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Numerical Analysis to Study Lateral Behavior of Cement Fly Ash Gravel Piles under the Soft Soil

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ABSTRACT

Cement Fly ash and Gravel Piles are modern soil improvement techniques widely used in China for infrastructure development. It significantly impacts the fundamental characteristics of load-carrying capacities and deformation. The cement fly ash and gravel (CFG) piles are located on highways, railway embankments, essential projects, and problematic soil. These are often subjected to high risk of external load like flooding, seismic, etc. In such a case, foundation design can be governed by a required lateral resistance. The present study is based on the deformation behaviour of a CFG pile subjected to axial, lateral, and combined loading in soft clay. Numerical analysis using Plaxis 3D on a CFG pile with various influencing parameters soil condition, diameters, length, length to diameter ratio, and pile head loading condition to observe its effect. Overall, the pile study found variations in initial stress level, pile type, and pile head constraint. Still, these were minor compared to the impact of soil behaviour and mobility. The soil models varied stiffness and strength properties. The effects originating from the boundary conditions used were responsible for significantly decreasing lateral resistance for inner CFG piles under the active and passive loading.

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NOMENCLATURE

CFG	Cement Fly Ash Gravel	*LE*	Linear Elastic Model
S	Spacing (Center to center distance of Piles)	*UD*	Undrained condition (B)
NSF	Negative Skin Friction	*DC*	Drained Condition
D	Diameter of CFG pile (mm)	*SS*	Soft Soil Model
L/D	Length / Diameter ration	C'_{ref}	Cohesion
FEM	Finite Element Method	*E*	Young's modulus
MC	Mohr column model	μ	Position ratio
k_x; k_y; k_z	Permeability in x; y (horizontal) ; and Z (vertical) direction	OCR	Over consolidation ratio
φ'	Friction angle	φ'	Dilatancy angle
$\lambda*$	Modified compression index	$\kappa*$	Modified compression index
E_{50}^{ref}/ E_{oed}^{ref}	Secant stiffness in standard drained triaxial test/ odometer loading	E_{ur}^{ref}	Unloading / reloading stiffness

1. INTRODUCTION

Population growth and rapid industrial expansion are land areas that have been highly required for road and railways embankments needed for the urban area for infrastructure development. As a result, lands once considered unsuitable for growth, such as low-lying areas, river bays, and coastal regions, are increasingly used for various infrastructural projects. India has a 7516-kilometre-long coastline, a 1596 km long coastal area in Gujarat state, and deposits of soft clayey soils can be found all along the coast and in nearby delta areas. The effect of the dispositional and weathering coastal area creates complex problems in geotechnical material across

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the region. The embankments are constructed on soft and highly compressible silty clay or soft clays. Experience a large vertical and lateral settlement; therefore, ground improvement like column technology is an obvious choice in the embankment to provide the reinforcing and enhance foundation soil strength [1-8]. Cement-fly ash gravel (CFG) piles the most effectively under axial and lateral load reduced the settlement and deformation, respectively, among the various ground in improvement techniques [8-12]. The CFG is a composite foundation made of cement, fly ash, gravel, aggregate chips, sand, and moderate water. The soil between the piles is a soil solidification process using a technique. A dry or wet binder variable mix is mechanically combined with in situ natural soil to build columns for improved soil. This type of foundation, called a composite foundation crowned with a cushion layer, [11, 13-15] that indirectly carrying the foundation load and enhances the bearing capacity of soft ground. Hence the cushion's deformability depends on its characteristics. Piles' head pricks into the mattress layer, which leads to relative CFG pile settlement that creates based on negative side friction (NSF) characteristic of soil and pile [11]. On the upper side, 15–50 percents of the pile length has achieved a high bearing capacity and small differential settlement. The fly-ash is an industrial waste that reacts with the cement and makes a natural bonding gel that increases the concrete's strength Feng et al. [16] A combination of multiple piles with differing stiffness introduced by Cao and Liu [8], Lai et al. [10] and length [11, 12] has been used in practice to achieve further economic advantages of CFG pile reinforced ground. Performed numerical analyses, by unit cell approach by Yu et al., [5] the CFG piles using embankment numerical analysis done by Dresden and Approach [7]. Liu and Jia [17] developed a differential equation based on a typical unit calculation model to derive the depth of neutral plane and pile-soil stress ratio calculation formulas. Many areas are subjected to temperature variation. Therefore, the effect of temperature and heart exchange soil and CFG pile behaviour studied by Nguyen and Phan [18]. According to Wu et al. [19], the CFG pile ground improvement treatment is very effective on a field test on different ground improvement techniques. It is also uhelpful for an important highway project by Nguyen and Phan [18]; Wu et al. [19]; Hashemi et al. [20], and Hamidi and Lajevardi [21]. It has been a less vertical settlement and minimum lateral deformation than other ground improvement tests. The technical china code for ground improvement treatment for railway engineering (TB -10106-2010) explains the installation spacing and further specification of CFG piles.

