Enhancement of Open-Ended Pipe Pile Embedded in Sand Using Steel Collar

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Abstract. The open-ended pipe piles are among the piles that are employed the most frequently because of their advantages, including their ease of transport and resistance to driving stress. It is further distinguished by the fact that the soil column formed inside the pile increases the pile capacity. Numerous ideas have been presented forth in the literature to enhance the performance of these piles. In this study, it is suggested that a steel collar be used at its lowest end to enhance the performance of the pile. Ten experimental tests for piles embedded in loose sand soil were carried out to determine the impact of the collar diameter and length concerning the pile diameter and length. Three diameters, 1.5D, 2D, and 3D, and three length ratios: 10, 20, and 30% were employed. The use of a steel collar improves the load capacity of the pile and reduces settlement, according to the data, although the collar with a diameter of 1.5D and a length of 10% had little effect. According to the study, using a collar with a diameter of 2D and a length of 20% is enough to double pile capacity and prevent the overlapping effect of stress bulbs between neighboring piles. As a result, using such a method minimizes the cost of constructing the foundations because of the reduction in the number of piles required.

Keywords: Steel collar; enhancement of pile; collar dimensions; improved pile capacity.

1. INTRODUCTION

One of the most common types of deep foundations that are commonly used in different structures is pile foundations. The piles are primarily employed when the soil at the surface has minimal bearing capacity or when the resulting settlement is more than the tolerable amount, affecting the structure's desired function. Other circumstances require the use of piles, such as when the building is subjected to high lateral loads, when pulling forces are present that could damage the foundation, or when the surface soil is subjected to the risk of scouring [1-7]. In general, a large variety of pile types are used. One popular type of pile is the steel pile (H-pile and pipe pile), which has the advantages of being lightweight to handle, strong enough to withstand heavy driving stress, and able to extend to the appropriate depth. One can utilize closed-ended or open-ended pipe piles. There are two modes to use pipe piles: closed-ended or open-ended. Less driving stress is experienced by the open-ended pipe pile [8].

During the driving of the open-ended pipe pile into the ground, it is very likely that during the early stage of pile driving at relatively shallow depths, the soil will enter inside an open-ended pipe pile. This activity is frequently referred to as "full coring state" or "unplugging" behavior if the pile penetration depth is equal to the length of the soil plug. The soil friction inside the pile wall increases as the pile is driven deeper into the ground, eventually forming a "soil plug" that may completely or partially prevent additional soil from entering the pile. which is known as "plugging." The soil plug length inside the pile is smaller than the depth of the pile penetration [9]. A column of soil develops inside the open-ended pile (soil plug) when it is embedded in the soil. This increases the amount of friction on the pile surface and, consequently, the pile capacity. Several suggestions have been made to enhance the performance of the open-ended piles [9], utilizing a steel plate to close the open-ended pile at a specific height above the pile tip. They investigated three different closing distances: 2D, 3D, and 4D. According to the results, the case of closing distance of 3D was found to be the optimum scenario.

Matsumiya et al. [10] evaluated the behavior of five piles with varied tapered tip diameters. The piles were evaluated under static compression while being set up in different sand densities, and the results showed that the tapered tip produced less soil plugging and had lower pile resistance than the straight shaft pile. Sahli [1] suggested adding several horizontal screws to the open-ended pile. The comparison of the original pile and the modified pile revealed that the addition of screws increased pile capacity, which in turn decreased associated settlement and resulted in a 36% reduction in the maximum settlement. Hamadi and Abdul-Husain [11] employed an experimental model pile in sand soil and investigated the effect of employing separation walls inside the pile under a pull-out load. Three different wall configurations were used: two walls at 180°, three at 120°, and four at 90°. They stated the case of three separation walls had been proven to give the optimum behavior.

