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Effect of de-sanding (recycling system) process on the piles bearing capacity

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Keywords: bored pile, bentonite, finite element, bearing capacity, recycling system.

Abstract. The technique adopted in this study includes an innovative and unconventional method, which plays an important role in enhancing the bearing capacity of piles, called a recycling system. Full-scale models were conducted on two groups of piles: the first group was constructed without using this system, and the second group was constructed using it. All piles were tested by static load test. 3D finite element in the PLAXIS program was adopted to understand the load-carrying response of piled, several parameters were studied such as the thickness of the filter cake, type of soil, L/D ratio, and separation between the friction and end bearing. The results revealed that using the recycling system significantly increased the pile-bearing capacity, reaching 50 %. The effectiveness of the recycling system in cohesionless soils is more efficient than in cohesive soils. Pile's bearing capacity improvement ratio reaches 65 and 38 % for sandy and clayey soils, respectively. In addition, the thickness of the filter cake significantly reduces the pile-bearing capacity, which may exceed 40 % if this system is not used. Using the recycling system, the pile bearing capacity was improved by 60–64 % and 85–98 % for friction and end bearing, respectively.

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1. Introduction

Bored piles are increasingly used to effectively transfer the loads of the superstructure to the sub-soil when the soil conditions at the site and certain other functional requirements cannot support the shallow foundations [1, 2]. The construction of bored piles is accompanied by the presence of drilling residues and sludge in the body of the pile; these residues and sludge significantly reduce the bearing capacity of the bored piles [3, 4]. The traditional methods of cleaning the pile from these residues and sludge are cleaning pocket [5] and airlifting [6], which are widely used methods. In this study, the cleaning pocket method, and a new method (recycling system) were used to clean the piles to determine their effect on the bearing capacity of the piles. The cleaning pocket method includes lowering a pocket with smooth ends to collect the drilling residues from the pile body after the drilling is completed.

The authors found that studies related to the recycling system are almost non-existent, as previous researchers did not deal with this process. Hence, the lack of research on this topic made the results of this study independent, and there is no possibility of comparing it with any previously published results. The recycling system (de-sanding) is a non-traditional method that relies on pumping fresh bentonite from the top of the pile and withdrawing it from the bottom of the pile by an integrated system to obtain an impurity-free pile body before starting the concrete casting process [7], as shown in Fig. 1.

The aim of this investigation was to assess the influence of the recycling system on improving the bearing capacity of bored piles. The impact of the thickness of the filter cake, soil type, L/D and the separation between the friction and end-bearing pile capacity on the behavior of the bored piles when using this technique were evaluated.

Figure 1. The recycling system used in situ.

2. Methods

The proposed site lies on area number (173/23 m 30) within Al-Muthana airport land in Baghdad. From a geological point of view, the investigated area is located on the Mesopotamian plain zone within the unstable shelf region according to the tectonic division of Iraq [8]. The field test showed that the soil profile consists mainly of the following layers: the uppermost layer (0–8.5 m) is classified as cohesive soil, and the second layer below the top layer consists of cohesionless soil. This layer consists mainly of brown to Gray-black sand/silty sand with fine gravel and/or gravel with sand. Table 1 shows the in-situ soil properties obtained using the standard penetration test (SPT).

Table 1. The soil parameters.

Geotechnical parameters	1st Layer (0–8.5 m)	2nd Layer (8.5–14 m)	3rd Layer (14–17 m)	4th Layer (17–35 m)
Cohesion (C) (kPa)	39	0	110	0
Angle of internal friction (Ø)	1.5	31.5	4.5	40
γ dry (kN/m^3)	15	15.5	16	16.5
γ sat (kN/m^3)	19.2	18.8	20.0	19.8
e_o	0.75	0.5	0.7	0.5
Soil classification	CL – CH	SC – SM	CH	SM – SW
μ*	0.4	0.3	0.4	0.3
E (kN/m^2) ×	12480	25500	21440	48500
G (kN/m^2) ×	4457.14	9807.69	7657.14	18653.85
LL	53	–	49	–
PL	28	–	26	–

* Poisson's ratio is extracted based on [9, 10].
× The elastic and shear modulus calculated by SPT N-values, based on [9, 11].

Full-scale models were conducted on two groups of piles. The first group was constructed without using the recycling system, and the second group was constructed using it. In addition to the construction of full-scale models in the field, forty-one models were modeled in the PLAXIS-3D program, which is a finite element package specifically developed for the analysis of deformation, stability, and flows in geotechnical engineering projects [12]. Construction of bored piles with bentonite liquid reduces the bearing capacity of the piles because it forms a layer called (filter cake), this layer leads to a decrease in the adhesion between the soil and the pile [13]. Therefore, the research methodology can be divided into two main parts: field study and theoretical study, as shown in Fig. 2.

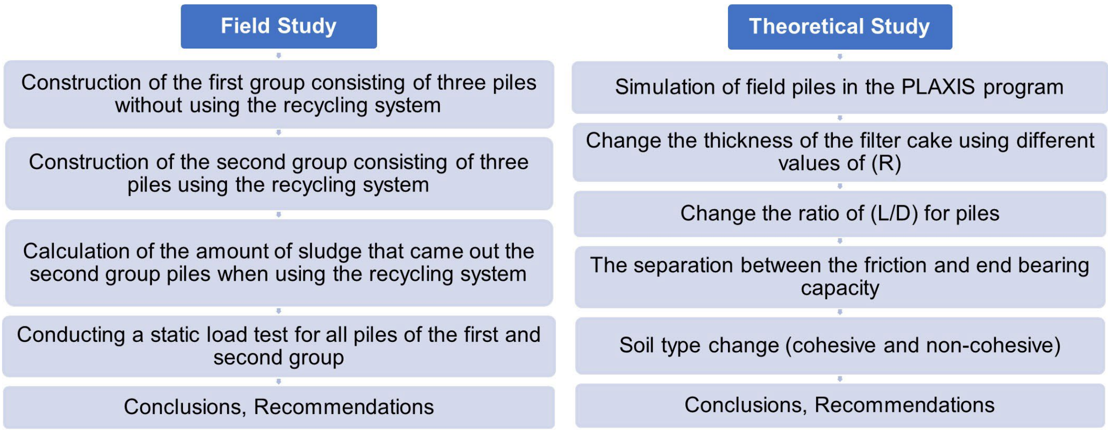

Figure 2. The flowchart of field and theoretical study.

