The 2021 World Congress on
Advances in Structural Engineering and Mechanics (ASEM21)
GECE, Seoul, Korea, August 23-26, 2021

Analysis of axially loaded helical piles in sand using HPCap program

Hyeong-Joo Kim[1)], *Peter Rey Dinoy[2)], James Vincent Reyes[3)], Hyeong-Soo Kim[4)], Jun-Young Kim[5)], and Tae-Woong Park[6)]

[1)] *Department of Civil Engineering, Kunsan National University, Gunsan 54150, Korea*
[2), 3), 4), 5)] *Department of Civil and Environmental Engineering, Kunsan National University, Gunsan 54150, Korea*
[6)] *Renewable Energy Research Institute, Kunsan National University, Gunsan 54150, Korea*
[2)] *peter_rey@kunsan.ac.kr*

ABSTRACT

In recent times, energy comes mainly from the petroleum and gas industry. However, due to increasing demand, it has become clear that petroleum and gas supply is not enough. Hence, a lot of alternative power sources have been utilized over the years including hydropower, geothermal, biomass, wind, and solar resources. Solar energy is a sustainable energy that can help alleviate climate change. In an effort to develop the reclaimed city of Saemangeum in Korea as a global frontrunner of green growth, solar farm projects have been initiated in the area. In recent times, helical pile foundation has been perceived as a viable alternative to conventional foundations used in constructing solar farms. In this study, the HPCap program, which is capable of analyzing both the axial and lateral capacity of helical piles, is introduced. The basic concept behind the analysis of the axial capacity of helical piles and the verification of the program is presented.

1. INTRODUCTION

In recent years, the use of helical piles to support a variety of loads has increased for its many advantages such as ease of installation, relatively small equipment, rapid installation speed, suitability in very limited access conditions, removable, and reusable (Kim et al. 2019). One of its many applications includes solar farms. In the Saemangeum Development Project (SDIA 2020), solar farms have already been constructed using helical piles as its foundation. Numerous research on helical piles under axial loading are

---

[1)] Professor
[2), 3), 5) 6)] Graduate Student
[4)] Ph.D.

present in literature. One of the simplest ways in assessing the axial capacity of helical piles is by solving for its ultimate axial capacity, however, the method cannot predict the settlement and behavior of helical piles. To further advance the technological development and design of helical piles, a theoretical approach that can capture the behavior of helical piles must be established. In this study, the HPCap program is introduced. The program utilizes soil springs to be able to analyze the load-deformation characteristics of helical piles.

2. THEORETICAL BACKGROUND

The typical displacement and the axial load with depth on a helical pile is shown in Fig. 1. To determine the displacement at any point along the helical pile and to solve the problem of the distribution of load along the helical pile for a given applied load, the nonlinear differential equation shown in Eq. (1) is solved by considering an element from the shaft, which is represented by length *h*, as shown in Fig. 1a. The load transfer from a deep foundation to the supporting soil is shown in Fig. 2. For a conventional pile, springs for tip and skin resistance are used, as shown in Fig. 2a. However, for a helical pile, additional springs for the helices are introduced, as shown in Fig. 2b. Sakr (2009) presented that shaft friction only occurs at an effective length above the top-most helix. Hence, springs for skin friction below the top-most helix is neglected. Therefore, axial load carried by skin friction can be negligible, as shown in Fig. 1b. The load transfer curves used by the HPCap program is shown in Fig. 3, which shows the curves for the tip resistance, skin resistance, helix resistance in compression, and helix resistance in uplift. The tip and skin resistance was taken from API RP 2A-WSD (2014) while the helix resistance was derived from load tests conducted in Saemangeum, South Korea.

