University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 28 Number 12 December 2022

Civil and Architectural Engineering

Evaluation of the Influence of De-sanding (Recycling System) Process on the Piles Bearing Capacity Using Full Scale Models

Haider N. Hasan*	A'amal A.H. Al-Saidi
M.Sc. Candidate	Professor
Department of Civil Engineering	Department of Civil Engineering
University of Baghdad	University of Baghdad
Baghdad, Iraq	Baghdad, Iraq
hayder.hasan2001m@coeng.uobaghdad.edu.iq	dr.aamal.al-saidi@coeng.uobaghdad.edu.iq

ABSTRACT

The present study investigates the effect of the de-sanding (recycling system) on the bearing capacity of the bored piles. Full-scale models were conducted on two groups of piles, the first group was implemented without using this system, and the second group was implemented using the recycling system. All piles were tested by static load test, considering the time factor for which the piles were implemented. The test results indicated a significant and clear difference in the bearing capacity of the piles when using this system. The use of the recycling system led to a significant increase in the bearing capacity of the piles by 50% or more. Thus it was possible to reduce the pile length by (15 % or more) thus, and implementation costs were significantly reduced. Furthermore, casting time for the pile group in which the system is used is less than for the pile group that did not use it (approximately half an hour per pile), and the amount of concrete was greater by an average of 2 cubic meters for each pile.

Keywords: Bored Pile, Bentonite, Support Fluid, Bearing Capacity, Recycling System.

تقييم تأثير عملية إزالة الرمل (نظام إعادة التدوير) على قدرة تحمل ركائز الحفر باستخدام نماذج كاملة المقياس

حيدر ناظم حسن *	امال عبد الغني السعيدي
طالب ماجستير	استاذ
جامعة بغداد – قسم الهندسة المدنية	جامعة بغداد – قسم الهندسة المدنية

* Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.12.06

Article received: 1/6/2022
Article accepted: 17/7/2022
Article published: 1/12/2022

الخلاصة

في هذه الدراسة، تم دراسة تأثير إزالة الرمل (نظام إعادة التدوير) على قدرة تحمل ركائز الحفر، حيث تم تنفيذ نماذج كاملة المقياس قسمت الى مجموعتين من الركائز، تم تنفيذ المجموعة الأولى دون استخدام هذا النظام، وتم تنفيذ المجموعة الثانية باستخدام نظام إعادة التدوير. تم اختبار جميع الركائز عن طريق اختبار التحميل الساكن، مع الأخذ في الاعتبار عامل الوقت الذي تم تنفيذ الركائز به. أشارت نتائج الاختبار إلى اختلاف كبير وواضح في قدرة التحمل الركائز عند استخدام هذا النظام. أدى استخدام نظام إعادة التدوير إلى زيادة كبيرة في قدرة تحمل الركائز بنسبة تصل الى 50% او أكثر، حيث من الممكن تقليل طول الركيزة بنسبة (15٪ أو أكثر) وبالتالي تقليل تكاليف التنفيذ بشكل كبير. علاوة على ذلك فإن وقت الصب لمجموعة الركائز التي تم استخدام النظام فيها أقل من وقت مجموعة الركائز التي لم تستخدمه (كمعدل نصف ساعة لكل ركيزة) وكمية الكونكريت أكبر بحوالي 2 متر مكعب كمعدل لكل ركيزة.

الكلمات الرئيسية: ركائز الحفر، البنتونايت ، سوائل الدعم ، قدرة التحمل ، نظام إعادة التدوير

1. INTRODUCTION

Piles are increasingly used to effectively transfer the superstructure loads to the sub-soil when the soil conditions at the site and specific other functional requirements discard the use of shallow foundations **(Chandrasekaran *et al.,* 1978)**.

The bored piles are usually bored by special machines and with the aid of using bentonite liquid, water, or polymer **(Tomlinson and Woodward, 2007)**. These fluids support the sides of the hole and cool and lubricate the machine **(Dreger *et al.*, 2020)**.

After the hole excavating process is completed, the boring residues remain suspended in the liquid for a certain period that depends on the properties of the liquid, or settle its deposited at the base of the hole or suspended between steel reinforcement if high steel density and may be adjacent to the walls of the hole from the inside.

