HELICAL PILE: AN INNOVATIVE AND SUSTAINABLE FOUNDATION TECHNIQUE

[a] Hamza Ahmad Qureshi *, [a]Muhammad Safdar, [b]Muhammad Haseeb Khan, [c] Hazarat Bilal

a: Earthquake Engineering Center, Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan.
b: Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan.
c: Department of Civil Engineering, Abasyn University Peshawar, Pakistan.
* Corresponding author: Email ID: 18pwciv4995@uetpeshawar.edu.pk

Abstract- Helical pile is an advanced sustainable deep foundation technique. Its importance in the construction sector is growing very hastily. However, being an advanced foundation technique, there is still an ambiguity about its usage, that whether to use helical piles or conventional piles in a construction project. The main objective of this paper is to compare helical piles with the conventional piles (i.e., Driven piles and Cast-in-situ piles) on the basis of different factors and draw conclusion between them. These factors include axial capacity, lateral capacity, method of installation, soil condition, cost, impact on environment and construction time. After extensive literature review the authors of the paper came to a conclusion that helical piles in many aspects are far better than conventional piles. Moreover, they cover several aspects of green construction like, less cost, fast construction, less carbon emission, low environmental impact, reusability etc.

Keywords- Cast in Situ Piles, Driven Piles, Helical Piles, Sustainable Foundation Technique

1 Introduction

This state-of-the-art literature review effectively shows the differences between helical piles (see Figure 1) and conventional piles in terms of several fundamentals. Helical piles, which were originally designed to support lighthouses and moorings, but they are now used to support the foundations of both old and new buildings because of their drastic improvement in term of efficiency and practicality. When soil becomes soft or oversaturated, it settles and compacts over time. This can cause the entire structure to shift out of alignment, which is dangerous. Helical piles, due to their high bounce resistance, are an excellent foundation choice for structures subject to frost heave or expansive soils [1]. Besides there advantages, the use of helical screw piles is limited by certain flaws like disturbance of the soil during installation within the pile helices' affected zone, the high displacement required to fully mobilize the bearing component of their bearing plates, and the low buckling resistance of their slender shaft under compression loading [2]. In recent years, the field of pile foundations has experienced a sharp increase in the use of helical piles [3]. Because of their high bearing capacity, fast installation and better recovery, they are now used in the foundation of offshore wind turbines [4]. The Christchurch earthquake caused only minor damage to a number of helical pile-supported structures in New Zealand, proving the viability of helical piles as a foundation material in seismically active regions [5].

Figure 1: Helical Pile [6].

The factors which were used to draw comparison between conventional and helical piles, and which make helical piles an innovative and sustainable foundation technique, includes axial capacity, lateral capacity, method of installation, soil condition, cost, impact on environment and construction time. Each one of them is discussed briefly as under;

2 Axial Capacity

According to Elkasabgy [7], when site subsurface conditions were taken into account, the ultimate capacity of a single-helical pile was approximately 18% greater than that of a conventional pile, while the ultimate capacities of double-helical piles were almost 45 to 85 % greater than that of a conventional pile. This extra increase in the capacity of the helical pile was due to the presence of double helixes. Similarly, Sakr [8] also conducted out full-scale tests in Alberta, Canada. He discovered that helical piles with same embedment depths provide approximately 230% to 290% larger capacities in cohesive soil than driven piles. Hence, he concluded that helical piles have higher capacities due to the use of single or multiple helices with diameters greater than the shaft diameter. Sakr [9] further conducted field test on high-capacity helical piles, using 5% failure criterion, he computed that the axial compressive capacities of helical piles ranged from 1500 to 2500 kN, while their uplift capability range from 1500 to 2000 kN. Hence, we can say that helical piles typically have axial uplift capacities of 60% to 70% of their axial compressive capacities. Similarly, another researcher Malik [10] analyses the axial capacities of helical and conventional piles in the same ground and soil conditions, taking into account the effect of increased overburden pressure. He uses dry Toyoura sand that has been compacted to 70%, 80%, and 92% relative density in his test. He found that around settlement equals 10% of pile tip diameter, the load settlement curve for conventional piles plunges downward without increasing load, but around settlement equals 15% of pile tip diameter, the load settlement curve for helical piles plunges. Helical piles with helix-to-shaft diameter ratios of 2–4.1 demonstrated 2–12 times greater end bearing capacity than conventional piles with comparable pile shaft diameter. Another researcher Ali [11] concluded from his experimental work that Screw piles (helical pile) have a high tensile and compressive strength (up to three times that of a conventional pile) and can be utilized in a range of soil strata above and below water.

