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FIELD STUDY ON SOFT SOIL IMPROVEMENT USING CONTINUOUS FLIGHT AUGER (CFA) PILES

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ABSTRACT: The continuous flight auger (CFA) piling technique is commonly used where the presence of groundwater or potentially collapsible material reduces the cost-effectiveness of bored piling techniques. Whilst generally considered a soil replacement technique, the process of pumping concrete under pressure during the pile installation can result in a significant improvement of the surrounding soil, particularly in low strength soil conditions. In this study, a case study is analyzed. An oil storage tank was intended to be constructed on soft clay in southern Iraq. The tank has a diameter of 46 m. Cone penetration test, drilling boreholes, and field tests have been conducted in the tank site. A decision was made to improve the mechanical properties of soft clay of the site by CFA piles before construction of the tank. The depth of CFA pile constructed is 16 m, with a diameter of 0.5 m and spacing between piles is 4.2 m. Three types of in-situ tests have been conducted: Conventional plate load test on the soil before and after improvement; large plate load test for soil after improvement; and pile load test on CFA pile. It was concluded that construction of CFA piles shows an increase in the bearing capacity by about 110% for the soil directly around piles and 70% for soil within 2 m from the center of piles. Large plate load test result for the pile with surrounding soil revealed that the ultimate bearing capacity increases to 500 kN/m^2. So that the overall loading area showed an increase in the bearing capacity of about 350% when CFA piles are constructed.

Keywords: Soft clay; Improvement; CFA pile; Plate load test, Bearing capacity.

1. INTRODUCTION

Clay consistency can be described qualitatively using terms like very soft, soft or stiff. The British Standard specifies how clayey soils are classified in terms of consistency (C.P. 8004, 1986) [1]. Such characterization depends on the cu "undrained shear strength", it tends to be seen, that delicate soft clay possesses a low shear strength that reaches between 20 to 40 kPa and under 20 kPa for extremely soft clay [2]. Soft clays are characterized by a lack of bearing capacity, high compressibility, and a long consolidation time. Bergado et al. [3] have handled this topic in an appropriate manner, with well-documented case histories demonstrating the inherent benefits of soft clay improvement.

The improvement of soft soil processed by concrete or lime profound mix has been utilized since the seventies. Such procedure was perceived as an impressive advancement in different nations like Sweden, Japan, France, and so on, . . .Soil adjustment could cause the soil to be more steady via utilizing an admixture for the soils [4]. The DMM (deep mix method) represents a kind of treating soils at the site where a local soil or fills get mixed with cementitious and additionally different material, ordinarily alluded to as fasteners. Contrasted with local soil or fill, the soils that cover composite materials that are made have improved designing features like expanded strength, lower penetrability, and decreased compressing ability. The soil most appropriate to DMM incorporates firm soil with high dampness substance and free, immersed, fine granular soil. DMM likewise is utilized effectively in a wide scope of soil with cohesion as well as fills, yet it can normally not be practical in thick or hardened material or in-ground with obstacles like cobble or rock. The treated soil features acquired via DMM can show the properties of the local soils, cover qualities, development factors, operational boundaries, cure period, and load circumstances [5].

Bouassida et al. [6] carried out a comparison between advantages of improvement techniques by illustration of typical case histories. Farouk and Shahien [7] studied the including of soil's cement column made via the deep mix method as a method of the soil stabilization which can be employed effectively to get rid of such problem.

The deep mixing method is cost effective and requires special equipment. So, some trials have been made to use stone columns [8].; [9]; [10]. It is also important to note that CFA piles are a semi-displacement and low-pressure injection method of pile installation which means that not only construction, but also structural and geotechnical performance is dependent on the means and method of construction [11].

Igant et al. [12] carried out a study on 2 dimension modeling of excavating that has a tied back sheet pile divider in connection with opposite lines of profound dried blended overlap sections got contrasted with a 3 dimensional modeling. It was examined the technique that considers the impact of the overlapping areas between segments in a 2 dimensional modeling, where the enhanced soils were displayed as composite materials, and the outcomes between the 2 dimension plus 3 dimension examinations were contrasted with an attention on anticipated failing load, failing system, along with distortions.

