Comparative Study of Existing Cement Fly Ash Gravel pile and Encased Stone Column Composite Foundation

N. B. Umrawia*1, & Dr. C.H. Solanki2

1Ph.D. Scholar, Department of Civil Engineering, Sardar Vallabhbhai Patel National Institute of Technology, surat -395007- Gujarat, India
2Professor, Department of Civil Engineering, Sardar Vallabhbhai Patel National Institute of Technology, surat -395007- Gujarat, India

Abstract. The Cement Fly Ash and Gravel (CFG) Pile and Encased Stone Column (ESC) are the ground improvement techniques. The main object of the study is to the numerical analysis of both techniques pile group were used to support the Embankment with and without the geotextile both techniques composite foundation by the Finite Element method under static and dynamic load analysis. Numerical simulation has been carried out in Plaxis 3D. A case study from china's high-speed embankment supported by CFG and ESC have investigated the load caring capacity by soil and pile. While the failure behaviors, settlement, excess pore pressure, and lateral behavior with variable embankment loading and number of geosynthetic effect moreover, the diameter of CFG piles and ESC at various locations in an embankment has been varied to study its influence on the load distribution among the CFG piles/ESC and lateral load displacement of the pile group. The results show that increasing the diameter of both techniques reduced the total settlement and differential settlement of embankment. It observed that the seismic load has a significant effect on the vertical and lateral displacement.

Key words: CFG (Cement/ Flyash and Gravel) Pile, ESC (encased stone column), Embankment structure, dynamic analysis, Pile Diameter

1. Introduction

The stabilization of soft soil is one of the popular techniques in soil engineering. Many good techniques have been extensively used in deep ground improvement techniques. The Cement fly ash and Gravel (CFG) pile and Enhanced stone column (ESC) are the deep ground improvement techniques to improve soil's inherent properties like deformation nature and strength. The CFG piles Technology is widely applied to India's rapid development highway projects and high-speed railway embankment in China. It has a good bonding strength pile formed by cement, fly ash, stone chips, gravel, and sand with a moderate amount of water. Moreover, CFG Piles used as a Marine structure are subjected to axial and lateral loads and are generally on plane and embankment supported ground. In recent years numerical investigation has been applied to study the behaviors of CFG composite foundation subjected to dynamic load [1], [2] because of demanding optimization design by designer. Column technology as a ground reinforcing method has been the subject of several articles in the past. Typically research and usage of various soft
soil foundation technologies have been consistently improved in China[3], thanks to the fast construction of expressways and high-speed railways. The stone column is embedded with geosynthetic, known as encased stone column. The installation of granular (stone column) piles enhanced the carrying capacity of slopes by up to four times and enhanced the factor of safety of slopes by around 25%, according to field research. They also stated that stone columns performed better than prefabricated vertical drains [4]–[6]. Another noticeable effect is that stone columns bulging controlled by lateral earth pressure coefficients [7]. The load sharing mechanism among these column technologies (which are supported embankment Structure ground on soft ground) is almost identical to the pile group present in a horizontal ground. The topic of foundation settling has been a prominent topic in recent studies. Horizontal reinforcement layers, reinforced material, and vertical reinforcement composite foundations (column) are frequently utilized to decrease post-construction settlement and differential settlement of the soft soil throughout the operating period [8]. They can fully use columns, column-nets, and soil with less settling deformation and better post-construction settlement management. The application of CFG pile in consolidating soft soil foundation is gradually applied in soft soil treatment [9]. The application of CFG pile in multi-storey residential building is introduced The governing criterion in the design of CFG pile foundations to resist lateral loads is the maximum deflection and the bending moment along the pile l
0x0]ength rather than its ultimate capacity of ESC. In additional load-carrying capacity of the subgrade soil has a significant impact on pavement design.[10]. The geosynthetic encasement increases the load-carrying capacity of stone columns by many folds due to the additional confinement from the geosynthetic [11]. Many researchers also work on laboratory experiments to study the behavior of SC, ESC [6], [12]–[14]. CFG pile increases the composite foundation's bearing capacity and lowers deformation. In addition, it is unreinforced piles; the use of industrial waste such as fly ash as an additive in pile construction has significantly reduced project costs. Composite foundation technology has a high bearing capacity, a short construction time, and a cheap production cost, thanks to long spiral drill pipes in the building process[15]. During construction operation, the essential advantages of using a pressure pump during the CFG pile are the absence of mud, noise pollution, and dewatering requirements. It is used in a variety of foundation therapy regimens. Along with these advantages, few are also subjected to ECS like high bearing capacity, short construction time. But to compare the lateral displacement, mud mix with embedded geosynthetic during the installation has few disadvantages. Both Approach infusing parameters are diameters, length and spacing that are depending upon the field condition, subjected load, and application geosynthetic horizontal layers of reinforcement.