To remove this sludge and residues from the pile body, some methods are used, including the cleaning pocket **(Chong *et al.,* 2018)** or air-lifting **(Lam *et al.,* 2014)** to avoid pile failure from a geotechnical point of view **(Al-Saidi *et al.,* 2021)**.

The previous two methods considered are traditional methods followed in many countries; in this study, a non-traditional method was used and derived from a cleaning mechanism of bentonite **(Manual, 2010)**.

The recycling system was used to remove sand and other sludge from the hole after installing the steel cage but before casting.

This method includes pumping fresh bentonite from the top of the hole and withdrawing the bentonite from the bottom using a tremie tube. The recycling process removes all drilling residues, thus obtaining a clean hole body of all impurities before starting the casting process.

2. SITE CONDITION

2.1 Ground Condition

The proposed site lies on area number (173/23 m 30) within Al- Muthana- airport land in Baghdad city with coordinates (33°19'54.62"N and 44°21'48.76"E) as shown in **Fig. 1**.
From the geological point of view, the investigated area is located on the Mesopotamian plain zone within the region of unstable shelves according to the tectonic division for Iraq **(Buringh, 1960)**.
The field test showed that the soil profile consists mainly of the following layers, the uppermost layer (0 – 8.5 m), classified as cohesive soil varied in-depth, 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, as shown in **Fig. 2**.
The field tests were carried out by the (Andrea Engineering Tests Laboratory and Consulting Engineering Bureau College of the Engineering at the University of Baghdad) and **Table 1** shows the in-situ soil properties, which were obtained using the SPT test.

Figure 1. Site location.

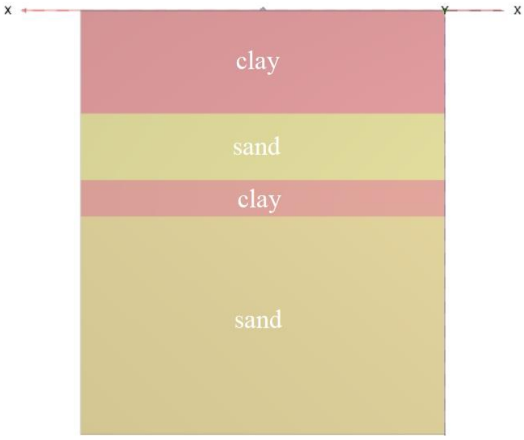

Figure 2. Soil layers.

Table 1. The in-situ soil properties.

Geotechnical Parameters	First Layer (0 – 8.5m)	Second Layer (8.5 - 14m)	Third Layer (14 – 17m)	Fourth Layer (17 – 35m)
Cohesion (C), kPa	32 – 46	0	100 – 120	0
The angle of Internal Friction (Ø)	0 – 3	28 – 35	3 – 6	35 – 45
γ dry, kN/m^3	14.5 – 15.5	15 – 16	15.5 – 16.5	16 – 17
w_c (%)	20 – 26	14 – 20	20 – 24	14 – 18
e_o	0.65 – 0.85	-	0.65 – 0.75	-
C_c	0.16 – 0.22	-	0.18 – 0.22	-
C_r	0.035 – 0.045	-	0.03 – 0.04	-
Soil Classification	CL – CH	SC – SM	CH	SM – SW
LL	53	-	49	-
PL	28	-	26	-

2.2 Groundwater

Groundwater was encountered in all boreholes during drilling at measured depths, and the groundwater level was recorded after 24 hours of drilling at about 2.8 - 4.0 m below the natural ground surface.

