Proceedings of the Second International Conference on Press-in Engineering 2021, Kochi, Japan – Matsumoto et al (eds)

Performance comparison of close-ended pressed-in steel pipe piles with helical pile in dense sand: An experimental study

M.A. Saleem, K. Takeuchi, N. Hirayama, A.A. Malik & J. Kuwano
Graduate School of Civil and Environmental Engineering, Saitama University, Saitama, Japan

ABSTRACT: Bearing behaviour of steel pipe piles and helical piles has been investigated in the past. However, their performance, considering similar pile tip diameter in dense ground condition is not well understood. Based on the above, the present study was focused on the model study of closed-ended steel pipe piles and single helix piles having similar tip diameters under dense ground conditions. Test results showed that steel pipe piles require 332% and 417% higher installation force than helical piles having equivalent tip diameters $D_{PS} = D_H$ = 43mm and 60mm respectively. However, the installation effort of screw pile in terms of power consumption was on average 29% higher than steel pipe pile. Also, helical piles exhibit 27% less ultimate bearing capacity than steel pipe piles having equivalent tip diameters. It was also observed that the installation force required to install the steel pipe pile is quite close to the ultimate bearing capacity of pile.

1 INTRODUCTION

Deep foundations are preferred worldwide when a shallow stratum does not offer sufficient resistance required to carry the superstructure load. In the evolution of pilling industry, various types of piles and construction methods have been developed and implemented at construction sites. This advancement includes driven/displacement piles, and are preferred both for onshore and offshore structures. The reason behind the preference of driven piles (steel pipe piles, helical piles, etc.) over classic non-displacement piles is attributed to legislation and restrictions on the allowable noise, generated during the installation of deep foundations, especially in urban environments. Araki (2013), Sato et al. (2015), Hirata et al. (2005) acknowledged the use of small-diameter steel pipe piles and spiral piles in solar power generations projects. The press-in piling technique is used for the installation of steel pipe piles (Deeks & White 2007). Whereas, the rotatory press-in method is used for helical pile installation (Lutenegger 2009). These installation methods are often labelled as "the silent method" owing to the reduced noise level and minimized vibration to abutting structure. Close-ended steel pipe piles cause minimized displacement compared to driven concrete piles (Leppanen 2000). Installation methods have different effects on the surrounding ground and the ultimate bearing capacity of the pile. According to Phuong et al. (2016), installation of jacked piles densify the surrounding ground and thus result in increased static bearing capacity. It was investigated through acoustic emission that breakage of sand particles occurred in the shear zone area when the close-ended pile is driven. Moreover, the sand below the pile tip, i.e. within the compression zone showed insignificant breakage (Mao et al. 2020). According to Perko (2009), crowd (axial) force should be applied for ensuring the advancement of the helical pile in the ground and should be equal to at least 80 percent of the blade pitch during each revolution. The geometry of helical elements, soil properties and depth of installation effect the installation torque (Ghaly 1991). Malik (2019) investigated that the thickness of helix also affects helical pile performance under dense ground conditions if it is deflected or deformed.

A lot of researches have been conducted on the axial capacity of driven pile in dense sand but still, it is the most arguable area with high uncertainty in foundation design (Randolph et al. 1994). Also, previous research studies were mainly focused on understanding individual behaviour of steel pipe piles and helical piles. Therefore, the current study was focused on the performance of close-ended steel pipe piles and single helix helical piles under similar pile tip diameter and ground conditions. In the current study, steel pipe piles were installed in dense ground using the pressing method of installation. Whereas, helical piles were installed in dense ground with a combination of pressing and rotation mechanism. In the case of helical piles, the pressing rate and rotation were adjusted in such a way that 1 pitch penetration was achieved in 1

DOI: 10.1201/9781003215226-24

rotation of helix. Steel pipe piles having different shaft diameters and helical piles having different helix diameters were considered in this study. Installation force was measured during the installation of steel pipe piles and helical piles. Whereas, the installation torque was also measured for helical piles. Subsequently, the bearing capacities, including shaft resistances as well as base capacities were observed. Installation effort (installation force, installation torque) required for installing the piles and bearing capacities of closed-ended piles (steel pipe pile and helical pile) having similar tip diameters were compared.

