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Effect of Helix Diameter on Carrying Capacity of Screw Pile under Inclined Loading

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ABSTRACT

The present study describes the effects of helix diameter on the carrying capacity of screw piles under the inclined loading conditions in dry sand with a relative density of 60%. The results of laboratory-scale physical model tests analysed to evaluate the influence of load inclination angle and helix diameter on the carrying capacity of the piles. The study begins by conducting a series of laboratory experiments on physical model piles with varying helix diameter of 45mm, 60mm and 90mm.A model foundation tank was designed to apply compressive loads at different inclinations as 0°, 30°, 45°, 60° and 80°. The load-settlement response and failure modes of the piles were carefully monitored. It was observed that as the load inclination angle increases, the carrying capacity of the screw piles decreases and it was also found that an increase in the helix diameter leads to an increase in the carrying capacity of the screw piles.

Keywords: **Screw pile; Helix plate; Inclined loading; Carrying capacity; Pile load test.**

INTRODUCTION

Screw piles, also known as helical piles or screw anchors, have gained significant attention in the field of geotechnical engineering as an innovative and efficient foundation system. Their unique design, which includes a continuous helical plate welded to a central steel shaft, offers advantages such as ease of installation, high load-carrying capacity and adaptability to various soil conditions.

Screw piles are installed into the ground by applying torque to the pile shaft, typically utilising a rotatory motor connected to the pile head. A rotation system to begin the installation and move the pile into the stratum was combined with a pressing system to apply download force. This helical shape enhances the pile's load-carrying capacity by increasing the surface area in contact with the soil, thereby improving load distribution and reducing settlement.

Screw piles have been successfully employed in a wide range of applications, including residential, commercial, industrial, and infrastructure projects. They are particularly beneficial in areas with poor soil conditions, such as soft clay, loose sand, or contaminated soils, where traditional foundation systems face challenges. Additionally, their ease of installation and minimal site disturbance make them suitable for temporary structures, rapid response projects, and environmentally sensitive areas. Screw piles provide a cost-effective and rapid foundation solution. Different components of helical pile are shown in figure 1.

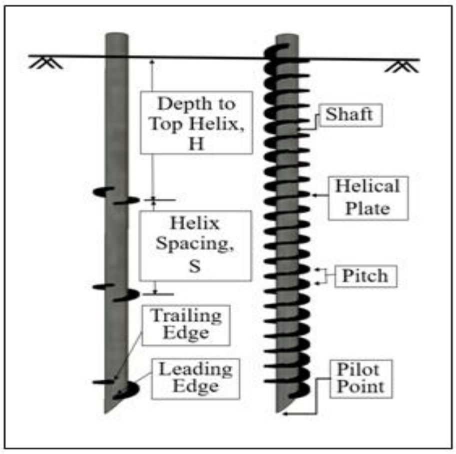


Figure 0 Components of helical pile

Soil investigation

The sand used for this experimental study was air dried orsang river sand which was brought from Bahadarpur, Sankheda. Sieve analysis had been performed on oven dried sand sample as per IS 2720-4 (1985) and grain size distribution curveis shown in Figure 2.The soil is classified as poorly graded (SP), according to the IS - standard classification for soil.Other properties of soil were analysed and listed in Table 1.

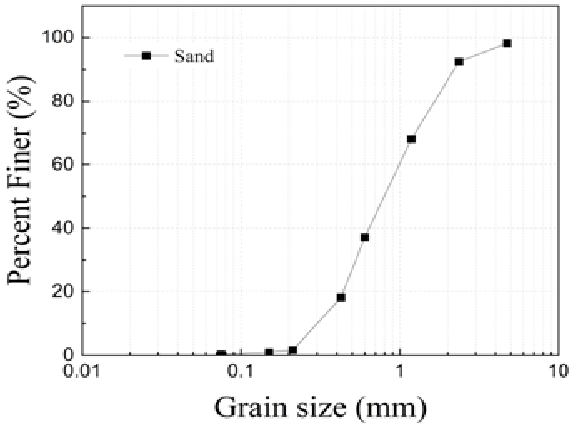


Figure 2 Grain size distribution curve

Table 1Properties of soil

Properties of sand	Values
D_{10}	0.442
D_{30}	0.702
D_{60}	1.161
Coefficient of Uniformity, C_u	2.627
Coefficient of Curvature, C_c	0.961
IS Soil Classification	SP
Specific Gravity, G	2.68
Silt Content	2.42%
Angle of Internal Friction, ϕ	36°
Maximum Density, $\gamma_{d\ Max}$	18.11 kN/m^3
Minimum Density, $\gamma_{d\ Min}$	14.91 kN/m^3
60%Sand Density, γ_d	16.83 kN/m^3