Al-Soudani and Al-Busoda [12] changed the shape of the lowest part of an open-ended pipe pile by giving it a tapered shape. The tapering part had a diameter that was half that of the pile and a length that equaled that of the pile. Two model piles with penetration ratios of 15 and 20 were employed in loose, dry sand soil. For the two models, the suggested modification increased the pile capacity by 28% and 36%, respectively. Based on an experimental load test in cohesionless soil, investigated the behavior of open-ended piles with a restriction plate at a predetermined distance above the pile tip. Two plates were used, one with one central hole and the other with four holes. They noticed that the use of restriction plates enhanced the pile capacity [13].

The present investigation aims to examine the influence of introducing a steel collar at the pile tip on the behavior (pile capacity) of an open-ended pipe pile embedded in sand soil and subjected to axial compression load.

2. EXPERIMENTAL WORK

A laboratory model of type 1g-model was used to investigate the impact of adding a steel collar to the open-ended pile. Details of the steel box, pile and collar, and the soil used, as well as the technique of conducting the test, are specified in the following sections:

2.1 Steel Box and Testing Frame

A loading system has been developed for the experimental work to mimic the field test. The system comprises a square steel box with dimensions of (50*50) cm and a height of 110 cm, see Figures 1 and 2. According to [9], the box size was chosen to avoid the effect of boundaries [14]. The center rod that applies the dead loads throughout the test is supported by a transverse steel girder that crosses two steel columns that make up the loading frame, as illustrated in Figures 1 and 2.

Figure 1: Steel box and loading frame.

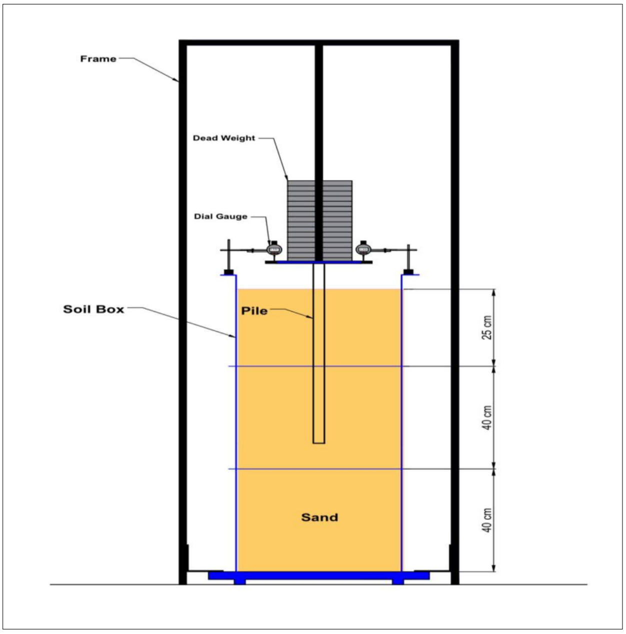

Figure 2: Schematic diagram of the steel box and loading frame.

2.2 Characteristics of Soil Used

The soil bed employed in the current work is brought from Al-Najaf City. Table 1 below exhibits the physical characteristics of the soil. The soil is classified as SP by the USCS. Figure 3 shows the grain size distribution of the soil used.

Table 1: Physical characteristics of the soil used.

Property	Value	Specification
D_{10}	0.176 mm	Grain size analysis ASTM D422-63
D_{30}	0.251 mm	
D_{60}	0.284 mm	
$\gamma_{d(max)}$	15.8 kN/m^3	ASTM D4253
$\gamma_{d(min)}$	14.6 kN/m^3	ASTM D4254
G_s	2.60	ASTM D 854