3. ULTIMATE LOAD CARRYING CAPACITY of PILES (THEORETICAL METHODS)

The ultimate load carrying capacity Qu, has been expressed in Eq.1 **(Meyerhof, 1976)** as

$$Qu = Qp \; x \; Qs \tag{1}$$

Where:

Qp = the load carrying capacity of the pile point (kN)

Qs = frictional resistance (skin friction) (kN)

in sand, the point load Qp can be expressed (Meyerhof 1976) as

$$Qp = Ap\ x\ qp = Ap\ x\ q'x\ N^{*}q \qquad (2)$$

in clay, the point load $\boldsymbol{Qp}$ can be expressed (Meyerhof 1976) as

$$Qp = Ap\ x\ qp = Ap\ x\ cu\ x\ N^{*}c \qquad (3)$$

Where:

$\boldsymbol{Ap}$ = the base area of the pile (m^2)

$\boldsymbol{qp}$ = unit point resistance (kN/m^2)

$\boldsymbol{q'}$ = effective vertical stress at the level of the pile tip (kN/m^2)

$\boldsymbol{Nq^{*}}$ = bearing capacity factor

$\boldsymbol{Cu}$ = undrained cohesion at the pile tip (kN/m^2)

$\boldsymbol{Nc^{*}}$ = bearing capacity factor = 9.0

The frictional resistance in sand $\boldsymbol{Qs}$, can be estimated as

$$Qs = \Sigma(p\ x\ \Delta l\ x\ f) \qquad (4)$$

The frictional resistance in clay $\boldsymbol{Qs}$, can be estimated as

$$Qs = \Sigma(p\ x\ \Delta l\ x\ Ca) = \Sigma(p\ x\ \Delta l\ x\ \alpha\ x\ cu) \qquad (5)$$

Where:

$\boldsymbol{p}$ = the perimeter of the pile cross-section (m)

$\boldsymbol{f}$ = unit frictional resistance (kPa)

$\boldsymbol{\Delta l}$ = Incremental pile length over which $\boldsymbol{p}$ and $\boldsymbol{f}$ are taken (m)

$\boldsymbol{Ca}$ = adhesion at the soil–pile interface (kN/m^2)

$\boldsymbol{\alpha}$ = a nondimensional quantity which is a function of $\boldsymbol{cu}$.

4. CONSTRUCTION DETAILS

4.1 Pile Details

Depending on the soil investigation, many methods are used to implement the pile, including using the casing to support the soil close to the surface and prevent it from collapsing **(Das and Sivakugan, 2015)**. This method (casing) was used to implement the piles in this study. Four test piles were identified for this study; the first two piles are (TP1 and TP2) with a diameter of 120 cm and a working load of 400, and 360 tons, respectively.

The length of the first pile (TP1) with 25 meters, and the second (TP2) with 30 meters, were carried out for a period of time ranging from five and a half to seven hours, and the piles were cleaned from the waste and the sludge of boring by the cleaning pocket method.

After 28 days, the two piles were tested by static load test, the two piles were tested, and both failed.

The two other test piles were selected using the recycling system (TP3 and TP4) with a diameter of 120 cm and a working load of 360 tons.

The length was 25 meters for the first pile (TP3), and a length of 30 meters for the second pile (TP4) was carried out for a period of time ranging from eight to nine hours, and the static

load test was conducted for them. The results were very good. **Table 2** shows the details of the four piles.
The four piles were implemented in an area not exceeding 120 square meters (4*30 m), and the groundwater level at the time of implementation was about (2.8-3 m).
It's worth mentioning that the sides of the surface soil were supported using a casing with a diameter of 130 cm and a length of 4 meters.
Three meters of it were planted in the soil, leaving one meter above the natural ground level to install a steel cage and support the tremie tube, as shown in **Fig. 3**.

Table 2. The details of the tested piles.

Pile Name	Diameter (m)	Length (m)	Recycling Time (hr.)	Working load (ton)	Construction time (hr.)
TP1	1.2	25	-	400	5.5
TP2	1.2	30	-	360	6.8
TP3	1.2	25	1.20	360	8.2
TP4	1.2	30	1.59	360	8.9

Figure 3. Illustration figure for soil supporting.

4.2 Support Fluid

Bentonite liquid (sodium bentonite) was used in boring and supporting the hole for all four piles, as shown in **Fig. 3**.
A bentonite mixing station was used consisting of two tanks and a de-sander with the necessary connections. The properties of bentonite used for each pile (density, viscosity, pH, and sand content tests) were conducted **(FPS, 2006)**. **Table 3** shows the properties of the bentonite used for each pile.

Table 3. The properties of the bentonite used for each pile.