2 TESTING EQUIPMENT

In this study, model close-ended steel pipe piles and close-ended single helix helical piles were used. Length of the pile (600mm) was identical in both types of piles. Steel pipe piles having different shaft diameters (D_{PS} = 21.7mm, 43mm and 60mm) were used in this study. Dimension details of steel pipe piles are shown in Figure 1. On the other hand, helical piles having an equivalent shaft diameter (D_{HS} = 21.7mm) but different helix diameters (D_H = 43mm and 60mm) were used (see Figure 1). To achieve the objectives of this study, equivalent tip diameters were used for both steel pipe piles and helical piles ($D_{PS} = D_H$ = 43 and 60mm). Consistent helix to pitch ratio (D_H/P = 3.6) were considered in this study. The pitch of helix was measured from the inner edge of the upper and lower helix blades. Both steel pipe piles and helical piles comprised of a hollow central shaft having a flat end attached at the bottom.

Strain gauges were also fixed on the bottom of the inner side of the pile wall to measure the shaft resistance during the pile load test. Preparation of model ground was accomplished in a steel container using Toyoura sand in dry condition. Toyoura sand was compacted to a relative density of 70% to assure homogeneity in all tests. The properties of Toyoura sand used are: specific gravity = 2.65, D_{50} (50% pass particle size) = 0.20mm, maximum void ratio (e_{max}) = 0.98 and minimum void ratio (e_{min}) = 0.60. Both pile types were designed to nullify the impact of pile size and soil on measured data.

According to Dickin (1983) and Abdoun et al. (2008), in the model-scale test, the size of the buried structure should be 48 times greater than the D_{50} value to eliminate the size effect. In this study, the shaft diameter of the steel pipe pile (D_{PS}) was ranging from 21.7mm ~ 60mm and the D_{50} value of the soil was 0.2mm. Thus, ratio D_S/D_{50} was ranging between 109 ~ 300. Helical piles used in this study also share the similar range because the steel pipe pile shaft diameter (D_{PS}) and the helix diameter (D_H) are consistent in this study. Hence, it is believed that the results were not affected by the size of the pile and the soil particles.

Also, the size of the model container is crucial owing to its influence on the pile capacity measurement. Previous research shows that the loading influence zone ranges from 3 to 8 times the pile diameter (Kishida 1963, Robinsky 1964). Yang (2006) proposed an influence zone in clean sand above the pile tip to be 1.5 to 2.5 times the shaft diameter and 3.5 to 5.5 times the shaft diameter below the pile tip. The dimensions of steel container were carefully selected in an attempt to avoid the influence of boundary conditions on the data measurement during installation and pile load testing. In this study, the cylindrical steel container having a diameter of 1000mm and a height of 1100mm was used. The container diameter was $15D_{PS}$ and the vertical clearance beneath the pile was $10D_{PS}$ for the pile having a maximum diameter (D_{PS} = 60mm). The displacement control loading system was used to install the pile. Whereas, the rotation system was used to rotate the pile during the installation. Installation force and torque were monitored with the help of load and torque transducers. The pile penetration during the installation and the pile load test were measured with the help of displacement transducer. The data logger was used to record all the data (Figure 2).

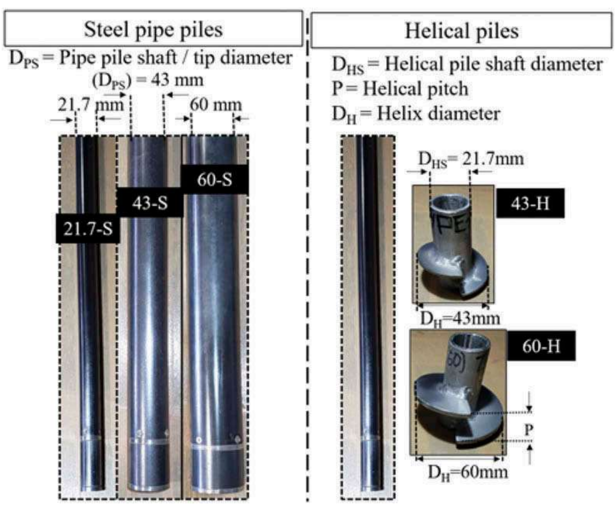

Figure 1. Model steel pipe piles and helical piles.

