Experimental Evaluation of Bearing Capacity of single CFG pile

N. B. Umravia[1]and Dr. C. H. Solanki[2]

[1]Ph.D Scholar, Applied mechanics Department, S.V.N.I.T Surat, Gujarat, India.
[2]Professors, Applied Mechanics Department S. V.N.I.T Surat, Gujarat, India.

Abstract. Nowadays, geotechnical engineers are facing the problem of soft ground, which results in to low bearing capacity and excessive settlement. On contrary, Cement Fly-ash and Gravel (CFG) pile is one of the emerging ground improvement techniques, which can be applied to enhance the load carrying capacity of the soft ground. It also reduces the possibility of settlement associated due to soft ground. This paper addresses the practical real time results of laboratory model of single CFG pile. Moreover, the comparative evaluation between simulation results (i.e. numerical analysis) and laboratory model has been carried out considering variation in parameters such as diameter of the CFG pile, length to diameter ratio of CFG pile, and gravel particle size. The results obtained from this analysis clearly proves superiority of CFG pile over soft ground in terms of enhancing load carrying capacity.

Keywords: CFG (Cement Fly ash Gravel) Pile, Mix design, Load carrying Capacity

1 Introduction

The bearing capacity of any piles depends on the types of pile, namely (i) bored cast in situ pile and (ii) precast embedded pile. Normally, CFG piles are bored piles. Its baring capacity depends on two components (i) negative skin friction and (ii) base resistance. Experimental full-scale modeling plays significant role for understanding geotechnical parameter. It is very difficult to develop a certain laboratory model of CFG pile for specific prototype condition. This laboratory model tests at abated scale would be able to identify basic information of stress, deformation, lateral resistance, and failure pattern of pile. In addition, the bearing capacity of the single pile has been also determined. However, a scale model of a static loading test of the pile has been considered more cost effective and reasonable option than the corresponding on full-scale model.

1.1 Literature survey

In recent past, it has been observed that CFG pile composite foundation plays an important role for improvement in soft soil foundation strength, stability, and reduce the settlement [1]. Many researchers work on the railway embankment CFG pile. Which also plays a significant role in reducing subgrade settlement[2]. CFG pile is a kind of high bond strength pile, which is consisted with macadam, gravel, sand, fly ash, and mix up cement &water. It forms composite foundation with cushion and soil between piles [3]. The soil between CFG piles has been compacted. Subsequently, the Strength has been improved and the liquefaction of loose foundation can be basically eliminated [4]. Based on reported literature on rapid development of high speed railways in China, it is inevitable that in order to meet challenges for High-Speed railway embankments (HSRE), it is essential to utilize CFG pile composite foundation instead of soft clay.[5],[6],[7],[8]. Moreover, in order to limit the friction at top and bottom, the CFG pile composite foundation has been developed using both linear distribution of friction along pile. In spite of applying this technique in the field, it is required to carry out detailed study of it considering different parameters, which influence the performance of CFG pile reinforced in soft clay bed. It is to be noted that the size of gravel particle plays vital role on the performance of the CFG pile.

2. Laboratory Experimental Setup & Materials

2.1 Loading Frame and Displacement sensors

In this paper, experimental investigations have been discussed using the small scale laboratory model of single CFG pile with variable L/d ratio means slenderness and area replacement ratio. Mostly, this ratio focuses on the analysis of stress versus settlement behaviors of single CFG pile. Further, the entire test was conducted on circular steel tank having 300 mm diameter and 600 mm depth. In[9], the experimental set up consists of loading frame, load cell, rigid steel container and other equipment is shown in Fig. 1.A capacity of 5 Ton self -weight steel framed structured fabricated and fixed a hydraulic jack at the center of main loading frame (attached with 130 mm plate). It had the power of 50 kN that was set on a horizontal beam of loading frame. In order to control the load rate during experimental work, hydraulic jack has been operated manually. A CFG piles are casted in center of the circular tank. The size of steel tanks does not cause any confinement against pile deformation. During the experimental, two different sensors have been used, which has been calibrated prior to testing. Further, one side of the high capacity, 100 kN, S-shape, load cell has been attached with connecting rod of the hydraulic jack and other end with loading plate. Moreover, two LVDT sensors with the capacity of 50 mm and accuracy 0.1 mm have been attached with loading frame. Tank size has been designed using unit cell approach. Here, the diameter and height of tank is taken 300 mm, and 600mm, respectively. In order to make this presented work more qualitative, the permissible accepted settlement is taken as 50 mm for isolated footing.