Pile Name	Density (in) mg./ml	Viscosity (in) second	pH (in)	Sand content (in) %	Density (out) mg./ml	Viscosity (out) second	pH (out)	Sand content (out) %
TP1	1.065	48	9.5	0.6	-	-	-	-
TP1	1.075	49	9.5	0.6	-	-	-	-
TP3	1.075	50	10	0.8	1.08	40	9	2
TP4	1.08	50	10	1	1.1	42	9.5	3.5

4.3 Recycling System (de-sanding)

The aim of the recycling system is to produce piles with no impurities to avoid pile failure; the reasons for failure are attributed to two main factors, as mentioned in **(Poulos, 1999)**.
The first factor is geotechnical defects that arise from incorrect assessment of conditions in the site during design.
The second factor is structural defects related to pile construction, which leads to structural pile failure **(Al-Mosawe *et al.,* 2006)**.
The main objective of the recycling system is to get rid of impurities and excavation residues during the implementation of the pile, thus preserving the pile from geotechnical defects.
Cleaning and recirculating bentonite slurry were achieved by removing sludge and sand from the drilled hole by cleaning equipment and returning the cleansed slurry **(PETE, 2003)**.
This method was used from the same mechanism as the bentonite cleaning system that comes out during pouring the pile **(Lam *et al.,* 2018)**, but the system was used to withdraw the bentonite that contains impurities and drilling sludge before pouring the pile, as in **Fig. 4**.
After the steel cage is installed in the hole, the tremie tube is inserted in the hole, and a small gap is left between the bottom of the hole and the tremie tube between 20 to 35 cm, and connect the tremie tube from the top with a suction pump with a capacity of (350 m^3/hr.) to withdraw the bentonite from the bottom of the hole, then connected the outside of the pump to the de-sander with a capacity of (2500 HP).
After the connections were set, the fresh bentonite was pumped from the top of the hole and the bentonite was withdrawn from the bottom (there must be a balance in the amount of bentonite that is pumped from the top and those that are withdrawn from the bottom of the hole) in order not to have an imbalance of hydrostatic pressure and collapsing in the body of the hole where the level of bentonite in the hole is monitored along the cleaning process, as in **Fig. 5**.
After checking the cleaning rate of these piles (TP3 and TP4), the cleaning process took from one to one and half hours for each pile with a diameter of 120 cm and a length of 25 to 30 meters. The process is stopped after checking the sand content of the bentonite that comes from the hole, which should be less than 4 percent **(Deese, 2004)**, as in **Table 3**.