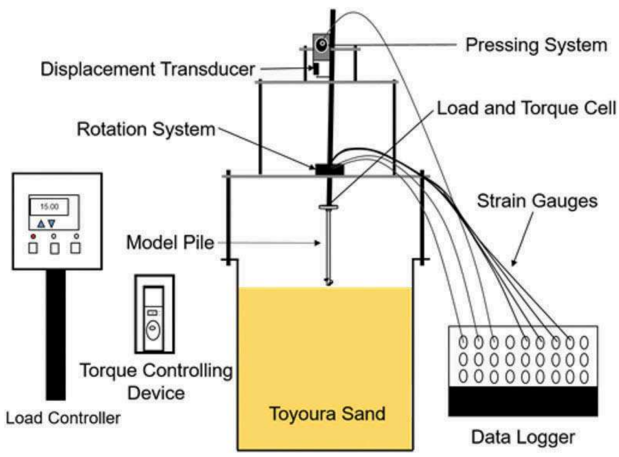

Figure 2. Schematic illustration of testing equipment.

3 TESTING PROCEDURE

The model ground was prepared using Toyoura sand, compacted using rammer in such a way that each compacted layer had a thickness of 100mm. The total depth of the compacted model ground was 1000mm. The relative density of each compacted layer was 70%. Uniformity of the model ground was maintained in all tests. Subsequently, model steel pipe piles and helical piles were installed in the model ground. Steel pipe piles were installed using the pressing method of installation. Whereas, helical piles were installed with a combination of pressing and rotation mechanism. The penetration rate for installing both types of piles was 15mm/min. In the case of helical piles, the rotation rate was adjusted in such a way that 1 pitch penetration was achieved in 1 rotation of helix. The embedment depth (E_d) of the piles during installation was measured with the help of displacement transducer. Whereas, the installation force (F) and the installation torque (T) were measured with the help of load and torque cell. Installation of piles was followed by pile load tests. During pile load testing, the penetration rate of the pile was reduced to 2mm/min. The settlement (S) of the pile during pile load test was measured with the help of displacement transducer. Whereas, the compressive force (P) was measured using the load cell.

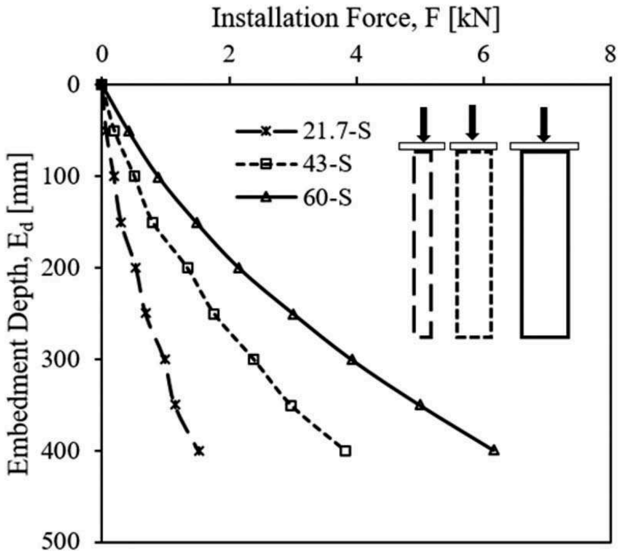

Figure 3. Effect of steel pipe pile shaft diameter on the installation force in dense sand.

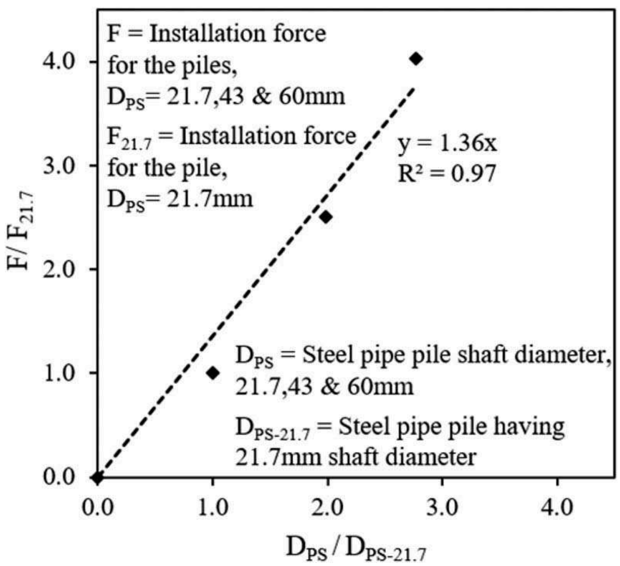

Figure 4. Relation of normalized pile shaft diameter with normalized installation force.

