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Practical Applications of Helical Piles: A State-of-the-Art Literature Review

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Abstract- Helical pile is an innovative, fast, cost effective, environment friendly, deep foundation technique, which is used for the construction of both lightly and heavily loaded structures. In this review article, use of helical pile have been discussed in different practical projects such as construction of new buildings, retrofitting of old buildings and bridges, billboards, electric transmission towers, solar farms, boardwalks and as a bracer in shoring support system. Helical piles have been successfully used in the foundation of onshore wind turbine and now researchers are looking forward to use it in offshore wind turbine foundations. Helical pile foundations may bring great change in green technology. The prime objective of this article is to increase the level of confidence in people using helical pile as a new foundation technique.

Keywords- Helical pile, Retrofitting, Onshore and Offshore Wind Turbine, Solar Farms.

I. Introduction

Helical pile is a prefabricated steel pile which is used as a modern deep foundation technique. Sakr [1] stated that helical pile is a type of deep foundation, which consist of galvanized steel shaft (square or circular) having single or multiple helixes attached to it as shown in Fig. 1. Numerous researchers like Sakr [1], Perko [2] and Naggar [3] briefly highlighted the significance of helical piles that they can be easily installed to any depth with the aid of extension segments, there speed of installation is also rapid i.e., helical pile of 10 m length roughly require 3-4 minutes with the help of two crew persons, it is also advantageous for construction in very restricted condition. Additionally, there installation does not make noise i.e., they are vibration free, which make them environment friendly and appropriate for use in built-up area. Albusoda [4] further added that helical pile is used in both new construction and retrofitting of old construction. There are some limitations of using helical piles also, like they cannot be used in very hard, dense, or gravelly soils, because either the helical plate will get damage [5] or direction of helical pile might change while encountering the hard strata [6].

In 20th century developed countries like USA and Canada adopted helical pile, as a modern foundation practice in structures like electric transmission, light house, wind turbines, solar panels, they also used helical piles as bracer in excavation and tunnel support system [2, 7]. Nowadays, use of helical pile have been shifted from lightly loaded structures to medium and heavily loaded structures [8]. Helical pile is also considered as a favorable foundation technique for short to mid span bridges in city areas [9].

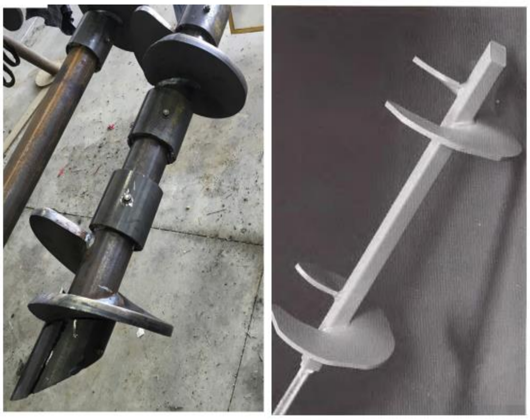

Fig. 1: Circular Shaft Helical Pile (left) [10], Square Shaft Helical Pile (Right) [11].

II. Design Methods

Initially the design of helical pile depends on two factors; a) capacity of pile; b) installation torque [6].

A. Capacity of pile:

Capacity of helical pile can be calculated considering the type of failure model [6]. Mohajerani [12] stated that according to failure mechanism, either individual bearing method or cylindrical bearing method will be used. He further added that these methods depend upon load and soil type. Perko [2] stated that in case of individual bearing model failure occur at each plate individually. The overall capacity of helical pile depends on the sum of the capacity of all helical plates along with the shaft resistance [1-3, 6]. In case of cylindrical bearing model, a frictional cylindrical surface is formed, the overall capacity of pile is the sum of shaft resistance, cylindrical shear resistance and bottom helical plate resistance [2]. Several theoretical equations have been introduced by researcher's which could be used to find ultimate capacity of helical pile [12-13]. Fig. 2 shows schematic diagram of Individual bearing method and cylindrical bearing method.