Experimental study

Physical model tank

A 1.5 m x 1.5 m x 1.5 m square model tank was utilised to conduct a pile load test on a model Screw pileas shown in Figure 3. A semi-circular loading frame with a hydraulic system for frame movement and a hydraulic jack for applying load at desired inclination were fitted to the model tank. In order to measure the imposed load, a 25kN proving ring (Proving ring constant = 27.0592 N/div.) was employed. To measure displacement, an LVDT with a sensitivity of 0.01 mm and a capacity of 100 mm was used.

Figure 3Model foundation tank

Screw pile

The screw piles were manufactured from high-strength steel. Screw piles had a length of 600 mm and a hollow circular cross-section with anouter diameter of 30 mm and inner diameter of 15 mm. Screw piles P1, P2 and P3 having helix diameters of 45 mm, 60 mm and 90 mm respectively. Helix plates are employed with a thickness of 3 mm and 35 mm helical plate pitch. Steel helical plate used to make helix, which was precisely and securely welded to the pile shaft. Helix plates are continuous throughout the pile shaft, from top to bottom. Screw pile geometry is shown in Figure 4.

Figure 4 Different types of screw piles that were used in this study

Test procedure

The experiments were carried out on screw piles P1, P2, and P3 with a relative sand density of 60%. Load was applied at different angles, including 0°, 30°, 45°, 60° and 80° with respect to the vertical axis. Each layer of 10 cm of sand in the tank was filled using free fall of 10 cm and vibrated using of a surface vibrator to attain 60% relative density. The model tank was filled with sand to the level of the pile head. Sand layers were filled till the pile could be embedded up to150 mm bottom of pile. The pile was pre-installed by applying torque using a rotating motion with hands in the sand bed. The pile was kept straight and centred using a plumb bob. Rest of the sand was filled by freefall and vibrated till the top of pile.

For the application of vertical and inclined load, a ball socket joint mechanism (as shown in Figure 5) was used to link the pile top to the proving ring. For the purposes of measuring displacement and for an inclined loading condition, a steel flat plate which was 3 mm thick was positioned between the proving ring and the ball socket joint. Hydraulic jack, pile top, and plumb bob were vertically lined up for vertical loading. The hydraulic jack was set on the semi-circular loading frame to the desirable loading inclination for inclined loading. When applying the load, care was taken to ensure that the imposed load's line of action would pass through the centre of the pile head. To measure the displacement of the pile head in the direction of the load, two LVDTs with a total measurement capability of 100 mm and a sensitivity of 0.01 mm were utilised.

In the laboratory tests conducted for the research, the Maintained Load Test (MLT) method was followed, adhering to the guidelines specified in IS 2911-4 (2013). The MLT method involves applying a load and maintaining it while monitoring the displacement of the pile top. During the tests, a load was applied to the pile until a displacement of approximately 1 mm was achieved. The load was then sustained while monitoring the displacement rate of the pile top. If the displacement rate reached 0.02 mm in the first 30 minutes or 0.04 mm in the first hour, whichever occurred first, the load was maintained at that level. Once the displacement of the pile head stabilized, the load was measured using a proving ring, which is a device for measuring force or load. Additionally, a Linear Variable Differential Transformer (LVDT) was used to record the displacement of the pile head in the direction of the applied load. This testing process was repeated until the load became constant or until a higher progressive displacement was observed.