Moreover, after installing CFG pile quality, bearing capacity under the soft soil, and efficiency check (less than 1-4% of total pile installation), it is required a loading test conducted by Anand and Sarkar [22], Abbas et al. [23], Zheng et al. [24]. The loading at field test suggested by with Chinese technical requirements for building foundation inspection (JGJ340-2015), Technical code for testing building foundation piles (JGJ106-2014), and Technical code for building ground treatment (JGJ106-2014) (JGJ 79-2012) [25]. Moreover, the basic concept of group CFG pile application with the geosynthetics materials that react like as a piled raft foundation behaviour [26-33]. The previous research focuses on various CFG pile composite foundation concepts and experiments to study the deformation behaviour under an axial (vertical) load. Moreover, there has been limited research on the design selection and parameter optimization of CFG pile (like length, diameters and grade of CFG) composite foundations, particularly in the deformable Indian soft soil condition.

Based on the literature review, the research gap was found there were fewer studies on the deformation behaviour of the single CFG pile subjected to active the passive lateral load. These techniques enhance the soft ground bearing capacity in the field, although lateral displacement was not deeply studied.

2. METHOD OF ANALYSIS

The numerical simulation approach is very significant in studying the behaviours of foundation, soil, and pile interaction. Moreover, CFG pile composite foundations have mechanical properties intermediate between shallow and deep foundations that depend on their stiffness nature. They are typically an unconnected form of foundation. The Finite Element Method (FEM); [16, 26-29] has risen in importance in geoengineering and design during the last two decades. In this study, the FEM constitutive models are used to simulate the structural characteristics of soils, and model parameters describe specific features of soil behaviour. These constitutive models can range in complexity from simple to complex. Simple models, in general, require only a small number of parameters to be chosen, but they may be missing some important aspects of soil behaviour. More complex models may encompass more aspects of soil behaviour, but they also necessitate the selection of more parameters based on soil investigation data. The main objective of present work is to understand the behaviour of a single CFG pile subjected to axial, lateral, and combined load in soft soil.

3. NUMERICAL MODEL DESCRIPTION

3. 1. Model Description The finite-element model was created using the commercial FE software PLAXIS 3D. The Mohr-coulomb (MC) consecutive models worked on the elastic and elastic-plastic behaviours of soil and structure interaction due to the MC model considered for the clay and soft soil. The CFG piles behaviour is linear; therefore, the CFG pile is considered a Linear elastic (LE) model [35]. The usual mesh geometry used in the model is depicted in Figure 1.

In numerical analysis, the effect of stress at the boundary was minimized by providing a large length and width (10D). The homogeneously treated soil medium was produced at least five times as broad as the foundation (b_r) in the lateral extent and more than twice as deep as the long pile length vertically. A stiff sand layer has been provided below the soft soil (approximately 2 m after soft ground) that fixed base to avid the significant vertical displacement. Hence, considering computational expenses without compromising accuracy, the mesh density was finer in the neighbourhood of structural members with gradual change to coarser mesh sizes for farther locations. Each part was discretized using a fifteen-node linear brick element with reduced integration and hourglass control.

The surrounding vertical boundaries were modeled to restrain lateral displacements, while the bottom was set to constrain both horizontal and vertical displacements. The top surface boundary was set to be free in each direction. The analysis was initiated by generating K_0 geostatic stress field within the soil mass that produced minimal deformation yet was in equilibrium with pore water pressure. The initial condition was followed by introducing piles sequentially, considering the soil and CFG pile surface are rough. Construction vibration has not been accountable. The shear strength effect increases with depth, the variation of the lateral factor with depth, and the impact of strength anisotropy.