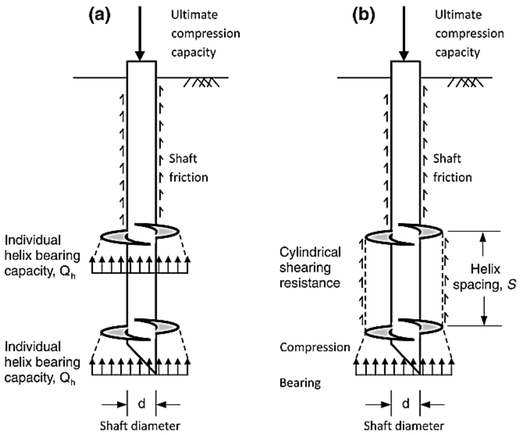

Fig. 2. (a) Individual bearing method (b) Cylindrical bearing method [1].

B. Installation Torque:

Hoyt and Clemence [13] introduced an empirical equation for finding the ultimate axial capacity of helical pile in a direct correlation with installation torque as given by equation 1. Byrne [6] stated that now adays this method is used for quality control assurance.

$$Q_u = K_T\, T \tag{1}$$

Where Q_u = ultimate axial capacity, K_T = empirical torque factor/ capacity-to-torque ratio [ft^{-1} or m^{-1}], T = average installation torque.

III. Practical Applications of Helical Pile

Some of the practical applications of helical piles are discussed as under;

A. Newly constructed building:

With the advancement in technology use of helical piles in foundation of newly constructed buildings is increasing day by day [8]. Helical piles have been used successfully in projects like;

Kempe Children Center, Denver, Colorado:

In 1997 four storey reinforced Kempe Children Center, Denver, Colorado was constructed using 105 vertical helical piles for resisting axial forces and 17 inclined helical piles for resisting lateral loads. Ultimate axial capacity of each helical pile was 445 kN, thus a total of three helical piles with a factor of safety 2, were used to support each reinforced concrete column in order to resist 667 kN load [14]. Fig. 3 shows Kempe Children Center, Denver, Colorado after completion.

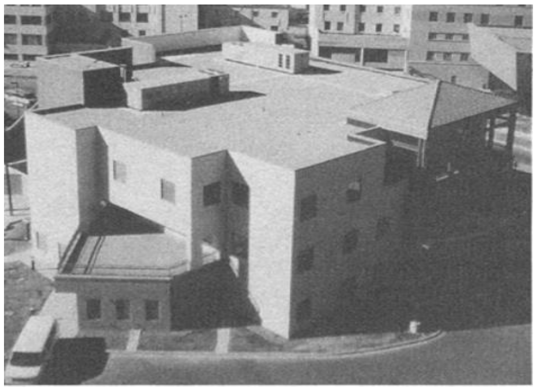

Fig. 3. Kempe Children Center, Denver, Colorado [14].

Hotel and convention center, Windsor, Ontario:

In 2007 construction of large hotel and convention center, Windsor, Ontario was completed. Fig. 4 Shows the picture of the project during construction period. Due to the near by-passing river Detroit, water table was very high, causing buoyancy forces on foundation. Therefore, the designer decided to use helical pile to resist uplift forces (tension). Hence a total of 259 solid steel square shaft (57.1 mm) was used with a grout column of 152 diameter in order to resist uplift loads between 444 to 734 kN [8].

Fig. 4. Hotel and Convention Center, Windsor, Ontario during construction. [8].

Mausoleum, Toronto:

In 2008, another construction project took place at a cemetery in Toronto, Ontario. The Construction project include main building a mausoleum along with, a pumping station, a masonry wall and large shoring walls. As the place was located near urban population and low bearing capacity of soil, helical pile was decided as a deep foundation technique for the project. A total of nearly 200 solid steel square shaft helical piles were used in the project. Fig. 5 shows picture of Mausoleum, Toronto after its completion [8].

Fig. 5. Picture of Completed Mausoleum, Toronto [8].