2.Materials and Construction Method [16]

2.1 Construction Method

2.1.1. Stone column: Experienced contractors use specialized equipment to build stone columns. The granular fill is put into a pre-bored hole and compressed with a hefty rammer; in this procedure, an excavator with a vibrating probe is used to feed stone into the earth, with casing and winch bailer material for backfill constructing a vertical stone column. At the same time, the Vibro Stone Columns are made with a vibrating mandrel that penetrates the earth to a predetermined depth. While compaction occurs, a void is created, which is gradually filled with inert granular material. The interaction between the stone column and the surrounding soils is the consequence.

2.1.2. CFG Pile: The construction process begins with selecting acceptable construction technology and a construction sequence acceptable for the field conditions. CFG piles are constructed by long spiral drilling machines follow[17]- During CFG piling, it must limit any soil disturbance between piles, noise, and dust
pollution. At machinery technology is typically used in the form of either vertical tube sinking (in silt and cohesive soils) or extended spiral drilling—bored. Perfusion cast in situ CFG pile (in clays, silts, and dense and medium sand above groundwater level) or concrete pumped (for strict pollution control), with the piling order being continuous or alternate (interval jump).

While the comparison in both methods followed the typical steps

- Survey and measurement
- Drilled the hole at desirable depth
- Clean up borehole
- Insert the casing pipe if required (i.e., collapsible soil)
- Prepare Materials (granular in SC / mix cement, sand, flash, and water in CFG piles)
- Continuous grouting
- Lift drill to the orifice.
- Moving to the following Pile location in the field.

2.2 Materials

2.2.1 Encased Stone column (ESC): in a stone column, Crushed stone aggregates with sizes ranging from 20 to 40 mm were used as stone column material. Additionally, Reinforcement sleeves for vertical encasement of stone columns are typically constructed with tensile strengths of up to 400 kN/m for columns with diameters of 40–100 cm in practice [6].

2.2.2 Cement, Fly ash, Grave (CFG) Pile: The basic materials like cement, fly ash, crushed stone, stone chips, and sand are mixed with water to create a CFG pile with higher bond strength (C-5 to C30; Where, C is Mix.

![Figure 1. Plaxis 3D Model](image)

Figure 1 shows the five components of a column-net composite foundation: 1) embankment fill; 2) Geosynthetics (encased in SC and horizontal in CFG respectively) sand cushion; 4) composite foundation (CFG/ESC) reinforcing zone, 5) soft clay, and the supporting course; (6) ESC/CFG piles.

3. Numerical Model

The numerical analysis was performed using the PLAXIS 3D software to compare the load-deformation
behavior with the model testing. Three-dimensional finite-element models of the same size as the embankment model were created and evaluated for the present study of ESC and CFG piles. Typically in highway embankment engineering problem was a flat strain problem with Axis-symmetry, therefore in research, half of the cross-sectional was considering to study the behaviors. The computing range establishing the finite element model had a vertical height of 20 meters and a horizontal width of 50 meters boundary. The typical cross-sections of three geosynthetic-reinforced embankments are analyzed using a nonlinear finite element technique. The three embankment cross-sections have a top width of 28 meters. The height of the embankment is 4.9 meters, with a fill height of 4 meters and a surface and base width of 0.69 meters. The soil model was considered as Mohr’s failure. Foundation soil was divided into three layers: the top layer was silty clay, the bottom layer was clay, and the middle layer was soft clay.