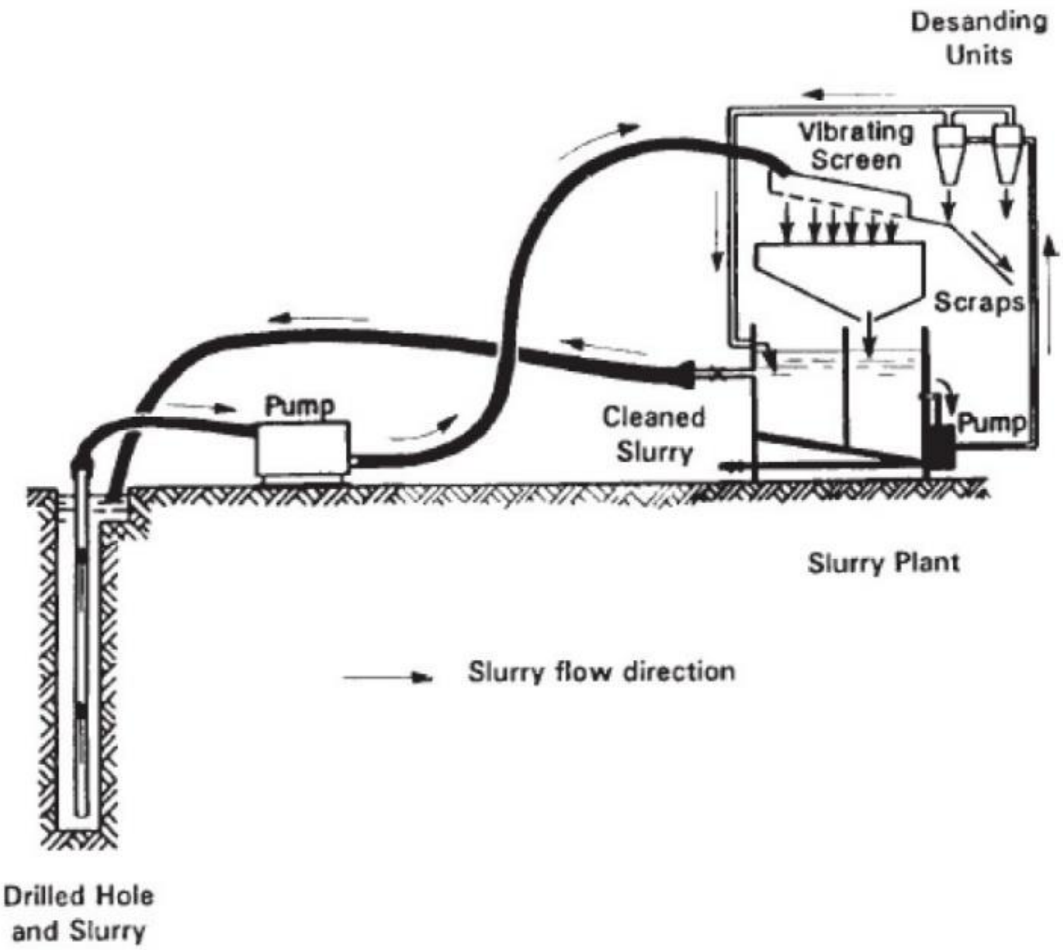

Figure 4. Recirculation and cleaning schematic (Manual CCDWU, 2008).

Figure 5. The recycling system used in situ.

5. ULTIMATE LOAD CARRYING CAPACITY of PILES (FIELD TEST)

The static loading testing was conducted on the four piles. The aim of the testing was to evaluate the static pile capacity and its associated settlement under axial compressive load **(Bowles, 1988)**.

A static load test simulates the load applied to the pile after the structure's completion when the pile foundation is usually subjected to vertical loads **(Al-Jeznawi et al., 2022)**.

According to the requirements of ASTM D1143-81, the maximum load applied to the pile during this test on this scheme shall be (Working Load multiplied by 2) **(ASTM D1143, 2007)**.

The loading frame was designed to apply a maximum axial compressive load plus more than 10% to accommodate the required load increments for loading test stages as recommended by the ASTM D 1143/D 1143M-07.

The cycle starts by loading the pile to two times of working load through eight load increments (sustained for at least one hour), sustaining the load for at least 12 hours then unloading the total applied load through four load decrements (sustained for at least one hour) **(ASTM D1143-81, 2007)**.

6. EVALUATION of the RESULTS of METHODS

The interpretation of the pile test results depends on the method in which the bearing capacity of the pile was calculated, where the bearing capacity of the pile varies based on the method used to find it. Most likely, these differences are insignificant **(AL-KINANI and Ahmed, 2020)**.

There are different criteria to evaluate the pile settlement after completing the loading and unloading stages during testing under static axial compressive load. The criteria belong to the following official building codes and references:

- Davisson offset Limit method, which has been proposed by Davisson as the load corresponding to the settlement that exceeds the elastic compression of the pile (PL/AE) by a value of 0.15 inch (4 mm) plus a factor equal to the diameter of the pile divided by 120 The load-settlement curve is plotted to a convenient scale so that the elastic line, represents the relationship between the load and shortening of an elastic-free axially loaded Colum which equals PL/AE. The ultimate line is drawn parallel to the elastic line at an offset distance (4+ 0.008 D). The intersection of the second line (offset line) with the load settlement curve gives the ultimate pile load (Q ult) **(Fellenius, 1975)**.
- Chicago and International Conference of Building Official Building Code, where the maximum allowable pile settlement at the end of the loading should not exceed (25mm) **(Code, 1997)**.
- Boston Building Code, where the maximum allowable pile settlement at the end of the unloading stage should not exceed (12.5mm) **(Orozco Herrera, 2021)**.
- The allowable load (Qa) is sometimes taken as equal to two-thirds of the final load, which causes a total settlement of 12 mm or a net (plastic) settlement is 6 mm **(Murthy, 2007)**.