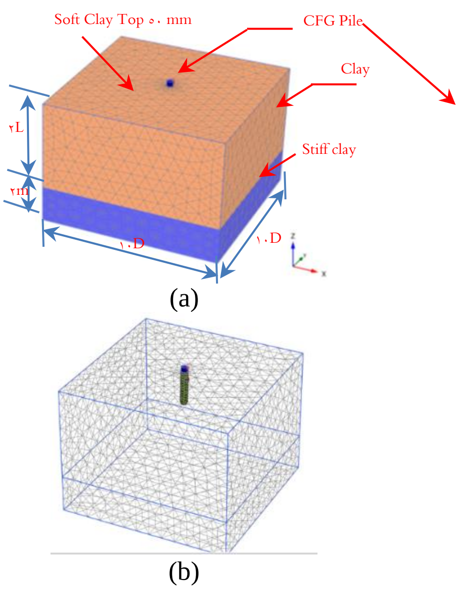


Figure 1. (a) Model Geometry (b) Finite Element Model (FEM) with model mesh

The selection of a constitutive model of soil mass when defining material properties is critical to the outcome. The Tresca yield criterion, von Mises yield criterion, Drucker–Prager yield criterion, Mohr-Coulomb yield criterion, and double-shear stress yield criterion are now used in geotechnical engineering. The present study considers the axial and lateral behaviour of a single CFG pile under the single layer soft soil model and an MC model. "Hard" contact in the normal direction and Coulomb friction in the tangent direction were used to represent the contact behaviour at the pile-soil surface. The Mohr-Coulomb model is based on graphing Mohr's circle in the main and minor axes for stress states at yield because a typical geotechnical test determines cohesiveness (C) and internal friction angle (φ). It plays an essential role in practical application and is extensively used. The present study is on the numerical analysis of axial behaviours of three different diameters (0.5, 0.7, and 0.9 m) with different L/D ratios (6, 12, and 18) of CFG piles. Its effect has been analyzed under the lateral load. To study behaviour under the combined load of axial and lateral. Moreover, the lateral behaviour of the CFG pile when its soil is subjected to passive lateral load. A settlement and deformation study was considered the prescribed 50 mm under the axial and 15 mm in lateral displacement, respectively.

3. 2. Model Assessment Criteria

Four different metrics materials models, LE, MC, SS, and HS, were chosen to appraise and compare the behaviours of CFG pile under the horizontal and verticle loading. The CFG pile foundation selects the LE model [34]. In order to model the interaction between pile and soil, ensure that the pile's element node coincides with the soil's element node and that the soil's mesh size is the same as the pile's mesh size. Effect of pile size on lateral displacement, pile diameter is set to 0.5, 0.7, and 0.9 m: active loading and passive loading condition. The CFG pile head, approximately 0.3 m above the ground level, was subjected to the lateral load in the active state. Therefore circular plate is fixed and loads in one direction. In the case of lateral load subjected soil passive, the upper 0.3 m soil mass moved, creating the lateral thrust. When the MC model, the upper layer of 0.3 m collapsed in numerical analysis; therefore, it was modified with the soft clay SS soil model in passive condition soil. This approach gives comparative results on lateral in active and passive loading conditions. Solid elements used. The Poisson ratio, cohesive, deformation modulus, and specific parameters are listed in Table 1.

4. RESULT AND DISSCUSION

Discuss the effect of D - 0.5, 0.7, and 0.9 m diameter CFG pile subjected to relative axial load conditions on

TABLE 1. Details of Material properties of pile and soil

Parameter	Unit	CFG pile	Clay	Soft Clay	Stiff Clay
Material Model	-	LE	MC	SS	HS
Drainage Types		Nonporous	UD	UD	Drained
Unit Weight	γ (kN/m^2)	22	14	16	18
Young's Modulus	$\grave{E}$ (kN/m^2)	2.4x10^6	12.5 x10^3	9x10^3	15 x10^3
Undrained shear strength	C'_{ref} (kN/m^2)	1.0	45	10	18
Poisson ratio	μ	0.15	0.25	0.4	0.3
Friction angle	φ'	--	0	23	25
Dilatancy angle	ψ	--	0	0	25
Modified compression index	$\lambda*$	--	--	0.18	--
Modified swelling index	$\kappa*$	--	--	0.04	--
Secant stiffness in standard drained triaxial test	E_{50}^{ref}/ E_{oed}^{ref} (kN/m^2)	--	--	--	50x 10^3
Reloading Stiffness	E_{ur}^{ref} (kN/m^2)	--	--	--	150x10^3
Power of stress- stiffness	m	--	--	--	0.5
Permeability	k_x ; k_y; k_z (m/day)	--	--	--	0.25x 10^3
Over consolidation Ratio	OCR	1.0	1.5	1.0	1.0
Pre overburden pressure	POP	0.0	0.0	5.0	0.0

deformation based on lengths 6D, 12D, and 18D. Significant the Effect of length that enhanced the load-carrying capacity of CFG pile.

