Experimental and Numerical study Behaviors on Single Cement Flyash Gravel pile under the combined effect of axial compression and Lateral load

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Abstract. A CFG Cement, Fly-ash and Gravel piles are one of the most popular approaches in geotechnical engineering for load transfer in soft soil and ground improvement in railway, road embankment, high rise building. Its behaviors are like as semi-rigid types of the pile. The analysis and computation of ultimate axial compression load and lateral load in soft soil experiments were conducted in a laboratory to obtaining the response of a single CFG pile. The experimental model of CFG pile is made up of cement fly ash and gravel cast in situ types ascertained using physical scaling fundamental, based on material size, properties, a grade of Mix and prototype of pile foundation. Moreover, the in-situ bored CFG piles have been cast in 70 mm and 100 mm external diameters for Laboratory tests. Hence the different CFG pile lengths are considered for variable L/D ratios. All the experiments were performed on soft clay under independent axial compression and lateral load test; it is also to investigate the combined effect of axial compression and lateral load. It has been observed that the behavior of CFG piles under independent individual loading is significantly different when compared with combined loading. It also derives the relationship between the ultimate load in axial compression and lateral loading as well as in the combined effect of loading. It observed that the ratio of ultimate lateral load and axial load in individual to combined loading are significantly increasing. However, the CFG pile vertical deflection /Lateral displacement at considering with its safe factor of lateral load/ axial compression was increasing effectively. In addition to determining the safe axial load / lateral load that has been considering in the present study may be required for design limiting displacement/ deflection failure criteria of the CFG pile effectively under combined load. It is noted that the CFG pile imposition with combined loading can substantially improve the soil properties and can lead to the economy in the design of foundations.

1. Introduction

Due to growth of urbanization and industrial development have been forced on infrastructures establishment, but the geotechnical engineer has faced the problem of unavailability of suitable ground for it. Therefore the ground improvement techniques are the use of the marginal site and weak soil construction of structure like railway embankment, high-rise tall building and others to ensure its stability, achieved required bearing capacity and reducing the settlement after construction. CFG pile composite foundations are used widely in china because after construction settlement and uneven settlement have been reducing. Many researchers had worked on optimization design of CFG pile [1-
2) for application in high-speed railway embankment, tall buildings [3-7], CFG piles combined with geogrid were adopted as an improvement method to reinforce the embankment built over Completely Decomposed Granite soils [8]; at site encountering as weak soil condition. However structure like Jetty structure, tall chimney, transmission tower and other structures which are subjected to a large lateral load, overturning moment due to the wind and ocean waves or combine effect of both. Many experimental works [9-11] and numerical analysis [12-13] studies have been conducted for investigate the behaviors of CFG pile supported embankment. Numerical analysis of lateral loading were study in Plaxis 3D followed based on [16].

2. Methodology
CFG piles are a new approach for the Indian environment In this present study a CFG piles models experiments were carried out in the laboratory to understanding the behaviors of CFG piles with influence with a diameter and its length. It was a significant help to measure the single CFG pile load versus settlement under a static axial compression load, lateral load, and combined load. Models were properly cast and cured 7 days under standard method, in this research paper focused to determine the primary function of lateral load transferring by applying the suspension lateral load. CFG pile can easily transfer the vertical load and lateral load. So the combined action of axial and lateral ground load can occur due to effect of an earthquake, heavy wind, slope failure and liquefaction lateral spared. Details methods of experimental setup and casting conducted are briefly discussion in the following Section.