$$\frac{dw}{dz} = \frac{Q}{EA} \tag{1}$$

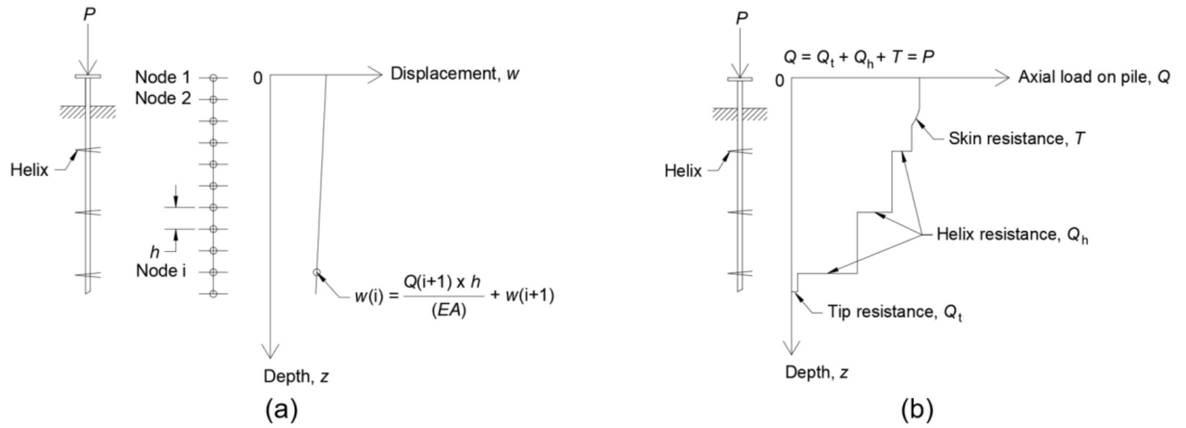


Fig. 1. Helical pile displacement and load: a) displacement with depth and b) axial load on helical pile with depth

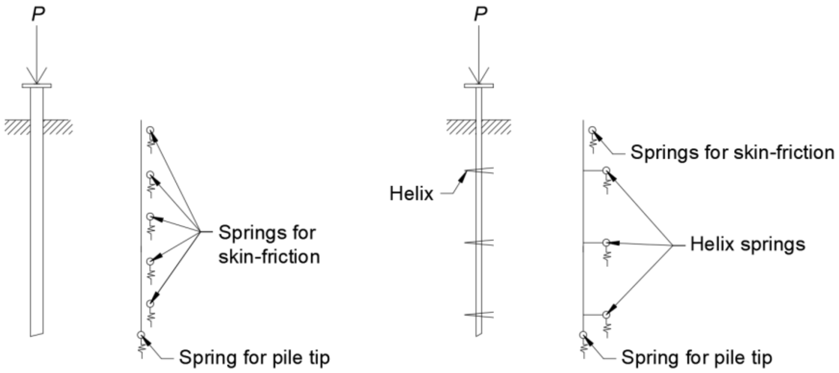


Fig. 2. Load transfer from a conventional pile and helical pile to the supporting soil

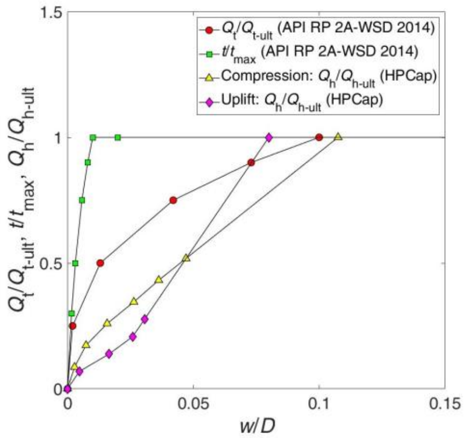
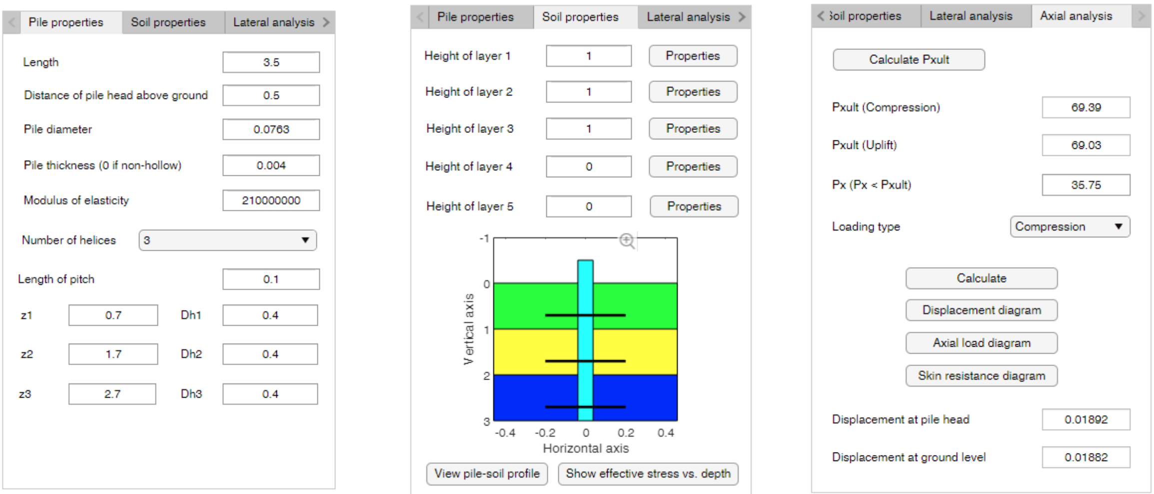