Three Multi-storey Hospital Woodstock, Ontario:
In 2008 construction of three multi story hospital Woodstock, Ontario was completed. The hospital covers 32,500 square meters area. A total of 13 load tests were done on the site in which 5 were compression tests and 8 were tension tests. Each test was done according to ASTM Quick Load Test Method guidelines for Static Axial Tensile or Compressive Loads. A total of 588 helical piles were installed upto the depth of 15 ft with a torque of 20,000 ft-lbs., in just 45 working days. Fig. 6 shows rendering picture of Hospital Woodstock, Ontario [15].

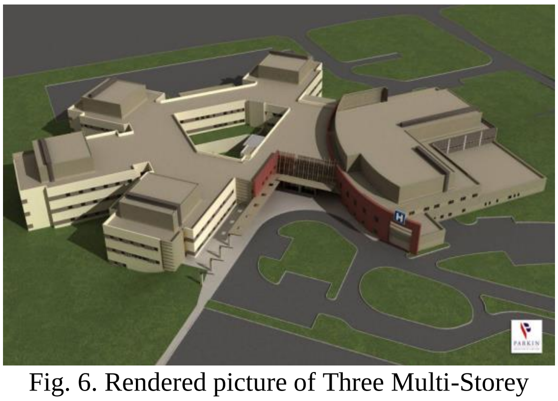

Fig. 6. Rendered picture of Three Multi-Storey Hospital Woodstock, Ontario [16].

13-storey condominium tower Cambridge, Ontario:
In Cambridge, Ontario another 13-storey condominium tower was constructed along the east bank of Grand River. 10 helical pile load tests were done according to ASTM standards for Quick Load Test Method. All the tests were giving satisfactory results. Therefore, a total of 730 steel solid square shaft helical piles were installed in just 40 working days which could resist an ultimate load of 285 kips in compression. Fig. 7 shows rendered picture of 13-storey condominium tower Cambridge, Ontario [15].

Fig. 7. Rendered picture of 13-Storey Condominium Tower Cambridge, Ontario [15].

B. Retrofitting/underpinning of old buildings:
Helical pile is also used to stop the settlement of foundations. There installation require little excavation around the existing foundation and they are best choice when we have restricted conditions. Underpinning brackets can be used with the aid of hydraulic cylinders to raise the foundation. Fig. 8 shows Helical pile with foundation bracket as underpinning [8].

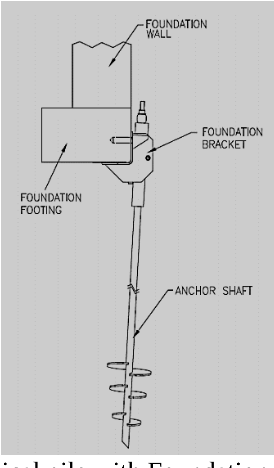

Fig. 8. Helical pile with Foundation Bracket as Underpinning [8].

11-Storey residential underpinning, Richmond Hill, Ontario:
In 1998 it was found that foundation of parking lot, 2 columns and 4 shear walls of 11 Storey residential building were settling. Therefore, an immediate action was taken and 83 (50.8 mm) solid steel square shaft helical piles along with 152 mm diameter grout column were used as underpinning to stop the settlement of foundation. Tests data shows that these helical piles were able

to resist 667 kN compressive load. The task was completed so quickly and effectively that even the settlers of the building were not shifted during the project. Fig. 9 shows picture of 11-Storey residential building, Richmond Hill, Ontario [8].

Fig. 9. 11-Storey Residential Building, Richmond Hill, Ontario [8].

13-Storey residential underpinning, Toronto, Ontario:

In 2003 oil tanker got leaked in the parking garage of 13-storey residential building in Toronto, Ontario. After the field investigation it was found that the soil under the foundation of the building is badly contaminated with petroleum hydrocarbon, therefore it was decided to remove the soil safely and treat it offsite. Fig. 10 shows picture of 13-storey residential building in Toronto, Ontario [8].

Fig. 10. 13-Storey Residential Building Toronto, Ontario [8].

As quick action was required and due to limited head level in parking garage, it was finalized to use helical pile for underpinning. A total of 51 (44.4 mm) solid steel square shaft were installed along with a grout column of 127 mm diameter. In order to make the helical piles safe from corrosion they were hot dipped galvanized, further protection was provided by the steel sleeve and grout column. The excavation was done upto the depth of 2.7 m below the base of footing and the soil was safely removed and treated. During the whole project the settlers remain in their homes and half of the parking garage was also functional. Fig. 11 shows Side section of the helical piles as underpinning [8].