4. 1. Study the Influence of Pile Length under Axial Load

The CFG pile was subjected to axial load analysis performed in two conditions. Frist condition is to analyze that have a direct axial load only. Then, it was analyzed under the combined axial and lateral load. The first condition analysis result of D -0.5 m with influences the variable pile length 6D, 12D, and 18D, respectively, as shown in Figure 2. The load settlement curve is nonlinear behaviour. Its plastic point of deformation is near an 8- 12 mm settlement. The CFG Pile length is categorized into short, medium, and long piles. The long pile has an extended NSF resistivity than the medium and short pile. Therefore 12D and 18D lengths of CFG pile's ultimate load-carrying capacity increased 1.93 and 9.25 times than the 6D length. The test results plot the load-displacement curve; the ultimate load is obtained by the tangent intersection method [35].

4. 2. Study the Influence of Pile Length under Axial Load

In order to compare the load settlement curve of D-0.5, 0.7, and 0.9 with the 6D length of the short pile shown in Figure 3. Its nature is, as usual, nonlinear, but the deformation curve's plastic point increased with increased diameters because of the weak contained effect of the CFG pile and the low shearing strength of the soil. As a result, the axial load carrying remarkable increases with the increased diameter. For example, in D-0.9 m and 0.7 m dia. of CFG pile, ultimate axial load are 4.08 and 8.78 times higher than D-0.5 m.

Similar behaviour is shown in a higher length CFG pile, as shown in Figure 4. The CFG pile length 12D and D- 0.5 and 0.7m diameter plastic point of deformation was found in soil near 10- 15 mm settlement. While in higher length, it may increase with increased diameter. The plastic deformation point is important in finding the ultimate load using the double tangent method.

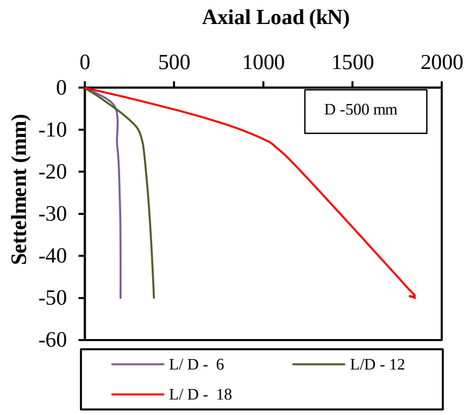


Figure 2. Relation between axial load and settlement of D – 0.5 m with variable length of CFG pile

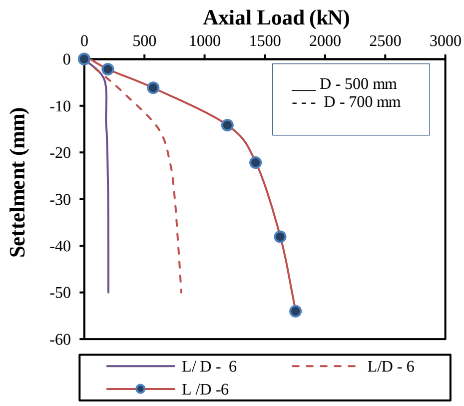


Figure 3. Relation between axial load and settlement with a variable diameter of CFG pile

Therefore, its ultimate load capacity is increased. However, to compare the stress concentration of 0.5 D value is significantly higher than the 0.7 and 0.9 D., The effective stress in the same diameter pile in a longer length of CFG, was found to be approximately 20 % higher than smaller length CFG pile in 0.5, 0.7 and 0.9 diameters.

4. 3. Study the Impact of Verticle Deformation under the Combined Load In the numerical analysis of piles, many researchers study axial or lateral load subjected to understand the behaviours of the pile under the settlement and its deformation nature. Still, it may be subjected to a combined effect in the field. For example, a combined load of axial and lateral pile D - 0.7 behaviours under the vertical settlements is shown in Figure 5. The axial load capacity has been decreased near 20- 30 % compared to only axial load subjected to CFG pile. In analysis, the CFG pile is a LE model subjected to only a one-dimensional effect in axial load. Still, in a combined load, the two-dimensional load effect of pile deformation has been distributed in both dimensional.