Fig. 3. Load transfer curves used by the HPCap program

3. HPCAP PROGRAM

The graphical user interface (GUI) of the HPCap program is shown in Fig. 4. The pile properties, soil properties, analysis type are separated by tabs. The program can analyze up to 3 helices, requiring the depth and diameter of the helices as input parameters. In the soil properties tab, as shown in Fig 4b, the soil-pile profile and the effective stress with depth can be viewed, and the properties of up to 5 soil layers can be inputted. The required parameters for a sand layer are the unit weight (γ), friction angle (ϕ), coefficient $K0$, and coefficient k, as shown in Fig. 5. Once, the input parameters have been stored, the displacement, axial load, and skin resistance diagrams can be calculated. The program can display the ultimate axial load capacity (Q_{ult}), and requires that the applied axial load (P) must be less than Q_{ult}, as shown in Fig. 4c. Sample displacement, axial load, and skin resistance diagrams for a helical pile with three helices is shown in Fig. 6. As shown in Fig. 6, most of the axial load is carried by the bottom-most helix. Furthermore, it can be seen that skin-friction is negligible.



(a) (b) (c)

Fig. 4. Graphical user interface (GUI) of the HPCap program

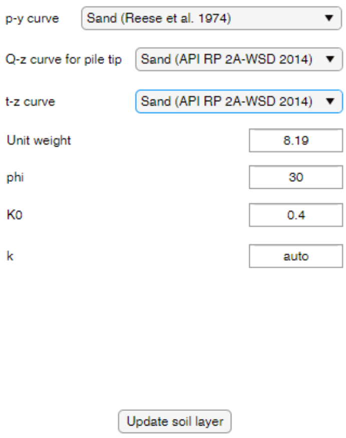


Fig. 5. Required parameters for a sand layer in HPCap

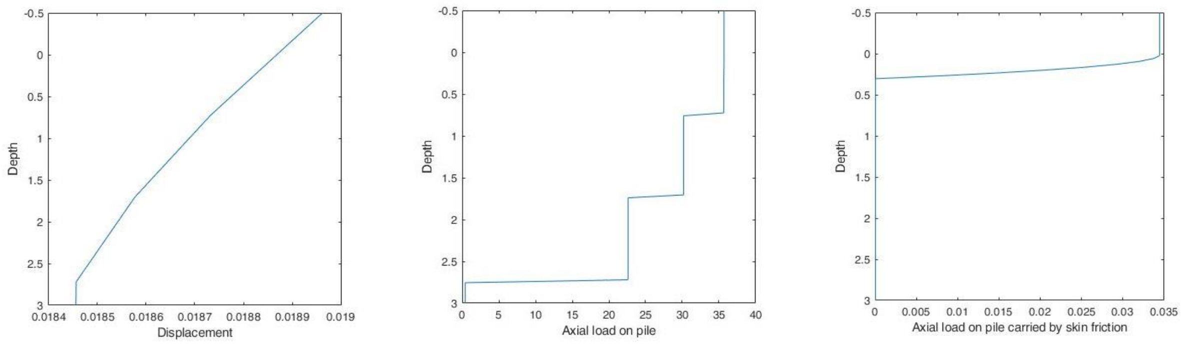
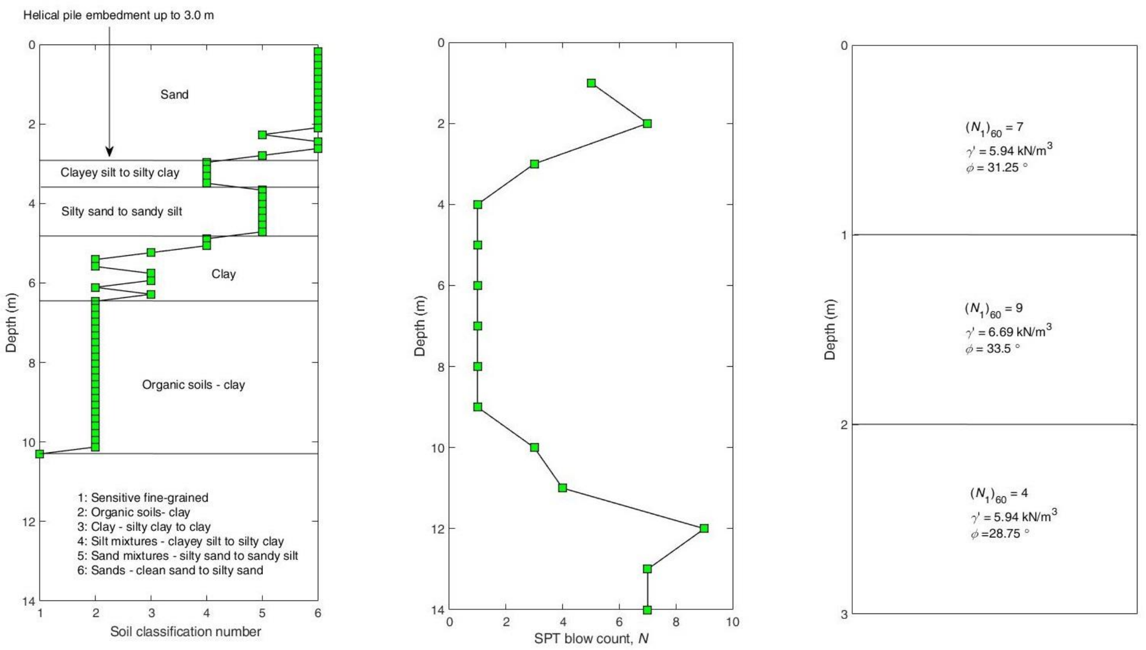


