

AN EXPERIMENTAL AND NUMERICAL STUDY OF LATERALLY LOADED SMALL GROUPS CFG PILE IN SOFT CLAY

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Abstract

The CFG pile comprises composite materials like cement, fly ash, and gravel with adequate water to achieve various grades. It is one of the best techniques to enhance ground bearing capacity in soft and problematic soil. CFG pile has a good amount of lateral resistance capacity. This research study's main objective is to study a single and small group of casted CFG piles in the laboratory. Also, discussion on the Installation procedure of CFG pile in a confined area, temperature, and curing process. In order to improve the workability of the CFG pile, several laboratory experiments were conducted on various groups of CFG in this experimental analysis. They are made up of a variety of Cement, Fly ash, and gravel particle proportions. Moreover, the research looked at nine pile group combinations (2×1 , 2×2 , 3×2 , 2×3 in square Paton, subjected to a lateral load in a longer direction when in three CFG piles triangular parallel and perpendicular to the base angle of triangular subjected to the lateral load) with a $1.5 D$ pile spacing values (where D is the pile diameter). In terms of load vs. lateral displacement, load vs. soil resistance, and associated double tangential curved method, the effects of load intensities, group configuration, and Pile are discussed. The improved plots can be used to plan laterally filled CFG piles and equations for group action design. As a result, architecture curves for assessing pile group activity using improvements were developed and implemented in experiments. Results show that the CFG pile was subjected to lateral load and lateral displacement within the permissible limit. The CFG Pile and Pile surrounding soil interaction comparative results were discussed. Suppose the suitable soil elastic modulus is selected. In that case, the numerical, analytical solution and the back load-settlement curve approach can reasonably estimate the lateral deformation concerning Depth and the group efficiency, respectively, according to the relation between numerical and experimental findings.

Keywords: CFG pile, Lateral load, Lateral deformation, Soil structure interaction

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Introduction

According to the current day, urbanization and industrial growth need land to build structures safely on soft soil. That having a low bearing capacity and high compressibility are characteristics of soft clays. Soft clays lose strength and stiffness, which results in excessive settlement and a failure of the carrying capacity, seriously damaging the foundations of structures. Therefore many ground improvement techniques are helping to enhance the bearing capacity of soft soil for excellent structure. Application of CFG (cement/fly ash/gravel) piles for ground improvement techniques is most effective while subjected to dynamic loading. The primary goal of reducing the vertical settlement. Lateral deformation an improved load carrying capacity. This technique is also applicable to minimize the soil liquefaction effect during earthquake shaking. Therefore, can accomplish this by increasing the density of the soil and improving its drainage potential. Moreover, These techniques are widely applicable in the last one decade in china's major projects, including retaining walls, highway/railway embankment building foundations, and bridges foundation. (Cao and Liu, 2014; Feng *et al.*, 2014; Pile, 2014; You *et al.*, 2016; Zhang *et al.*, 2017, 2018), (Kwa *et al.*, 2018) some of the alternative ground improvement methods and to support the embankment such as ESC (enhanced stone column) DMC (deep mixing column). Such a study to improvement the bearing capacity of soft soil by stone column and Enhanced stone column at laboratory investigation with different L/D ratio The experiments showed that the stress concentration and bearing capacity of soil treated with stone column increase with increasing the undrained shear strength (c_u), number of columns and L/d ratio (Fattah *et al.*, 2016) when requirement to reducing the settlement, by CFG pile techniques the optimum design of a CFG pile is essential when the primary purpose of adopting a CFG pile-supported composite foundation is to apply. (Jin *et al.*, 2011) they also observed that the interaction of the existing CFG pile composite foundation with an adjacent new foundation pit excavation inevitably presents a complex soil-structure interaction mechanism among the fundamental components (Uge, 2020). The CFG piles supported Embankment performed excellently under the dynamic effect subjected o moving vehicle/train its lateral and vertical settlement or

stress concentration below the embankment reduced measured (Zeng *et al.*, 2009; Jiang and Wang, 2011, 2012; Zheng *et al.*, 2011a, 2011b; Feng *et al.*, 2014; Jiang *et al.*, 2014; Zhang *et al.*, 2015; Zhenxing *et al.*, 2015; Zhuang and Cui, 2015; Shen and Wang, 2016; Zhang *et al.*, 2018). In India, industrial wastes are increasingly being used as dust and/or aggregate, which can work easily applications geotechnical around. The CFG pile-supported is such as techniques site-based, which use as the by-product fly ash as a constituent material to enhance the engineering properties of soft or problematic base soils using column technology. Therefore many researchers are work on an experimental laboratory base to study the behaviors of CFG pile based ground improvement techniques (Doanh *et al.*, 2009; Xiao *et al.*, 2018). similar Laboratory and An analytical calculation of the bearing capacity of soft soil reinforced by the deep mixing method to determine the behavious of soft soil by (Brown *et al.*, 1998) In minimizing lateral displacements, the work combination of CFG piles and geosynthetic layer works remarkable (Zhang, 2015a, 2015b; Solanki *et al.*, 2020; Umravia, 2020). Cement-fly ash-gravel (CFG) piles along with geogrid were used to strengthen an approach embankment over a silty clay deposit in three-dimensional (3D) centrifuge model experiments. (Xiao *et al.*, 2018). CFG piles, an emerging and sustainable building material, may be used in the base to provide a cushion between the top of the Pile and the raft slab in a high-experimental base study for the value of the stress concentration ratio by manufacturing a model of a single stone column with rigid instrumented loading plates such that the total load applied to the model footing, and the load applied to the stone column can be measured alone. (Fattah *et al.*, 2011, 2013).

In summary, the research primarily focuses on various hypotheses and Experimental tests of CFG pile in soft soil. There are few Experimental studies on single and small group CFG piles communication with lateral displacement at various diameters and length-based design selection and parameter optimization. In soft soil, result, this paper incorporates a wide range of theories and studies on CFG pile ground improvement techniques.

Experimental Setup

In this study, six major configuration experiments were carried out at a laboratory with a reducing scale at the Government engineering college Dahod, Gujarat, India. The model container tank is made of Iron and has dimensions 1500 mm × 500 mm × 500 mm (length × width × height). The schematic diagram of the experimental setup is shown in Figure 1.