3 Lateral Capacity

Wind loads, earthquakes, imbalanced ground pressures, snow loads, axial force on pipes, and load eccentricity are all elements that affect lateral loads and moments on piles. As a result, deep foundations are often constructed to resist such loads, and thus helical piles are also used to counteract horizontal forces. Sakr [12] conducted field test on high-capacity helical piles installed in dense to exceptionally dense clayey soil, he computed that helical piles can withstand high lateral load resistance as compared to conventional piles. He also investigated that shaft length was nearly involve in controlling the lateral load behaviour. Bien [13] conducted experimental study on helical and conventional piles with the same shaft diameter and wall thickness. According to his results, helical and driven piles show identical long-term lateral behaviour. His research discovered that the lateral resistance of both helical and driven piles is predominantly controlled by shaft diameter and embedment depth. However, when he inspected the piles after four years of their installation, he found that the helical piles' long-term lateral resistance increased by an average of 10% to 20%, outperforming the driven piles. The lack of total stiffness of the coupling joints along the pile shaft can impact pile performance under lateral loads [14]. Therefore, grouting technology was used to overcome the limits of helical screw piles, resulting in "Grouted Helical Pile." The concept of a grouted helical pile can be characterised as placing a cylindrical grout column around the helical pile's thin shaft to strengthen its buckling resistance, stiffen the coupling joints, and boost pile capacity by increasing the pile shaft resistance contribution to overall pile capacity [15].

4 Method of Installation

The method of installation of conventional piles and helical piles is brilliantly explained in this paper, which will essentially be an effective comparison analysis. The purpose of this comparison is to show how their installation methods affect the environment and the long-term sustainability of civil engineering works. In order to install conventional piles, A standard pile is made up of a cylindrical steel shaft with an open or closed end and the installation characteristics of open-ended and closed-ended piles are different. Because there is less driving resistance, installing an open-ended pile is significantly easier [10]. To install conventional piles, we have two basics techniques;

4.1 Displacement Piling Installation

The method of installing piles into the ground without removing any soil or other material is known as displacement piling installation method (i.e., Dropping weight, Vibration, Jetting).

4.1.1 Dropping Weight

A hammer about the weight of the pile is raised to recommended height and then released to strike the pile head, which is a simple dropping hammer technique.

4.1.2 Vibration

Vibratory hammers are composed of helical contra-rotating unusual pieces within a covering affixed to the pile's head and are either electrically or hydraulically propelled.

4.1.3 Jetting

Water jetting can help piles penetrate sediment or gravel-filled soil. This method, on the other hand, has had little impact on stiff clays or terrain with a lot of coarse gravel, cobbles, or pebbles.

4.2 Non-Displacement Piling Installation

Similarly, by removing any soil or other material is known as non-displacement piling installation method (i.e., The Continuous Flight Auger and Underreaming method)

4.2.1 Continuous Flight Auger (CFA)

The Continuous Flight Auger (CFA) is a mobile foundation carrier with a porous flight drill that is dragged in the soil to the required piling depth. As the pile is being lifted from the ground, concrete is poured via the flight auger to create it.

4.2.2 Underreaming

An underream is created by inserting an underreaming tool into the straight part of a pile shaft and then enlarging it at the pile's bottom. After installation and before concrete is put, a man carrying cage is normally dropped and the pile's shaft and underream are inspected.

4.3 Drilling of Pile (Helical Pile Installation)

For installation of Helical piles, Helical piles are driven in the earth in the same way that a screw is implanted into wood, but on a much greater scale. They are screwed into the ground using machine-mounted hydraulic or electrically powered drilling tools as shown in Figure 2. The benefit of helical piles is that the torque demonstrated during installation can be linked to axial capacity [10]. The torque-to-capacity ratio is monitored in real time during installation, therefore helical piles have built-in quality control. Another feature that sets helical piles apart from ordinary piles for bridge applications is the speed with which they can be installed while producing the least amount of noise and vibration [9]. Due to their ease of installation, rapid use, and other advantages over conventional pile systems, helical piles have become more popular as a deep foundation for a range of structures [11].

Figure 2: Drilling of Helical Pile [16].