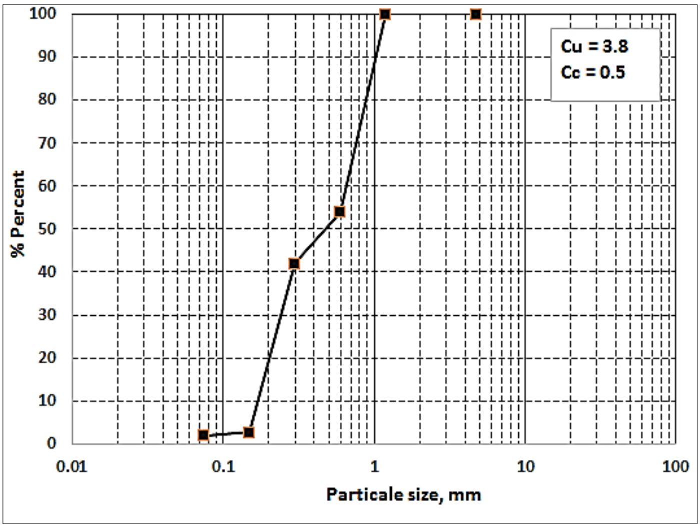

Figure 3: Grain size distribution curve of the soil used.

2.3 Pile and Collar Used

In order to simulate the pile experimentally, a steel pipe with a circular section and an outside diameter of 30 mm is utilized. A pile penetration ratio (L/D) is set to be 20 for all tests. A steel collar similar to the pile material with a different diameter and height has been used. See Figure 4.

Figure 4: Details of the pile and collar used.

3. PREPARATION AND TESTING PROCESS

Ten experimental models have been tested in the present work. Each test comprises the preparation of the soil bed, the model pile's installation, and the testing load's application. The dry tamping technique has been adopted in the study to place the soil in the steel box and prepare the required soil bed [11]. The following procedures are followed to accomplish the research's major goals, as shown in Figure 5.

It was determined the total thickness of the soil bed, based on the length and diameter of the pile, must be at least five times the diameter of the pile. Divide the soil bed thickness into sub-layers that are each 5 cm thick. The soil required for each sub-layer is weighed by knowing its volume and unit weight density. Use a specific tamper to compact the weighed soil mass in order to achieve the required sub-layer thickness. Used a tamper steel plate with dimensions of 20*20*1 cm and a steel rod 30 cm long after achieving the full thickness of the soil bed and choosing the appropriate pile model (diameter and penetration ratio). Insert the pile tip through the holes of the center two plates; attach the installation frame, which consists of two wooden plates held together by four screws, to the steel box top until the bottom of the pile touches the surface of the soil; Use the hammer to drive the pile into the soil to the required depth in the soil bed. Fasten the steel frame with the box soil and fasten the loading plate at the center of the pile head. Place two digital dial gages with an accuracy of 0.0001 mm on the loading plate to record the vertical movement corresponding to each gradual increase in load. By applying compression loads gradually, the pile begins to move gradually, corresponding to the increase in the reading of the dial gages, until a state of failure is reached.