Fig. 6. Results of HPCap program: a) displacement diagram, b) axial load diagram, and c) skin resistance diagram

4. VERIFICATION OF HPCAP PROGRAM

To verify the HPCap program, measured data from load tests in Saemangeum, South Korea is compared with the predicted data. The soil profile of the test site based on the cone penetration test (CPT) is shown in Fig. 7a, which indicates that ground consists of sand up to 3.0 m from the surface, and is underlain mostly by clay soil. The clay soil is soft, as shown by the standard penetration test (SPT) blow count N in Fig. 7b, which shows a value of 1.0 at depths 4.0-9.0 m. The properties of the sand layers based on the SPT data are given in Fig. 7c.



(a) (b) (c)

Fig. 7. Properties of test site: a) soil profile based on CPT, b) SPT blow count *N*, and c) properties of the sand layers based on the SPT data at depths 0-3.0 m

The helical piles in the load tests are only embedded to 3.0 from the ground surface. The properties of the helical piles used in the test are summarized in Table 1. It should be noted that each helical pile has three helices and that the three helices have the same dimension. Compression and pullout tests were conducted on two helical piles having helix diameters of 400 mm and 450 mm. The results of the test and analysis are shown in Fig. 8, which indicates that the HPCap program can adequately predict the behavior of helical piles in sand under compressive and uplift loads.