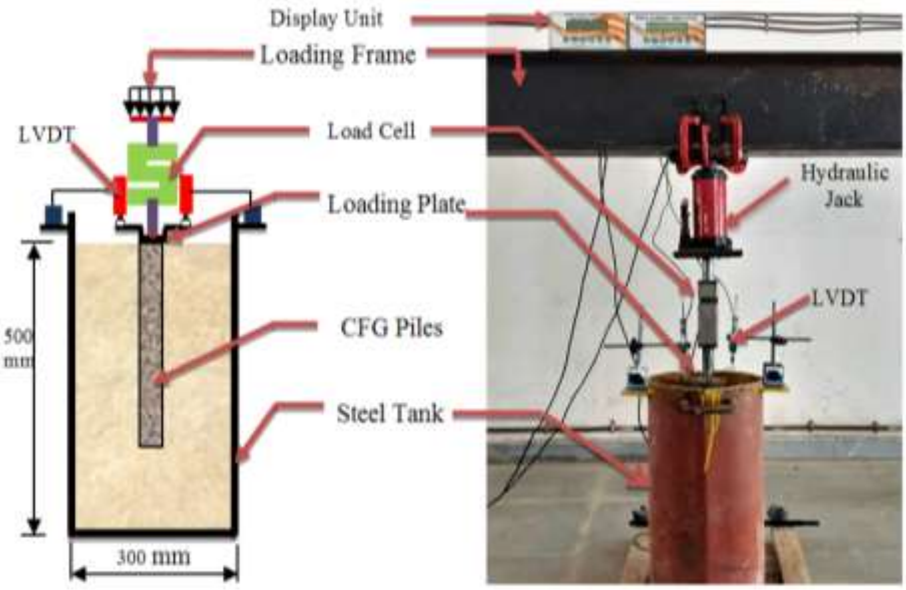

Fig. 1. Laboratory Experimental setup

2.2 CFG Pile Experimental Model &Model Consideration

In this presented work, total 15 numbers of experimental cases have been developed generated by changing the parameters such as different gravel size, length of pile, diameter of the pile etc. (as shown in Table-1) for single CFG pile. However in field practices, this type of CFG pile has been considered as short column pile. The experimental results have been compared with the Finite Element Method (FEM) results. It has been concluded from this comparison that the field results are almost mapped with the FEM results.

Many researchers have discussed the application of unit cell idealization method by assuming pile in a triangular pattern in column technology [2],[10],[11],[12],[13]. The same have used for this experimental work. In this experimental set length is represented using L/d ratio (i.e. 2.5, 3.0, 3.5, 4.0 and 4.5). It is to be noted that in this presented work, the shear strength of the soft soil has been maintained of the order of 13 kPa. In this study, all the boundary conditions are considered. Here, the area replacement ratio was defined as percentage area of virgin soil is replaced by the CFG pile. Further, during this study, the variation of CFG pile diameter is also represented as area replacement ratio. Here, the center to center distance and area replacement ratio (Ar) are taken as (i) 3.0d and 12% considering 70 mm dia and (ii) 2.8 d and 10% for100 mm dia. CFG Pile length to diameter ratio changes from 5-to-14 and soil replacement ratio varies from 0.08-to-4 it has been reported [11], [14],[6][15].

Table 1. List of single CFG pile Tests

Test	Diameter of Pile (mm)	Garvel type	Length of pile		Types of Pile	No of Test
			70 mm	100 mm		
Clay bed	--	--	--	--	Soft Clay	02
CFG Pile	70	G1	450	--	Floating Pile	01
	70	G2	450	--	Floating Pile	01
	70	G2		175, 210, 245, 280, 315	Floating Pile	05
	100	G2		250, 300, 350, 400	Floating Pile	04
	70	G1	500	---	End Bearing	01
	100	G2	500	---	End Bearing	01

G1 and G2 are variable gravel size used for present study

2.3 Soil Properties

In this presented work, the soil was collected from rural area of Dahod city. It is yellow colour, low plasticity soil, which is classified as CL (clay) based on I S: 1498: 2000. Fig. 2 shows the particle size analysis of soil. Prior to use, the soil has been air dried using oven. Thereafter, it is stored at room temperature before all experimental tests. The soil particle size is less than 75 Micron. Subsequently, it easily passes from 200 no sieve. The physical properties of clay are presented in Table – 2.