7. RESULTS and DISCUSSIONS

After conducting a static load test by (The al-Tariq Bureau for Engineering Consultation and Pile Tests), the settlement was recorded for each pile with each loading stage. **Fig. 6** shows the (load–settlement) curve for the four tested piles.

And based on the allowable load (Qa) is taken as equal to two-thirds of the final load, which causes a total settlement of 12 mm. This method was chosen as it directly gives the bearing capacity of the pile, while the other methods may not be applied to all loading and settlement results.

The allowable load for the four piles is shown in **Table 4**, where a clear difference can be observed in the settlement rate of the two groups.

Several other benefits of this system were noted, which can be summarized as follows:

1. It was observed that the length of each pile of the second group (TP3 and TP4) cleaned by the recycling system increased by 20 to 35 cm. This indicates that the result of cleaning the bottom of the pile was very good, although the pile length measurement was taken immediately after excavating the pile.
2. The amount of sand and sludge that came out of the second group piles (TP3 and TP4) using this system is very large; where it was noted that the average quantity was about two cubic meters (this quantity was calculated from the two piles of the second group).
3. The process of casting the piles in the second group (TP3 and TP4) has taken less time than the piles in the first group (TP1 and TP2); this indicates that the flow of concrete inside the pile was very good as there was no sludge blocking the flow of concrete inside.
4. The amount of concrete in the piles of the second group (TP3 and TP4) was greater than the piles of the first group (TP1 and TP2), by an average of 2 cubic meters.
5. The recycling system has improved the bearing capacity of the piles in terms of friction and the end bearing, as the recycling of bentonite inside the hole helped to remove sand and sludge from the bottom, as well as reduce the filter cake layer from the sides of the hole, where 4 and a half meters were excavated, and it was noted that the pile's body does not contain a clear cake filter that can be measured, which indicates that the process has sanded the filter cake layer in addition to cleaning the base of the pile.
6. It is possible to reduce the length of the pile by (15 % or more) of the length of the assumed pile according to the design. Based on the experiment results, the pile length was reduced from 30 meters with a design load of 360 tons to a pile with a length of only 25 meters and the same design load, which led to a reduction in implementation costs.
7. The recycling system took an average of an hour to an hour and a half; if that time is subtracted from the pile implementation time, it's fine.
8. After testing the first pile (TP1) and its failure, the working load of the second pile (TP2) was reduced to 360 tons in the hope of obtaining less settlement, but it also failed.
9. Settlement of 12 mm was not reached when loading the fourth pile (TP4) when loading 200%, so the last load was taken to find the bearing capacity of the pile.
10. The sand content of each pile was checked approximately 2 to 3 times before stopping the recycling process until a sand percentage of less than 4 percent was reached.