4 RESULTS AND DISCUSSION

4.1 *Steel pipe piles*

In this test series, steel pipe piles having an equivalent pile length but different shaft diameters were installed by the pressing method. The pressing rate of 15mm/min was considered during the installation of piles. Steel pipe piles having three different shaft diameters (D_{PS} = 21.7mm, 43mm and 60mm) were installed in the dense ground.

Pipe piles were installed to an embedment depth of 400mm. The installation force (F) was recorded during the test. Test results indicated that the installation force was increased almost linearly with depth as shown in Figure 3. Also, an increase in shaft diameter increased the installation effort (installation force) as shown in Figure 4. Increase of 40% shaft/tip diameter of pipe piles (from 43mm to 60mm) increased the installation force by 61%.

After the installation of the pile by adopting the pressing method, pile load tests were conducted for steel pipe piles having different shaft diameters. The loading rate of 2mm/min was used for the pile load test. It was observed that the bearing capacity of the pile was increased with increase in pile shaft diameter. Increase of 40% shaft/tip diameter of pipe piles (from 43mm to 60mm) increases the ultimate bearing capacity (measured at plunging state; state at which load to settlement ratio becomes constant) by 64%. Al-Soudani & Fattah (2020), investigated the effect of diameter on bearing capacity of close-ended steel pipe piles through the model study using fine sandy soil. It was reported that an increase in pile diameter of close-ended steel pipe piles from 20mm to 40mm increased the bearing capacity by 320-680%.

Contribution of shaft resistance and base capacity in the bearing capacity of steel pipe piles was also explored. It was observed that both shaft resistance and base capacities were increased with an increase in shaft diameter (Figure 5). Chow (1995) and Randolph et al. (1994) investigated that the unit skin friction capacity (shaft resistance) of a pile may be influenced by lateral effective stress at the pile-soil interface. Increase in shaft resistance can be attributed to increased surface area (increases with the diameter of the pile). Similarly, an increase in base capacity can be attributed to the increased bearing area for large tip diameter piles compared to piles having small tip diameters. It was also observed from test results that there was a nominal difference between the maximum installation force and the ultimate bearing capacity (considered at settlement equal to 15% of pipe pile shaft diameter) of steel pipe piles (Figure 6).

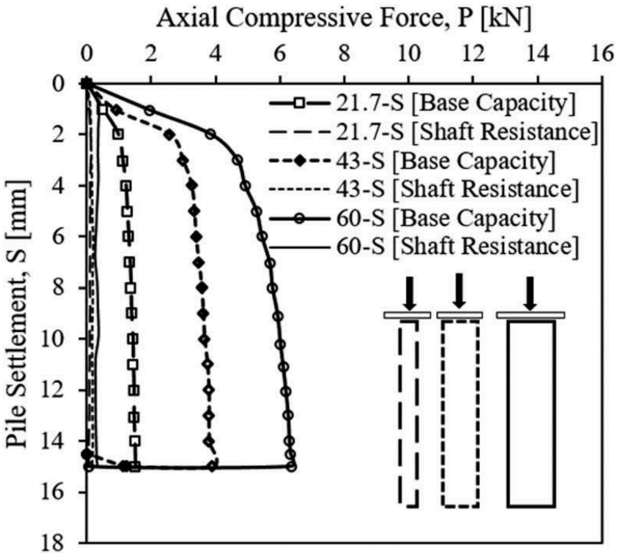

Figure 5. Load-settlement curves of steel pipe piles having different shaft diameter in dense sand.