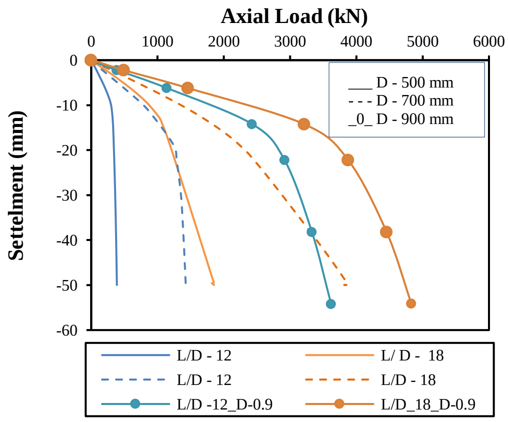


Figure 4. Relation between axial load and settlement with a variable diameter of CFG pile

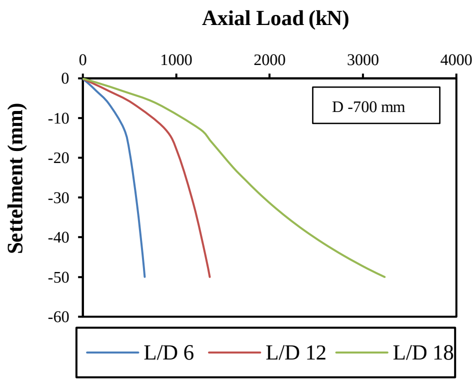


Figure 5. Load and settlement curve with variable length of CFG pile

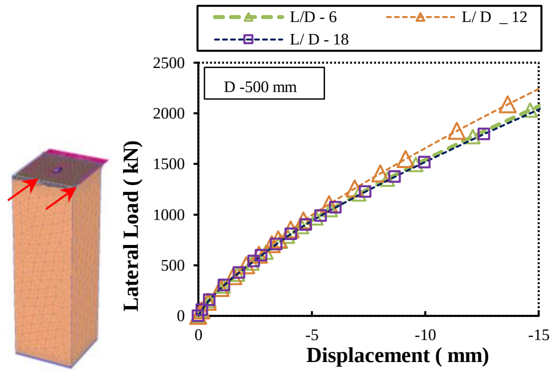


Figure 6. Lateral load and displacement curved of single CFG pile with passive load

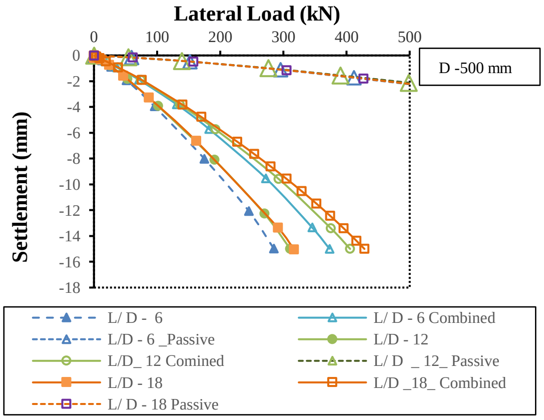
4. 4. Study the Influence of Pile under The Lateral Load The CFG pile subjected to only the lateral load with variable length study has been considered. Normally, the lateral load is directly applied at the pile top and evaluated its deformation. However, our study has considered the three different conditions of lateral deformation.

Following loading conditions, (I) the lateral deformation of the CFG pile is subjected to only lateral load; (II) lateral deformation of CFG pile under the combined load of axial and lateral; (III) Lateral deformation of CFG pile under the passive. Figure 6 explains the relationship between the passive lateral load and variable-length CFG pile deformation. The upper 0.3, m. modelling soil layer moved horizontally; therefore, the condition of load on CFG pile top is defined as passive lateral load. The model of upper soil is defined as SS-type Soft soil considering. The results are very near in all diameter conditions. The pile bodies and top lateral displacements change slightly as the pile diameter grows from 0.6 m to 0.9 m. The CFG pile body and pile top lateral displacements were barely at 1500 KN and were reduced, rarely decreasing from 10.15 mm to 10.42 mm. However, when the pile diameter increased from 0.7 to 0.9 m, the maximum lateral displacement at the pile top reduced to 2.31 mm at increased diameter, indicating a nonlinear connection.