2.1. Test set up for axial compression test
As shown in Figure 1 major equipment were used in all laboratory experiment are circular steel tank, loading frame, hydraulic jack, load cell with a display unit and 2 LVDT with a display unit.
- The inside dimension of the tank were fixed as 0.3 m (diameter) and 0.6 m (length) and the side and bottom of the tank were made up 8 mm thick steel sheet molded and made as a circular tank.
- The vertical loads were applied with a constant rate of 1.2 mm/ min in all experiments with help of hydraulic jack having maximum 100 kN capacity. Moreover the each load increment was carried out maintained constant rate of loading until CFG pile top head settlement uniformly. The applied load to the CFG pile was measured by using S type load cell having 100 kN capacity suspended from the spindle of the jack through an connecting rod and resting on a CFG pile with a ball bearing. Two LVDT (linear variable differential transformer) was used to measure settlement of loading plate. Minimum least count was 0.01 mm and maximum 50 mm.
- Display units were used to measure Load and settlement behaviors. The static compression loading tests are performed according to the (ASTM D1143–1994) for axial loading tests.

2.2. Laboratory setup for lateral loading
- The lateral loads were applied in a laboratory experiment by a manually suspended load, it was hangout under the gravitational load this load connected with high-level flexible wire and durable which maximum tensile load capacity 30 kN capacity. This was connected horizontally with CFG pile head collar.
- High flexible wire passed from a frictionless pulley. It was a special arrangement made and welds with steel tank as shown in figure 2. Wire one end is fixed with pile collar and while other end attached with a suspended load
- It was very difficult to measure the lateral load increment was maintained the constant until displacement was no significant change (i.e, 0.04 mm/min). For measuring the lateral displacement by LVDT were fixed horizontally.
2.3. Laboratory setup for combined loading

a. Figure 2 (c) shows also a photo of the combined loading experimental setup.
b. Axial compression load were applied on the CFG pile by hydraulic jack who have been connected with load frame and vertical displacement were measured by digital dial gauge.
c. Lateral load were measured as same method follow in lateral loading.

![Figure 1. Photograph of experimental setup for axial loading.](image)

![Figure 2. Experimental set up for Lateral Loading (a) 3D view of Experiment set up (b) Plane of Experimental setup (c) photograph of laboratory experimental setup](image)

3. Model test

A Casted CFG pile tests were conducted in soft clay. The requirement of the materials and sample preparation are explained as per mention briefly in followed section.

3.1. Materials

In this study, casted CFG pile the cement, sand, and aggregate were used locally available from dahod city, India for casting bore pile in a laboratory. However, the standard sand 600 μ size according IS: 383-.2016 was also used to improve the capacity of the pile. The aggregate size was 6.3 mm less than and greater than 4.75 mm its coefficient of curvature Cc and coefficient of uniformity Cu was 2.86 and 0.38 respectively, the specific gravity was 2.55 and bulk unit weight was 16.2 kN/m³.

3.1.1 Soil properties and sample preparation

The soil used for laboratory model tests it is clay. Test laboratory model end bearing CFG pile tank bottom 100 mm layer the sand used locally available river sand. The sand was cleaned and dry. Direct
Shear test were performed on this sample for laying a bed at 60% relative density (RD) Friction angle 29.4% and Coefficient of curvature (Cc) and coefficient of uniformity Cc was to be 2.42 and 1.06 respectively. Preparation of soft clay a uniform moisture 23% added, which was determine results of unconfined compression test on clay. Clay mixture was kept 36 hrs. in five isolated plastic box for vaporization process. 11kg clay were filled in test tank and compacted uniformly by 9 kg weighted temper complete it for test tank in 10 layers 50 mm each layer achieve the bulk unit weight 18 kN/m³. The experimental model of CFG piles were prepared cast in situ type bored pile made by cement (C) sand (S), gravel (G), fly ash (F) and amount of water (W) with maintain as per design mix proposal (i.e, C:S:G:F:W ratio 1: 3.2 :4.13 :0.50: 0.61) a constant density of mix CFG piles were maintain for all tests to provide a similar test tendency in vertical axial load and lateral load. Test CFG piles installation has been followed by the procedure described by [14]. During the experimental, there are the two types of tests namely axial vertical compression test were consider IS 2911 Part 4 guideline on and other lateral pull types loading were follow according to ASTM-D3966-07. This experimental study, including laboratory model test of vertical, laterally loaded CFG pile and combined loading is an important measurement for comparison and validation of any design approach. where the vertical compression load specifically way as not induce the horizontal deflection and any friction resistance. So that’s a factor that may be minimized using the plate and roller assemble according to ASTM A – 36. In this paper, a laboratory combined axial/ lateral load test compare with that of Finite element analysis by Plaxis 3D, this approach follows the [15]. The combined axial/lateral load test was conducted on a 70 mm diameter CFG piles with variable length 2.5 d, 3.0d, 3.5 d, and 4.0 d mm length. This test was executed in experimental unit slightly based on ASTM D 3699 testing procedures. It is expected that laboratory piles are subjected to allowable load/ ultimate load only. It is a small scale model test. The safe load is obtained by considering the different factors of safety (FOS = 1.3 to 2.5) according to many codes of practice. Hence tests were done in two-part; first part by providing constant 30, 50 and 70% of ultimate axial load magnitude in conducting lateral load test and the second part of test conducting by keeping constant magnitude 30% of ultimate lateral load. The overall test program is mention in Table 1.