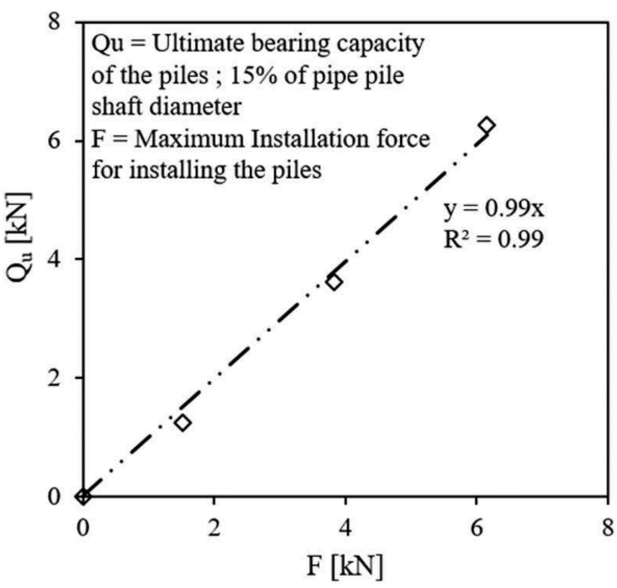

Figure 6. Relation of maximum installation force and ultimate bearing capacity of steel pipe piles in dense sand.

4.2 *Helical piles*

In this test series, helical piles having an equivalent pile length were installed by the pressing and rotation method. The pressing rate of 15mm/min was considered during the installation of piles. The pressing rate and rotation were adjusted in such a way that 1 pitch penetration was achieved in 1 rotation of helix (recommended by Perko (2009)). Helical piles having a similar shaft diameter (D_{HS} = 21.7mm) but with different helix diameters (D_H = 43mm and 60mm) were installed in the dense ground. Helical piles were installed to an embedment depth of 400mm.

Installation force (F) and installation torque (T) were recorded during the tests. It was observed that the installation force was increased with depth in all tests. It was also revealed by the test results that increase in helix diameter increased the installation force (Figure 7).

Installation torque (T) also experienced an increase with depth (Figure 8). This increase in installation torque with depth is in line with the study conducted by Ghaly et al. (1991). Ghaly et al. (1991) investigated that installation torque increases with an increase in soil strength parameters and/or installation depth. It was observed that the pile having a greater helix diameter (60mm) required greater torque for installation compared to that having a small helix, 43mm (Figure 8). The discrepancy in torque requirements, by helical piles having different helix diameters, for achieving the final installation depth is in line with findings of Ghaly et al. (1991). Ghaly et al. (1991) support the increment of installation torque requirements with the increase in shaft to helix diameter.

Pile load tests were also conducted for helical piles using 2mm/min loading rate (also adopted by

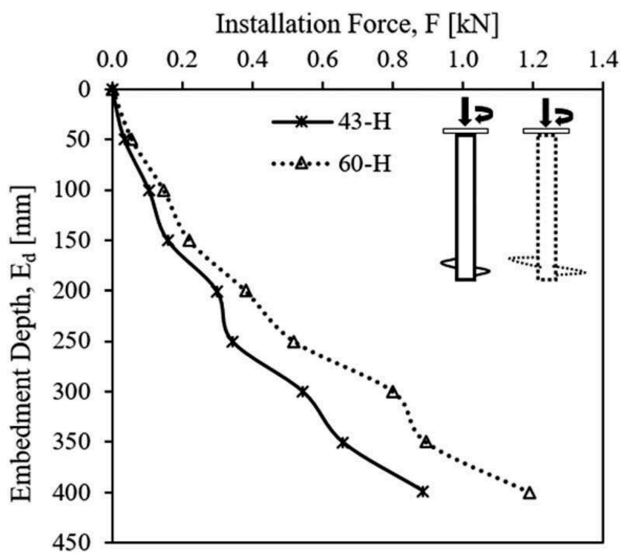

Figure 7. Effect of helix diameter of the helical pile on installation force in dense sand.

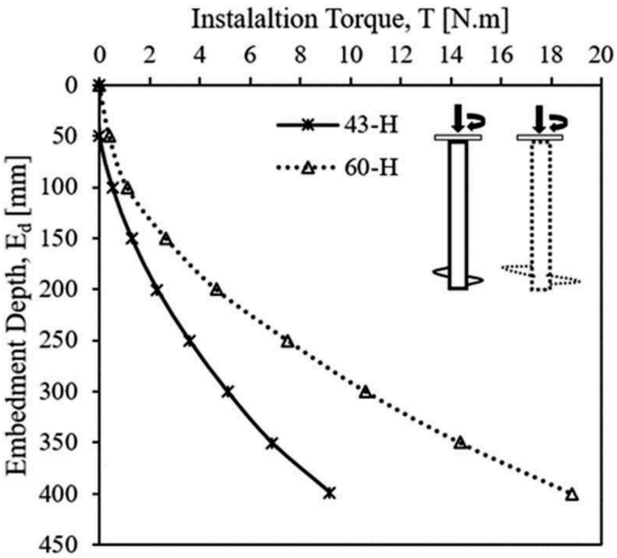

Figure 8. Effect of helix diameter of the helical pile on installation torque.