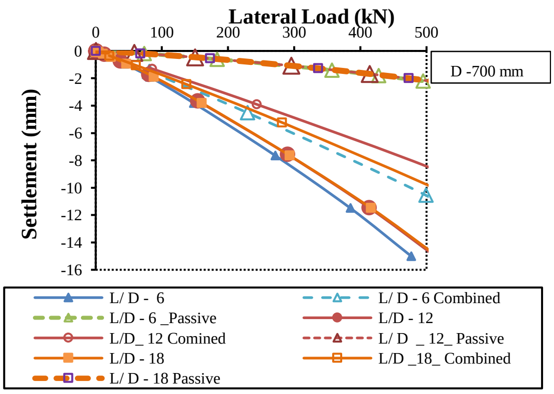
4. 5. Study of the Influence of Pile with Variable Lateral Load The soil mass in front of piles creates active earth pressure, whereas the soil mass behind piles generates passive earth pressure due to the lateral displacement of piles (axis direction). When the ground pressure exceeds the strength of the soil mass, plastic displacement occurs. Figure 7 explains the greatest primary plastic strain of soil mass under (I) and (II) under three loading conditions. The lateral displacements of the pile body are rather modest. Moreover, there are no plastic zones in the foundation soil. However, with increasing operating conditions (III), the lateral displacement of the pile body grows, and the soil mass range in the accessory section around the piles creates a plastic zone.

In comparison to Figures 7(a), 7(b), and 7(c) detail the relationship of the lateral displacements of the CFG pile with variable length subjected lateral load under the active passpile. When the diameter was 0.5 to 0.7 and 0.7 to 0.9 m increased, the lateral load was 67.5 and reduced by 16.5 percents, respectively, Because providing lateral force at the pile top is comparable to imposing one constraint, this conclusion suggests that the load at the pile top can greatly minimize the lateral displacement of the pile body. As a result, the pile top's free displacement turned into restricted displacement, limiting pile top movement to some extent. However, one uninformative result was found that lateral capacity of CFG pile is increased nominal with increased length in case (I) and (II) loading, but it is remarkable increased lateral load (8- 24 %) in equal length and equal diameter of CFG pile in case (I) to case (II) loading. Because in case II loading, the resistance of CFG pile is increased due to the axial load (overburden load)on it that prevention the lateral movement.

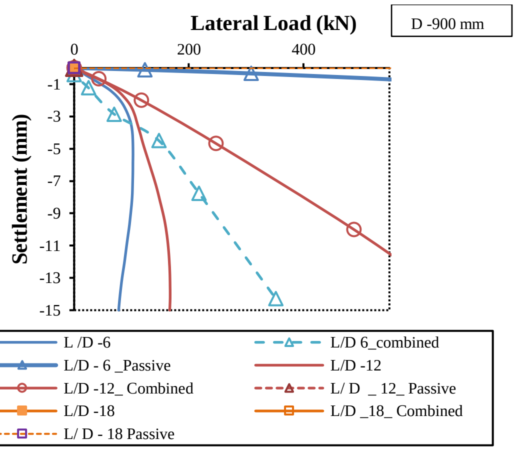
Figure 7(c) shows lateral load vs settlement of L/D-6 and L/D-12 behavious under the active lateral load is a non linear as which is explain that pile failed with



(a)



(b)



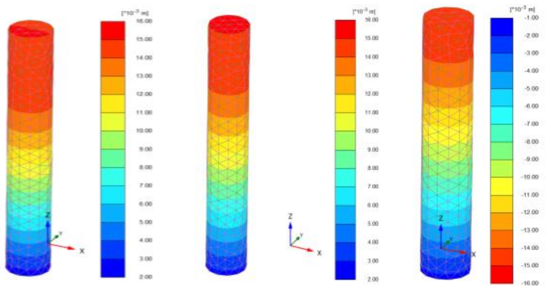
(C)

Figure 7. (a) 0.5 D (b) 0.7 D (c) 0.9 D ; Lateral load deflection curved Inflence with varable L/D ratio

subjected to a nominal load. Because both cases were considered floating pile conditions. The CFG pile subjected to only displacement it loadloadlemententent relation linear it is like as a Figure 12(a) and if Pile is sudden fail as a Figure 12(b).