The selection of ESC/CFG pile length in preliminary design can be improved based on the study of post-processing findings. In Plaxis, 3D ESC/CFG Pile were considered as Volume pile and linear elastic model. The ESC/CFG pile lengths for 14m, 13m, and 12m, with 0.5 m dia. were then computed and examined. PLAXIS accepts an ‘interface strength reduction factor’ as an input to account for a drop in soil strength caused by installation. Typical values range from 0.6 to 1.0, depending on the soil type; the present study accepted 0.85. In addition, its physical and mechanical properties are described in table-1.

| Parameters | Bulk Density ($\gamma_b$) [kN/m$^3$] | Saturated Density ($\gamma_s$) [kN/m$^3$] | Modulus of Elasticity (E) [kPa] | Poisson Ratio (\(\mu\)) | Cohesion (C) [kPa] | Angle of Internal Friction (\(\phi\)) [\(^\circ\)] | Permeability (K$\_d$) [m/day] |
|------------|-------------------------------------|---------------------------------------|-------------------------------|----------------------|------------------|---------------------------------|------------------------|
| Embankment | 18.3 | 21.15 | 16000 | 0.34 | 5 | 26 | 0.02 |
| Cushion (sand) | 19 | 19 | 22500 | 0.33 | 1.5 | 24 | 1.14 |
| Silty Clay | 18.2 | 20.4 | 8500 | 0.33 | 6 | 16 | 3.4 x 10$^{-4}$ |
| Soft clay | 16.4 | 19.5 | 12650 | 0.36 | 6 | 14 | 6.9 x 10$^{-4}$ |
| Clay | 18.8 | 20.2 | 14500 | 0.31 | 7 | 25 | 5.1 x 10$^{-4}$ |
| CFG | 22 | 22 | 2550000 | 0.22 | -- | -- | NonPorous |
| ESC | 16.2 | 16.5 | 55000 | 0.3 | 0 | 42 | 1.10 x 10$^{-5}$ |

The geogrid used in the embankment base's sand cushion is Type SG-550 and can only extend. The deformation stiffness of this material is 118.9 kN/m. The topmost two foundation soil layers are punched in this example to reach the top of clay with a lower permeability coefficient. Reinforcement sleeves for vertical encasement of stone columns are often manufactured with tensile strengths of up to 400 kN/m in practice.

4. Results and Discussion

4.1 Influence the length of ESC/CFG pile

The influence of pile (ESC/CFG) was investigated using studies. The analysis was carried out on columns with diameters of 0.5, length 12 and 14m, with encasement stiffnesses of 250 and 5000 kN/m in ESC.
Figure 2 shows the obtained load-deformation responses. The load capacity of a typical ESC/CFG can be observed to be highly reliant on the cohesive strength of the surrounding clay soil. On the other hand, when the stiffness of the geosynthetic rises, the influence of surrounding soil strength on the capacity of the encased stone columns steadily increased. The pressure-settlement response of an encased column is essentially independent of the strength of the surrounding clay soil when the encasement stiffness is raised to 5000 kN/m. The lateral bulging of the stone column decreases as the stiffness of the encasement rises, decreasing the forces transmitted into the surrounding soil. The stiffness in CFG pile based on its grade C-5 to C-25 Mix the higher grade mix’s excellent stiffness. As a result, the stiffness of encasement rises, the contribution of the surrounding soil to the stability of the ESC/CFG decreases.

Figure 2. Influence of the column length with variable stiffness in soft foundation soil

For highly rigid encasement, this phenomenon renders the capacity of encased columns essentially also independent of the strength of the surrounding soil. When the length of pile increased from 12 and 14 with a stipulated pressure of soil, it decreased settlement linearly 1.35 times in all cases.