Matsumiya et al. 2015). The test results showed that a pile having a large helix exhibit enhanced bearing capacity compared to a pile having a small helix (Figure 9).

It was observed that the ultimate bearing capacity (considered at settlement equal to 15% of helical pile shaft diameter) of helical piles increased by 60% by increasing the helix to shaft diameters by 40% (D_H/D_{HS} = 1.98 to 2.76) as shown in Figure 9. This increase in the ultimate bearing capacity owing to increased helix diameters is in line with the study by Sakr (2011). Sakr (2011) identified that trimming the pile helices results in reduction of axial capacity of piles because of reduced bearing area.

4.3 *Comparison of steel pipe piles and helical piles having equivalent tip diameter*

Steel pipe piles and helical piles having equivalent tip diameters were also compared for their installation effort requirement and bearing behaviour. The installation force of steel pipe piles having tip diameters (D_{PS}) of 43mm and 60mm were compared with helical piles having similar helix diameters (D_H). It was observed that, in general, the axial force requirement for installing steel pipe piles is quite high compared to helical piles having equivalent helix diameters. This discrepancy in axial force required for installation is owing to different installation mechanism; steel pipe piles are installed using the pressing method. Whereas, the rotation also accompanied pressing for installing helical piles. The comparison of steel pipe piles and helical piles having the equivalent tip diameter shows that the installation force of steel pipe pile was increased by 332% for $D_{PS} = D_H$ = 43mm and 417% for $D_{PS} = D_H$ = 60mm (see Figure 10). However, the installation effort of screw pile (installation force and torque) in terms of power consumption was on average 29% higher than steel pipe pile. The comparison of load-settlement curves of steel pipe piles and helical piles having the equivalent tip diameter shows that steel pipe pile bearing capacities are more than helical piles as shown in Figure 11. Figure 12 showed that the ultimate bearing capacity of the helical pile is 27% less than a steel pipe pile having a similar pile tip area under dense ground conditions.

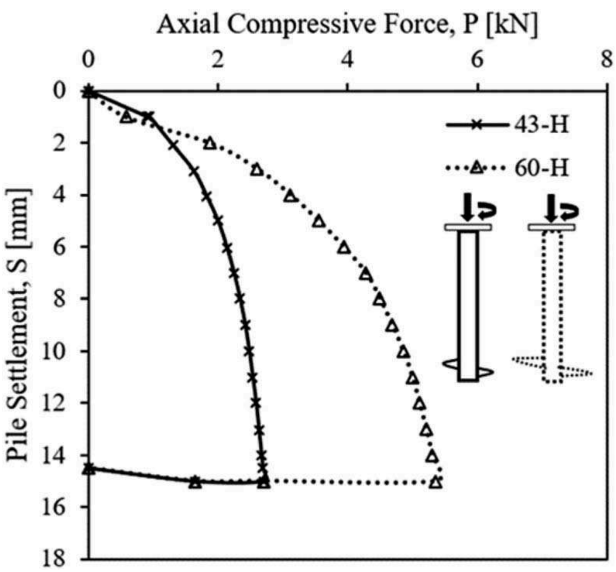

Figure 9. Load-settlement curves of helical piles with different helix diameters in dense sand.