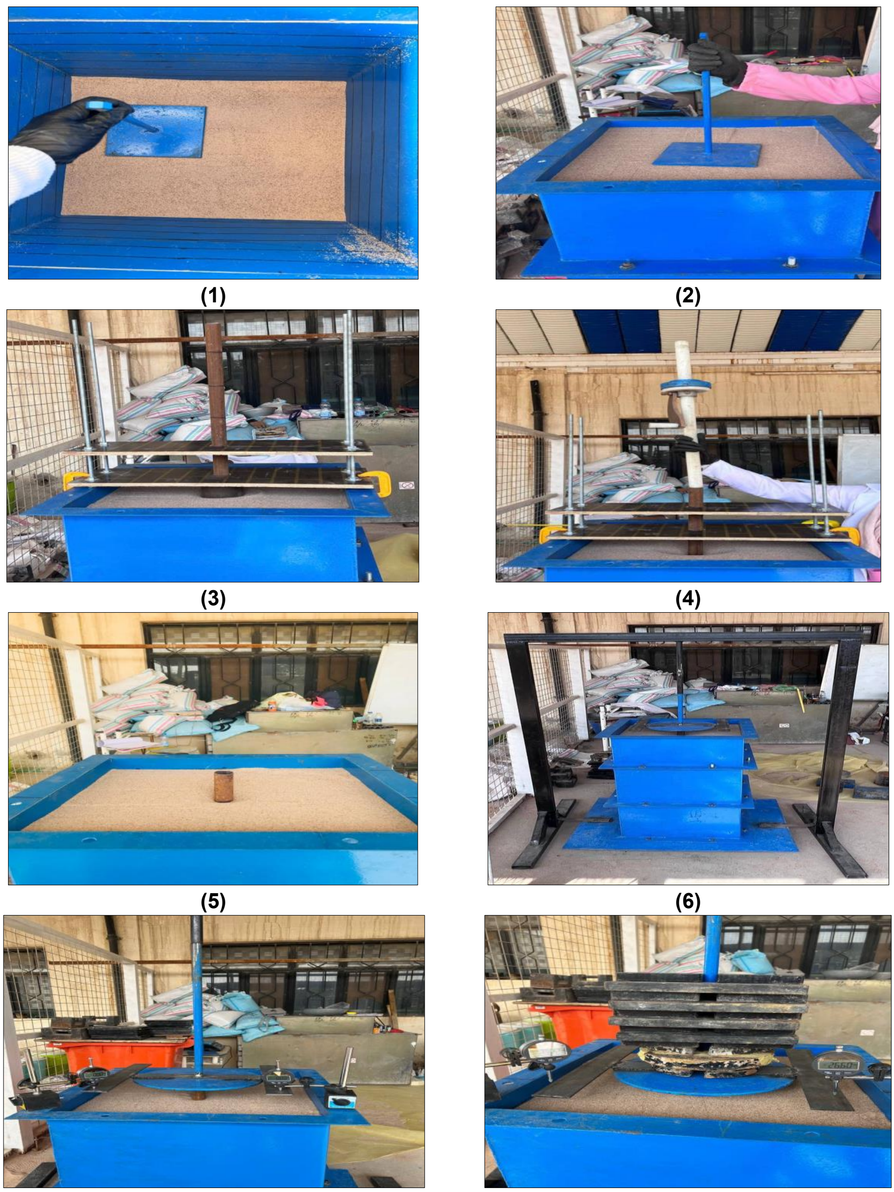

Figure 5: Preparation of the model and testing process.

4. TESTING PROGRAM

The testing program comprises ten model tests. These tests are conducted to investigate the effect of collar geometry on the behavior of the open-ended pile. In general, three different collar diameters have been adopted, which are 1.5D, 2D, and 3D. Each diameter was used in three different lengths, representing 10%, 20%, and 30% of the total pile length. Table 2 demonstrates that each model is assigned an identification symbol (ID), as shown in Table 2, to simplify the notation for piles. ID for each pile is used to identify the model pile based on collar dimensions (collar-to-pile diameter ratio and collar-to-pile length ratio), as shown in Figure 6.

Table 2: Identification of model piles with/without a collar.

Collar dimensions		D_c/D	L_c/L	ID
Diameter, D_c	Length, L_c			
Without collar		-	-	0.0PW00
45 mm	6 cm	1.5	10%	1.5PC10
	12 cm		20%	1.5PC20
	18 cm		30%	1.5PC30
60 mm	6 cm	2	10%	2.0PC10
	12 cm		20%	2.0PC20
	18 cm		30%	2.0PC30
90 mm	6 cm	3	10%	3.0PC10
	12 cm		20%	3.0PC20
	18 cm		30%	3.0PC30

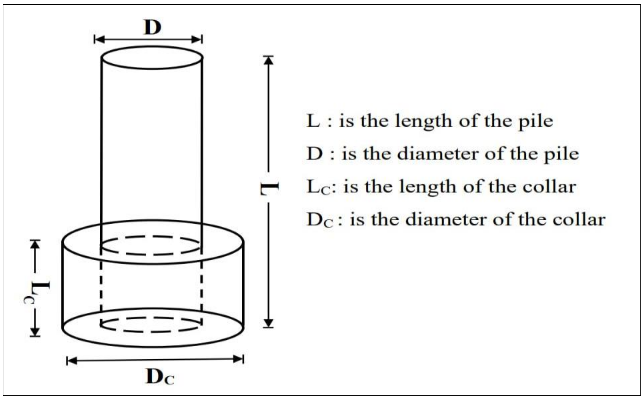

Figure 6: Schematic model pile used with the collar.