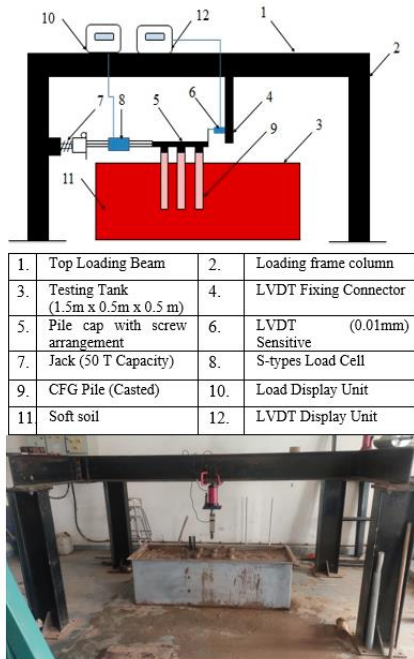


Figure 1. (a) Experimental setup for dynamic lateral loading (b) Rectangle Testing Tank, Load Cell, and Jack

During all test list of equipment was fixed as shown in the schematic diagram. Here the soil tank size enough to provide for boundary condition was extended 7-11 D (D -CFG pile diameters), 2-3D in load direction, and perpendicular to the direction of lateral loading. Moreover, the soil thickness was held below the CFG pile tip by at least 5D to reduce box boundaries. The CFG circular pile cast using a 50 mm, 70 mm diameter, and 450 mm Depth were used. To make the CFG piles requirement of the necessary amount of cement (OPC), Fly -ash (Class B) I.S. - (3812 - 2016), and Grit (4.23 <Size <6.3mm) with an adequate amount of water. Design mixed of CFG piles and installation was followed by (You *et al.*, 2016). The CFG pile behaves like a Semi-Rigid pile. The tank fills with clayey soil that met the requirements for two shear strengths of 13 kPa and 16 kPa. The CFG piles were cast in the

correct positions where required in the clay tank. To determine the CFG pile potential for lateral load under free head conditions, the model CFG piles were subjected to lateral loads in the downward direction at horizontal surface level without restraint. The CFG piles deflection along the length of the pile (i.e. Deflection of pile with respect to depth) to measure by PLAXIS-3D. Basically CFG pile is cast in situ pile it is difficult to fixed stain gauge therefore to study the nature of pile deflected with respect to depth using a FEM approach For the validation of experiment the input data by using Plaxis 3D for the Soft soil and CFG pile as mention in table 6 The CFG piles were connected to the 50 T capacity loading frame by a Special plate steel Frame were used as a CFG pile cap for differential spacing 1.5 D as shown in Figure 2. The CFG pile and Pile load frame connected with screw arrangement for applying lateral load by dead weights using the hydraulic jack were attached horizontally with loading frame and pile cap frame. The primary jack function during the test applies regular/ control various loads with regular interval and pile head horizontal displacement to calculate it was measured by two Linear Variable Differential Transducers (LVDT). Hence LVDTs fixed in front and behind the cap in load used the direction. To assess cap rotation accuracy. While the bending and relocation were entirely done after 15 minutes of each load/ incremental load, took displacement. for accountability. The Pile cap subjected under lateral load with gradually increment that measuring by load cell, which was connected between the loading frame and pile cap frame as shown Figure 1(a)

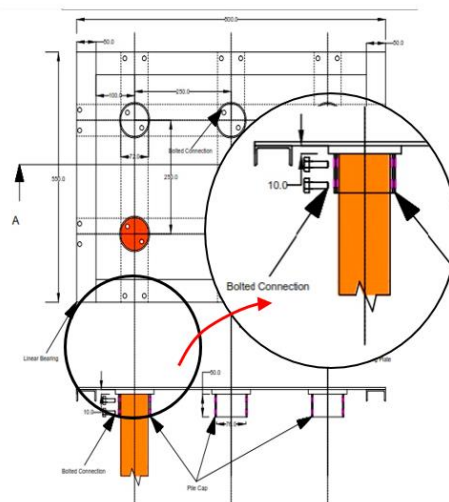


Figure 2. Pile Cap with Special screw Arrangement

Preparation of the Test Soft Clay and Soil Properties

The experiments were carried out on soil moisturized based on its shearing strength (at laboratory temperature). To make the model clay beds with locally available soil that was 70% finer than 75 mm. It has a liquid limit of 23%, a plastic limit of 6%, and a plasticity index of 17%. (ISSCS). The soil can be categorized as clay with low plasticity under the Unified Soil Classification System (USCS, ASTM D2487, 2006). (CL) other physical properties explained in Table 1.

Table 1. Index properties of Clay

Sr No	Properties	Value (13 kPa)	(16kPa)
1	Liquid limit (%)	29%	29%
2	Plastic limit (%)	12%	11%
3	Plasticity index (%)	17 %	16 %
4	Undrained shear strength	13 kPa	16 kPa
5	Specific gravity	2.65	
6	Bulk unit weight (kN/m ³)	18	18.1
7	Grain size distribution		
	Sand	0.6 %	0.9
	Silt size	25.2 %	23.6
	Clay size	74.2	75.5
8	IS-classification	CL	CL

To developed a soft soil bed, investigators have developed many methods such a compacted by tamping, increasing water content; in this experiment, to achieve the required shear strengths, combined soil with a predetermined amount of water. For shear strengths of 13 and 16 kPa, the necessary amount of clay was air-dried, and the required amount of water was applied to achieve a moisture content of 26 and 23 percent, respectively, based on the vane Shear test (IS-2720-30). The soil shearing strength is less than 15 kPa defined as a very soft soil and soil 15 -20 soft soil, Present study based on an experimental work on soft soil. It was borrowed from the near city. When prepare a clay bad the amount of (26 and 23 %) water added which is based on the UCS (unconfined compression test) test to achieving 13 and 16 kPa. Hence the soil liquid limit is very low. if during the experiment chose the soil high sharing strength the density (unit weight) 18 kN/m³ of soil will not be achieved after defined compacted by rod shown in Figure 3 with defined 25 no of blows