4.2 Relation between the distance and settlement of ESC and CFG pile supported embankment

Figure 3. a) Cross Section of Embankment; b) Relation between the distance and settlement of ESC and CFG pile a supported embankment
The Embankment load was heavy on soft soil. The soil was treated by the column technology Figure 3(a) shows the distance of the road base center to the half side of the model. When fig 3(b) shows that when a CFG pile is utilized to support a soft soil foundation, road surface settlement drops to 1 mm, with a differential settlement of just 0.1 mm. embankment road surface settling is about 2.13 millimeters at a horizontal distance of 7 meters from the center of the pavement when a long-short pile is used to strengthen loose soil foundations, from this point to the side of the pavement, the settlement progressively increases to 1.73 mm with a divergence of 0.11 mm. when an ESC is used to compel the foundation, the road surface settlement reaches its maximum level of 6.8 mm on average with a discrepancy of 0.07mm. To investigate the influence of encasing the stone column with a geosynthetic/ CFG pile, all previous evaluations were carried out by applying pressure directly to the top surface of the stone column. To investigate the influence of encasement on load transmission into the ESC/CFG, additional investigations were conducted by building soil layers on top of the ESC/CFG reinforced foundation soil.

4.3 Relation between the ESC/ CFG piles with vertical and horizontal deformation with variable length.

The selection of ESC/CFG pile length in preliminary design can be improved based on the study of post-processing findings. The pile lengths for 14m, 13m, and 12m were then computed and examined in four different scenarios. Figure 4 (a) describes the relationship between pile length change and subgrade horizontal displacement. Figure 4 (b) displays the relationship between pile length change and settlement.

![Figure 4](image-url)

Figure 4. influence pile length (a) Relation between Pile Length and lateral deformation (b) relation between the pile length and vertical settlement.

Figure 4 (a) shows the average horizontal (lateral) deformation of foundation soils under the ultimate embankment load, and it decreased as pile length changed. When the pile length increased, the average lateral settlement decreased in the CFG pile by approximately 19% compared to ESC. When the pile length is less than 13m, horizontal deformation decreases noticeably; however, horizontal deformation decreases gradually when the pile length is greater than 13m. the curve explains the inequality linear relation between the ESC and CFG pile lateral deformation with variable length. Longer length piles have an excellent capacity to transfer load quickly to hard strata.
Therefore, lateral deformation decreased in both methods. Figure 4 (b) shows the relation between ESC and CFG pile length and vertical settlement of foundation soil under the embankment load. It shows that the vertical settlement decreased with an increase in the length of the pile. To compare the average value of settlement of ESC and CFG Pile. The CFG pile has a remarkable vertical resistivity. Its vertical settlement reduced around 24%. These results are based on the material which used in ESC and CFG pile. In ESC used granular material that partially doesn’t have a bond; therefore, its lateral deformation and vertical settlement were higher than the CFG pile.

When the pile-supported embankment is subjected to the arching effect, it was produced below the embankment base, as shown in fig.5(a). in the common practice of construction, reducing this arching effect provides a cushion and various no geogrid layers. It was arching fundamentally create only in CFG pile-supported embankment. While in ESC, due to encased geosynthetics, less reaction creates to resist the action loads; therefore, its behaviors are flexible. The distance between the pile cap surface and the equal settlement plane or equal stress plane determines the height of soil arching.

The equal stress plane is the point at which the average vertical stresses above the pile-cap and above the subsoil are equal. For the 12 and 14 m lengths, Fig. 5 (b) illustrates the height of soil arching vs. subsurface settlement. The results reveal that once the subsurface settlement reaches 10 mm, the arching height rises. Then it stays the same.

5. Conclusion

The soil pressure and its group effect in the GRPS embankment were investigated using a three-dimensional finite element model and modeling in this work. The following basic concepts are obtained by computations of CFG piles, ESC piles, variable length of piles, and geogrid-reinforcing soft soil foundation.

- The elastic modulus of the geosynthetic encasement contributes significantly to the capacity and stiffness of the encased columns. For stiffer encasements, the confining pressures created in the stone columns are higher.
- The CFG mix grade effect on the stiffness. It is found that CFG piles are confined minimized lateral deformation. In terms of minimizing settlements and lateral displacements, the CFG pile reinforcement improves efficiency compared to ESC. In addition, it concludes that pile length
significantly influences the stress distribution percentage between the pile and surrounding soils based on the stress concentration ratios measured experimentally. The longer piles length can be able to distribute the more significant stress percentage.

- The results show that subsurface settlement mainly affects the above-ground soil arching but has little effect on the neighboring soil arching. The weight transmission efficiency in the center is higher than at the shoulder, even though the height of soil arching in both locations is about the same.

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