5. RESULTS AND DISCUSSION

Theoretically, the pile capacity of the enhanced pile consists of four components: friction along the outer surface of the original pile above the collar, friction along the outer surface of the collar, friction along the inner surface of the pile due to soil plugs, and bearing resistance under the base of the collar. The purpose of adding the collar to the open-ended pipe pile is to increase the capacity and efficiency of the pipe pile. The enhancement is brought about by developing the main parameters of the driven pipe pile's maximum bearing capacity. The ultimate shaft friction capacity of the pile depends on the surface area that is exposed to the surrounding soil and the soil below the pile tip, which becomes more compacted as a result of the soil that forms inside the collar due to an increase in shaft friction along the collar. The loading results for all of the cases listed in Table (2), together with the monopile condition, are presented in the form of load-settlement curves in order to analyze the impact of enhancing the open-ended pipe pile by the steel collar at the lowest part of the pile, as demonstrated in Figure (7). The method used to determine the failure criteria is the two tangents method. The ultimate pile capacity for each model test has been evaluated by drawing a tangent line from the beginning of the load-settlement curve and a second tangent line from the end of the load-settlement curve, where the point of intersection of the two tangents represents the final bearing capacity [15].

It can be seen that the use of a collar with a diameter of 1.5D and a length of 10% of the pile length yields minimal improvement in the pile capacity. In both cases of 2D and 3D collars, the collar length has very little impact on the behavior of the pile. Also, the settlement of the pile in both cases was reduced by more than 93% for all collar lengths. Figure 8 explains the percentage of enhancement in the pile capacity due to the collar. The results show that the pile capacity is influenced by both the collar diameter and length and that this effect follows the pattern for all three length ratios. As a result, the capacity of the pile increases as the collar length increases. This may be attributed to the increase in the surface area of the collared part, which in turn increases the amount of friction developed.