Before and after all experiment work three different place from clay bed soil collected for the water content and UCS (IS 2720-10) sample to measure moisture content and shearing strength ensure the water content and its shearing strength (13 or 16 kPa) after installation of CFG pile cover clay bad with the plastic to maintain the water

content for 7 days. Therefore, Tank bottom 50 mm filled with the uniform sand which was passing 600 μ its density based on a standard relative density test, minimum and maximum unit weights of sand was 18.37 kN/m³ and 22.61 kN/m³. The test tank size height is 0.5 m (500 mm). Tank each side is marked 50 mm layered to by red marker. The 50 mm layered soil required for filling tank calculate amount of dry soil keep in a plastic boxes and with the required amount of water mixed properly and kept covered with a plastic cover for 36 hours to achieve a uniform consistency. The soil was carefully mixed and manually in plastic containers before fill in the tank soil was layered 50 mm thick into the tank using the kneading compaction technique to achieving the soil density (18 kN/m³) by the compacting rod of 11 kg temping rod as shown in Figure 3. During the laboratory experiment maintained, these protocols were held in all experiments. Sliced the clay bed's final surface keep horizontally to provide an appropriate surface for the measurements. During each test, conducted unconfined compression for specimens collected from various depths of the test tank to ensure that the undrained shear strength was correct. In all circumstances, it took a proper cure to preserve the water content $\pm 1^0$ during the test. (Rao *et al.* 1998) (Sivapriya and Gandhi, 2013; Tandel *et al.*, 2013)



Figure 3. Temping Compacted Rod

CFG Pile installation and test

The casting of CFG piles was fixed at desirably positioned at the required location for a single pile installation in the clay bed. Mainly followed main five steps were considered during the installation. (1) Casing Pipe setting: According to the CFG pile

desirable centre of clay bad, make a mark respectively pile center to center distance 1.5 or 2.5 D. for installation of single first set up PVC pipe (50 mm and 70 mm; Outer Diameters) one by one casing pile fixed with a CFG Pile cap frame installation must be horizontal; the Casing pipe should be attached to the CFG pile cap vertically, casing pile with Sharp edge than gently push in a soft clay bed by using a hydraulic jack (rate of installation was 2.5 mm/ min). ensure the all on the same axis, and then move the submerged tube perpendicular to the level. The vertical difference shall not be more than 1 %. Therefore A thin layer of grease was coted on outer and inner side of casing pile to reduce the friction between the casing pipe and soil. Casing Pipe submerged in soft clay at requiring depth of CFG pile. (2) Immersed Casing pipe & soft soil remove: After installed all casing pile ensure it level and soil did not disturbed during the installation than a helical augur used to removed the inside soil of casing pipe. Its diameter is 4 mm less than an external diameter of pipe before started excavation. Ensure that the casing pipe's Eccentricity must be avoided during a submerged phase and always check whether the casing pipe tip is buckled whether the casing pipe is offset or inclined. If the above condition arises, it must address right away augur was submerged only 60 mm interval. (3) Soft clay removed into the casing pipe using augur; there is no way for water or mud to get into the casing pipe. The casing pipe made by PVC. It was function as separator between the inside and outside soil therefore, and no way water or mud come inside during extraction from the casing outer side soil moreover tank bottom (50 mm) layer was filled with the sand that permeability is higher than clay. The concrete (CFG) mix was pore after cleaning the pile if some amount of water was remaining that water absorbed by cement Moreover, soft clay is extracted easily; a thin layer of lubricant was also coated inside the casing pile, although clay particles have remained clean properly before adding the CFG pile mix. (4) CFG pile concrete poring: As concrete is poured into pile casing during pile casting, as much concrete as possible should be poured at a regular time. Similar method fallowed during experiment. The CFG mixed When an approximate 60 mm height filled in casing pile CFG mix concrete compacted by rod (30 Blows). After compacted measured required depth. To satisfy the amount of concrete volume fill before the second amount concrete pouring, the height of the first evacuate of pipe for pull must be kept within the appropriate range. The casing pipe pull should not be too heavy. The concrete surface inside the tube is not

deteriorating. Mean basically three steps of installation first steps the CFG pile mixed 60 mm fill in casing pipe. Second steps compacted Third steps smoothly removed pipe repeat all this steps until pile casted 50 mm above the ground. (5) Curing time: The CFG pile having a two-binder material cement and flyash both are react with water therefore the kept a minimum of 7 days CFG piles for properly cured with a sprinkling of water on its head. When inside piles cured were moisture present inside the clay

CFG piles tests were conducted with different configurations, as shown in Figure 4. The 12 tests with 13 kPa and 12 tests for 16 kPa, shearing strength of soft soil were conducted with variable center-to-center distance, length of CFG pile, and diameters mentioned in Table 2.

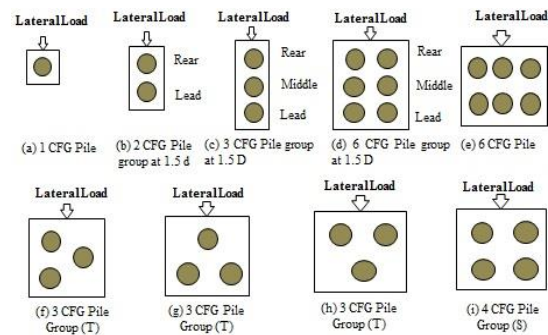


Figure 4. CFG Pile group configurations and CFG pile spacing

Table 2. List of Experiment and CFG pile Group configuration with spacing

No Of CFG Piles	Shorter	Longer	Diameter (mm)	Length (mm)
1	--	--	50, 70	450
2	--	1.5 D	50, 70	450
3	--	1.5 D	50, 70	450
4	1.5 D	1.5 D	50, 70	450
6 (Al)	1.5 D	1.5 D	50, 70	450
6 (Ac)	1.5 D	1.5 D	50, 70	450

(Note- Al - Along Axis; A.C.: Across Axis loading; D - CFG Pile Diameter).

The Soil Shearing strength is less than 15 kPa defined as a very soft soil and soil 15-20 soft soil, Present study based on a experimental work on soft soil. It was borrow from the near city. When prepare a clay bad the amount of (18 and 15 %) water added which is based on the UCS test to achieving 13 and 16 kPa. Hence the soil liquid limit is very low.

The CFG piles (fixed with the pile cap) were cast successfully placed in the middle to a desired distance of the soil tank and supported by a supportive Steel in a vertical statue. The CFG pile was fixed with a fabricated Cap and screw arrangement. Functionally while the lateral load is applied on the fabricated cap, it can efficiently distribute the load equally to all CFG pile. In these arrangement two no. of the screw were used. It can hold all piles vertical as well as prevent against the rotation at the palace. Therefore each Pile was cast 60 mm above the clay top surface, and top-level kept equally measured by water level. When the necessary fixer fixed, ensure the horizontal level of the clay surface model. until load cell and LVDTs were doing set. used device (load cell and LVDS) data acquisition system used to the data collection.