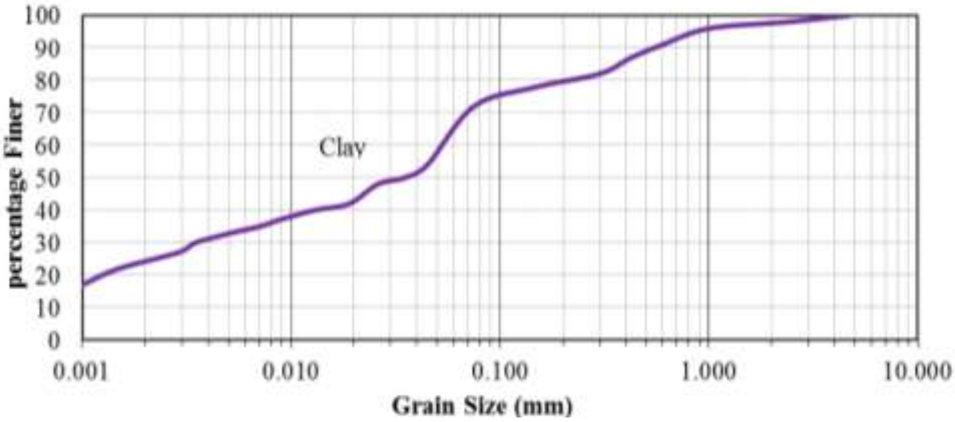

Fig. 2. Particle size distribution

2.4 Gravels

In CFG pile, gravel plays significant role to transfer the load. Further the gravel enhances the strength of CFG pile. In this present study, two different sizes of particle sizes gravels have been used. These gravels are discussed as below. (i) G1: ranges from 6.3 mm-to-10 mm. (G1: Cu = 2.19, Cc = 1.40) and (ii) G2: 6.3 mm-to-4.75 mm. (G2: Cu = 2.86, Cc = 0.38). Further, the physical properties of gravels G1 and G2 are described in table – 2. In case of gravel G1, the maximum and minimum unit weight is 15.9 and 15.3 kN/m3 respectively. Whereas for G2 maximum and minimum unit weight 16.4 and 15.9 kN/m3 respectively. The particle size distribution curve is illustrated in Fig.3.

2.5 Cements and sand

In this experimental work, the cement of 53 grade ordinary Portland cement, has been used in all experimental work was as per confining IS: 269- 2015. The physical properties of cement, initial settlement time and final setting time are mention in Table -3. Here, based on IS: 383-2016. The sand from a local query and river sand (i.e. natural disintegration of rock by alluvial sand) has been used in this study. Further, the size of particle is maintained from 1.0mm-to- 0.6 mm.

Table 2. Properties of Soil and Gravel G1 and G2

Parameters	Unit	Clay	Gravel G1	Gravel G2
Natural Water Content	(%)	14	-	-
Specific Gravity	-	2.64	2.53	2.55
Maximum Dry unit weight	kN/m^3	19.10	-	-
Bulk Unit Weight	kN/m^3	21.62	15.5	16.2
Liquid limit	(%)	29.5	-	-
Plastic Limit	(%)	0	-	-
Plasticity index	(%)	29.5		
Uniformity coefficient (Cu)	-	-	2.19	2.86
Curvature coefficient (Cc)	-	-	1.40	0.38
Unified classification symbol	-	CL	GP	GP