Fattah et al. [13] examined the conduct of the embankment model laying on delicate soil supported with standard and ESC (encased stone columns). Model's testing was conducted with various dividing distances among stone-columns and two length-to-breadth proportions (L/d) of the stone-columns, notwithstanding extraordinary dike statures. It was discovered that whether a segment was gliding or end bearing (laying on an inflexible layer), encasement of the column by a geogrid was best in improving the bearing proportion of built up soil by roughly 1.29, 1.39, and 1.63 occasions and 1.4, 1.57, and 1.83 occasions that of untreated soil.

Fetherston et al. [14] reviewed the consequences of ground improvement checking through the establishment of CFA pile in delicate thixotropic clay named CIS (Coode Island Silt) in Melbourne. The observing information got gathered from two destinations by electronic information lumberjacks introduced in the ground at different good ways from the pile's establishment areas, to profundities up to 25 m. The consequences of the observing were back-examined utilizing limited component programming PLAXIS 2D to set up benchmark models dependent on the real pile establishment succession. It was set up the impact of fluctuating distance between a focal point and the pile's establishment area and diverse pile measurements.

El-Ghaffar et al. [15] studied hypothetically the pile load – settlement conduct of CFA piles at various areas in Gharbia governorate in Egypt, in given of static pile load test results. The examination intended to play out an all out overview of the bearing limit of CFA piling in the delta zone of Egypt which contains urban areas, for example, Tanta, Zifta, Samannoud, AlMahalla Al-Kubra, Alsanta, Qu-visit, Kafr El-zayat, and Bassyun. The investigation was completed with the guide of various programming, for example, (2D PLAXIS, rendition 8.2), which relies on versatile consummately plastic limited component models, just as (All Pile, form 7; SHAFT, adaptation 8) which are dependent on (p-y) examination bend. Furthermore, the examination showed that there is a union between the orientation limits of the heaps determined as far as far as possible determined from the consequences of the trial of the apparatus of the heaps in the delta area up to 82% of the exhausted heaps so a definitive heap limit is activated at settlement equivalent to 2% of heap distance across, which is in concurrence with the ECP esteems for little widths.

The case histories outlined by [11] provides a small sample of CFA projects that have been successfully installed and tested in the Prairies over the past 15 years. Static load testing has been conducted on most of the sites which resulted in a good understanding of geotechnical design parameters and allowable load capacities. Collaboration with specialty contractors can result in optimization and significant cost-savings for Owners. Contractors can also provide useful feedback and ideas when engaged in front-end engineering and design (FEED).

2. RESEARCH SIGNIFICANCE

The current work aims at investigating the ability for the enhancement of soft clay using CFA piles. The development in bearing capacity has been determined based on field tests carried out including plate loading tests and pile load tests. Moreover, the current work comperes the cost between using normal piles in site project and use improvement of soft soil by use CFA piles. The paper suggests a method to validate the enhancement in bearing capacity of soft clay improved with CFA piles. Conventional plate load test is carried out on the soil before and after improvement to get the natural bearing capacity of soil and the bearing capacity for the soil after improvement.

3. EXPERIMENTAL WORK

3.1 Soil investigation

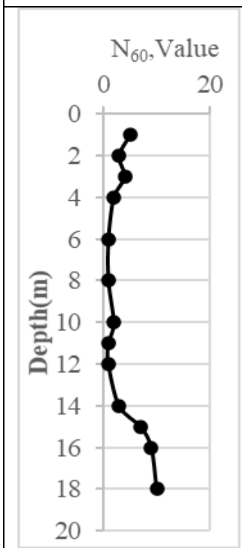
In this study, a case study is analyzed. An oil storage tank was built upon soft clay in Al-Amarah city, which is located south of Iraq. The tank has a diameter of 46 m. Cone penetrating testing was executed, in addition to boring boreholes, and field testing at the tank location. The soil samples got exposed to routine laboratory testing to decide the mechanical and physical properties of soils. Fig. 1 presents the borehole log, cone penetrating test outcomes, and standard penetrating resistance (N) in the site. Table 1 shows the mechanical and physical properties of. soils.