5 Soil Condition

Except for expansive soil, conventional piles may be installed in any type of soil. However, helical piles are best suited for expansive soils of any kind of soils. But there are still some conditions (e.g., hard strata and granular soils) in which conventional piles are preferred. Borehole data and professional experience can be used to assess the likelihood of discovering hard or soft soil layers that require advanced methods and equipment. The degree of soil consistency, whether cohesive or non-cohesive, is strongly connected to the difficulties of installing helical piles in the ground. The three soil types (dense to very dense sand, hard till, and hard clay) plus "gravel/cobble" are considered relatively difficult for helical pile placement [17]. Khazaei [18] stated that helix plates might break during installation process, as a result, helical pile technology is not suitable for foundations in gravely or stiff soil. Similarly, Safdar [19] also stated that helical piles can't be used in very hard, thick, or gravelly soils because the helical plate will get damaged or the helical pile's direction might change when it comes into contact with the hard stratum. Helical piles have a high tensile and compressive strength (2 to 3 times that of a conventional pile) and can be employed in a variety of applications for a variety of soil strata both above and below the surface of the water [20].

6 Cost of Construction

The process of constructing a concrete foundation is not only time-consuming, but also costly. A third-party company digging the hole, constructing (and dismantling) the shuttering/forming, pouring the concrete, and removing any residual soil can cost a significant amount of money as well as construction time. A helical pile system, on the other hand, should be less expensive because we only require a helical pile and a hydraulic machine [21]. Helical piles are thought to be more cost-effective because they require less people, don't require expensive equipment when used onshore, and can be recycled [22]. A report published by Almita Piling Inc. in 2015 stated clearly that helical pile is cost effective than driven piles and cast in situ piles as shown in table 1. For example, a cost comparison is made between helical pies system and conventional pile systems in the following categories: Material cost, Shipping cost, Labour cost, Equipment cost, Other Direct cost, and Total cost, of power substation project near High River City, Calgary, Canada.

Table 1: Cost Comparison of the Three Pile Systems

Pile Type	Material Cost ($)	Shipping Cost ($)	Labor Cost ($)	Equipment Cost ($)	Other Overhead Cost ($)	Project Duration (day)	Total Cost ($)
Helical Pile	468,084	18,450	236,912	128,240	41,282	29	892,968
Driven Pile	459,552	97,580	270,570	207,785	64,698	32	1,089,585
CIP Pile	242,346	4,100	508,300	464,278	54,098	53	1,305,974

According to Almita Piling Inc., among the pile systems designed and installed for the defined project (power substation project near High River City, Calgary, Canada), the helical pile has the lowest installation cost, being the cheapest from conventional pile as they have the highest installation cost [23].

6 Installation Time

The installation of helical pile is much faster and easier than that of conventional pile. Rapid installation, immediate loading, relatively accurate capacity verification, and installation in all-weather conditions, are all advantages of helical pile construction [24]. With the help of two crew members, 10 m of helical pile may be installed in just 30 minutes [25]. The helical piles are drilled directly into the ground by machine-mounted hydraulic or electrically driven drilling equipment and can be joined in groups with a steel load transfer grillage. The relationship between (1) torque, (2) installation time, (3) soil layer, and (4) depth may exist in particular patterns in helical and conventional piles which affect the construction time rates. The construction time of helical piles is substantially faster than that of conventional heaps, since conventional piles must be hammered into the earth, which takes longer than helical piles. Helical piles can also be loaded right after installation and installed without casings through groundwater [26]. The U.S. Army Corps of Engineers in New York turned the Stony Brook University campus into a temporary field hospital, converting 255,676 square feet of space to provide care for up to 1,028 non-coronavirus patients and low acuity coronavirus patients. Helical piles, as compared to ordinary piles, were the best foundation solution since they can be swiftly installed and removed when the hospitals are no longer required [27].