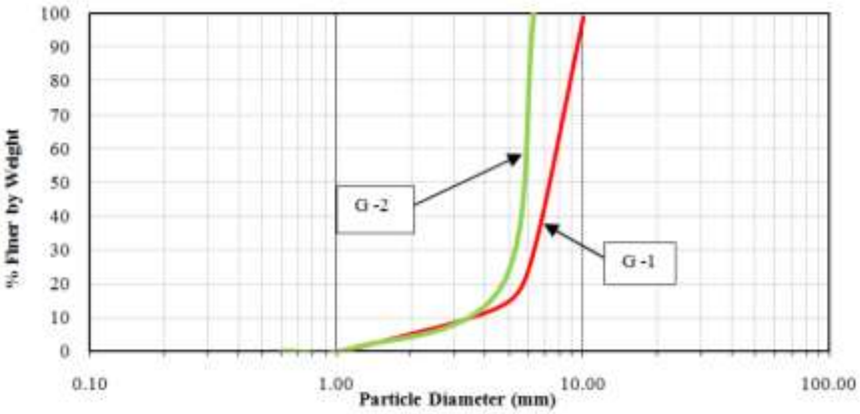

Fig. 3. Different particle distribution curved of gravel

Table 3. Basic Properties of Fly-ash

Properties	Value
Classification	Garde-1
Colour	Black
Specific Gravity	1.55
Grain Size Distribution	--
(a) % Gravel	0
(b) % sand	25
(c) % Silt and Clay	75
Maximum Dry Unit Wt. (kN/m^3)	13.21
Optimum Moisture content (%)	21.5
Fineness, m^2/kg, Min (Blaine Air permeability)	312
A particle retained on 45 μ IS sieve (Wet sieving).	22 %

2.6 CFG Pile Concrete Mix

The CFG pile Mix designs based on its compressive strength which is laying between C-5 to C- 25 design. The Mix design methods have been adopted from ‘China Academy of Building Research’ guide line. The Making of concrete mixed was by the cement, sand, gravel, fly ash, water reducing agent and water. It is required the compressive strength of cubic would be approximate 28 MPa after casting 28-day. Design of C-20 grade of concrete have been considering for mix design proportional as per Shuang you, et al (2016)[16]as the reference bench mark for study. The results of that concrete mixed have not been adopted worked in Indian fly ash and cement proportion. New concrete mixes for the present are mention in table 4. It is adopted for all the experimental works.

Table 4. CFG Pile Mix Design Proportion

Material	Cement	Sand	Gravel	Fly ash	Water
Unit	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3
Mix Design C-20	1	3.2	4.13	0.51	0.59
Unit Wt.	265	848	1094	135	160

2.7 Soft Clay Bed Material Preparation

In order to prepare a soft soil clay bed for the all experimental work having shear strength of the order of 13 kPa, additional 23% water has been added in oven dry soil. The shear strength of the soft soil has been measures by performing Unconfined Compression Strength (UCS) test at the laboratory. The results of this tests are shown in Table 5. Initially, 50 kg dry soil has been divided in five equal parts and stored in the plastic boxes. Thereafter, 23 % water has been added. This mixture has been placed by covering plastic cover for 36 hours. Afterwards, this mixture has been poured in cylindrical tank at 50 mm height (as shown in Fig.1). Further, each layered have been compacted using 9 kg temper rod. This rod is shown in Fig 4. However, this compaction of soil has been achieved 18kN/m3 bulk density

Table 5. Results of unconfined compressive strength tests for clay

Water Content (%)		23%	22%	21%	20%	19%	18%	17%
Undrained shear Strength (kPa)	7 Day	13.01	16.15	18.16	23.23	26.24	35.55	43.22

Fig. 4. Tamping Rod

2.8 Construction of CFG Pile in laboratory

The CFG pile has been constructed using below mentioned step wise procedure

1. A long hollow-stem pipe has been inserted gently to the standard depth in to soft soil clay bed in the cylinder. In order to reduce the friction, lubricant has been applied on both the surface of the hollow pipe. Thereafter, the soil has been removed from the hollow pipe using auger.
2. After removal of soft soil from the hollow pipe, concrete mixture has been filled in that space. During this filling, the hollow pipe has been lifted upwards at the rate of 10 mm/ minute.
3. After complete removal of hollow pipe, from top surface, the upper layer (approx. 50 mm of length) has been removed.
4. In order to provide sufficient time to gain the adequate strength of pile, this mixture is keep ideal for 07 days.

3 Numerical modeling

In this presented analytical (simulation) study, Plaxis 3D software package has been used. Further, the software codding for CFG pile model has been carried out using finite element code. The dimensions of this CFG pile is taken same as experiment model. In this study, the boundary conditions of CFG pile are considered circular rather than rectangular (i.e. conventional). During this study, mesh size of 15 nodes with triangular element pattern has been used.

Based on the literature reported in this area, most of researchers used rectangle boundary surface with non-rigid confinement. On contrary, in this experimental set up, circular boundary surface has been used. Moreover, the rigid confinement is provided using steel plate.