Table 1. Properties of helical piles in the load tests

Property	Description
Shaft diameter, D_p	76.3 mm
Helix diameters, D_h	400 mm, 450 mm
Pile length, L_p	3.5 m
Length of pile embedment, L_e	3.0
Number of helices	3
Depth of top-most helix, z_1	0.7 m
Depth of top-most helix, z_2	1.7 m
Depth of bottom-most helix, z_3	2.7 m

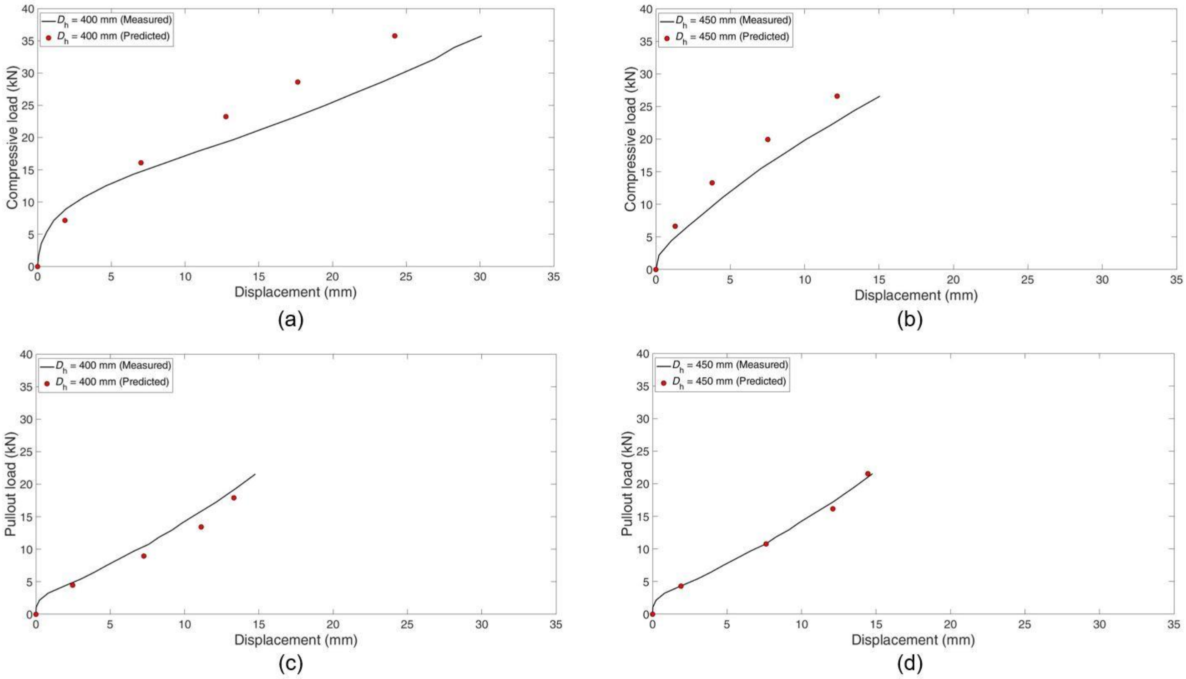


Fig. 8. Comparison between measured data from load tests and predicted data using HPCap

5. CONCLUSION

To further advance the technological development and design of helical piles, a theoretical approach that can capture the behavior of helical piles must be established. In this study, the HPCap program is introduced. The program utilizes soil springs to be able to analyze the load-deformation characteristics of helical piles. To verify the HPCap program, measured data from load tests in Saemangeum, South Korea was compared with the predicted data. The results have shown that the HPCap program can adequately predict the behavior of helical piles in sand under compressive and uplift loads.

ACKNOWLEDGMENT

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF), funded by the Ministry of Education (NRF2021R1A6A1A1A0304518511, NRF2020R1I1A3A04036506).

REFERENCES

American Petroleum Institute (API). (2014). “Recommended practice for planning, designing, and constructing fixed offshore platforms-working stress design.” API RP 2A-WSD, Washington, DC.

Kim, H.J., Park, T.W., Kim, H.S., & Dinoy, P.R. (2019). A study on the behavior of various foundations during earthquake and liquefaction. *The 2019 World Congress on Advances in Structural Engineering and Mechanics (ASEM19)*, Jeju Island, Korea, September 17-21 2019, pp. 1-9.

Sakr, M. (2009). Performance of helical piles in oil sand. Canadian Geotechnical Journal, 46, 1046–1061.
(doi:10.1139/T09-044)

SDIA (Saemangeum Development and Investment Agency). http://www.saemangeum.go.kr (accessed 05/25/2021).