2.1. Field Study

Many methods are used to construct bored piles. One of these methods is to use the casing to support the soil close to the surface and prevent it from collapsing [14]. Depending on the soil investigation, the casing method was used to construct the piles in this study. Six piles were identified for this study; the first group of piles was B1, B2, and B3 with a diameter of 1.2 m and the length of the piles was 25, 30, and 30 m, respectively, and were carried out for a period ranging from 5.5 to 8 h, and the piles were cleaned from the residues and drilling sludge by the cleaning pocket method [5]. The working load was 400 tons for the first pile B1 and 360 tons for the second and third piles B2 and B3. The second group of piles was selected using the recycling system B4, B5, and B6 with a diameter of 1.2 m and a working load of 360 tons. The length of the piles was 25, 30, and 30 m, respectively, which were carried out for a period ranging from 8 to 9 h. The six piles were constructed in the same zone, so the groundwater level at the time of construction was 2.8–3 m.

The control of the properties of the bentonite liquid is one of the most important factors that help to complete its tasks correctly [15], so the six piles were drilled with the same type of bentonite (sodium bentonite) and its properties were kept close during the construction. Table 2 shows the dimensions, working conditions, and properties of the bentonite used for each pile.

Table 2. The dimensions, working, and properties of the bentonite used for each pile.

Pile No.	Pile diameter (m)	Pile length (m)	Working load (ton)	Density (mg./ml)	Viscosity (sec.)	pH	Sand content (%)
				In (during boring)			
B1	1.2	25	400	1.065	48	9.5	0.6
B2	1.2	30	360	1.075	49	9.5	0.6
B3	1.2	30	360	1.065	45	10	0.6
B4	1.2	25	360	1.075	50	10	0.8
B5	1.2	30	360	1.08	50	10	1
B6	1.2	30	360	1.07	45	9.5	0.6
				Out (after use the recycling system) after boring			
B1	1.2	25	360	–	–	–	–
B2	1.2	30	360	–	–	–	–
B3	1.2	30	360	–	–	–	–
B4	1.2	25	360	1.08	40	9	2
B5	1.2	30	360	1.09	42	9.5	3.5
B6	1.2	30	360	1.08	39	9	1.5

2.1.1. Recycling system (de-sanding)

The main objective of the recycling system is to get rid of impurities and drilling residues during pile construction, thus preserving the pile from geotechnical defects. Cleaning and recirculating the bentonite slurry includes removing sludge and sand from the drilled hole using cleaning equipment and returning the cleansed slurry [16]. This method was used from the same mechanism as the bentonite cleaning system that comes out during the pouring of the pile [17], but the system was used to withdraw the bentonite that contains impurities and drilling sludge before casting the pile. After the steel cage is installed in the hole, the tremie tube is inserted into the hole, leaving a small gap between the bottom of the hole and the tremie tube between 25 and 30 cm. The tremie tube is connected from the top with a suction pump (dewatering pump) with a capacity of 350 m^3/hr., as shown in Fig. 3, to withdraw the bentonite from the bottom of the hole. Then, the outside of the pump is connected to a de-sander with a capacity of 2500 HP, as shown in Fig. 4.

To determine the amount of sludge and sand that came out from the piles using the recycling system, three containers were manufactured with dimensions 2, 1.25, and 1 m, as shown in Fig. 5.

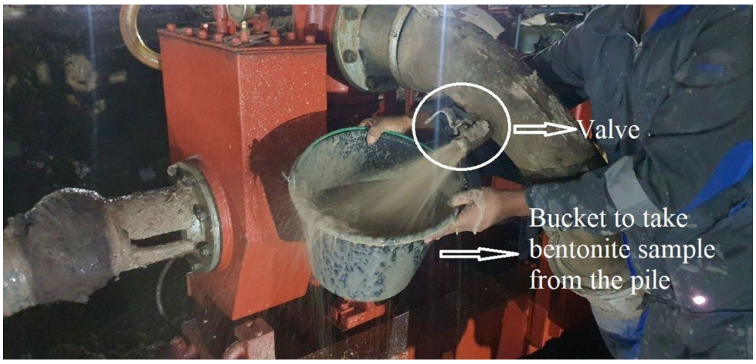

Figure 3. Bentonite sample coming out of the pile in-situ.

Figure 4. Filter sand and sludge by desander in-situ.

Figure 5. Collect sludge and sand in-container.

2.1.2. Static load test

There are several methods for determining the bearing capacity of a pile, and the static load test is one of the most important field tests [18]. The static load was conducted after 28 days of casting the piles according to ASTM D1143 (2007) [19]. The allowable load Qa was taken as equal to two thirds of the final load, which causes a total settlement of 12 mm or a net (plastic) settlement of 6 mm [20]. The specification states that the axial pressure load to be applied to the pile shall be increased by 10 % to accommodate the increase in load required during the test [21]. The objective of the test is to determine the pile's bearing capacity during one cycle of loading and unloading [22], where the pile is loaded to two times the design load and at a rate of eight load increments (one hour for each load) sustaining the load for at least 12 h, and then the load is lowered at a rate of four times (1 h for each unload), as shown in Fig. 6. Figs. 7–12 show the load-settlement curve for the piles after the static load test.

Figure 6. Static load test in-situ.

2.2. Theoretical Study

The PLAXIS-3D program has been used to find several parameters and knows the extent of their impact on the bearing capacity of the piles, and to determine the program's validity, six piles TR1, TR2, TR3, TR4, TR5, and TR6 were modeled in the PLAXIS program for comparison with those from the field [23]. To model the bored piles in the PLAXIS-3D program, knowledge of the soil parameters, groundwater level, pile dimensions, and the type of analysis is required [24]. The More–Coulomb model was chosen to model the soil parameters because it is closer to reality and requires fewer soil parameters [25]. To model concrete in the PLAXIS program, one must know the modulus of elasticity, Poisson's ratio, and density. Therefore, the modulus of elasticity ranges between 25 and 30 GPa, Poisson's ratio is between 0.15 and 0.25, and density is 25 kN/m^3. In this study, the density of the concrete was 25 kN/m^3, the modulus of elasticity was 30 GPa, Poisson's ratio was 0.2, and the (non-porous) property was selected [8]. Because the groundwater level when construction of the test piles was 2.8–3 m, the worst case of the groundwater level was chosen, which was 2.8 m, to model the piles.