The soft soil was modelled using the “Undrained A” approach of Plaxis (undrained effective stress analysis with effective strength parameters). The CFG piled was modelled as a nonporous. The stiff soil providing end bearing was modelled as drained. Both stiff soil and soft soil were modeled by Mohr–Coulomb behavior, the parameter values and CFG piled was modeled by linear elastic material for analysis other details of numerical input data are listed in Table. While a small effective cohesion (c = 1 kPa) was adopted to avoid numerical problems. A bulk unit weight (γ) of 22 kN/m^3 has been adopted for the CFG pile. It has been reported in [17]’ [18] that the young’s modulus of elasticity constant changes narrowly due to the effect of bearing earing capacity of CFG pile. Therefore, in this study, the Young’s modulus of elasticity constant has been selected of the order of E = 21000 MPa instead of 25000 MPa. Here, the angle of dilation (ψ') has been calculated according to the formula $\psi' = \varphi -$ 30. Moreover, the poison ration of the order of 0.2 and 0.3 has been considered for CFG pile and soft soil, respectively. The experimental and Plaxis 3D models are described in Fig. 5.

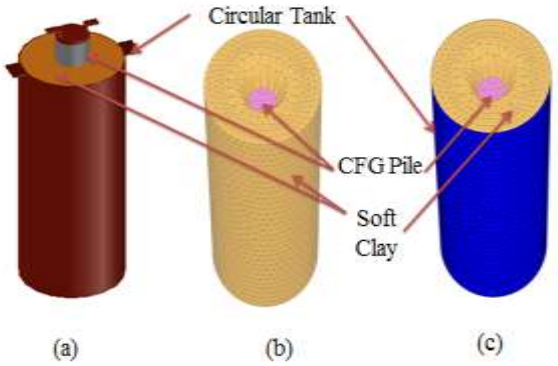

Fig. 5. Numerical Model compare with Experimental model (a) Experimental Model, (b) Plaxis 3D Model without cylinder tank, and (c) Plaxis 3DModel with cylindrical tank

4 Experimental Results with Numerical Analysis

In this section, the influences of some parameters on the load-carrying capacity of CFG pile and the stress-settlement behavior of CFG Pile for each section are presented. Here, the load on CFG pile has been increased up to maximum limit and subsequent load settlement curve are noted and plotted. The numerical analysis results of CFG pile for total vertical settlement against the given load are shown in Fig. 6. It has been observed from Fig. 6 that the linear displacement (bulging effect) changes narrowly. Clay Bed

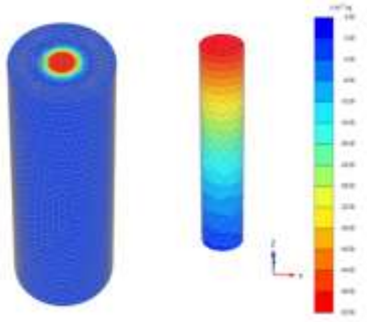

Fig. 6. Plaxis 3D image of Total vertical displacement sheading

The experiment results for the stress settlement behavior of Soft Clay bed are shown in Fig. 7. It has been observed from Fig. 7 that the maximum stress of the order of 83 kPa has been obtained for corresponding 50 mm settlement. Further, the failure point has been easily identified.

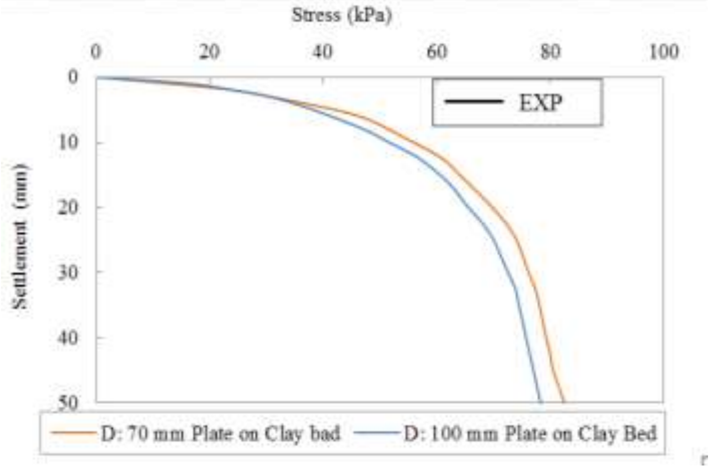

Fig. 7. Stress – Settlement Behaviors of Clay bed Under 70 mm and 100 mm foundation plate