7 Impact on Environment

Conventional piles generate noise and vibration during the process of installation. With more stringent environmental restrictions, it is becoming increasingly vital to determine if the foundation should be able to completely removed or not, during demolition of the building. To get higher bearing capacity, drilled shafts or conventional piles are installed in deeper depths and in stronger areas, then they are difficult to remove entirely during plant deconstruction. Helical foundations provide outstanding building performance and are simple to install even in difficult-to-reach situations. Furthermore, helical piles offer the environmental benefit of being easy to take out, as well as the economic benefit of being recyclable as compared to conventional pile [28]. All across the world, cementitious materials are widely used in construction. However, the cement business has a significant impact on the environment due to Carbon dioxide emission and the use of natural resources for manufacturing energy. As a result, lowering cement use is critical for achieving long-term green construction practises. Helical piles are utilised, because they are composed of steel rather than cement, to achieve long-term green construction standards. Conventional piles are pure cementitious works, which have a major impact on the environment owing to carbon dioxide emissions [15]. In New Forest England, according to Chestnut Farm Mobile Dwelling project, several houses needed to be constructed, so due to low impact on environment and aesthetic view, helical piles were used in these prefabricated mobile homes (as shown in Figure 3) [29].

Figure 3: Chestnut Farm Mobile Dwelling project [29].

Conclusion

The authors of this research study came up to a conclusion that helical piles are considerably superior to conventional piles in many ways after conducting a thorough literature review. Some of the outcomes are given as under;

1. The ultimate capacities of single-helical piles were roughly 18% greater than those of conventional piles, while those of double-helical piles ranged from nearly 45 to 85 percent higher. Another researcher stated that the end bearing capacity of helical piles with helix-to-shaft diameter ratios of 2-4.1 was 2–12 times larger than that of conventional piles with similar pile shaft diameters. This extra increase in the capacity of the helical pile was due to the presence of helixes.
2. The helical piles' long-term lateral resistance increased by an average of 10% to 20%, outperforming the driven piles. To increase their lateral resistance further, grouting technique will be used.
3. They can be easily installed with the help of hydraulic machine, without making any noise and vibration thus making it environmentally friendly and green construction technique.
4. Helical piles are best suited for expansive soils or any kind of soil, however they can't be used in very hard, thick, or gravelly soils because the helical plate will get damaged or the helical pile's direction might change when it comes into contact with the hard stratum.
5. Helical piles require less people, does not require expensive equipment when used onshore, higher capacity (thus less number of piles will be required) and can be recycled, making it cost effective construction material.
6. With the help of two crew members, 10 m of helical pile may be installed in just 30 minutes, thus fast installation technique.

Acknowledgment

The authors of the paper would like to thank there final year project supervisor **Dr Muhammad Safdar**, for his continuous guidance, proper supervision, valuable suggestion, encouragement and full co-operation in the course of the project. We are also very thankful to **Engr. Akib Ahmed** research assistance, for his immense guidance and help during the long and tiring experimental work. We are also grateful to the staff of **soil mechanics lab**, **concrete lab** and **material testing lab** of **Uet Peshawar** for their technical support during experimental test in laboratory. Also, the careful review and constructive suggestions by the anonymous reviewers are gratefully acknowledged.

Reference

[1] H. A. Qureshi, N. Ahmad and M. Safdar, "Parametric Study for Lateral Capacity of Helical Piles: A State-of-the-Art Literature Review," *Journal of Applied and Emerging Sciences,* vol. 11, no. 2, 2021.

[2] F. Bagheri and M. H. El Naggar, "Effects of the Installation Disturbance on the Behavior of the Multi-Helix", Montreal City, Quebec, Canada: . 66th Canadian Geotechnical Conference, 2013.

[3] K. Shao, Q. Su, J. Liu, K. Liu, "Optimization of inter-helix spacing for helical piles in sand", *Journal of Rock Mechanics and Geotechnical Engineering,* Volume 14, Issue 3, June 2022.

[4] Y. Lin *et al., "*Bearing Characteristics of Helical Pile Foundations for Offshore Wind Turbines in Sandy Soil", *Journal of Marine Science and Engineering*, volume 10, 2022.

[5] M. K. Elsawy, M. H. El Naggar et al., "Seismic performance of helical piles in dry sand from large-scale shaking table tests", Geotechnique, Volume 69 Issue 12, 2019.

[6] "Helical Pile, John Lawrie Tubulars LTD," 2022. [Online]. Available: https://www.johnlawrietubulars.com/products/helical-piles.

[7] M. Elkasabgy and M. H. El Naggar, Axial compressive response of large-capacity helical and driven, University of Western Ontario canada: *Can. Geotech. J.,* 2014.

[8] M. Sakr, Comparison between high strain dynamic and static load tests, Sherwood Park, Alb., Canada T8H 0G2: Geotechnical Engineering, Elsevier, 2013.

[9] M. Sakr, "High Capacity Helical Piles- A New Dimensions for Bridge," in *8th International Conference on Short and Medium Span Bridges* , Niagara Falls, Canada, 2010.