The drainage type for the soil in the PLAXIS program is essential; therefore, the undrained type was chosen for clayey soil and the drained type for sandy soil [8]. In this study, the amount of settlement will be given and the ultimate load that the pile can bear at reaching a total settlement of 25 mm (failure). Figs. 7–12 show the results of the comparison between field tests and those resulting from the program.

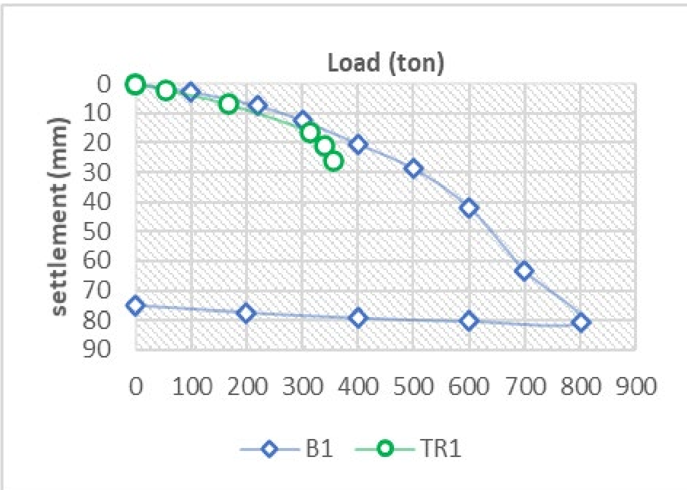

Figure 7. Load – settlement curve for B1&TR1.

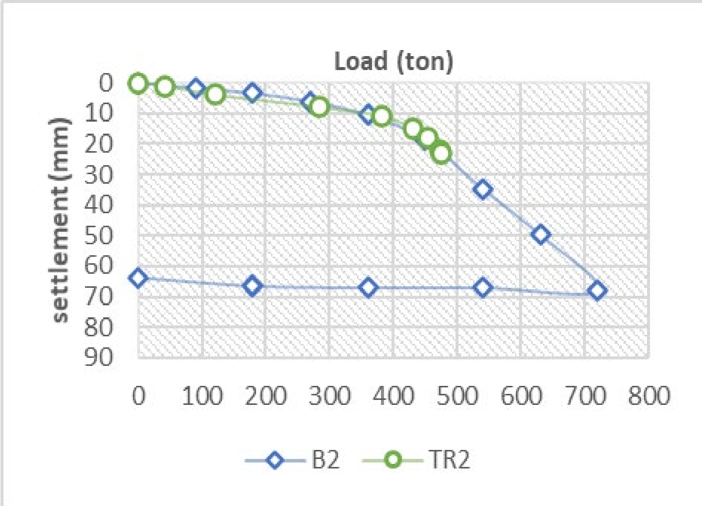

Figure 8. Load – settlement curve for B2&TR2.

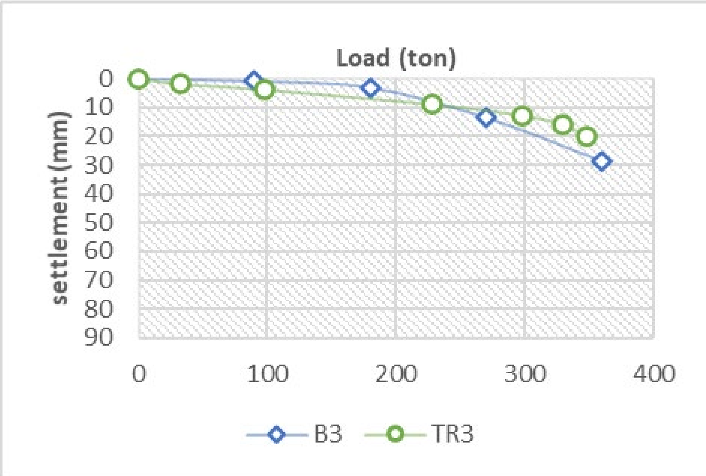

Figure 9. Load – settlement curve for B3&TR3.

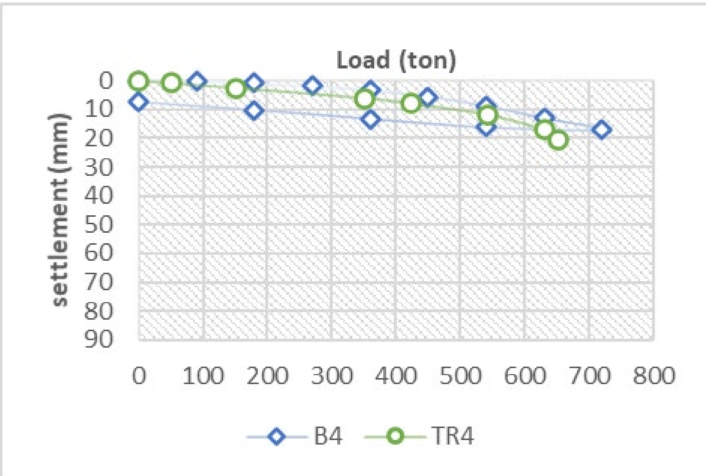

Figure 10. Load – settlement curve for B4&TR4.

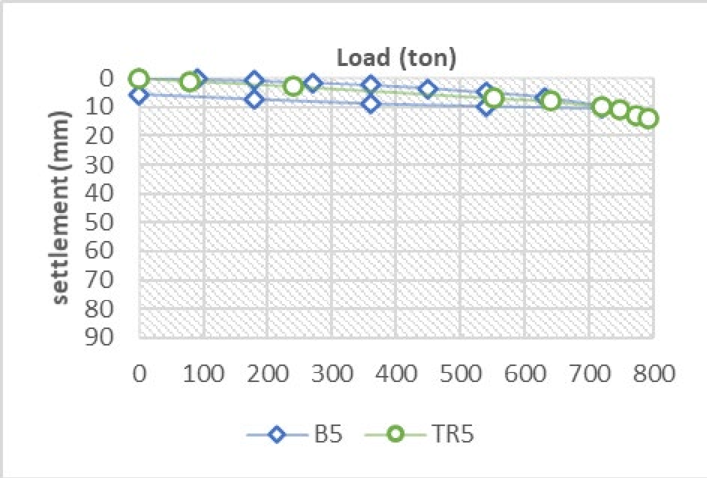

Figure 11. Load – settlement curve for B5&TR5.