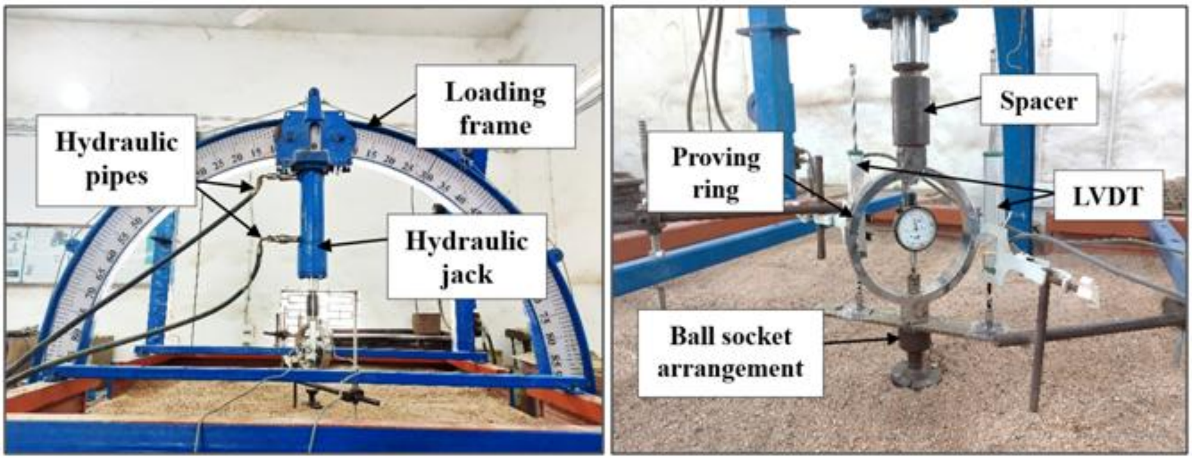
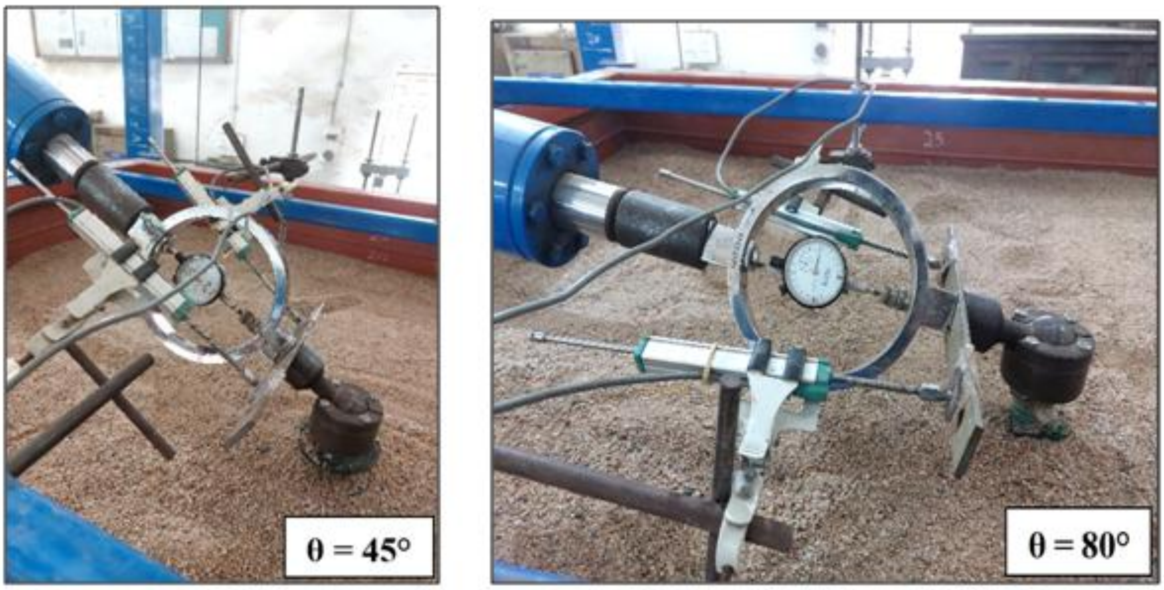


Figure 5 The experimental setup, proving ring and LVDT arrangement at vertical loading condition



(a) (b)

Figure 6 Proving ring and LVDT arrangement at different load inclination

Test result and discussion

This study set out to analyse the behaviour of continuous-helix screw piles and their performance under inclined loading conditions. To ascertain the maximum load capacity, total 15 pile load tests on three screw piles with continuous helix were undertaken. Failure happens when a specific maximum amount of compressive force is seen or when a significant downward movement occurs as a result of a tiny increment of applied load; this load is known as the failure load. A graph of various loads and displacements have been presented for analysis.