3.2 Construction of CFA piles

Installation of CFA piles is a method to improve soft soils through the rotation of a hollow-stem auger in the earth to 16 m depth with 500 mm diameter. C15 concrete is infused through the auger shaft below ceaseless positive pressure, when withdrawing the auger, to apply a positive vertical pressure upon the earth-filled auger flight just as horizontal pressure upon the soils encompassing the put solid section. CFA piles as characterized here involve: a) customary ceaseless flight auger pile; b) bored relocation piles planned to introduce a cast set up piles with full displacing as well as negligible soil ruin; and, c) non-complete displacing pile that might dislodge soils yet not acting as a full displacing pile.

There is a difference between CFA piles and traditional drill shafts or bored pile. The main difference is that no need to use of casing and it is quicker compared to drill a shaft excavating, an activity that is needed to bring down the drill piece on numerous occasions to finish the excavating is small. Due to drilling and casting CFA piles as opposed to drive them, CFA piles also eliminate splices as well as cutoffs. Therefore, CFA piles are widely used in civil work in the world wide. The depth of CFA pile constructed is 16 m, with a diameter of 0.5 m and the spacing among piles is 4.2 m.

Depth, m	Description
0-3.0, Layer A	Brown Inorganic soft to medium dry strength lean silty clay, CL
3.0-13.0, Layer B	Gray inorganic Very soft to soft dry strength silty clay, CL
13-18.5, Layer C	Brown Inorganic medium dry strength lean silty clay, CL



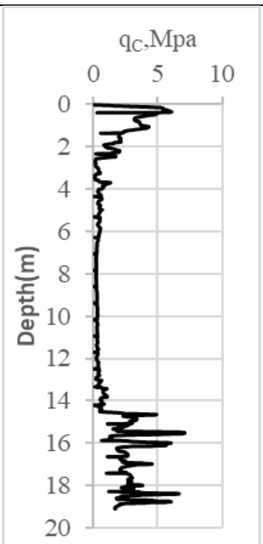


Fig. 1 Borehole log, cone penetrating test outcomes, and standard penetrating resistance (N) in the site.

Table 1: Soil properties.

Property	Soil A	Soil B	Soil C	Specific-action
Liquid limit (LL), %	46	39	41	ASTM D 4318-16 [16]
Plastic limit (PL), %	22	16	22	
Plasticity index (PI), %	24	23	19	
Specific gravity (GS)	2.69	2.65	2.73	ASTM D 854-14 [17]
Sand content %	3	2	12	ASTM D 422-10 [18]
% Passing sieve No. 200	97	98	88	
Silt content %	22	52	43	
Clay content %< 0.005 mm,	75	46	45	
Natural unit weight kN/m3	18.13	17.76	18.42	ASTM D7263[19]
Natural water content, %	16	39	21	ASTM D2216 – 19 [20]
Undrained shear strength, cu (kPa)	23-26	2-4	80-115	ASTM D2166 - 16[21]
Cohesion soil, c' (kPa)	21.5	2	39.6	ASTM D4767 – 11 [22]
Friction angle, ϕ (deg)	2	1	9	
Organic matter %	2-3	0-1	1-2	ASTMD2974 - 20e1 [23]
Compression coefficient, Cc	0.412	0.64	0.20	ASTM D2435-2020, [24]
Swelling coefficient, Cs	0.026	0.05	0.011	
Creep coefficient, Cα	0.007	0.012	0.0084	

The bearing capacity of piles is calculated usually according to modern approach for CFA piles taking into account the difference of installation technology, excavation and displacement of the soil, Fig. 2.

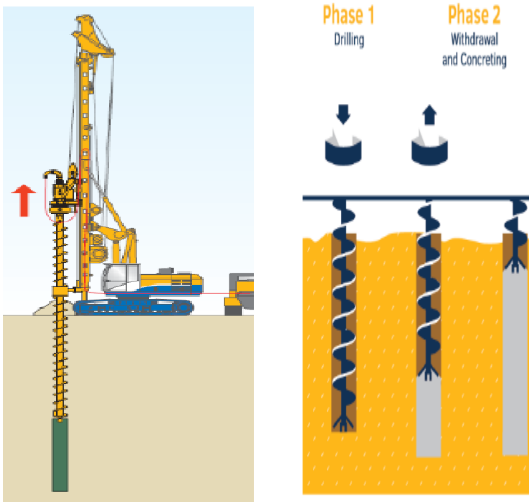


Fig 2. Installation technology and sequence of CFA pile.