Table 1. Overview of Test Program

| CFG pile Dia. | Length (mm) | Axial compression load (Vu) | Lateral Load |
|---------------|-------------|---------------------------|--------------|
|               | Without Lateral Load | With lateral load (H/Hu) | Without axial load | With axial load (V/Vu) |
| 70 mm         | 175         | Yes                       | 0.3, 0.6, 0.9 | Yes             | 0.3, 0.5, 0.7 |
|               | 210         | Yes                       | 0.3, 0.6, 0.9 | Yes             | 0.3, 0.5, 0.7 |
|               | 245         | Yes                       | 0.3, 0.6, 0.9 | Yes             | 0.3, 0.5, 0.7 |
|               | 280         | Yes                       | 0.3, 0.6, 0.9 | Yes             | 0.3, 0.5, 0.7 |
|               | 315         | Yes                       | 0.3, 0.6, 0.9 | Yes             | 0.3, 0.5, 0.7 |
| 500   End bearing | Yes         | 0.3, 0.6, 0.9 | --             | --             |

3.2. CFG pile subjected to Combined load

- A desire vertical load was applied in four increments and maintained for approximately one hour before applying a lateral force. The lateral force was applied initially by tension cable passed from the frictionless pulley and fixed with a suspended load. The loading should be applied in regular interval 5 percentage continuous at a rate sufficient constant rate of lateral displacement 0.01 mm per minute) this incremental repeated until failure of CFG piles or the specific deflection value of 13 mm. Vertical settlement of CFG pile measured by digital dial gauge which is position on the top of the pile Cap. The lateral load was reduced to every regular increment load every 30 minutes. Similarly test was then reduced to zero in five decrements. The remaining lateral force was removed over a three minutes period. End load reading was taken for 30 minutes.
4. Test Results and Discussion

Test were conducted on CFG pile at the constant bulk density and shear strength of soil the results corresponding to the CFG pile under consider axial, lateral and combination are presented in these sections. Figure 3 shows the load-displacement curve for the CFG pile at variable length under axial compression load. The ultimate load capacities of the CFG pile are interpreted using the tangential method for the analytical approach hence for validation of experimental work by Plaxis 3D modeling. It is seen in figure 3 (a) typical load – settlement behaviors are nonlinear and all the experimental CFG piles are short pile. However, the failure range of all pile were consider as nonlinear nature and its range maybe 12-20 mm vertical settlement. In the present study for axial compression laboratory, test settlement were measured up to 50 mm. To investigate the effect of end bearing CFG pile with hard strata and soft strata at the bottom it seems as per figure 3(b) it has been increasing 4.5 times.

![Figure 3](image)

**Figure 3.** Load -Settlement curve for (a) Floating Pile with Variable length (b) Comparative of Floating and end bearing pile

Figure 4 shows the lateral load-displacement curve of various lengths it seems that Different length of pile lateral behaviour under lateral load figure 5 shows the relationship of different dia of CFG pile Lateral behaviour. It is clearly observed 2.1 times more in 100 mm dia pile compare to 70 mm.

