlement of about 15–20%, and encasement contributes to an extra 10% decrease (see Fig. 5).

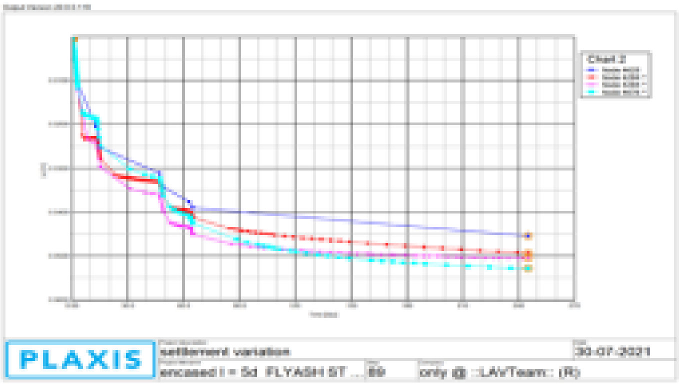

Fig 5: Comparison of total settlement v/s time

5.2. Stress Comparison of Stone Columns

Table 2 displays the total vertical stress for various column types. Encased columns demonstrate an increase of roughly 5% in stress capacity when compared to standard stone columns, while replacing stone with fly ash leads to a minor increase of about 0.13%.

Table 2: Stress Analysis Comparison

Stone column	Ordinary SC	Ordinary FC	Encased SC	Encased FC
Total stress (kN/m^2)	80.88	80.55	84.41	84.30

5.3. Effect of Encasement Length

By changing the encasement length with l/d ratios of 2, 5, and 8, it was found that both settlement and total stress decrease as the encasement length increases. There was no notable reduction in stress beyond an l/d ratio of 5, indicating that this length is optimal (see Fig. 6).

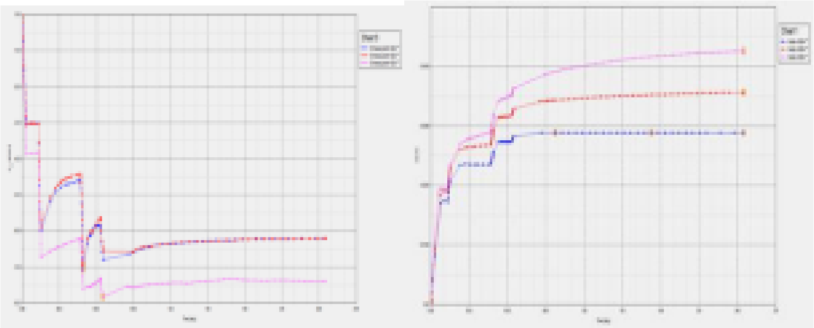

Fig 6: Total settlement Stress comparisons with l/d ratio

5.4. Effect of Axial Stiffness

The axial stiffness of the geogrid encasement ranged from 500 to 2250 kN/m. The results show that increasing stiffness helps to reduce settlement by offering better lateral confinement. Specifically, a 10% increase in stiffness results in an additional decrease in settlement of about 0.3% (see Fig. 7).

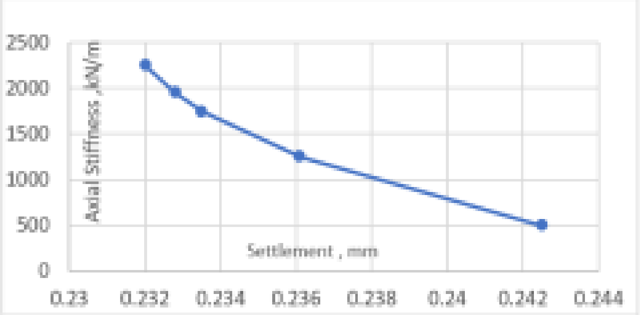

Fig 7: Settlement v/s axial stiffness of encasement

6. Results and Discussion

The investigation shows that substituting stone aggregates with fly ash can lead to a 15–20% reduction in settlement, and that adding encasement can further decrease settlement by 10%, while also enhancing the column's load-bearing capacity by about 5%. These results align with previous research that highlights the advantages of using sustainable filler materials and geosynthetic reinforcement. Additionally, the stress analysis reinforces the positive impact of encasement on column performance. The parametric study regarding encasement length reveals that an l/d ratio of 5 is optimal, and it also emphasizes the significance of geogrid stiffness in reducing settlement, underscoring the need for careful material selection. Overall, these findings provide important insights for designing stone columns aimed at stabilizing soft soils.

7. Conclusion

The investigation shows that substituting stone aggregates with fly ash can lead to a 15–20% reduction in settlement, and that adding encasement can further decrease settlement by 10%, while also enhancing the column's load-bearing capacity by about 5%. These results align with previous research that highlights the advantages of using sustainable filler materials and geosynthetic reinforcement. Additionally, the stress analysis reinforces the positive impact of encasement on column performance. The parametric study regarding encasement length reveals that an l/d ratio of 5 is optimal, and it also emphasizes the significance of geogrid stiffness in reducing settlement, underscoring the need for careful material selection. Overall, these findings provide important insights for designing stone columns aimed at stabilizing soft soils.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this work.

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