3.3 In-situ tests

Three types of in-situ tests have been conducted as follows:

1. Conventional plate load test on the soil before and after improvement to get the natural bearing capacity of soil and the bearing capacity for the soil after improvement. The test is performed in accordance with the requirements of ASTM D1194 [25] to determine the load carrying capacity of foundation soil by centrally applying a gradual, compressive load to a steel plate while monitoring its settlement due to loading. The diameter of the plate may vary from 300 mm to 600 mm. Plate with 500 mm diameter was used in this study. In principle, the larger is the plate size, the more comparable will be the result for footing performance. The plate load test has been done between piles after improvement to measure enhancement on bearing capacity, the test was conducted at a distance of one meter from the pile center and also at a distance of 2 m from the pile center.
2. Large plate load test for soil after improvement. This test is carried out on CFA pile and soil together which directly reflects the bearing capacity of the foundation for the improved soil, square plate 2 m x 2 m was used in this study. Four dial gages were used to read the settlement, the steps followed in the test are as follows, Fig. 3:
   - i. 100 mm~150 mm coarse or medium sand bed course can be set under the test plate.
   - ii. Pre-load shall be applied before the main test is started for the compacted sand with soil and pile, pre-load shall not exceed 5% of the total test load.
   - iii. The maximum test load shall not be less than 2 times the design foundation bearing capacity.
   - iv. The total test load is departed to 8~12 stages, each time before and after increasing the test load, the settlement is recorded one time. After that, every 0.5 hour, one record is made. When the settlement becomes less than 0.1 mm per hour, the next stage can be started.
   - v. Unloading stages required lowering the load to half its value, the time interval of each stage is 0.5 hour, the rebound is recorded of each stage. Then 3 hours after removal of the entire load, the total rebound is recorded.
3. Pile load test on CFA pile. The test is performed under the requirements of ASTM D 1143 [26] to determine the load carrying capacity of CFA pile by centrally applying a gradual, compressive load to pile while monitoring its settlement due to loading as shown in Fig. 4.

4. RESULTS AND DISCUSSION

A total of 12 in-situ tests for the tank area have been done. For each test, the load-settlement curve is drawn from which the ultimate bearing capacity is estimated using the intersection of two tangents method where a tangent line is drawn to two parts of the load-settlement curve, the intersection of which determines the ultimate pile load. The test results are summarized as follows:

Fig. 5 shows the normal plate load test on the natural soil. The results show that the ultimate bearing capacity for the first layer is 140 kN/m^2 before improvement. This result can be realized for the first layer within one-meter depth because the pressure bulb caused by the loaded plate does not penetrate the soil to a deeper depth. The top soil is considered as desiccated crest which is almost strong due to drying by weather.

Fig. 6 shows the second case of the plate load test which has been done after the construction of CFA pile at a distance of one meter from the center of CFA piles. The test results reveal that the ultimate bearing capacity is increased to 320 kN/m^2.

Fig. 7 shows the test result for plate load test after construction of CFA piles at a distance of 2 m from the pile center. The results show that the ultimate bearing capacity becomes 250 kN/m^2.

Comparison between the previous cases and the case after construction of CFA piles shows an increase in the bearing capacity by about 110% for the soil around piles and 70% for the soil within 2 m from the center of piles. Also using a larger plate extended the stresses induced by the plate to deeper soil which is softer than the top soil.

Fig. 8 shows the pile test results for CFA pile alone, the test results reveal that the ultimate bearing capacity of pile is 900 kN.

Fig. 9 shows the large plate load test results for the pile with the surrounding soil, the ultimate bearing capacity from the large plate test is 500 kN/m^2. So that the overall loading area showed an increase in bearing capacity of 350% when CFA piles are constructed.

Fig. 3: Large plate load test on CFA piles and surrounding soil.