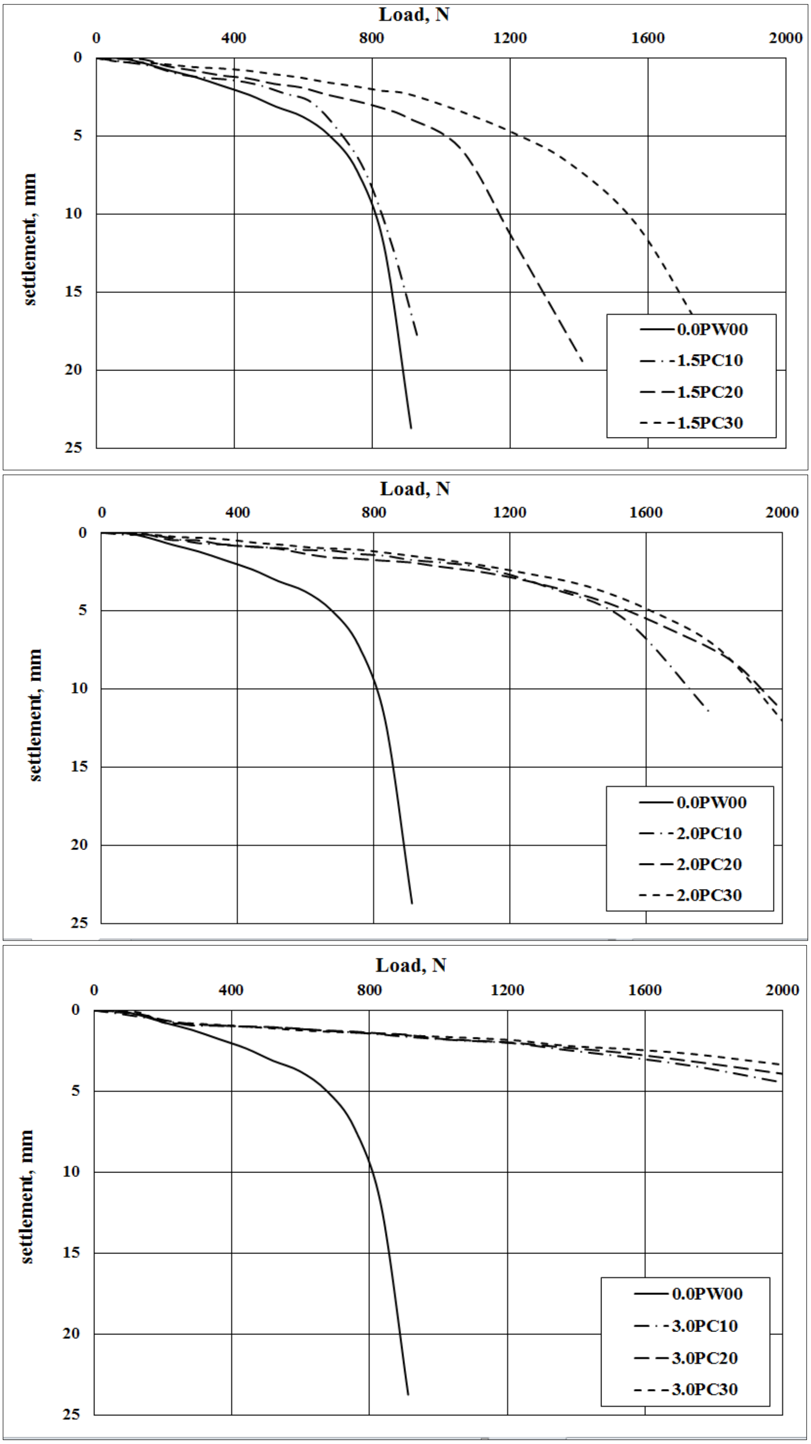

Figure 7: Load-settlement of piles with collar for different collar dimensions.

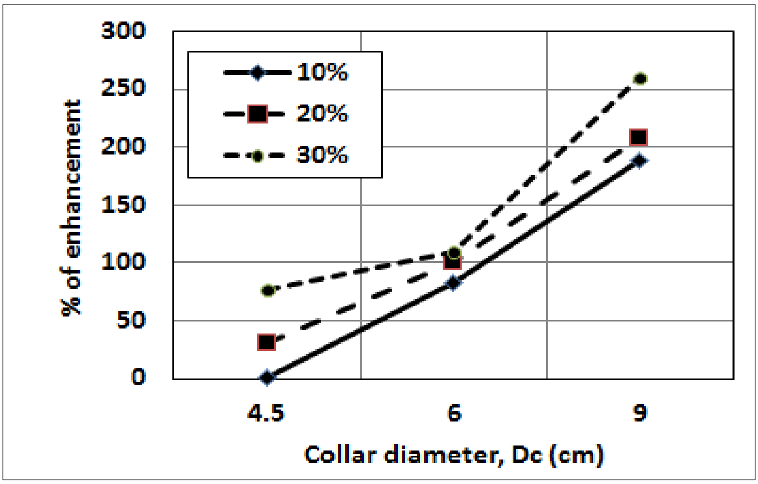

Figure 8: Variation of the enhancement percentage in the pile capacity for different collar diameters and lengths.

For all length ratios, employing a collar with a small diameter results in a greater increase in pile capacity than using one with a higher diameter. This pattern could be attributed to the fact that the soil around the collar and the pile were disturbed more as the collar diameter increased, which reduced the amount of friction generated per unit area. In addition, the soil confined between the collar and the pile may not have developed tip resistance as a unit with the pile due to the increase in diameter.

Therefore, when applying this technique, using a collar with a diameter of 2D and a length ratio of 20% can increase the pile capacity up to 100%. Also, this collar diameter is recommended for a group of piles to minimize the effect of neighboring piles due to the overlapping of the stress bulbs.