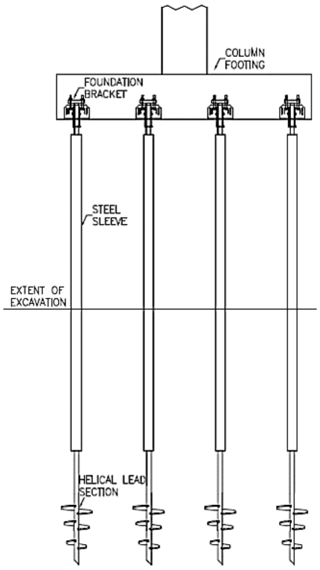

Fig. 11. Side section of the helical piles as underpinning [8].

C. Use of helical piles as a bracer in shoring:

Helical pile is also used as a bracer in shoring support system. In 2007 a large manhole for a sanitary trunk sewer was decided to construct in London, Ontario. As the soil near by the construction site was critical, therefore 33 (57.1 mm) solid steel, square shaft helical piles were used to support the steel sheet piles. These helical piles were able to resist 333 kN tension load. Fig. 12 shows Fox Hollow sanitary trunk sewer manhole London, Ontario [8].

Fig. 12. Fox Hollow Sanitary Trunk Sewer Manhole London, Ontario [8].

Similarly, Fig. 13. Shows use of helical pile as an anchor in shoring system of residential building [2].

Fig. 13. Shoring System of Residential Building [2].

D. Use of helical piles in Billboard support system:

In 1999, it was decided to use helical pile to support a series of billboards in Toronto, Ontario. 78 (44.5 mm) solid steel square shaft helical piles with 3 helixes were used in the project. Each pile was able to sustain lateral load of 400 kN. Fig. 14 shows Billboards Series Toronto, Ontario [8].

Fig. 14. Billboards Series Toronto, Ontario [8].

E. Use of helical piles in boardwalks:

The use of helical pile in boardwalks and pedestrian bridges is also increasing day by day. In 2000, a 3 m wide boardwalk was constructed around Silver Lake, Waterloo, Ontario. A total of 117 helical piles were installed to support the boardwalk at a depth of approximately 3.65 m. Out of 117, 12 of them were round shape (88.9 mm) with 3 helix configurations while the rest of them were solid steel square shaft (38.1 mm) of 2 helix configuration. The round pile was able to resist compressive loads between 78 to 201 kN, while the square shape piles could resist 44 to 122 kN, as specified by the designer. Fig. 15 shows Boardwalk Silver Lake, Waterloo, Ontario after construction [8].

Fig. 15. Boardwalk Silver Lake, Waterloo, Ontario [8].

F. Use of Helical Piles in Bridge Retrofitting

Use of helical pile in bridge retrofitting is also increasing day by day. Multi-helix Micro pile method (MH-MP) is one of the fastest and cost-effective bridge retrofitting technique. Many of the bridges have been retrofitted using this technique. Some of the examples are as under; [17]

Yokohama Bridge Japan:

In 2011 earthquake some of the piers of Yokohama Bridge Japan were found to be badly damaged and they require quick retrofitting. Therefore, Multi-helix Micro pile method (MH-MP) was considered to be the most effective technique for pier reinforcement. A total of 20 helical piles were installed at an angle of 20.8° around the foundation of each pier. Fig. 16 shows Retrofitting plans for Yokohama Bridge Japan piers [17].

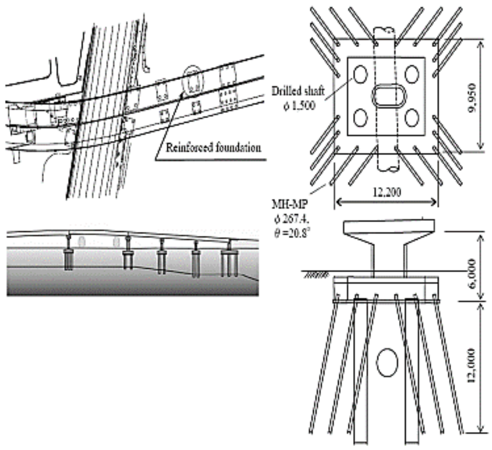

Fig. 16. Retrofitting plans for Yokohama Bridge Japan piers [17].