Fig. 4: Pile load test on CFA piles.

CFA piles were constructed of C15 concrete; this concrete is spread around the pile leading to inhibiting the lateral displacement around the pile which resulted in densification for the soil around the CFA pile. This is explained by the result of the plate load test within one meter from the center of CFA pile. While the effect of densification is decreasing when moving away from the test location.

Large plate load test shows improvement in the soil behavior, the loading applied is more than 2120 kN. A large plate with 2 m width results in stress effect on the soft clay layer, the results showed 11.8 mm as maximum settlement for three tests, and the ultimate bearing capacity for the soil increased to 500 kN/m^2 compared to 140 kN/m^2 for the natural soil, this is due to the extension of the stress to the second layer which consists of soft clay. Therefore, the bearing capacity increases by 350%. The above results indicate that the site area has been improved and the cost for the foundation can be lowered by using C15 concrete for CFA piles, and spacing between piles is 4.2 m because using CFA piles with two or three-time diameter spacing (2D to 3D) between piles, the number of piles will be across three times when CFA pile are used as a soil improvement technique.

Generally, drilled shaft group efficiencies for traditional CFA piles will be conservative if construction techniques are employed properly, as verified with appropriate construction monitoring. An additional spacing of the group piles will result in a higher probability of the block failure mode occurring.

The results obtained by [27] indicated that the ultimate pile capacity of the CFA piles was about 19 to 41% greater than the theoretical ultimate pile capacity calculated with a total stress method if cast-in place concrete piles were considered.

Gavinet et al. [28] found that CFA piles developed very high shaft resistance and, in contrast to piles driven into Boulder Clay that exhibit friction fatigue, the shaft distribution was uniform along the pile shaft. This resulted in the normalized average shear resistance being mobilized by a bored pile exceeding that of a pile driven in similar ground conditions.

Abd Elsamee [29] found that the percentage of friction load carried by the shaft along the pile length is about 46% of total load, while the pile load carried by the end bearing is 54% of the total load. This means that CFA piles develop a considerable percent of skin friction.

Monitoring the storage tank after construction showed that the tank settled only 1.9 mm after 12 months of its construction.

Liu et al. [30] performed model axial compression tests in moist alluvial silty sand, but did not describe the soil density for side-shear resistance. The group impacts on the side-shear and end-bearing components of a 3 by 3 pile group were investigated as a function of the spacing to diameter ratio (spacing/B). The association was demonstrated for both scenarios of the pile cap being in contact with the ground and not being in contact with the ground. It was noted that when the cap is in contact with the ground, the efficiency is lower but the end-bearing efficiency is better than when the cap is not in contact with the ground for comparable spacing-to-diameter ratios.

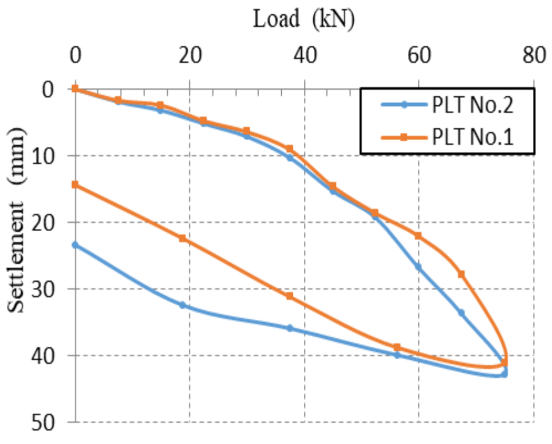


Fig. 5: Plate load test (PLT) No. 1 and No. 2 results on the natural soil.

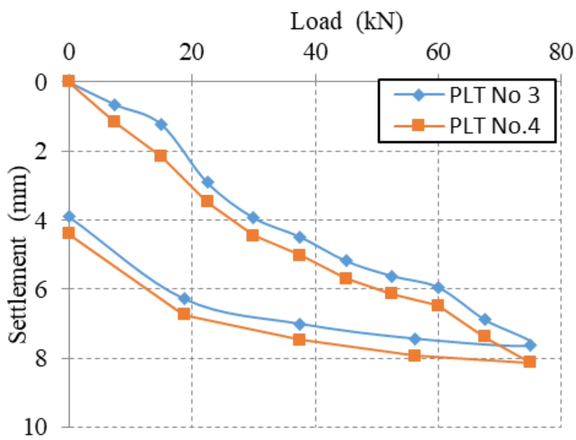


Fig. 6: Plate load test (PLT) No. 3 and No.4 results for soil after improvement at a distance of one meter from the center of CFA pile.