4.1 Influence of CFG Pile

In order to compare the performance of single CFG Pile, load tests has been performed on soft clay bed and single CFG pile. Fig. 8 shows the stress-settlement response obtained using laboratory tests and numerical analysis for both ends bearing CFG pile along with the untreated clay bed. These results were obtained by loading the CFG pile area only or an equivalent area in the case of the clay soil. It can be ascertained that after a very small vertical settlement, the mobilized vertical stress on top of the CFG pile is always greater than for the Soft Clay Bed, and the difference increases with the additional settlement. It can be observed that clay bed fail at very nominal load whereas there was not failure observed in the CFG pile. It is observed the experimental results of soft clay and 70 mm end bearing CFG pile stresses at 50 mm settlement were 83 kPa and 2230 kPa respectively which is approximate 27 times higher than the soft clay. This is due to the rigidity of the CFG pile which enhances increase in load-carrying capacity. Fig. 6 shows the shading of vertical settlement along with the depth of the CFG pile. It can be observed that vertical settlement is distributed throughout the length of the column. This is due to the rigidity of the CFG pile.

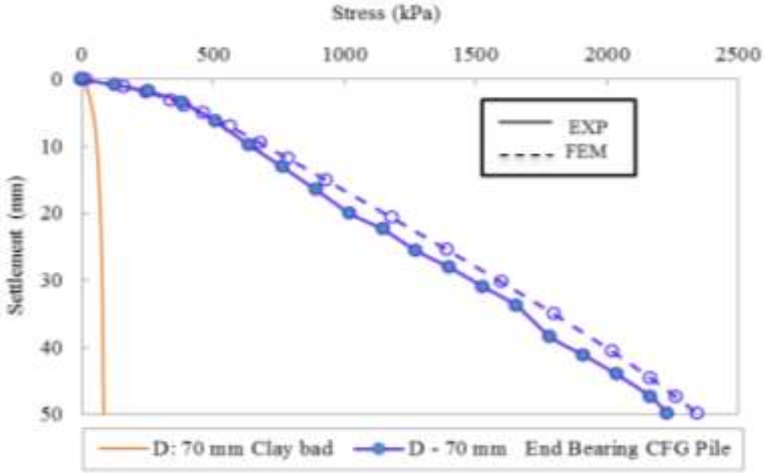

Fig. 8. Stress - Settlement Behaviors of Experimental soft Clay Bed and 70 mm CFG pile.

4.2 Influence of column Diameter

Fig. 9 shows the experimental performance of 70 mm and 100 mm Diameter of end bearing CFG pile having 500 mm length. By analyzing the experimental results, it has been observed that the maximum stress for 70 mm and 100 mm diameter CFG pile is 2230 and 1811kPa, respectively, i.e. the load carrying capacity of the 100 mm diameter CFG pile is about 1.23 times more than that of 70 mm diameter pile. On contrary, the stress concentrations have been reduced increasing the diameter of pile.

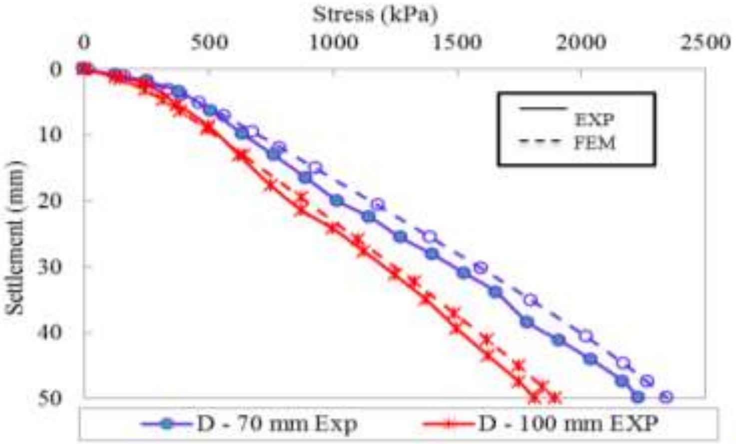

Fig. 9. Stress versus Settlement response of 70 mm and 100 mm single CFG pile with End bearing.