[10] A. A. Malik, J. Kuwano, S. Tachibana and T. Maejima, "End bearing capacity comparison of screw pile with straight pipe," *Acta Geotechnica,* 2016.

[11] O. K. Ali and H. O. Abbas, "Performance Assessment of Screw Piles Embedded in Soft Clay," *Civil Engineering Journal,* vol. 5, no. 8, 2019.

[12] M. Sakr, "Performance of laterally loaded helical piles in clayey soils established from field experience," *The Journal of the Deep Foundations Institute,* 2018.

[13] B. Dinh, J. Liu, J. Dunn, J. Zhang, P. Huang, "Long-term Lateral Resistance of Helical Piles in Cohesive Soils," *Almita Piling Inc.,Ponoka, Alberta, Canada, Geo Regina,* 2014.

[14] R. A. Vickars and S. P. Clemence, "Performance of Helical Piles with Grouted Shafts. In New Technological," in *In New Technological and Design Developments in Deep Foundations GeoDenver* , Reston, Virginia, USA, 2000.

[15] M. Mansour, M. Aboutabikh, A. M. Soliman and M. H. E. Naggar, "Sustainable Grouted Helical Piles: Materials and Performance," in *Conference: CSCE 2016 Annual General Conference*, London, Ontario, Canada, 2016.

[16] A. J. Lutenegger, "Foundation Alternatives for Ground Mount Solar Panel Installations," *Geotechnical and Structural Engineering Congress* , 2016.

[17] Yi, Chaojue, Li, Baocheng, Zheng, Chaoyu and Lu, Ming, "Simulation Based Contingency Estimating for Helical Pile Iinstallation," *Leadership in Sustainable Infrastructure,* 2017.

[18] Khazaei, Javad, and A. Eslam, "Geotechnical Behavior of Helical Piles via Physical Modeling by Frustum Confining Vessel (FCV).," *International Journal of Geography and Geology,* Vols. 5, no. 9, 2016.

[19] M. Safdar and H. A. Qureshi, "Practical Applications of Helical Piles: A State-of-the-Art Literature Review," *Technical Journal,* vol. 26, no. 4, 2021.

[20] Al-Baghdadi, M. J. Brown, J. A. Knappett and A. H. Al-Dafae, "Effects of Vertical Loading onLateral Screw Pile Performance," in *Institution of Civil Engine, Geotechnical Engineering 170*, 2017.

[21] W. C., "Super Tiny Houses," 2021. [Online]. Available: https://www.supertinyhomes.com/screw-pile-foundations-for-tiny-houses-and-backyard-offices/.

[22] P. P. Kumar, Patar and Haldar, "A Critical Review on Design Aspects of Screw Piles for Renewable Energy Devices," in *1st International Screw Pile Symposium on Screw Piles for Energy Applications*, Scotland, 2019.

[23] C. Yi and M. Lu, Foundation Construction Cost Comparison: Helical Pile, Driven Pile, and CIP Pile, University of Alberta, 2015.

[24] H. A. Perko, Helical Piles: A Practical Guide to Design and Installation, Wiley, 2009.

[25] M. Safdar, H. A. Qureshi, F. Shah and N. Ahmad, "Parametric Study and Design Method for Axial Capacity of Helical piles: A Literature Review," *Journal of Applied and Emerging Sciences,* vol. 11, no. 2, 2021.

[26] D. E. Bobbitt and S. P. Clemence " Helical Anchors: Application and Design Criteria," in *9th Southeast Asian Geotechnical Conference*, Bangkok, Thailand: 6-105 to 6-120., 1987.

[27] "IDEAL", Helical Pile Foundations for Covid-19 Field Hospitals in New York, 2020. [online]. Available: https://www.idealfoundationsystems.com/helical-pile-foundations-for-covid-19-field-hospitals-in-new-york/

[28] J. Bak, B.-h. Choi, J. Lee, J. Bae, K. Lee and D. Kim, "Behaviour of Single and Group Helical Piles in Sands from Model Experiments," in *2nd International Conference on Building Materials and Materials Engineering (ICBMM)*, Republic of Korea, 2018.

[29] "Screw Fast Foundation", Chestnut Farm Mobile Dwelling, 2022. [online]. Available: https://www.screwfast.com/case-study/chestnut-farm-mobile-dwelling/.