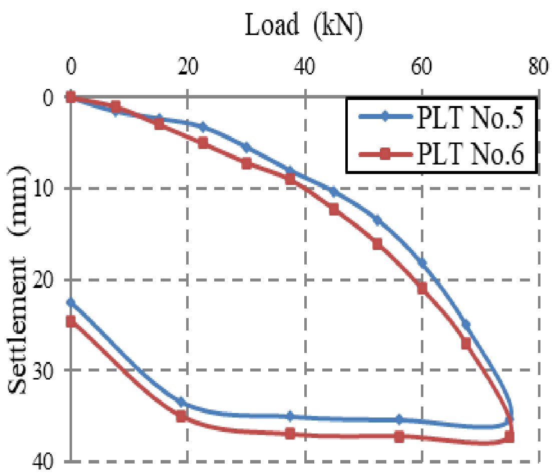


Fig. 7 Plate load test (PLT) No. 5 and No. 6 results for soil after improvement at a distance of 2 m from the center of CFA pile.

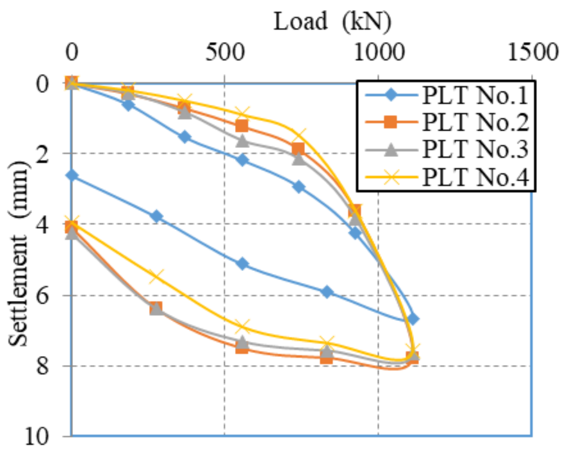


Fig. 8 Pile load test (PLT) No. 1, 2, 3 and No. 4 results for the CFA piles.

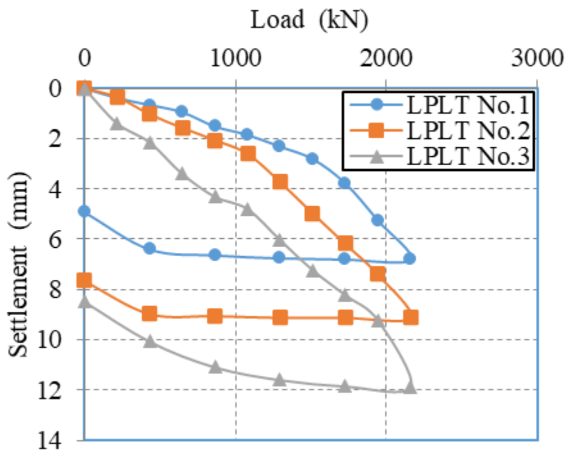


Fig. 9 Large plate load test (LPLT) No. 1, 2 and No. 3 results for the CFA piles and the surrounding soil.

5. CONCLUSIONS

1. Construction of CFA piles shows an increase in the bearing capacity by about 110% for the soil directly around piles and 70% for the soil within 2 m from the center of piles.
2. Large plate load test results for piles with surrounding soil revealed that the ultimate bearing capacity increases to 500 kN/m^2. So that the overall loading area showed an increase in bearing capacity of 350% when CFA piles are constructed.
3. The results indicate that the site area has been improved and the cost for the foundation can be lowered by using C15 concrete for CFA, and spacing between piles is 4.2 m because using CFA piles with two or three-time diameter spacing (2D to 3D) between piles, the number

of piles will be across three times when CFA pile are used as a soil improvement technique.

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