Description of Experiment Results

A total of 24 CFG pile tests were conducted to study behaviours of variable soil shear strength/density and various pile configurations, which were affected the overall lateral resistance of mono and a small group of CFG pile efficiency. The CFG pile groups were subjected to lateral loaded in a step-by-step manner. The CFG pile cap's nonlinear load versus lateral displacement and vertical settling may be well described.

Figure 5 shows the influence of soil shear strength on CFG single piles versus average pile deflection. The load-deflection curves were nonlinear, as seen in the diagram, and showed a similar pattern. In both 13 and 16 kPa, shear strength dense settings. Compared to horizontal deflections, vertical displacements were negligible as Plaxis results, consistent with previous research that could measure soil-pile contact independently under lateral and vertical loads. As the variable shear strength of soft clay was increased from 8 % to 11% under the exact moment of load, the lateral deflection disparities increased in both experiment and numerical results, which were well arranged. As a result, a higher density will have stiffer resistance if a CFG pile expose under lateral loads because clay gets stiffer, while its shear strength increases in soft clay. In other words, the relationship between the underlying soft clay and the CFG pile material determines CFG pile other activity when exposed to lateral loads applied in Plaxis numerical analysis. That based on the The finite-element model. It was created using the commercial FE software PLAXIS 3D. The elastic and elastic ideal plastic Mohr-Coulomb constitutive models were used to (Soft soil

and sand) and CFG pile portions of the model considered a linear elastic model Hance considering computational expenses without compromising accuracy, the mesh density was made finer in the neighborhood 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 K0 geostatic stress field within the soil mass that produced minimal deformation yet was in equilibrium with pore water pressure (Reese *et al.*, 1974) The initial condition was followed by introducing piles sequentially, considering the soil and CFG pile surface are rough. Construction vibration has been not accountable. The ultimate lateral capacity of a single CFG pile (D-50mm) in 13 kPa and 16 kPa soft soil are 4.75 kN and 5.86 kN, respectively, as shown in Figure 5 in the point where the load - CFG pile head become substantially linearly that point were considered as ultimate load.

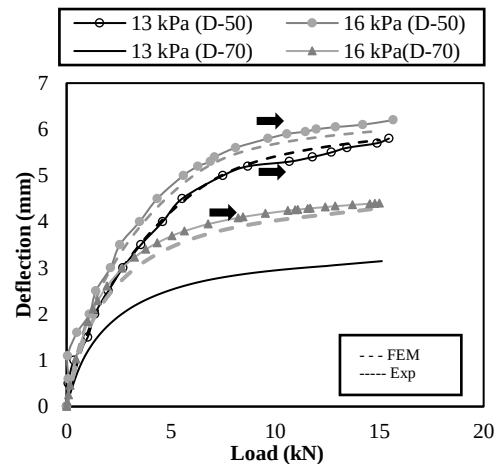


Figure 5. Load vs. Deflection relation of a CFGpile with variable shear strength

Figure 6 explain the effect of a CFG pile lateral pressure on soft clay; in both cases, soft clay resists the lateral load of structure effect were nearest. Lateral soil pressure along the CFG pile was continuous, as explained in it.

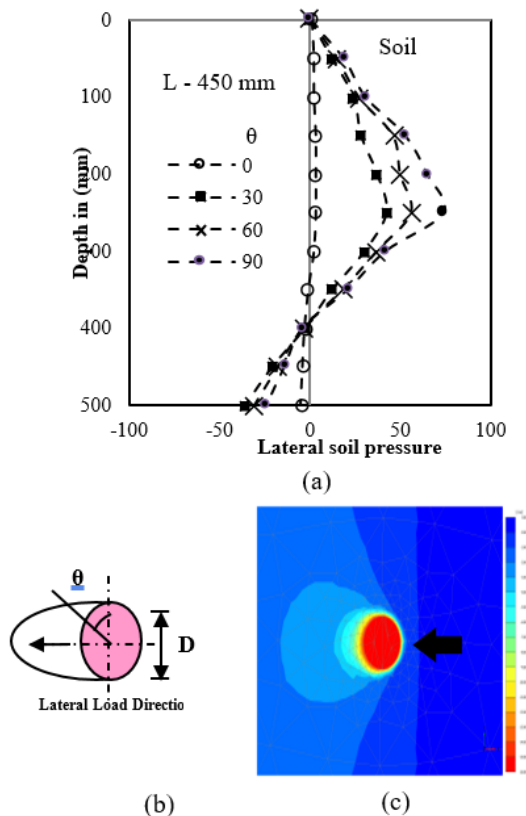


Figure 6. (a) Numerical analysis results (Plaxis 3D) (b) Soil pressure distribution across section; Soil Pressure distribution (c) cross-section in Plaxis 3D

These pressure profiles corresponding to the ultimate lateral load in Figure 6(a) based on Plaxis analysis. Here soil pressure variable with angular distance θ (0, 30, 60, 90) hence θ is zero consider the opposite face of the CFG pile subjected to the lateral load face. The soil lateral pressure distribution as shown in Figure 6(b) here soil pressure at the center was maximum than pressure decrease until it becomes to zero.

During the experiment, it was difficult to fix the strain gauge on the surface of the CFG pile because CFG piles were bored-casted piles at a laboratory. To study the lateral behaviors of two CFG pile groups by using the numerical FEM approach using Plaxis 3D software. Figure 7 (a) explained the shade of combined two CFG piles in one row. The nature of the CFG pile is semi-rigid; it is stiffer than the stone column and much flexible than RCC pile (Cao and Liu, 2014).