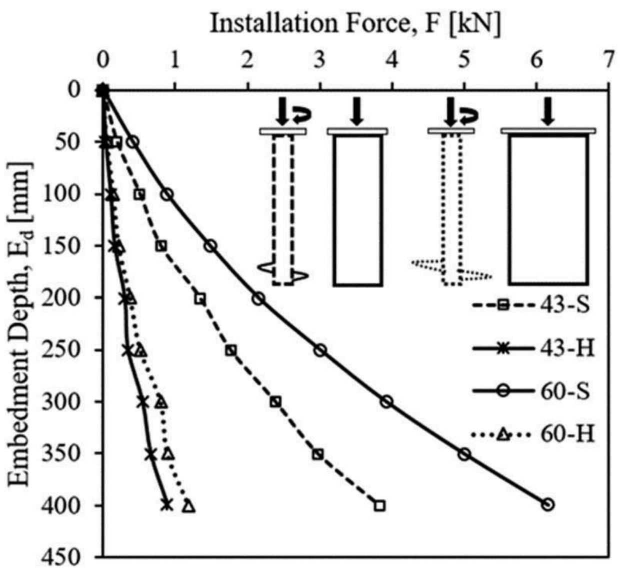

Figure 10. Comparison of installation force of steel pipe piles and helical piles having equivalent tip diameter.

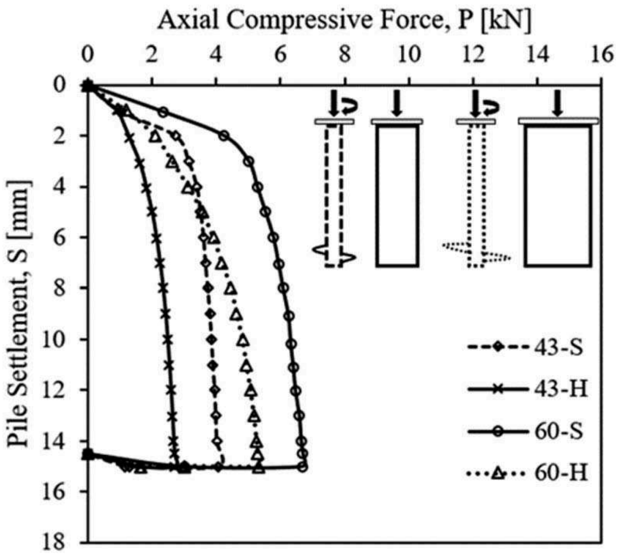

Figure 11. Comparison of load-settlement curves of steel pipe piles and helical piles having equivalent tip diameter.

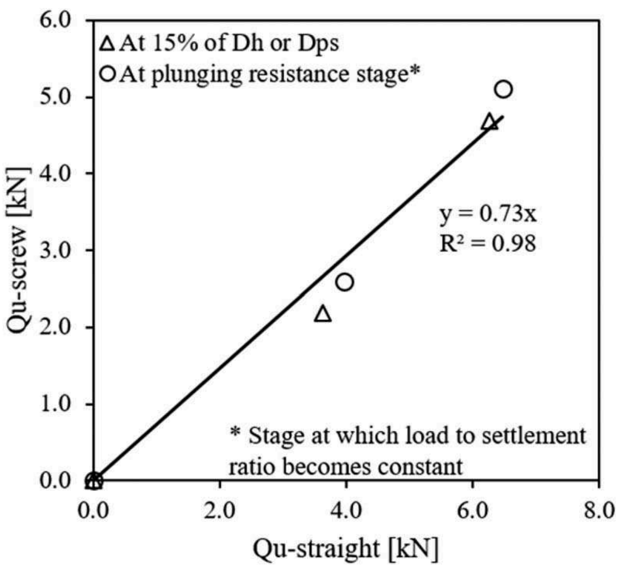

Figure 12. Relationship of ultimate bearing capacity between steel pipe pile and helical piles in dense sand.

5 CONCLUSIONS

This study was based on the comparison of steel pipe piles and helical piles having equivalent tip diameters. Following conclusions are drawn from the test results:

1. Steel pipe piles require 332% and 458% higher installation force than helical piles having equivalent tip diameters $D_{PS} = D_H$ = 43mm and 60mm respectively. However, the installation effort of screw pile (installation force and torque) in terms of power consumption was on average 29% higher than steel pipe pile.
2. Helical piles exhibit 27% less ultimate bearing capacity than steel pipe piles having equivalent tip diameters.
3. In the case of steel pipe piles, the installation force required to install the pile is quite close to the ultimate bearing capacity of the pile (considered at settlement equal to 15% of pipe pile shaft diameter). The ultimate bearing capacity of steel pipe piles is 0.99 times the maximum force required for their installation.

This study is particularly useful for design engineers involved in decision making regarding the type of driven deep foundations to be used for a construction project. To decide which pile type is more efficient in dense ground conditions, it is recommended that the effect of stress level and lateral ground disturbance due to pile installation should be studied in future.