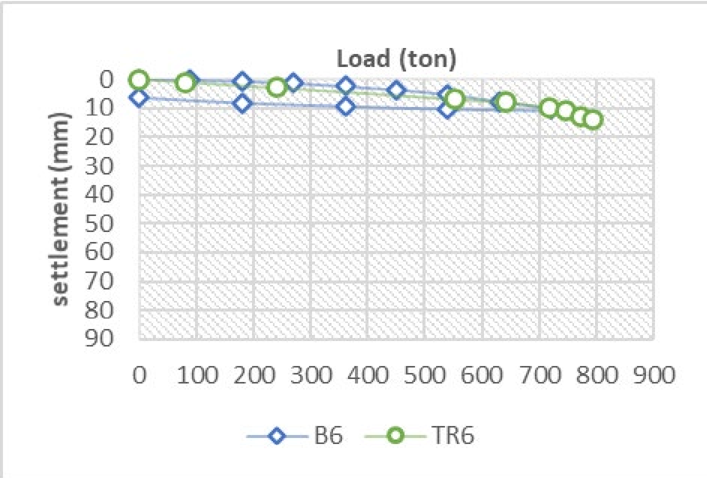

Figure 12. Load – settlement curve for B6&TR6.

2.2.1. Thickness of filter cake

Two piles were modeled with diameters equal to 1.2 m, and lengths equal to 25 and 30 m. In the normal case, the program uses an R = 1, where R is an interface coefficient (friction coefficient), which means that no parameters related to the pile or soil are reduced (full attachment between the pile and soil). Because field piles are constructed using bentonite liquid, there must be a reduction in the friction coefficient between the soil and the pile because bentonite leads to the formation of a filter cake or an insulating layer between the pile body and soil [13]. This layer of the filter cake cannot be handled by the program by giving a specific thickness such as 1, 2, 3 mm, etc., so the only way is to manipulate the R value that simulates the thickness of this layer. Therefore, different values of the interface coefficient R (1, 0.95, 0.9, 0.85, 0.8, 0.75, 0.7, 0.65, 0.6, 0.55) were used to achieve a real simulation of the piles that were constructed using the recycling system and those that were constructed without using this system. As a result of using different values of R, a new value must be extracted for each of the parameters (cohesion C, angle of internal friction Ø, Young's modulus E, and shear modulus G), the Equations (1–4) used to find the parameters above [12]:

$$C_i = R_i \times C; \quad (1)$$

$$\varnothing_i = \tanh^{-1}\left(R_i \tan\varnothing\right); \quad (2)$$

$$G_i = R_i^2 \times G; \quad (3)$$

$$E_{oed} = 2G_i \times \frac{1-\mu}{1-2\mu}. \quad (4)$$

2.2.2. Type of soil

To determine the efficiency of the recycling process on different types of soil, two types of soil were selected: clay and sand. Table 3 shows the properties of these soils, where piles of 15 m in length and 1.2 m in diameter were modeled. The symbols are as follows:

TC1 refers to the pile modeled in clay soil using the recycling system;

TC2 refers to the pile modeled in clay soil without using the recycling system;

TC3 refers to the pile modeled in sandy soil using the recycling system;

TC4 refers to the pile modeled in sandy soil without using this system.

Table 3. Soil properties used to model the piles at different soil types.

Geotechnical parameters	Clay (0–16 m)	Sand (0–16 m)
Cohesion (C) (kPa)	39	0
Angle of internal friction (Ø)	1.5	31.5
γ dry (kN/m^3)	15	15.5
γ sat (kN/m^3)	19.2	18.8
Soil classification	CL – CH	SC – SM
μ	0.4	0.3
E (kN/m^2)	12480	25500
G (kN/m^2)	4457.14	9807.69

2.2.3. L/D ratio

Because the piles constructed in the field were of different lengths 25 and 30 m, but the pile diameter of 1.2 m did not change, the length of the piles will be fixed, and the pile diameter will be changed to 1.5, 1.4, 1, and 0.8 m. To determine the effectiveness of the recycling process and its effect on the bearing capacity of the piles when the L/D ratio was changed, 16 piles were modeled in the PLAXIS program, as shown in Table 4.

Table 4. Details of piles at different value of L/D.

Pile No.	R	Length (m)	Diameter (m)	Modelling method
TD1	0.95	25	1.5	De-sanding
TD2	0.95	25	1.4	De-sanding
TD3	0.95	25	1	De-sanding
TD4	0.95	25	0.8	De-sanding
TD5	0.95	30	1.5	De-sanding
TD6	0.95	30	1.4	De-sanding
TD7	0.95	30	1	De-sanding
TD8	0.95	30	0.8	De-sanding
TD9	0.65	25	1.5	Without de-sanding
TD10	0.65	25	1.4	Without de-sanding
TD11	0.65	25	1	Without de-sanding
TD12	0.65	25	0.8	Without de-sanding
TD13	0.65	30	1.5	Without de-sanding
TD14	0.65	30	1.4	Without de-sanding
TD15	0.65	30	1	Without de-sanding
TD16	0.65	30	0.8	Without de-sanding

2.2.4. Separation between the friction and end bearing

To separate the bearing capacity in relation to the friction and end bearing for the piles that used the recycling system in their construction, two groups of piles were modeled. The first group (TF1, TF2, and TF3) was modeled using a recycling system for the interface between the pile and the soil and a non-recycling system for the interface between the base of the pile and side soil (to neglect the end bearing capacity or reduce it as much as possible because it was not cleaned well). In the second group (TF4, TF5, and TF6), these piles were modeled as tension piles, where the piles were modeled using a recycling system to determine the friction capacity of the pile, as shown in Table 5.