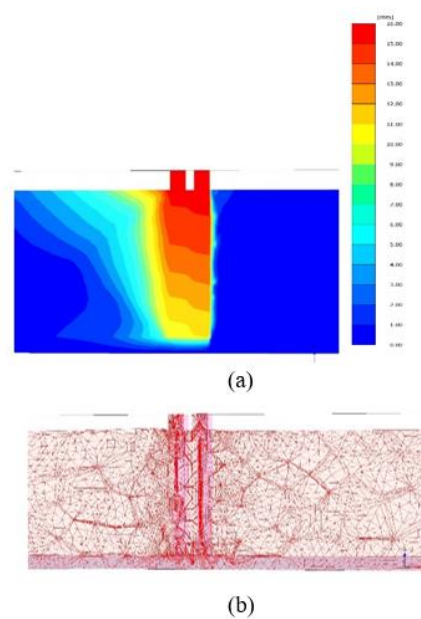


Figure 7. Plaxis Lateral displacement of 2 nos CFG pile Group (a) shading of Lateral Displacement (b) Distribution plane in lateral displacement

The capacity increases about 18-24 % when CFG piles are subjected to lateral load in single to double CFG piles in a row. Figure 8 shows the relationship between the lateral load and lateral displacement of two different shear strengths, and The CFG pile spacing was considered 1.5 D (D = Diameter of CFG pile). It observed that the behaviors of both CFG piles were nonlinear. This can result in CFG pile brittleness failure nature. There is a negative friction region around the strengthened pile body with soft soil, resulting in a drop-down load, which reduces the CFG pile real lateral load potential and the protection degree of the pile weight.

Figure 9(a) represents the deformation of the CFG pile concerning Depth. In FEM analysis each pile center and 25 mm above the ground node i.e. (0, 0, 25) of each CFG pile was selecting. Deformation in front of the Pile is consistent with passive deformation, whereas deformation behind the CFG pile is consistent with active deformation. When lateral displacement exceeds 5% of pile diameter, a zone of soil movement extends from the ground surface to half of the pile length, extending to eight times to the pile diameter; at the back of the Pile, a zone twice the CFG pile diameter is affected.

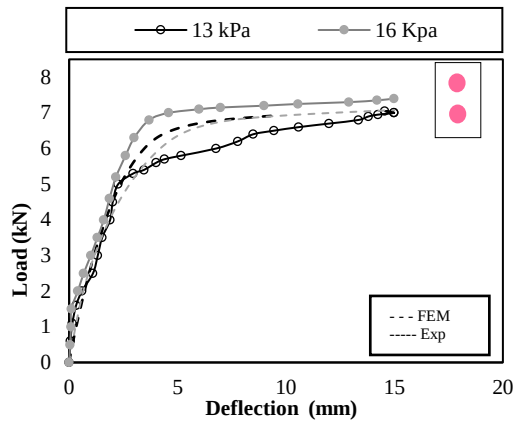


Figure 8. Lateral load and displacement relationship of two CFG piles in single row

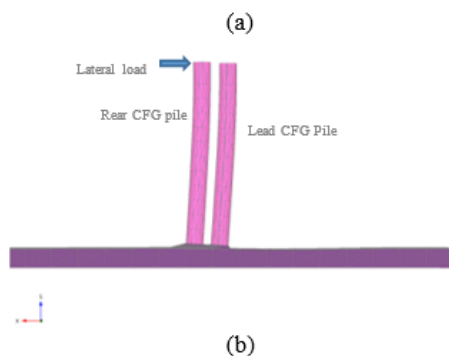
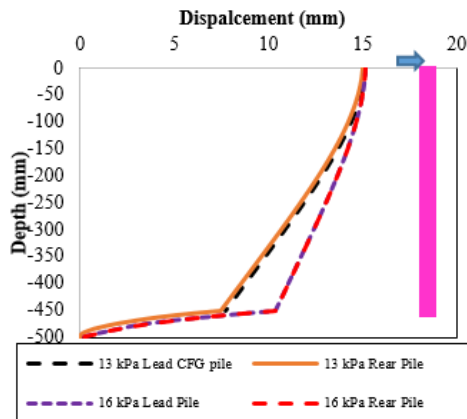


Figure 9. (a) relation between the Depth and displacement of two CFG pile group (b) Plaxis Output for Lateral deformation

Notably, the maximum lateral displacement of soil occurs just behind the Pile, with no gap between the CFG pile and the soil developing during the experiment. Soil near the trailing CFG pile head

moves forward to fill the gap (Void) created by active soil pressure.

The Figure 10 shows load-displacement curves for three CFG piles groups in sequence. In the numerical analysis of CFG piles were considered volume pile models. The noticeable difference in lateral bearing capacity between variable shearing strength of soft clay, implying that both plaxis models results can qualitatively match well-known CFG pile group behavior with experiment.

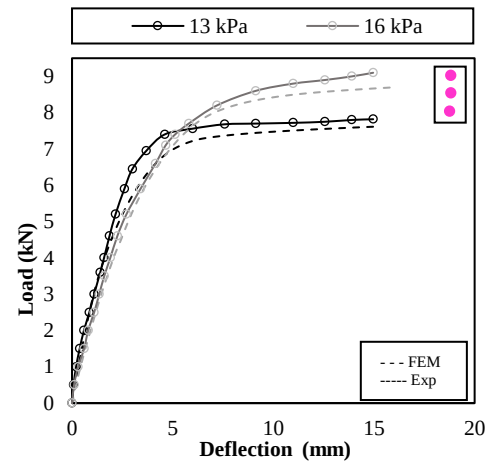


Figure 10. Lateral load and displacement relationship of 3 x 1 CFG piles in single row

In the 3x2 group CFG piles, lateral behaviors concerning Depth well explained in Figure 11. It can show in Figure 11(a) the transmission on lateral deflection is related to the CFG piles position. Hence the lateral load directly applied 1-row Pile defined as rear Pile, 2-row form later load direction piles described as middle and 3-row Pile defined as a lead pile (Figure 11(b)). The lateral deflection in soft soil (transition depth) is the function of $S_u/\gamma D$ (where S_u - shear strength of soil; γ - the unit weight of soil; D - diameter of Pile) only explain in table 3. The soil failure mechanism's transition depth is predicted to be unaffected. The Figure 11(c) illustrated lateral displacement of rear, middle, and lead CFG pile in 3x2 group at 1.5 D Spacing square patron arrangement hence CFG piles submerged in soft clay 450 mm from the top surface. Normally, CFG piles and clay interaction (bonding) failure occur while the 0.1 - 0.15 D displacement happens in all load with variable shear strength. Moreover, all piles were rigidly connected with the cap, although lead pile displacement measure high compare to lead and middle Pile.