![Figure 4](image)

**Figure 4.** Lateral load vs displacement curve of various length of CFG pile

![Figure 5](image)

**Figure 5.** Typical Lateral load vs displacement curve of various diameters
Table 2. Ultimate Lateral load measured with and without constant ultimate axial load.

| CFG pile dia. | Length (mm) | Ultimate Lateral Load Hu (N) |
|---------------|-------------|------------------------------|
|               | V = 0       | V = 0.3 Vu                   | V = 0.5 Vu                   | V = 0.7 Vu                   |
| 70 mm         |             |                              |                              |                              |
| 175           | 440         | 460                          | 510                          | 580                          |
| 210           | 500         | 520                          | 580                          | 630                          |
| 245           | 580         | 620                          | 670                          | 780                          |
| 280           | 830         | 850                          | 900                          | 920                          |
| 315           | 850         | 840                          | 900                          | 940                          |

Figure 6. Variation of lateral load with pile top deflection measured under constant Axial load with a variable length of CFG pile the ultimate lateral load shows in table 3 during the combined loading the failure criteria consider 12 mm in lateral displacement and 25 mm in vertical displacements.

Table 3. Ultimate Axial load measured with and without lateral load 25 mm permissible settlements.

| CFG pile dia. | Length (mm) | Ultimate Axial compression Load Vu (N) |
|---------------|-------------|---------------------------------------|
|               |             | H = 0                                  | H = 0.3 Hu                   | H = 0.6 Hu                   | H = 0.9 Hu                   |
| 70 mm         |             | 1750                                   | 1600                         | 1540                         | 1440                         |
| 210           | 1960        | 1850                                   | 1740                         | 1650                         |
| 245           | 2140        | 1910                                   | 1750                         | 1610                         |
| 280           | 2310        | 1995                                   | 1860                         | 1890                         |
| 315           | 2460        | 2240                                   | 2160                         | 2030                         |
| 500           | 3110        | 2980                                   | 2880                         | 2760                         |
| 500 EB        | 8820        | 8320                                   | 7850                         | 7580                         |

Figure 6 shows the Variation of lateral load with pile top deflection measured under constant axial load with a variable length of CFG pile the ultimate lateral load shows in table 3 during the combined loading the failure criteria consider 12 mm in lateral displacement and 25 mm in vertical displacements.
displacement taken in all the laboratory test. It is observed those lateral loads were increasing with increasing L/D ratio. Figure 7 relatively of the axial load – settlement curve CFG pile deflection with 0.3 Hu, 0.6 Hu and 0.9 Hu lateral loads.

![Graphs of Axial Load vs Deflection](image)

**Figure 7.** Variation of axial load with pile deflection measured under constant lateral load (a) L - 500 mm; (b) L -500 EB; (c) L – 175 mm; (d) L-210 mm; (e) L- 245mm; (f) L-280 mm ;

5. **Conclusion**

The study captures the behavior of single CFG pile subjected to axial, lateral and combined loading in soft clay soil, the lateral deflection being limited to 12 mm and vertical displacement being limited 25 mm in combined loading the following conclusions can be made:

- The axial load test in single CFG pile load-carrying capacity significantly increasing a 6-9 % increase with an increasing (L/D) ratio.
- The ultimate lateral bearing capacity of CFG piles in clay significantly increasing with the increasing length of CFG pile. The lateral deflection was observed for the CFG pile subjected to only lateral load but in increasing. The axial load-carrying capacity of a pile is decreasing 3-5 % in lateral load 0.3Hu; 6-8 % in lateral load 0.6 Hu and 9- 11 % in lateral load 0.9 Hu in combined load. Due to lateral load distribution and relative moment generation.
- The presence of a vertical load had increased the lateral load capacity with increasing L/D ratios but the influence of vertical load decreases with an increasing slenderness ratio of CFG piles at all vertical load levels for both types of CFG piles. The lateral load-carrying capacity increased by 4-6 % 8- 10 and 11-13%, in 0.3 Vu, 0.5 Vu and 0.7 Vu respectively.
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