The influence of load inclination

Experiments were conducted in a lab on piles P1, P2 and P3 at 60% relative density with loads inclined at 0°, 30°, 45°, 60° and 80° with a vertical axis to analyse the influence of load inclination. Figures 7-9exhibit the curves for the P1, P2 and P3 piles respectively. Initially, as the load increases, the displacement of the pile top increases gradually, indicating a relatively slow response. However, as the loading progresses, the displacement rate becomes more pronounced, leading to a linear relationship between load and displacement.

Furthermore, the effect of load inclination on the load-carrying capacity of the pile can be observed. As the load inclination angle moves away from the vertical axis, the load-carrying capacity of the pile decreases. This is evident from the curves showing a downward trend towards the displacement axis. The decrease in load capacity can be attributed to the introduction of additional lateral forces due to inclined loading, which reduces the pile's capacity to resist vertical loads effectively.

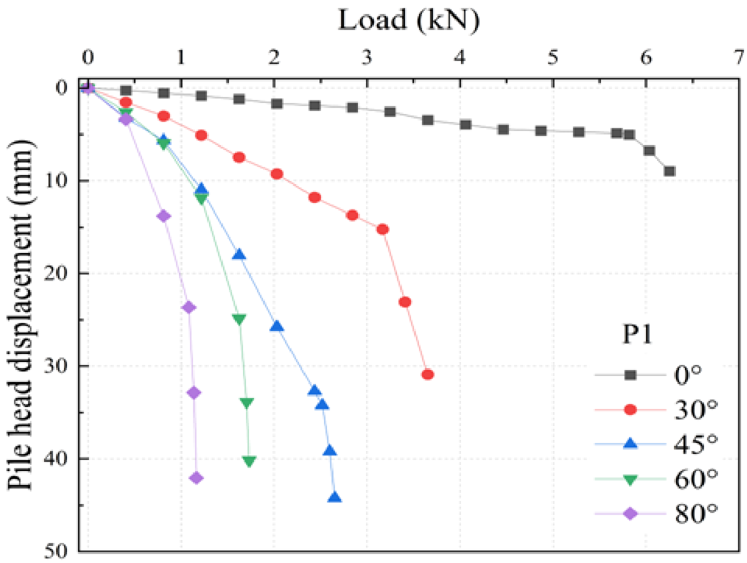


Figure 7 Load vs Pile head displacement in the direction of load for P1pile

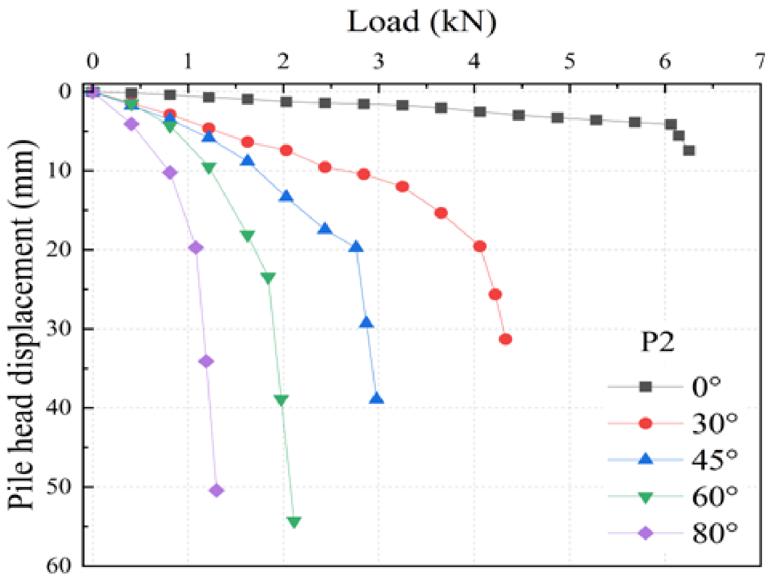


Figure 8 Load vs Pile head displacement in the direction of load for P2pile

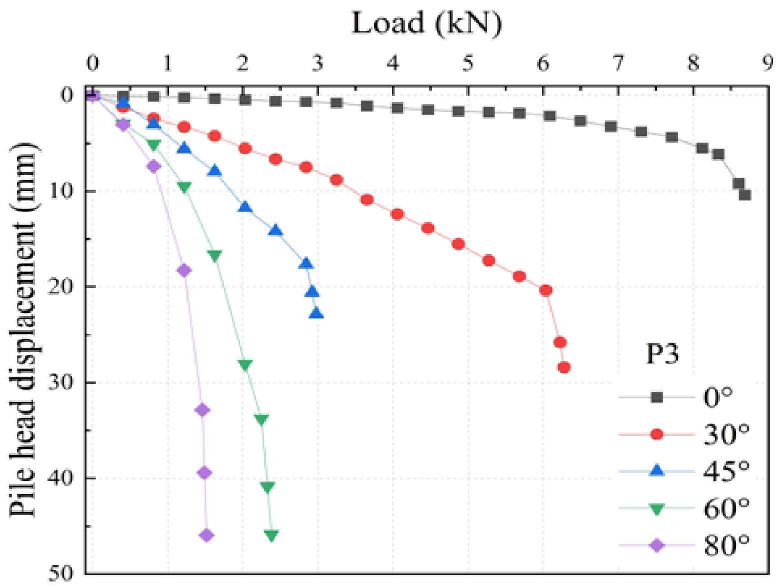


Figure 9 Load vs Pile head displacement in the direction of load for P3pile