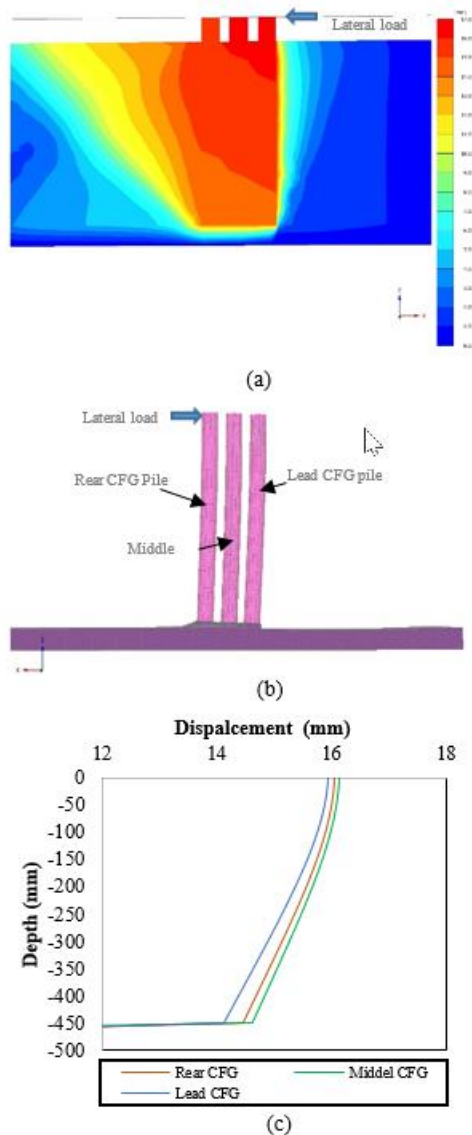


Figure 11. Plaxis Results of (a) Shearing Effect of 3x2 group CFG Pile; (b) CFG pile actual bending under lateral load (c) relation between the lateral displacement and Depth of CFG with a position in the group

Table 3. Summary of analyses with CFG pile deflection at top surface soft soil failure

Case	1	2	3	4
S_u (kPa)	13	13	16	16
D (mm)	50	70	50	70
γ (kN/m ³)	18.0	18.0	19.5	19.5
Deflection (mm) measured by FEM	16.03	11.32	16.50	12.69

Table 3 explain about the summary of measured maximum deflection in a variable shearing strength of soil CFG pile failed. case 1 and case 2 show the maximum deflection of 50 mm and 70 mm CFG pile measured by FEM at 13 kPa respectively when case 3 and 4 shows the maximum deflection of 50 and 70 mm CFG pile at 16 kPa shearing of soil respectively. Results shows that CFG pile installed 16 kPa shearing strength soil is less amount of settlement compare to 13 kPa in both 50 mm and 70 mm. Because of the interaction with the failure surface of the piles in front of it, piles in trailing rows tend to have reduced lateral resistance, which is known as “shadowing” (Brown *et al.*, 1998; Dulić and Aladžić, 2016). As pile distance increases and overlapping decreases, group interaction becomes less critical. A laterally loaded pile group study is a three-dimensional issue, with significant soil nonlinearity and complicated interactions between structural parts as governing factors, necessitating contemporary numerical methods to solve the problem correctly in load transfer techniques.

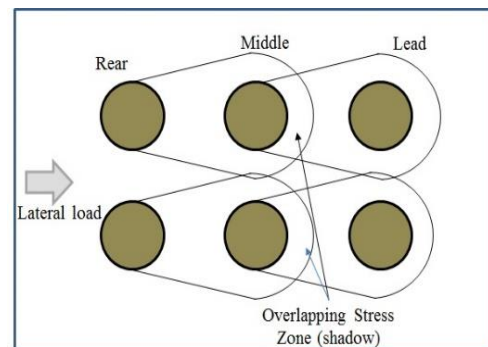


Figure 12. Rear, middle and lead rows in pile group with shear zone overlapping (Brown *et al.*, 1998)

The performance of 3x2 CFG pile groups does not modify the lateral subject displacement in soft clay. Lateral displacement numerically analyzed lateral displacement in soft clay Based on laboratory experiment methods by different sharing strength of clay and diameter of CFG pile measured and computed, lateral displacement with load is compiled on Figure13.

These curves are derived from experimental and analytical observations. These curves show the pile groups' experiment responses while carrying

a pure lateral force. In 16 kPa (D-50mm) curve shows that it has good lateral load resistance; Its behaviours are nonlinear. the higher diameter CFG pile group ultimate lateral capacity is less compare to smaller diameter group CFG pile because of the overlapping stress zone.

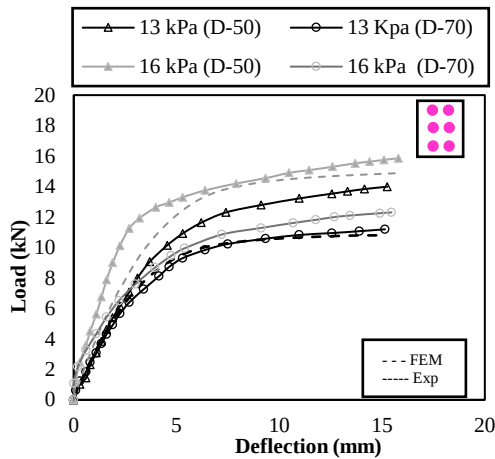


Figure 13. lateral load vs. lateral deflection (3×2 pile group)

to the Depth of the rotation point, based on this phenomenon, soil-pile shearing contact areas were reduced. There fore Lateral resistivity in CFG piles reduced can decrease shearing contact area. The smaller diameter CFG pile L/D and higher diameter CFG pile L/D ratio was considered 9 and 6.42, respectively.

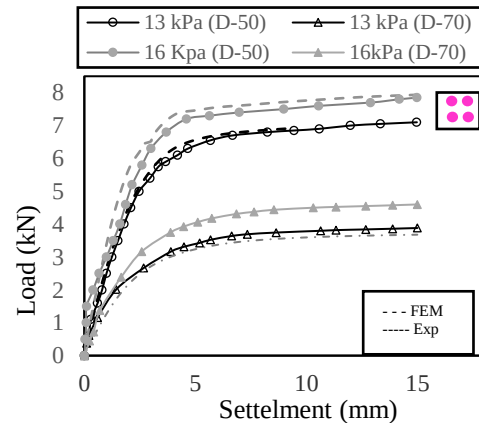


Figure 14. lateral load vs. lateral deflection (2×2 pile group)

The lateral load-displacement curves relationship of 2×2 CFG piles with variable shear strength is shown in Figure 14. The results show the effect of the increasing diameter of the CFG pile with 1.5 D spacing, and it is noticeable. Also found this kind of significant difference in single CFG pile experimental results. The ultimate lateral load has increased in the lower diameter of the CFG pile approximately 1.8 times. Typically, in the Pile, when diameter increases, its load-carrying capacity increases. However, it was not found in numerical and laboratory tests. The fact behind the CFG pile stiffness was infusing by changing the soil mobilization and the CFG pile. (Zhang *et al.*, 2016). As shown in Figure 15, when two similar piles (same length and materials) with two variable cross-sectional under the lateral load affected depends upon its failure nature. The stiffness of the Pile may influence the Depth of the gap if gapping between the soil-pile contacts occurs.