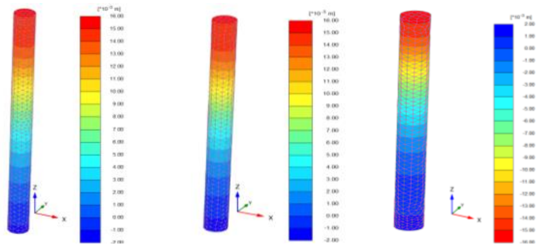
4. 6. To study the Stiffness of CFG pile Under The Variable Diameter

It is termed long if the effective length is higher than 12 times its least diameter. The pile is deemed short if the effective length to the least lateral dimension ratio is less than or equal to 12. Figures 8, 9, and 10 show the lateral displacement distribution cloud diagram of the CFG pile body subjected to the case (III) passive loading conditions for various pile diameters and its constant L/D -6, 12, and 18 ratios. The computed indicates that as the pile diameter increases, the lateral displacements of the CFG pile body and pile top decrease gradually. When foundation soil mass reacts under the load, increased deformation depends on stiffness, the necessary foundation treatment to be identified, and the pile body's lateral resistance demands to be satisfied. For square and hexagonal piles, the primary interpreted failure loads correspond to settlements of 0.1d, where d is the equivalent pile diameter, which refers to an equivalent circle diameter. Such a formulation ignores the elastic shortening of the pile, which might be significant for long piles but insignificant for small piles. The settlement, in actuality, refers to the movement of the superstructure (pile with soil), not the capacity of the soil in reaction to the loads delivered to the pile in a static loading test. The lateral stress effect is with the increased diameter of the CFG pile. According to the studies, a substantial lateral displacement will be created under structural stress to measure its safety. The movement of the CFG pile process was implemented by incorporating the findings of the parameter analysis in case (III). Spinning pile processing can improve the strength of the



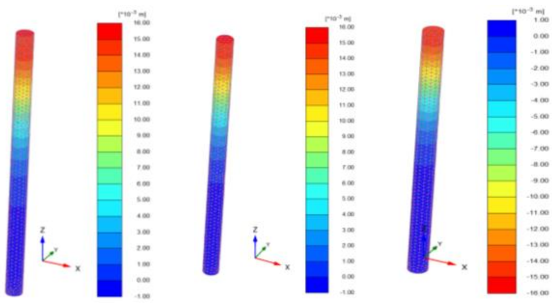
(a) D-0.5 m (b) D-0.7 m (c) D-0.9 m

Figure 8. Passive Lateral effect of Sigle CFG pile in Soft clay L/D -6



(a) D-0.5 m (b) D-0.7 m (c) D-0.9 m

Figure 9. Passive Lateral effect of Sigle CFG pile at L/D - 12, in soft clay



(a) D-0.5 m (b) D-0.7 m (c) D-0.9 m

Figure 10. Passive Lateral effect of Sigle CFG pile at L/D - 18 in Soft clay

soil mass encircling the pile top, limiting the pile body's lateral movement. After processing, the Lateral displacement at the pile top is just 3.6 mm.

In the case of lateral loads, the CFG pile acts as a transversely loaded beam, transferring the lateral load to the surrounding soil via the earth's lateral resistance. When a weight is applied to a pile, it bends, rotates, or moves horizontally, resulting in bending, rotation, or translation.

Furthermore, the processing can enhance CFG pile stiffness depending upon its L/D ratio. A long pile load-carrying capacity is lower than a short column with the same cross-sectional area. Crushing is the cause of the short CFG pile failure shown in Figure 11 explains the effect of the length of the CFG pile under the lateral deformation. When the CFG pile length is short (L/D< 15), it behaves like a rigid, as shown in Figures 11(a) and 11(b) the failure pattern defined under the shear. While the long pile failed Due to buckling, all of the long CFG piles failed like Figure 11(c). because It has a larger radius gyration, and its stiffness compared to a shorter CFG pile is less.

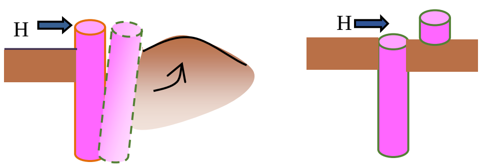
4. 7. Model Validation Sivapriya and Gandhi [36]

Sivapriya and Gandhi [36] studied experiment and numerical analysis to determine lateral deformation subjected to lateral load on the horizontal and sloping ground using instrumented (aluminium pile) single pile having a diameter of 16 mm outer diameters with 450 mm length. The geotechnical properties of the soil used in the model are given in Table 2.