Damietta Bridge Egypt:

Over the river Nile, Damietta bridge connect Damietta dam and cofferdam. After its construction excessive settlement were recorded in the foundation of some of its piers. Initially the problem was tackled down by uplifting the bridge deck and then installing steel plates under the beam supporting system. However, after some years again settlement was recorded. This time after the detail survey three solutions were suggested, use of board piles, jet grouting and micro pilling. Out of the three suggested methods, micro pilling was considered to be the best option. Fig. 17 shows General view of Damietta dam during the rehabilitation works [17-18].

Fig. 17. General view of Damietta dam during the rehabilitation works [18].

The micro pile used in the project was 32 m long and 150 mm in diameter. It was a cemented grouted type pile. These helical piles were able to take load of 180 kN against the negative friction caused by soft clay. A total of 105 micro piles were used in the retrofitting of two piers and the abutment of the bridge [18]. Fig. 18. (left) show wide gab above pier no 3 due to excessive settlement of the pier foundation. In 2001 survey was done after 3 years of rehabilitation and it was found that no further displacement was recorded [17-18]. Fig. 18. (right) shows the status of the joint above pier no 3 taken in 2001.

Fig. 18. Wide gap above pier P3 due to excessive settlement of the pier foundation (left), Status of the joint above pier number 3, 2001(right) [18].

G. Use in the electrical utility market:

One of the modern applications of helical pile is it use in electrical utility market;

Guy Wire Anchors:

Helical piles when used is uplift application is usually called as helical anchor. Fig. 19. shows that three square shaft helical piles attached to five high tension wires and are embedded in ground at inclined angle [2].

Fig. 19. Utility guy wire anchors [2].

Transmission Towers:

Use of helical pile in foundation of transmission towers is also increasing day by day. Fig. 20. Shows a transmission tower has been constructed on concrete pile cap, beneath which contain several helical piles. It was certified by the designer that each helical pile was able to resist uplift load of 222 kN [2].

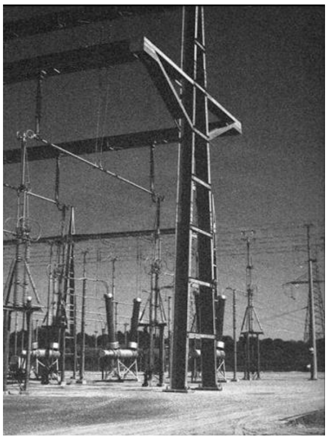

Fig. 20. Transmission tower [2].

H. Use of helical piles in wind turbines:

Helical piles are widely used in the foundation of onshore and offshore wind turbines;

Onshore wind turbine:

In 2006 three wind turbines have been installed in Kasigluk village of Alaska. The soil condition was very critical, along with the limitation of road access, no other method, beside using helical piles was found feasible. It was also found that around 100 Kips uplift force would act on the foundation of wind turbine. Therefore, large capacity helical pile was used having 20-inch diameter and two 36-inch helical plates. Helical piles were installed to a depth of 36 to 40 feet deep. These wind turbines have the capacity to generate 415,500 kWh power per year, which reduces 20-25 % of overall electricity need for Alaska villages. Alaska Village Electric Cooperative (AVEC) also admired to install 17-21 wind turbines in other villages of Alaska in near 3-5 years [19]. Fig. 21 shows Onshore Wind Turbine, Kasigluk, Alaska.

Fig. 21. Onshore Wind Turbine, Kasigluk, Alaska [19].