After modeling the previous six piles TF1–TF6, it was noted that the difference between the friction capacity when using the pile modeling method as tension piles and as the recycling system was used for the interface between the pile and the soil and the non-recycling system was used for the interface between the base of the pile and side soil was very close. Therefore, the method of tension piles was adopted to determine the friction capacity of the TF1-A, TF2-A, and TF3-A piles when the recycling system was not used in its construction, as shown in Table 5.

Table 5. The details of piles TF1–TF6 and TF1-A–TF2-A.

Pile No.	Pile length (m)	Pile diameter (m)	Modelling method
TF1	25	1.2	As (R = 0.95) for side interface and (R = 0.65) for end pile interface
TF2	30	1.2	As (R = 0.95) for side interface and (R = 0.65) for end pile interface
TF3	30	1.2	As (R = 0.95) for side interface and (R = 0.65) for end pile interface
TF4	25	1.2	As a tension pile
TF5	30	1.2	As a tension pile
TF6	30	1.2	As a tension pile
TF1-A	25	1.2	As a tension pile
TF2-A	30	1.2	As a tension pile
TF3-A	30	1.2	As a tension pile

3. Results and Discussion

After constructing the field piles and modeling them in the PLAXIS program, the following results were obtained:

1. The quantities of sludge and sand that emerged from the second group of test piles in the field B4, B5, and B6 during the recycling process were calculated using containers with dimensions of 1, 1.25, and 2 m, as shown in Table 6. Based on the sieve analysis, the sample was black poorly sand, as shown in Fig. 13. The amount of sand and sludge that came out of the second group piles B4, B5, and B6 using the recycling system is very large, where it was noted that the average quantity was approximately 0.08 m^3 for each cubic meter of the pile body. Since the quantities were 2–2.45 m^3 and based on the wet density of the poorly sand that came out from the piles was 16.12 kN/m^3, the wet weight of these quantities ranges from 3224 to 3949 kg, so there is no doubt that these quantities cause the first group of piles to fail or to obtain a low bearing capacity when it remains inside the hole before pouring.

Table 6. Quantities of sludge and sand.

Pile No.	Depth of sludge in container (m)	Vol. of sludge (m^3)	Vol. of pile (m^3)	Percentage of sludge in pile (per m^3)
B4	0.8	2	24.87*	0.08
B5	0.98	2.45	30.52*	0.080
B6	0.93	2.325	30.52*	0.076

* The size of the pile, depending on the length of the pile, is equal to 22 m (25 m – the length of the casing embedded in the soil (3 m)).

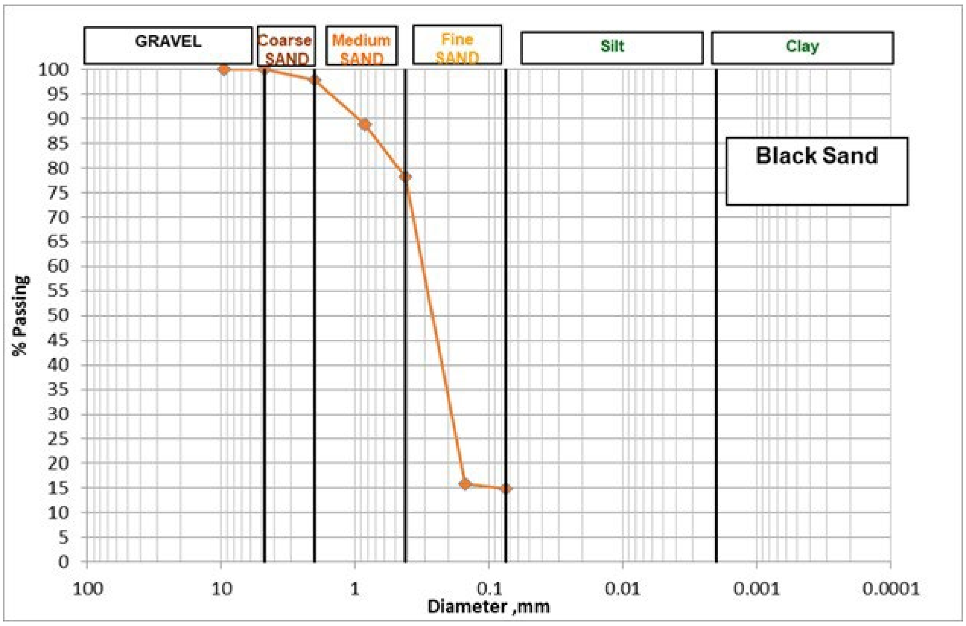

Figure 13. Sieve analysis of the sludge and sand that came out from the piles.

2. After conducting the static load test for the six field piles B1–B6, the allowable load was obtained, as shown in Table 7. After testing the first pile B1 and its failure, the working load of the second pile B2 was reduced to 360 tons in the hope of obtaining less settlement, but also failed and settlement of 12 mm was not reached when loading the fourth and fifth piles B4 and B5 when loading 200 %, so the last load was taken to find the bearing capacity of the pile. The use of the recycling system reduced the reduction in the bearing capacity of the piles to only 5 % when using an R value equal to 0.95. This means that the thickness of the filter cake layer on the sides of the pile and the thickness of the sludge layer at the base of the pile was the least possible because this system helped to get rid of large quantities of sludge and sand that were inside the pile. When the recycling system is not used, the bearing capacity of the piles reduces from 35 to 45 % when using an R value equal to 0.65–0.55. This means that the difference between using the recycling system and not using it is 30–40 % of the bearing capacity of the pile.

Table 7. Simulation of field piles in the PLAXIS program by changing R value.

Load from field (static load test)			
Pile No.		**Final load at 12 mm (ton)**	**Allowable load (ton)**
B1		290	193
B2		369	246
B3		260	173
B4		600	400
B5		720	480
B6		720	480
Load from PLAXIS			
Pile No.	**R**	**Final load at 12 mm (ton)**	**Allowable load (ton)**
TR1	0.65	263	175
TR2	0.65	392	261
TR3	0.55	282	188
TR4	0.95	561	374
TR5	0.95	759	506
TR6	0.95	759	506

3. After modeling different values of R, it was concluded that the bearing capacity of the piles at a value of R equal to 0.95 is similar to the bearing capacity of the piles when using the recycling system, and that the bearing capacity of the piles at a value of R close to 0.65 is similar to the

bearing value of the piles that were not used the recycling system during construction, as shown in Table 7. Therefore, the value of R at 0.95 will be fixed to simulate the constructed piles using the recycling system in modeling the piles that will change in type of soil, L/D ratio, and separation between the friction and end bearing. The value of the reduction in the third pile R was 45 % (R = 0.55), so this value was neglected and the value of R = 0.65 was relied on when referring to the non-use of the recycling system.