Figure 15 mention the failure criteria depending with respect to depth if Pile length/ depth (L/D) ratio is less, it is fail as rigid and pile length / depth (L/D) is higher it was failed like as a buckling present study all pile (L/D) ratio less pile subjected a lateral load failure criteria is a rigid Because CFG pile subject to the stiffness of the CFG pile with the Depth of gap growth must be restricted

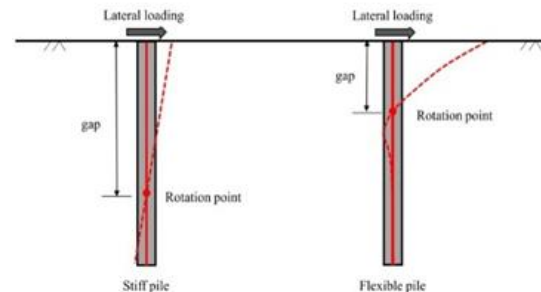


Figure 15. Schematic illustration of the effect of pile stiffness (Zhang *et al.*, 2016)

Based on the triangular paten, three CFG pile group configurations are shown in Figure 16 and Figure 17. In both group parameters, length of CFG pile, center to center spacing, and shearing strength of soil were considered the same only its lateral load applies direction was variable. In one configuration, the lateral load subjected to the perpendicular side of the triangular means to the CFG pile. While another configuration load subjected to parallel to the side of triangular other wards two CFG pile arrange in sequentially which was parallel to the action of load.

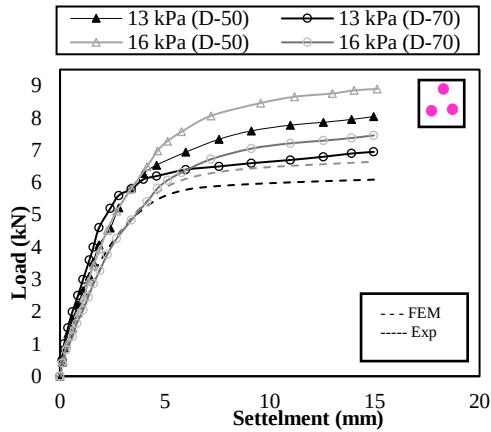


Figure 16. lateral load vs. lateral deflection (3 Triangular pile group; across loading)

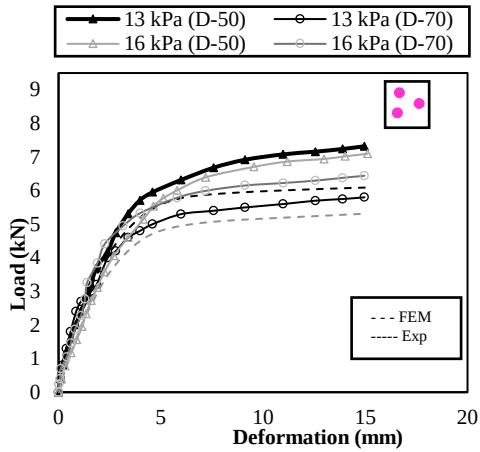


Figure 17. lateral load vs. lateral deflection (3 pile group triangular; Along with loading)

In order to compare both configuration results, it is seen that while arranged the CFG pile perpendicular to the act of load, its ultimate lateral load was higher than other arrangements of the Pile. Typical lateral displacement response of single, two, three in sequence, 2×2, 3×2, configuration CFG pile groups illustrated in Figure 18. To compare does not appear to be modifying the subject single CFG pile lateral displacement. In comparison, CFG pile 3×2 group subjected to low displacement. To lateral displacement is reduced at the toe in 3×2 (6 pile) group to single, two (2×1), three (3×1) and four (2×2) group CFG pile to 4.95, 3.25, 2.68, and 1.91 times respectively. Additionally, the curve in six, four groups are approximately linearly, and three, four, and six pile group behaviors are nonlinear.

In high shear strength soil, the ultimate lateral load remained unchanged as the parallel arrangement of CFG piles from 1.5D. However, in a sequence of CFG piles, it can see the increase rather than in a single CFG pile. The volume fraction affects ultimate resistance because of the passive pressure zone in front of the pile 1×3, 2×2, and 3×2 group, as seen in the diagram. Due to the stressed zone in front of the pile group, the spacing of the piles in the perpendicular direction to the applied load can influence the ultimate resistance load.

In this study, the ultimate resistance is considered as the load corresponding to the double tangential methods on the load-deflection curve. In addition, the group efficiency (η) describes the variable of pile group resistance at a given deflection and is computed as follows: (Khari *et al.*, 2013)

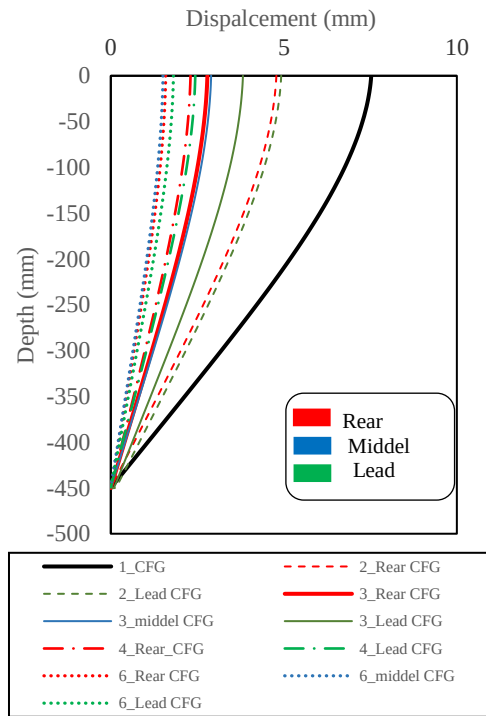


Figure 18. Lateral Displacement vs. Depth

$$\eta = \frac{Q_{LG}}{n_1 n_2 Q_{LS}} \quad (1)$$

Where, Q_{LS} and Q_{LG} are the ultimate lateral capacity of a single CFG pile and CFG pile group respectively; n_1 define the number of rows in CFG pile group; and n_2 is number of columns in the CFG pile Group. This parameter helps determine the

efficiency of CFG Pile groups' ultimate lateral load resistivity of the soft clay.