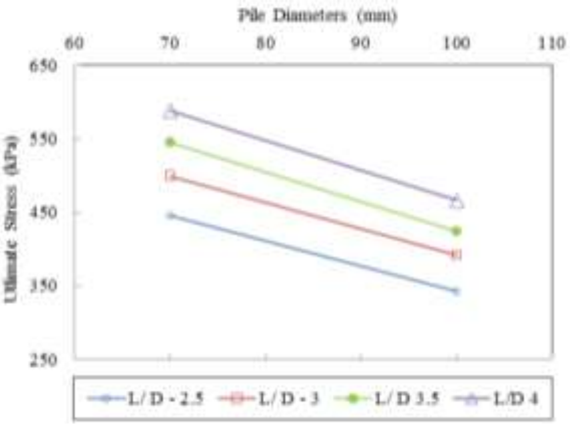

Fig. 10. Relationship between Diameters versus ultimate Stress with different L/D ratio

In order to investigate the ultimate stress of the CFG pile in floating condition at 50 mm settlement with 2.5, 3, 3.5, 4 L/D ratio are elaborate shown in Fig. 10. It may be noted that irrespective of CFG pile diameter, the stress carrying capacity of the soil decreasing by CFG pile.

4.3 Influence of Gravel Particle size (d)

In order to investigate the effects of gravels particle size on the axial load carrying capacity of single CFG floating pile for soft clay, the tests (analytical study and experiments) have been performed. Here, soft clay bed and single CFG Piles of 70 mm diameters with 450 mm length with using G1 size grave particle (10 mm < d < 6.3 mm) and G2 size grave particle (6.3mm<d< 4.75) are used. Further, in this case, d represents the average gravels particle size. Fig. 11 illustrates experimental and numerical results of stress- settlement behaviour of the single CFG pile with G1 and G2 size gravel particle. It can be clearly seen from Fig. 11 that the load carrying capacity of smaller size grave particles CFG pile is greater than CFG piles having bigger size grave particles (roughly 20%). This is due to the densest packing forms by small size of gravel particle provides more strength than the bigger particle s

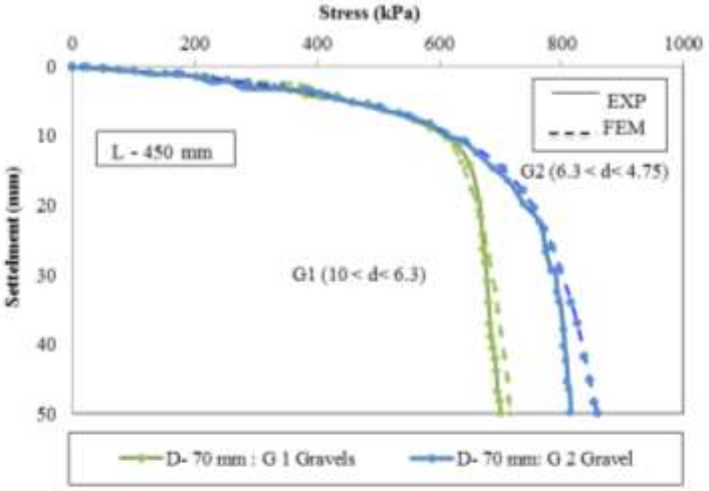

Fig. 11. Relationship between ultimate stresses with different L/D ratio (Diameters)

5 Conclusion

Both experimental and numerical investigations have been carried out to evaluate the stress -settlement behavior of CFG pile in soft soil. It is concluded that the CFG pile is considered as more suitable option compare to soft soil for ground improvement technique.

1. The experimental and numerical result of CFG pile has been compared with soft clay. It has been clearly observed that CFG pile improve the stress ratio approximate 28 time in comparison to soft soil.

2. The effect of different types of gravels G1 and G2 (shapes of particles and their distribution) on the load-carrying capacity has been discussed. It has been concluded that as the size of gravel increases the stress concentration of the CFG pile decreases
3. The results obtained from numerical analysis are almost mapped with the experimental results.
4. It is essential to study the behaviors of CFG pile scale effects of experimental model. This has been validated using small- scale test at laboratory model.
5. Behaviour of the semi stiffened rigid CFG pile on 10 mm – 18 mm settlement mobilize vertical load is discussed and find improved results.
6. It can be concluded that by increase in diameters of CFG pile, the stress concentration in soil settlement decreases.

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