4. The bearing capacity of the piles was calculated for each ratio of L/D using the recycling system and without it, and the results showed the efficiency of the recycling process in large piles. Figs. 14–17 show the Load–Settlement curve for each group of piles. The improvement rate (the ratio of increase in pile bearing capacity) of the pile increases when L/D is lower, which means that the recycling system is more effective in large piles. Therefore, it cannot give a specific percentage of the optimum value for the improvement rate, but it can be said that the efficiency of the recycling process increases directly when the diameter and length of the bored pile increase because that increase in the diameter and length of the pile (side friction and end bearing) leads to a higher bearing capacity. In addition, increasing the diameter of the piles from 1.2 to 1.5 m and without using the recycling system does not lead to a real increase in the pile-bearing capacity.

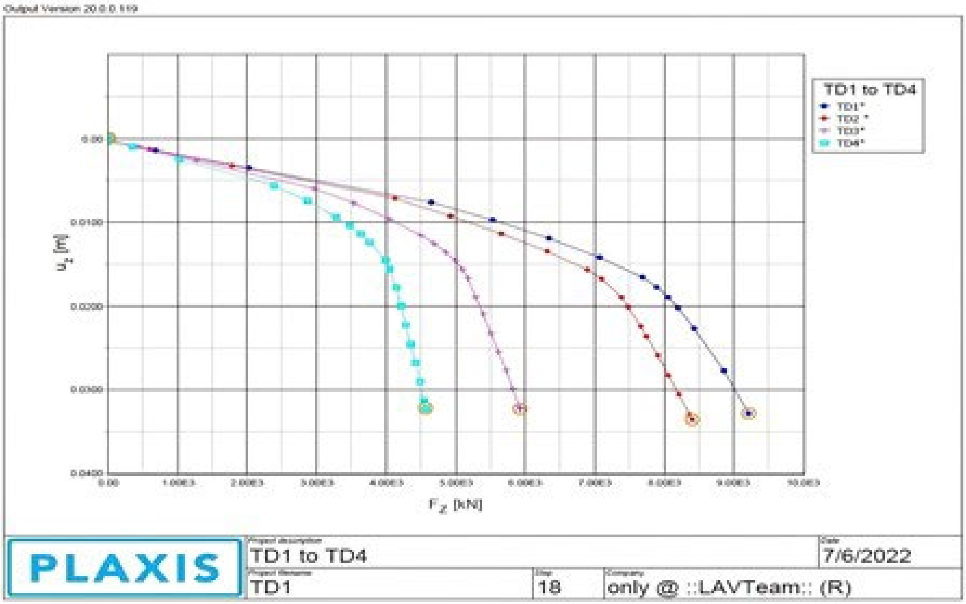

Figure 14. Load (FZ) – Settlement (UZ) curve for TD1–TD4.

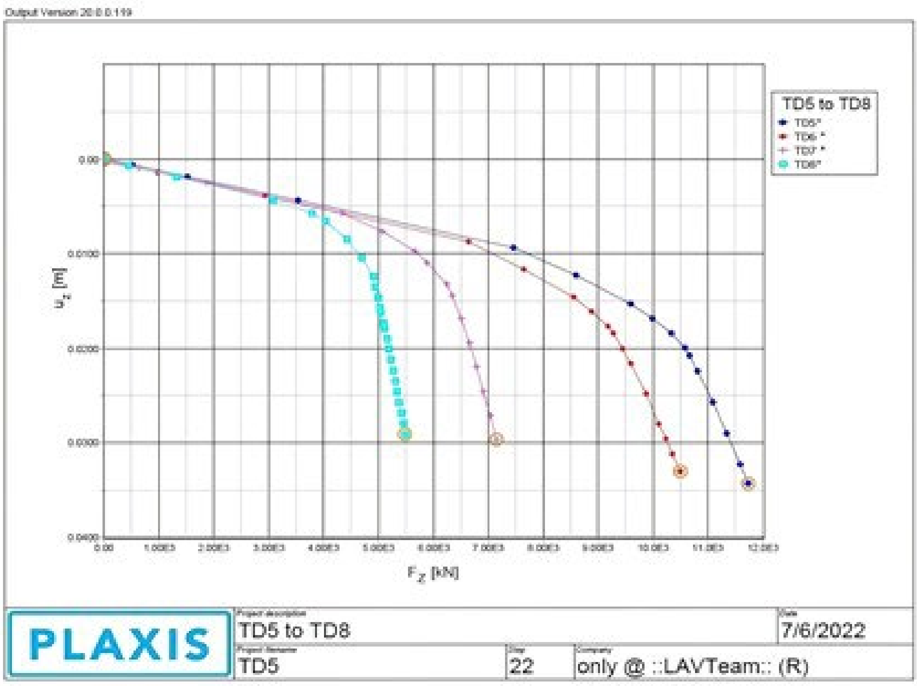

Figure 15. Load (FZ) – Settlement (UZ) curve for TD5–TD8.