The estimated group efficiency at 0.25-0.95 at the basic on the ultimate lateral load can determine by the load-deflection curve. Tables 4 and Table 5 represent the CFG pile group efficiency. In order to compare single, single row and group CFG pile results by one of the methods to compare ultimate lateral load resistivity The group efficiency value is higher its lateral load resistivity is higher. Based on these results, the efficiency is higher when the soil shearing strength of the soil is higher. The group efficiency was higher in the 2×1 pile group in shear strength 13 kPa because there is no stress dissipation like as shadow effect. In case of 2×2 pile group, efficiency was observed at 0.24-0.29 % and 0.32-0.34 % for S_u - 13 and S_u -16 kPa respectively.

The fact that the CFG pile is not embedded, therefore, accounts for lateral sliding between the Pile and the surrounding soil, maybe the most significant shortcoming by Plaxis numerical modeling method. It cannot take the influences of CFG pile installation since the accurate circumference of the Pile is not represented during the experiment. However, depending on the CFG pile type (e.g., bored piles or driven piles), the installation might significantly impact real soil-structure interaction. The load-deflection curves were used to measure the overall lateral resistance in various configurations of CFG pile classes. The side friction and the natural front reaction could involve the soft soil resistance to CFG piles under lateral load. These two reactions are influenced by the shape element, which considers the non-uniform distribution of earth stress.

When considering the ultimate load in a group and a single pile, the results of the shadowing process can be observed, with increasing pile

spacing causing the same in both groups and individuals. The ultimate lateral load for a single pile was about 25% of the ultimate load for a three-pile category, while it was about 47%.

Table 5. Summary of Lateral load Efficiency (Shear strength - 16KPa)

<i>Dia. D</i> (mm)	<i>CFG pile No</i>	<i>Lateral load</i> kN	<i>Efficiency</i> (%)
50	1	5.86	--
	2	6.98	0.59
	3-Al	7.16	--
	3-Ac	6.01	--
	4	7.89	0.25
	6-Al	11.89	0.33
	6-Ac	9.96	0.28
70	1	3.89	--
	2	6.62	0.85
	3-Al	6.82	--
	3-Ac	5.94	--
	4	4.61	0.29
	6-Al	9.98	0.37
	6-Ac	8.60	0.43

Table 6. Plaxis input details of CFG pile and soil Material properties

<i>Parameter</i>	<i>Unit</i>	<i>CFG pile</i>	<i>Clay</i>
Material Model	-	LE	MC
Drainage Types		Nonporous	UD
Unit Weight	γ (kN/m ³)	22	18
Young's Modulus	E (kN/m ²)	2.46x10 ⁶	13 x10 ⁵
Undrained shear strength	C_{ref} (kN/m ²)	1.0	45
Poisson ratio	μ	0.2	0.30
Friction angle	ϕ'	--	0
Over consolidation Ratio	OCR	1.0	1.5
Pre overburden pressure	POP	0.0	0.0

Table 4. Summary of Lateral load Efficiency (Shear strength - 13KPa)

<i>Dia. D</i> (mm)	<i>CFG pile No</i>	<i>Lateral load (Q)</i> kN	<i>Efficiency</i> (%)
50	1	4.75	--
	2	6.52	0.69
	3- Al	6.49	--
	3- Ac	5.23	--
	4	6.56	0.34
	6-Al	13.69	0.48
	6-Ac	11.15	0.39
70	1	2.96	--
	2	5.69	0.96
	3- Al	6.39	--
	3- Ac	5.12	--
	4	3.79	0.32
	6-Al	10.79	0.61
	6-Ac	9.85	0.55

Conclusions

Based on a thorough analysis of the literature, it was discovered that there are no detailed instructions for calculating the lateral capability of CFG piles cast in soft clay at the laboratory. The capability of CFG piles on soft soil was calculated in this analysis using model experiments in a laboratory test tank and numerically using PLAXIS-3D. The results of various CFG pile configurations and coherent soil strengths are described in the excellent arrangement described.

When a single CFG pile holds in variable shear strength, the Pile lateral capacity increases by around 18% - 24%, depending on the cohesive shear strength.

The ultimate lateral resistance of the community was calculated using load-deflection curves and scaling variables. The results of the volume fraction of the soil have been studied numerically and graphically. The ultimate lateral load was raised by 37% as the increasing diameter 50 mm to 70 mm.

The leading row in the load direction performs (i.e deflection) similarly to a single row in (2×3 and (1×3) group. with the reduction in lateral resistance with respect to depth. and in case of single piles are deflection is higher compare to group pile. In the following rows, the effect becomes more prominent. The risks are minimal, according to the majority of this study.

In closely spaced CFG piles, the group or “shadow effect” reduces the overall lateral load of a piling group's resistance. Additionally, when in group CFG pile subjected to the same average Lateral load per Pile, the pile group deflects substantially more than the isolated single Pile.

At 0.12 d deflection criteria for various conjugation CFG piles, the ultimate lateral load capacity increases with the increasing soils shearing strength.

The increasing the number of CFG piles in sequence, the efficiency of its reduced. Because of the increased overlapping areas and active wedges. Because it only experiences edge effects, the leading row of CFG piles has the highest resistance of any of the rows in the group. Under the same stress, the piles in the front row are only marginally less resistant than a single isolated pile. Because of edge and shadowing effects, the piles in the next two rows, 2 and 3, exhibit even less resistance. The gaps that grow behind the piles also help reduce the group piles resistance in front of them.

In present study single pile, (2×1), (2×2) (3×2) along and across loading with square patton if spacing is 2.5 D the load is subject to along direction it is better lateral resistivity capacity. In case of triangular patton lateral load subjected along direction subjected give a better result. In order to compare square and triangular arrangement, the triangular is a best in a lateral load resistivity because in tri angular arrangement soil between the pile confinement area modified and enhanced bearing capacity Therefore triangular arrangement of group pile is recommended for ground improvement technique.

Scope of work

Although the current study findings are intriguing, large-scale experiments to examine the implementation of optimization of CFG pile with variable configuration and compare outcomes with

CFG piles enhance the strengthened with layered geosynthetics reinforcement.

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