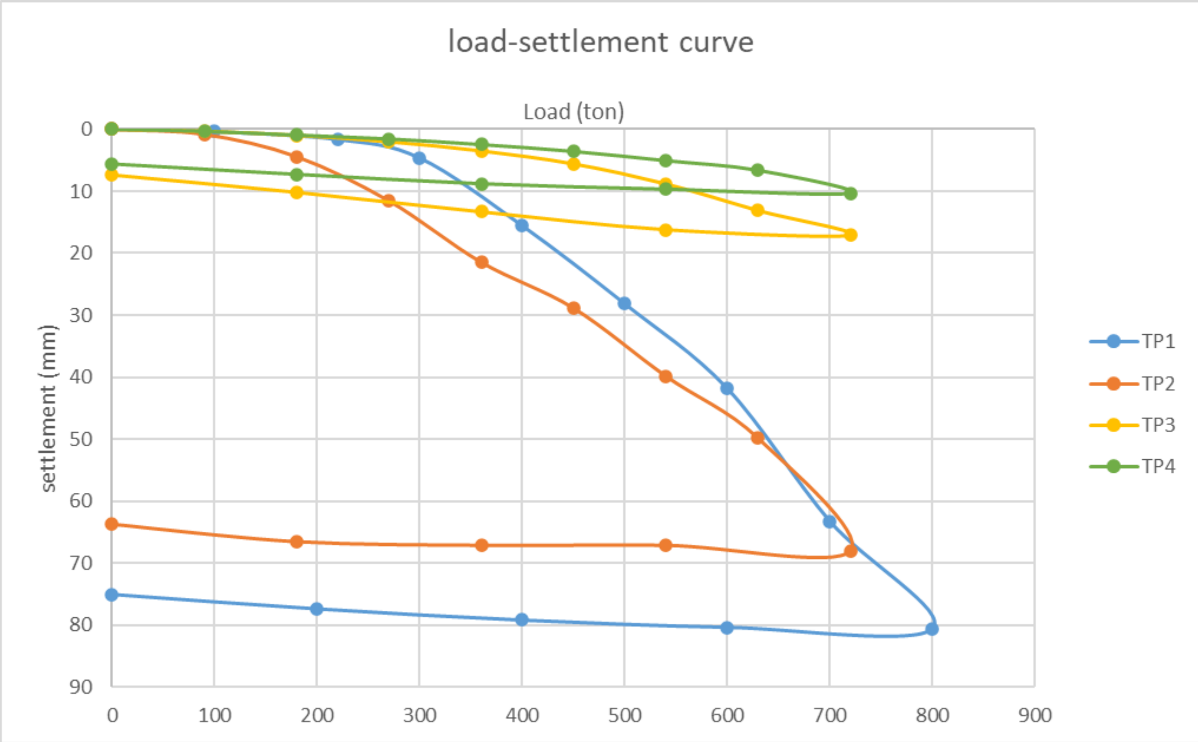

Figure 6. (Load – settlement) curve for the tested piles.

Table 4. The allowable load for the tested piles.

No. of Pile	Final load (ton) at (12 mm)	Allowable load (ton)	No. of Pile	Final load (ton) at (12 mm)	Allowable load (ton)
TP1	369	246	**TP3**	600	400
TP2	275	184	**TP4**	720	480

8. CONCLUSIONS

After conducting the static load test for the two groups of piles, the following main conclusions can be drawn:

1. This system's use has helped obtain a high bearing capacity for the second pile's group (TP3 and TP4) by 50 % or more.
2. The length of each pile of the second group (TP3 and TP4) cleaned by the recycling system increased by 20 to 35 (cm); this indicates that the result of cleaning the bottom of the pile was very good although the pile length measurement was taken immediately after boring the pile.
3. A large amount of sand and sludge that came out of the (TP3 and TP4) piles indicates that the use of this system is very effective.

And that the failure of the first two piles (TP1 and TP2) is due to the fact that not all sand and sludge were extracted from those piles despite using the pocket method to clean them.

4. The casting time for the piles (TP 3 and TP4) in which the system is used is less than for the piles (TP1 and TP2) that did not use the same system.
5. The amount of concrete was greater for the piles of the second group (TP3 and TP4), and this explains that this amount of concrete was instead of the sludge and sand that came out of the pile compared to the piles of the first group (TP1 and TP2).
6. It is possible to reduce the pile length by (15 % or more), which led to a reduction in implementation costs.

NOMENCLATURE

C = soil cohesion, kPa
C_c = compression index, unitless
CH = fat clay
CL = lean clay
C_r = recompression index, unitless
e_o = void ratio, unitless
LL = liquid limit, %
PL = plastic limit, %
SC = clayey sand
SM = silty sand
SW = well-graded sand
w_c = water content, %
γ dry = dry unit weight of soil, kN/m^3

REFERENCES

Al-Jeznawi D., Ismacahyadi Bagus Mohamed Jais, Bushra S. Albusoda and Norazlan Khalid, 2022. The slenderness ratio effect on the response of closed-end pipe piles in liquefied and non-liquefied soil layers under coupled static-seismic loading, *Journal of the Mechanical Behavior of Materials*, 31(1), pp. 83–89.