REFERENCES

Al-Soudani, W. & Fattah M.Y. 2020. Effect of diameter on the load carrying capacity of closed-open ended pipe piles. *IOP Conference Series: Materials Science and Engineering* 737(1)

Araki, K. 2013. Simplified foundation method subject to small-scale structure "PILE FOUNDATION METHOD". *The Japanese Geotechnical Society* 61(8): 32–33. (in Japanese)

Chow, F. 1995. Field measurements of stress interactions between displacement piles in sand. Ground Engineering. July/August: 36–40.

Deeks, A.D., & White, D.J. 2007. Centrifuge modelling of the base response of closed-ended jacked piles. *Advances in deep foundations-proceeding of the international workshop on recent advances of deep foundations, IWDPF07*: 241–251.

Dickin, E.A., & Leung, C.F. 1983. Centrifugal model tests on vertical anchor plates. *Journal of Geotechnical Engineering* 109(12): 1503–25.

Foray, P., Balachowski, L., & Colliat, J.L. 1998. Bearing capacity of model piles driven into dense overconsolidated sands. *Canadian Geotechnical Journal* 35: 374–85.

Ghaly, A., Hanna, A., & Hanna, M. 1991. Installation torque of screw anchors in dry sand. *Soils and Foundations* 31(2): 77–92.

Ha, D., Abdoun, T. H., O'Rourke, M. J., Symans, M. D., O'Rourke, T. D., Palmer, M. C., & Stewart, H. E. 2008. Buried high-density polyethylene pipelines subjected to normal and strike-slip faulting—a centrifuge investigation. *Canadian Geotechnical Journal* 45(12): 1733–1742.

Hirata, A., Kokaji, S., & Goto, T. 2005. Study on the estimation of the axial resistance of spiral bar based on interaction with ground. *Shigen-to-Sozaiitle* 121: 370–377. (in Japanese)

Kishida, H. 1963. Stress distribution of model piles in sand. *Soils and foundations* 4(1): 1–23.

Leppanen, M. (ed.) 2000. *Steel pipe piles*. Helsinki: Finnish national road administration.

Lutenegger, A.J. 2009. Cylindrical shear or plate bearing-uplift behaviour of multi-helix screw anchors in clay. *Proceedings of international foundation congress and equipment expo (Orlando, Florida: United States/ ASCE)* (185): 456–463.

Malik, A.A., Kuwano, J., Tachibana, S., & Maejima, T. 2019. Effect of helix bending deflection on load settlement behaviour of screw pile. *Acta Geotechnica* 14(5): 1527–43.

Mao, W., Aoyama, S., & Towhata, I. 2020. A study on particle breakage during pile penetration process using acoustic emission source location. *Geoscience Frontiers* 11(2): 413–427.

Matsumiya, H., Ishihama, Y., & Taenaka, S. 2015. A study on the bearing capacity of steel pipe piles with tapered tips. 6th Japan-China Geotechnical Symposium, SJGS 2015: 47–52.

Perko, H.A. 2009. *Bhelical piles: A practical guide to design and installation*. New Jersey: John Wiley & Sons, Inc.

Phuong, N.T.V., Van Tol, A.F., Elkadi, A.S.K., & Rohe, A. 2016. Numerical investigation of pile installation effects in and using material point method. *Computers and Geotechnics* 73: 58–71.

Randolph, M.F., Dolwin, J., & Beck, R. 1994. Design of driven piles in sand. *Geotechnique* 44 (3): 427–448.

Robinsky, E.I., & Morrison, C.F. 1964. Sand displacement and compaction around model friction piles. *Canadian Geotechnical Journal* 1(2): 81–93.

Sakr, M. 2011. Installation and Performance Characteristics of High Capacity Helical Piles in Cohesionless Soils. *DFI Journal-the journal of the deep foundations institute* 5(1): 39–57.

Sato, T., Harada, T., Iwasaki, N., Hayashi, S., & Ohtani, J. 2015. Effect of shaft rotation of spiral piles under its installation on vertical bearing capacity. *Japanese Geotechnical Journal* 10(2): 253–26. (in Japanese)

Yang, J. 2006. Influence zone of end bearing piles in sand. *Journal of Geotechnical and Geoenvironmental Engineering, ASCE* 132(9): 229–37.