6. CONCLUSIONS

Combining a steel collar with an open-ended pipe pile improved pile behavior and increased pile capacity for all scenarios included in the study. However, a collar with a 1.5D diameter and a 10% length ratio showed only slight improvement. It was found that lengthening the collar has relatively little effect on the pile capacity in the two cases when the collar has a diameter of 2D or 3D. The results showed that the settlement amount decreased to 7% of the mono-pile by using open-ended pipe piles enhanced by steel collars. Where utilizing piles with steel collars helps reduce the number of piles needed for pile groups or the area of raft required for pile-raft foundations. As a result, the suggested enhancement is seen as a very cost-effective idea. In the case of a group pile foundation, it is recommended that one use a collar with a diameter of 2D and a length ratio of 20% to double the pile capacity and prevent the stress bulbs of nearby piles from overlapping.

REFERENCES

[1] Salih N B. A novel technique to increase the load capacity of the steel pipe pile. Journal of Duhok University. 2018 Jul 27.
[2] Karkush MO, Aljorany AN. Analytical and numerical analysis of piled-raft foundation of storage tank. InConstruction in Geotechnical Engineering: Proceedings of IGC 2018 2020 (pp. 373-384). Springer Singapore.
[3] Karkush MO, Sabaa MR, Salman AD, Al-Rumaithi A. Prediction of bearing capacity of driven piles for Basrah governorate using SPT and MATLAB. Journal of the Mechanical Behavior of Materials. 2022 Mar 29;31(1):39-51.
[4] Murthy, V. N. S. Advanced foundation engineering. New Delhi: CBS publishers & distributors. 2007.
[5] Karkush MO. Impacts of soil contamination on the response of piles foundation under a combination of loading. Engineering, Technology & Applied Science Research. 2016 Feb 5;6(1):917-22.
[6] Karkush MO, Aljorany AN. Analytical and numerical analysis of piled-raft foundation of storage tank. In Construction in Geotechnical Engineering: Proceedings of IGC 2018 2020 (pp. 373-384). Springer Singapore.
[7] Karkush M, Kareem MS, Jasim MM. Ultimate lateral load capacity of piles in soils contaminated with industrial wastewater. Civil Engineering Journal. 2018 Mar;4(3):509-17.
[8] Prakash S, Sharma HD. Pile foundations in engineering practice. John Wiley & Sons. 1991 Jan 16.
[9] Fattah MY, Al-Soudani WH. Bearing capacity of open-ended pipe piles with restricted soil plug. Ships and Offshore Structures. 2016 Jul 3; 11(5):501-516.

[10] Matsumiya H, Ishihama Y, Taenaka S. A study on the bearing capacity of steel pipe piles with tapered tips. Japanese Geotechnical Society Special Publication. 2015 Aug 30; 1(6):47-52.
[11] Hamadi HS, Abdul-Husain HA. Influence of Geometry and Separation Walls on The Behaviours of Pull-out Pipe Piles Embedded in Sandy Soil. In IOP Conference Series: Materials Science and Engineering. 2021 Mar 1; 1090(1):012010.
[12] Al-Soudani WH, Albusoda BS. A New Proposed Type of Open-Ended Pipe Pile (Open-Ended Pipe Pile with Tapered Tip Pile (OE-TTP)). In IOP Conference Series: Materials Science and Engineering. 2020 Feb 1; 737(1): 012079.
[13] Guo Y, Li J, Yu X. Experimental Study on Load-Carrying Behavior of Large Open-Ended Pipe Pile in Cohesionless Soils. Sustainability. 2022 Sep 27; 14(19):12223.
[14] Poulos, H. G., & Davis, E. H. Pile foundation analysis and design. New York: Wiley.1980; 397.
[15] Abdul-Husain HA. Comparative study of theoretical methods for estimating pile capacity using 1-g model pile tests in cohesionless soil. In IOP Conference Series: Materials Science and Engineering. 2020 Feb 1; 737(1): 012111.