Offshore wind turbine:
Besides use of helical piles in onshore wind turbines, researchers are now moving towards the use of helical piles in offshore wind turbine [20]. Byrne [21] in his research work point out three methods for the foundation of offshore wind turbine. They are; a) conventional driven pile, b) multiple suction caisson foundations of reduced length and c) single suction foundation with extended length. However, with the increase in advancement of helical pile Byrne [6] give new idea of using helical piles in the foundation of offshore wind turbines.
Ullah [22] did centrifuge modelling tests and found that helical pile if used in the foundation of offshore wind turbine can resist significant uplift and lateral forces. He stated that besides installation speed and cost effective, one advantage of helical pile is that it is not dangerous for marine life. As its installation is vibration free thus marine life will be safe from harmful acoustic emissions as produced by driving piles.

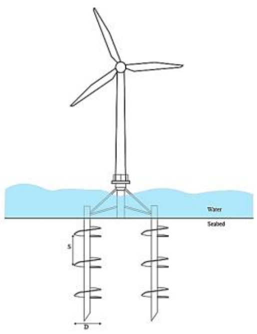

Fig. 22. Schematic picture showing helical pile used in the foundation of wind turbine [22].

He further added that helical pile can be install in seabed using installation rotary rigs. Fig. 22. shows Schematic picture showing helical pile used in the foundation of wind turbine. Byrne [6] outlined that large capacity helical piles can be used in the foundation of offshore wind turbine; however further research work needs to be done especially in the area of installation of helical pile. He further added that field tests need to be done in order to verify the design of helical pile for offshore wind turbine.

I. Use of helical piles in solar panels:
Helical pile is also a best choice for the installment of solar farms. These solar farms are subjected to excessive uplift forces (especially wind storms). In recent years it was noted that most of the solar farms were badly damaged by wind storms, as happened on 17 April 2019 in Bhadla Rajasthan, when extreme wind layers hit the solar farm and cause damage to them as shown in Fig. 23 [23].

Fig. 23. Solar farm in Bhadla Rajasthan after wind storm [23].

Similarly, another wild wind hit the solar farm in Gunma, and cause excessive damage it as shown in Fig. 24 [23].

Fig. 24. Solar Farm in Gunma, Japan after wind storm [20].

Therefore, new design of using helical piles for solar farm were introduced, as helical piles can resist excessive uplift load [23]. Seider [24] analyzed three solar farms (20 MW Solar Farm near Alamosa, 20 MW Solar Farm near Amherstberg, Ontario, and the LIPA 31.5 MW power plant at Brookhaven National Labs on Long Island) constructed in North America and found that they are still in their accrual position since their installment after many wind storms. He further stated that the shaft diameter of those helical pile range in between 3.5 to 8 inch and their embedment depth were from 7 to 15 foot. 16,800 helical piles were installed in Alamosa solar farm. Fig. 25 shows Alamosa Solar Farm.

Fig. 25. Alamosa Solar Farm [24].

IV. CONCLUSION

The above discussed case studies shows that helical piles can be successfully used in different type of practical projects. As the number of practical project increases, level of confidence of contactors and peoples also increases. These practical projects shows that helical piles can be successfully used in construction of new buildings, rehabilitation of old building, retrofitting of bridges, as a bracer in shoring support system. They are also used as a foundation in solar farms, billboards, transmission towers. They have been successfully used in foundation of onshore wind turbine. Now a days researchers are looking to use helical pile in the design of offshore wind turbine which would bring revolution in the green technology in the coming years.

REFRENCES

[1] M. Sakr, "Performance of helical piles in oil sand," *Can. Geotech. J.*, vol. 46, p. 1046–1061, 2009.

[2] H. A. Perko, Helical Piles A Practical Guide to Design and Installation, New Jersey: John Wiley & Sons, Inc., 2009.

[3] B. Livneh and M. H. E. Naggar, "Axial testing and numerical modeling of square shaft helical piles under compressive and tensile loading," *Can. Geotech. J*, no. 45, p. 1142–1155 , 2008.

[4] B. S. Albusoda and H. O. Abbase, "Performance assessment of single and group of helical piles embedded in expansive soil," *International Journal of Geo Engineering*, vol. 8, pp. 1-20, 2017.

[5] D. Sego and K. Tappenden, "Predicting the Axial Capacity of Screw Piles Installed in Canadian Soils," in *OttawaGeo*, Canada, 2007.