AL-KINANI, A. M., and Ahmed, M. D., 2020. Comparison of Single and Group Bored Piles Settlement Based on Field Test and Theoretical Methods, *Journal of Engineering*, 26(2), pp. 144–158. DOI: 10.31026/j.eng.2020.02.11.

Al-Mosawe, M., Al-Shakarchi, Y., and Al-Saidi, A., 2006. Influence of defect in the concrete piles using non-destructive testing, *Journal of Engineering* (3).

Al-Saidi, A. A., Al-Mosawe, M. J., and Al-Shakarchi, Y. A.S., 2021. Behavior of Defective Cast in Place Piles, *Journal of Engineering*, 27(4), pp. 96–117. DOI: 10.31026/j.eng.2021.04.08.

ASTM 2007. Deep Foundations Under Static Axial Compressive Load, *Astm D1143/D1143M-07*, D1143/D114(Reapproved 2013), pp. 112–126. Available at: www.astm.org.

ASTM D1143, 2007. ASTM D 1143/D 1143M-07 Standard Test Methods for Deep Foundations Under Static Axial Tensile Load, *ASTM International*, 07(Reapproved 2013), p. 15.

Bowles, J. E., 1988. *Foundation analysis and design*.

Buringh, P., 1960. *Soils and soil conditions in Iraq*, Ministry of Agriculture. Baghdad.

Foundation Manual, 2010. *ReVision*, (November 2008).

Chandrasekaran, V., Garg, K. G., and Prakash, C., 1978. Behaviour of Isolated Bored Enlarged Base Pile Under Sustained Vertical Loads, *Soils and Foundations*, 18(2), pp. 1–15, DOI: 10.3208/sandf1972.18.2_1.

Chong, W. L., Le, X., and Rex, S., 2018. Base cleanliness of bored piles revisited–a case study.

Code, U. B., 1997. International building code, *International Code Council, USA*.

Das, B. M., and Sivakugan, N., 2015. *Introduction to geotechnical engineering*, Cengage Learning.

Deese, G. G., 2004. Slurry sand content and concrete interaction in drilled shaft construction, pp. 1–106. Available at: http://etd.fcla.edu/SF/SFE0000500/Slurry_Sand_Content_and_Concrete_Interaction_in_Drilled_Shaft_Construction.pdf.

DREGER, M., MARCIN D., MIECZYS£AW P., CEZARY K., MICHA M., LESZEK R., and MARIUSZ W., 2020. Bentonite-loess slurry for construction of diaphragm walls and bored piles, *Roads and Bridges - Drogi i Mosty*, 19(2), pp. 97–106 DOI: 10.7409/rabdim.020.006.

Federation of Piling Specialists Bentonite Support Fluids in 2006, January.

Fellenius, B. H., 1975. Test loading of piles and new proof testing procedure, *Journal of the Geotechnical Engineering Division*, 101(9), pp. 855–869.

Lam, C., Jefferis, S. A., and Martin, C. M., 2014. Effects of polymer and bentonite support fluids on concrete-sand interface shear strength, *Geotechnique*, 64(1), pp. 28–39, DOI: 10.1680/geot.13.P.012.

Lam, C., Jefferis, S. A., and Suckling, T. P., 2018. Treatment of bentonite fluid for excavation into Chalk', *Proceedings of the Institution of Civil Engineers: Geotechnical Engineering*, 171(6), pp. 518–529. DOI: 10.1680/jgeen.18.00043.

Meyerhof, G. G., 1981. The bearing capacity of rigid piles and pile groups under inclined loads in clay, *Canadian Geotechnical Journal*, 18(2), pp. 297–300.

Orozco Herrera, J. E., 2021. Ground Movements and Vibrations Caused by Impact Pile Driving of Prestressed Concrete Piles in Central Florida.

PETE, 2003. Department of Petroleum Engineering, DRILLING ENGINEERING, (April), pp. 12.

Poulos, H. G., 1999. Behaviour of pile groups with defective piles, in *International Conference on Soil Mechanics and Foundation Engineering*, pp. 871–876.

Tomlinson, M. and Woodward, J., 2007. *Pile design and construction practice*. CRC Press.

Murthy, 2007. Advanced Foundation Engineering Geotechnical Engineering Series, pp. 795.