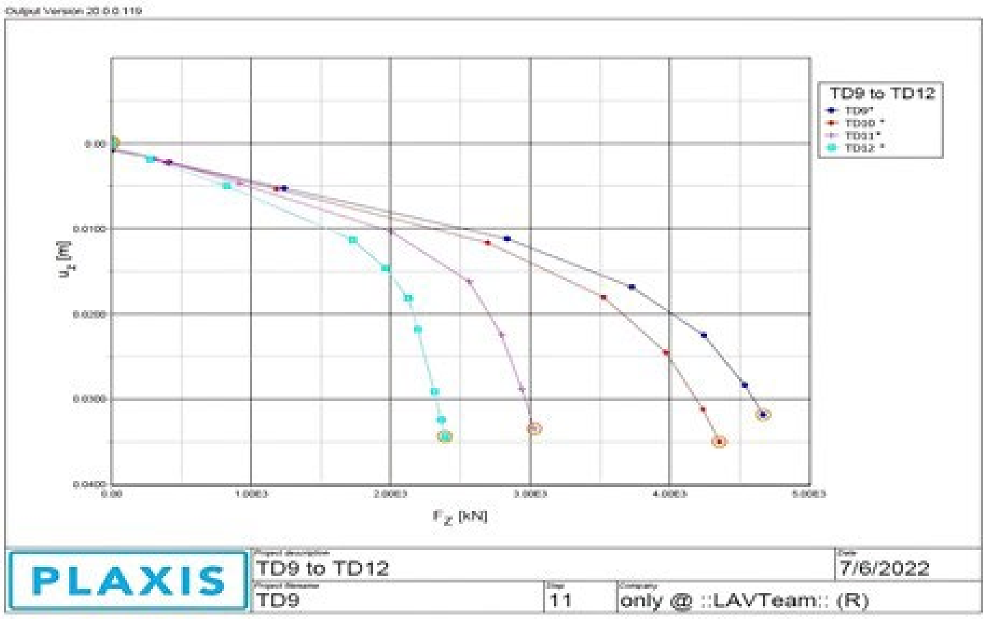

Figure 16. Load (FZ) – Settlement (UZ) curve for TD9–TD12.

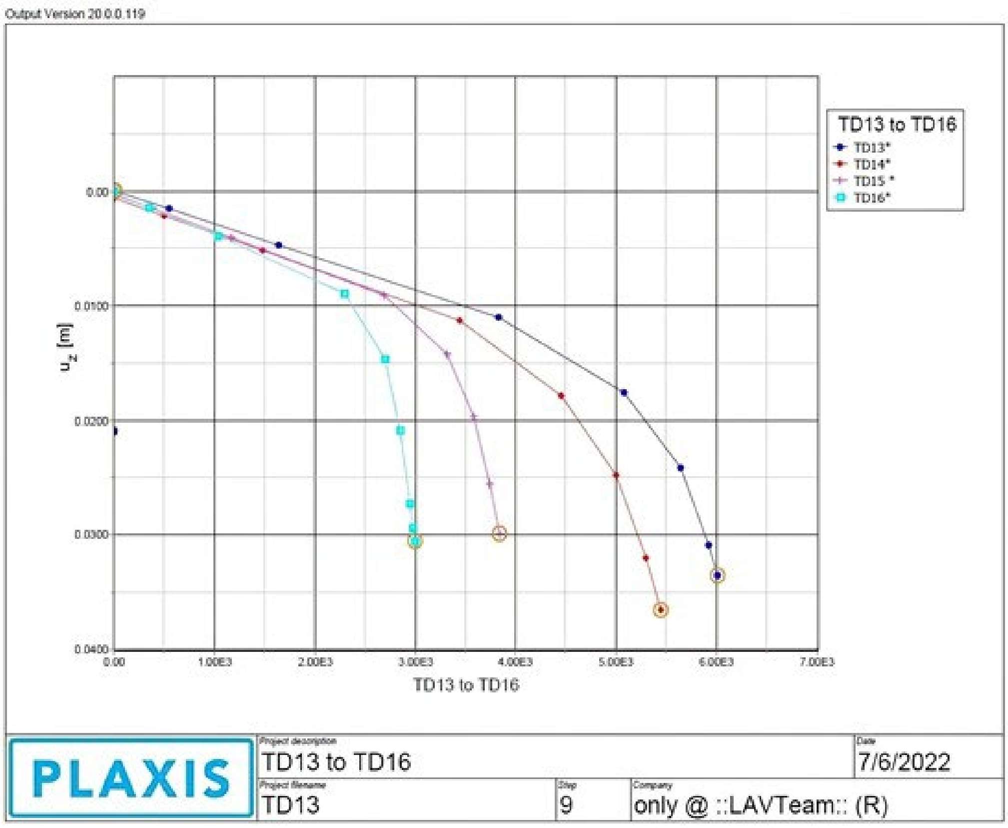

Figure 17. Load (F_Z) – Settlement (U_Z) curve for TD13–TD16.

5. After modeling the piles in clay and sandy soils, as shown in Table 8, it was observed that the use of the recycling system led to a close bearing capacity of the piles in both soils, where the allowable bearing capacity of the pile in the clay soil TC1 was 190 tons and the allowable bearing capacity of the pile in the sandy soil TC3 was 211.5 tons, which is an additional indicator of the efficiency of that process. It was also noted that the non-use of the recycling system led to a lower allowable bearing capacity for the pile in sandy soil TC4 than that of the pile TC2 in clay soil. As shown in Table 8, the difference in the improvement ratio between the piles in clay and sandy soils is 38 and 65 %, respectively, indicating that the efficiency of the recycling process in sandy soils is higher.

Table 8. Details and bearing capacity of TC1–TC4 piles.

Pile No.	R	Soil	Load from PLAXIS		
			Allowable load (ton)	Diff. (ton)	Improvement ratio %
TC1	0.95	Clay	127	49	38
TC2	0.65	Clay	78		
TC3	0.95	Sand	141	92	65
`TC4	0.65	Sand	49		

6. It was noted that the improvement in the bearing capacity of the pile with respect to friction ranged from 60 to 64 %, while the bearing capacity of the end bearing ranged from 85 to 98 %, as shown in Table 9, and the pile bearing capacity relative to the end bearing when not using the recycling system in pile with length 25 m and diameter 1.2 m was close to zero, and 15 % for the pile with length 30 m and diameter 1.2 m compared with the recycling system, which means that using the recycling system indicates that the effectiveness of this system is very active in cleaning the pile.

Table 9. Bearing capacity of piles from static load test and PLAXIS to TF1-A–TF3-A with B1–B3.

Load from field (static load test)			Friction capacity from PLAXIS			
Pile No.	Final load at 12 mm (ton)	Allowable load (ton)	Pile No.	Final load at 12 mm (ton)	Allowable friction capacity (ton)	End bearing capacity (ton)
TR1	263	175	TF1-A	260*	173	2
TR2	392	261	TF2-A	370*	247	14
TR3	282	188	TF3-A	255*	170	18

* Final load at modeling the piles as tension piles.