To validate the model, a numerical analysis is conducted using PLAXIS, and compared to the present study the results are very closer to each other as shown in Figure 13.

(a) L/D -6 (b) L/ D -12 (c) L/ D -18

Figure 11. CFG Pile model behaviours under variation length



(a)_ (b)

Figure 12. Failure Parton of CFG pile (a) Lateral displacement without fail (b) Failure under the horizontal trust

TABLE 2. Input parameters –a numerical study

Parameter	Name	Clay	Pile
Material Model	Model	MC	LE
Drainage type	type	Undrained C	-
Young's Modulus	E (kPa)	8025	70e6
Unit weight	Γ (kN/ m^3)	17.9	25
Poisson's ratio	μ	0.495	0.21
Cohesion	C(kPa)	30	-
K_o	-	Automatic	Automatic

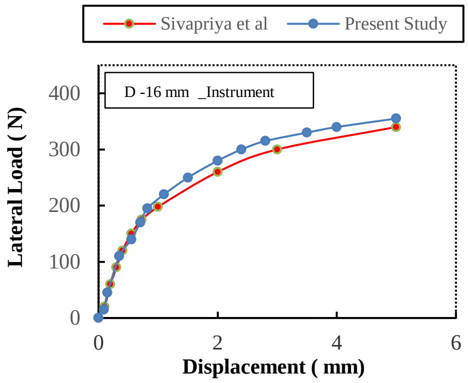


Figure 13. Model Validation

5. CONCLUSION

This study is based on a series of three-dimensional analyses to investigate the behaviour of a single CFG pile subjected to vertical, lateral, and combined vertical and lateral load. Separate numerical evaluations were performed on the single pile under combined loading with varying diameters and lengths to evaluate vertical load. In terms of lower diameter and thick sands situations, the effects of relevant factors such as pile/soil interface friction coefficient and shear strength (angle of internal friction and dilatation angle) of soil. For instance, in dense sand, the results reveal that pile behaviour under a combination of vertical and lateral loads has higher lateral load resistance than pile behaviour under single lateral stress. The cause may be traced back to the creation of extra lateral soil strains in front of the pile and increased frictional resistance throughout its length. In addition, the increase in enhancement depths until the CFG pile tips approach or are immersed in the strong strata significantly lowers both settlement and lateral movement while also increasing the overall bearing of soft soil.

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Persian Abstract

چکیده

خاکستر بادی سیمان و توده های شنی تکنیک های مدرن بهبود خاک هستند که به طور گسترده در چین برای توسعه زیرساخت استفاده می شود. این به طور قابل توجهی بر ویژگی های اساسی ظرفیت های باربری و تغییر شکل تأثیر می گذارد. شمع های فلاش و شن سیمان (CFG)ر بزرگراه ها، خاکریزهای راه آهن، پروژه های ضروری و خاک مشکل دار قرار دارند. اینها اغلب در معرض خطر بالای بار خارجی مانند سیل، لرزه، و غیره هستند. در چنین حالتی، طراحی فونداسیون را می توان با مقاومت جانبی مورد نیاز کنترل کرد. مطالعه حاضر بر اساس رفتار تغییر شکل یک شمع CFG تحت بارگذاری محوری، جانبی و ترکیبی در خاک رس نرم است. تجزیه و تحلیل عددی با استفاده از Plaxis 3D بر روی یک شمع CFG با پارامترهای موثر بر شرایط خاک، قطر، طول، نسبت طول به قطر و شرایط بارگذاری سر شمع برای مشاهده اثر آن. به طور کلی، مطالعه شمع تغییراتی را در سطح تنش اولیه، نوع شمع و محدودیت سر شمع پیدا کرد. با این حال، اینها در مقایسه با تأثیر رفتار و تحرک خاک جزئی بودند. مدل‌های خاک ویژگی‌های سختی و مقاومتی متفاوتی داشتند. اثرات ناشی از شرایط مرزی استفاده شده مسئول کاهش قابل توجه مقاومت جانبی برای شمع‌های CFG داخلی تحت بارگذاری فعال و غیرفعال بودند.