[6] B. W. Byrne and G. T. Houlsby, "Helical piles: an innovative foundation design option for offshore wind turbines," *Philosophical Transactions A*, no. 373, 2015.

[7] V. Vignesh and M. Mayakrishnan, "Design parameters and behavior of helical piles in cohesive soils—A review," *Arabian Journal of Geosciences* , no. 13, p. 1194, 2020.

[8] D. Vito, "Case histories on the use of helical piles for retrofitting and new construction," in *Pan-Am CGS Geotechnical Conference*, Canada, 2011.

[9] M. Sakr, "High Capacity Helical Piles – A new dimension for bridge foundations," in *Proceedings of 8th International Conference on Short and Medium Span Bridges*, Niagara Falls, Canada, 2010.

[10] S. A. Lanyi-Bennett and L. Deng, "Effects of inter-helix spacing and short-term soil setup on the behaviour of axially loaded helical piles in cohesive soil," *Soils and Foundations* , no. 59, p. 337–350, 2019.

[11] H. O. Abbase, "Pullout Capacity of Screw Piles in Sandy Soil," *Journal of Geotechnical Engineering*, vol. 4, no. 1, pp. 8-12, 2017.

[12] A. Mohajeranin, D. Bosnjak and D. Bromwich, "Analysis and design methods of screw piles: A review," *Soils and Foundations*, vol. 1, no. 56, pp. 115-128, 2016.

[13] R. Hoyt and S. Clemence, "Uplift Capacity of Helical Anchors in Soil," in *Soil Mechanics and Foundation Engineering*, Rio de Janeiro, Brazil, 1989.

[14] J. S. Pack, "Design of Helical Piles for Heavily Loaded Structures," in *American Society of Civil Engineers*, Denver, Colorado, United States, 2000.

[15] D. Vito, "Highly loaded helical piles in compression and tension applications: A case study of two projects," in *Pan-Am CGS Geotechnical Conference*, Ontario, Canada, 2011.

[16] M. Killeavy, "Woodstock General Hospital-Value for Money Assessment," Knowles Consultancy Services Inc., Ontario, 2008.

[17] D. P. Doshi, A. K. Desai and C. H. Solanki, "Multi Helix Micropile for Retrofitting of Bridge Foundations," in *Proceedings of Indian Geotechnical Conference*, Kochi, 2011.

[18] U. A. Morsy, "Repair of Damietta Bridge Foundations Using Micro-piles: A Case Study," in *Annual Conference of the Canadian Society for Civil Engineering*, Canada, 2002.

[19] L. M. Dilley and L. Hulse, "Foundation Design of Wind Turbines in Southwestern Alaska, a Case Study," The Aractic Energy Summit, Alaska, 2007-2008.

[20] S. N. Ullah and Y. Hu, "Discussion: A review on the behaviour of helical piles as

a potential offshore foundation system," *Marine Georesources & Geotechnology,* vol. 9, no. 38, pp. 1121-1127, 2020.

[21] G. T. Houlsby and B. W. Byrne, "Foundations for offshore wind turbines," *Philosophical Transactions of The Royal Society A Mathematical Physical and Engineering Sciences,* no. 361, pp. 2909-2930, 2003.

[22] S. N. Ullah, Y. Hu and C. O'Loughlin, "A green foundation for offshore wind energy - helical piles," in *World Engineers Convention*, Melbourne, Australia, 2019.

[23] A. Agarwal, H. Irtaza and M. A. Khan, "Experimental Study of Pulling-Out Capacity of Foundation for Solar Array Mounting Frames," *Indian Geotech J,* vol. 2, no. 51, pp. 414-420, 2021.

[24] G. L. Seider and J. B. Chisholm, "Lateral Capacity of Helical Piles – Actual vs. Theoretical Foundations for Solar Power Plants," *GeoCongress ASCE,* pp. 315-325, 2012.

[25] V. Vignesh and M. Mayakrishnan, "Design parameters and behavior of helical piles in cohesive soils—A review," *Arabian Journal of Geosciences,* no. 13, p. 1194, 2020.