4. Conclusions

The most important results obtained from this study can be summarized as follows:

1. Using this system leads to a noticeable increase in the bearing capacity of the piles by about 50 % compared to not using it.
2. Using this system is very effective in obtaining a pile free of impurities and, in turn, will prevent pile failure because of not extracting all the sand and sludge while they are constructed.
3. The casting time for the piles that used the recycling system was about half an hour less than the piles that did not use it, and the amount of concrete was large, with an average of 2 m^3.
4. Using this system reduces the pile length by 15 % or more from the assumed pile length, according to design, which leads to reducing implementation costs.
5. The efficiency of the recycling system is increased, as the L/D value decreases.
6. The efficiency of the recycling system in sandy soils is higher than that of clay soils by about 27 %.
7. The pile bearing capacity was improved by 60–64 % and 85–98 % for friction and end bearing, respectively, when the recycling system was used.

References

1. Chandrasekaran, V., Garg, K.G., Prakash, C. Behaviour of Isolated Bored Enlarged Base Pile Under Sustained Vertical Loads. Soils and Foundations. 1978. 18(2). Pp. 1–15. DOI: 10.3208/sandf1972.18.2_1
2. Goudar, S., Kamatagi, A. An Experimental Evaluation of Axial Load Bearing Capacity of Belled and Straight Piles Embedded in Sand. International Journal of Engineering. 2022. 35(8). Pp. 1599–1607. DOI: 10.5829/ije.2022.35.08b.16
3. Al-Saidi, A.A., Al-Mosawe, M.j., Al-Shakarchi, Y.A.-S. Behavior of Defective Cast in Place Piles. Journal of Engineering. 2021. 27(4). Pp. 96–117. DOI: 10.31026/j.eng.2021.04.08
4. Al-Mosawe, M., Al-Shakarchi, Y., Al-Saidi, A. Influence of Defect in the Concrete Piles Using Non-Destructive Testing. Journal of Engineering. 2006. 12 (3). Pp. 1804-1816. DOI: 10.31026/j.eng.2006.03.14
5. Chong, W.L., Le, X., Rex, S. Base cleanliness of bored piles revisited–a case study. 13th Australia – New Zealand Conference on Geomechanics. Perth Convention and Exhibition Centre. Perth, 2019.
6. Lam, C., Jefferis, S.A., Suckling, T.P. Construction techniques for bored piling in sand using polymer fluids. Proceedings of the Institution of Civil Engineers: Geotechnical Engineering. 2014. 167(6). Pp. 565–573. DOI: 10.1680/geng.13.00128
7. Hasan, H.N., Al-Saidi, A.H. Evaluation of the Influence of De-sanding (Recycling System) Process on the Pile Bearing Capacity Using Full Scale Models. Journal of Engineering. 2022. 28(12). Pp. 80–92. DOI: 10.31026/j.eng.2022.12.06

8. Yahia, H.M. Soils and Soil Conditions in Sediments of the Ramadi Province (Iraq), Their Genesis, Salinity, Improvement and Use-Potential. University of Amsterdam. Amsterdam, 1971. 144 p.
9. Bowles, J.E. Foundation Analysis and Design. 5th edn. The McGraw-Hill Companies, Inc. New York, 1988. 1241 p.
10. PLAXIS. CONNECT Edition V21.01. PLAXIS 3D – Tutorial Manual. Bentley, 2021. 255 p.
11. Das, B.M., Sivakugan, N. Principles of Foundation Engineering. 9th edn. Cengage Learning, 2018. 944 p.
12. PLAXIS. CONNECT Edition V21.01. PLAXIS 3D – Reference Manual. Bentley, 2021. 576 p.
13. Federation of Piling Specialists. Federation of Piling Specialists. Bentonite Support Fluids in Civil Engineering. 2nd edn. FPS, 2006. 13 p.
14. Das, B.M., Sivakugan, N. Introduction to Geotechnical Engineering. Cengage Learning, 2015. 448 p.
15. Ibrahim, A.S., Al-bidry, M.A. Study the Effect of Particle Sizes and Concentration on the Rheological Properties of Iraqi Bentonite for Using as Drilling Fluids. Journal of Engineering. 2020. 26(3). Pp. 65–76. DOI: 10.31026/j.eng.2020.03.06
16. Department of Petroleum Engineering. PETE 203: Drilling Engineering: Laboratory Manual. King Fahd University of Petroleum & Minerals, 2003. 98 p.
17. Lam, C., Jefferis, S.A., Suckling, T.P. Treatment of bentonite fluid for excavation into Chalk. Proceedings of the Institution of Civil Engineers: Geotechnical Engineering. 2018. 171(6). Pp. 518–529. DOI: 10.1680/jgeen.18.00043
18. Shooshpasha, I., Mola-Abasia, H., Amiri, I. Evaluation of Static and Dynamic Methods for Determining the Bearing Capacity of the Driven Pipe Piles. International Journal of Engineering. 2014. 27(2). Pp. 307–314. DOI: 10.5829/idosi.ije.2014.27.02b.15
19. ASTM D1143/D1143M-2007 (R 2013). Standard Test Methods for Deep Foundations Under Static Axial Tensile Load ASTM International. West Conshohocken, PA, 2013. 15 p.
20. Murthy, V.N.S. Advanced Foundation Engineering. CBS Publishers & Distributors, 2007 795 p.
21. Astm, A.S.T.M., 2020. D1143/D1143M-20: Standard Test Methods for Deep Foundation Elements Under Static Axial Compressive Load. *West Conshohocken, PA, USA: ASTM International*.
22. Wrana, B., 2015. Pile load capacity–calculation methods. Studia Geotechnica et Mechanica, 37(4), Pp.83-93.
23. Bowers, J.T., Webb, M.C. and Beaver, J.L., 2019. Soil parameters for design with the 3D PLAXIS hardening soil model. *Transportation Research Record*, *2673*(10), pp.708-713.
24. Elkhawas, E.N.M., 2021. *ANALYSIS AND ASSESSMENT OF OFFSHORE PILES* (Doctoral dissertation, Zagazig University).
25. Brinkgreve, R.B., 2005. Selection of soil models and parameters for geotechnical engineering application. In Soil constitutive models: Evaluation, selection, and calibration (pp. 69-98).

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