The influence of helix diameter at various angles of load inclination

The experimental investigation focused on comparing the performance of three different screw piles, labelled as P1, P2 and P3 with helix diameters of 45mm, 60mm and 90mm respectively. The aim was to analyse the influence of helix diameter on the load-carrying capacity of the piles under various load inclination angles. The performance of piles under five different load inclination as discussed earlier were analysed. The load-carrying capacity of each pile was assessed at these inclination angles to understand how the helix diameter affects their performance (shown in Figure 10-11).

The experimental results revealed a clear trend that the pile with a larger helix diameter exhibited a higher load-carrying capacity compared to the piles with smaller helix diameters. By increasing the helix diameter, the surface area in contact with the soil increases, leading to improved load distribution and enhanced load-carrying capacity. The larger helix diameter allows for better soil interaction, increasing the overall resistance to vertical loads. Also, it highlights the benefits of utilizing larger helix diameters, particularly in scenarios where higher load-carrying capacities are required.

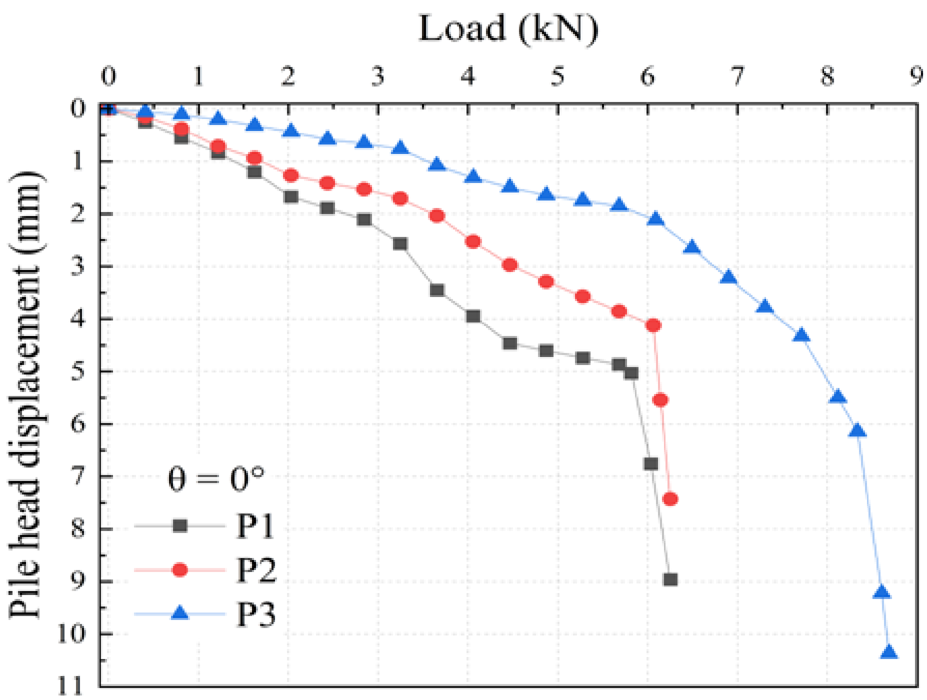


Figure 10 Load vs Pile head displacement in the direction of load for P1, P2 and P3piles at 0° inclination

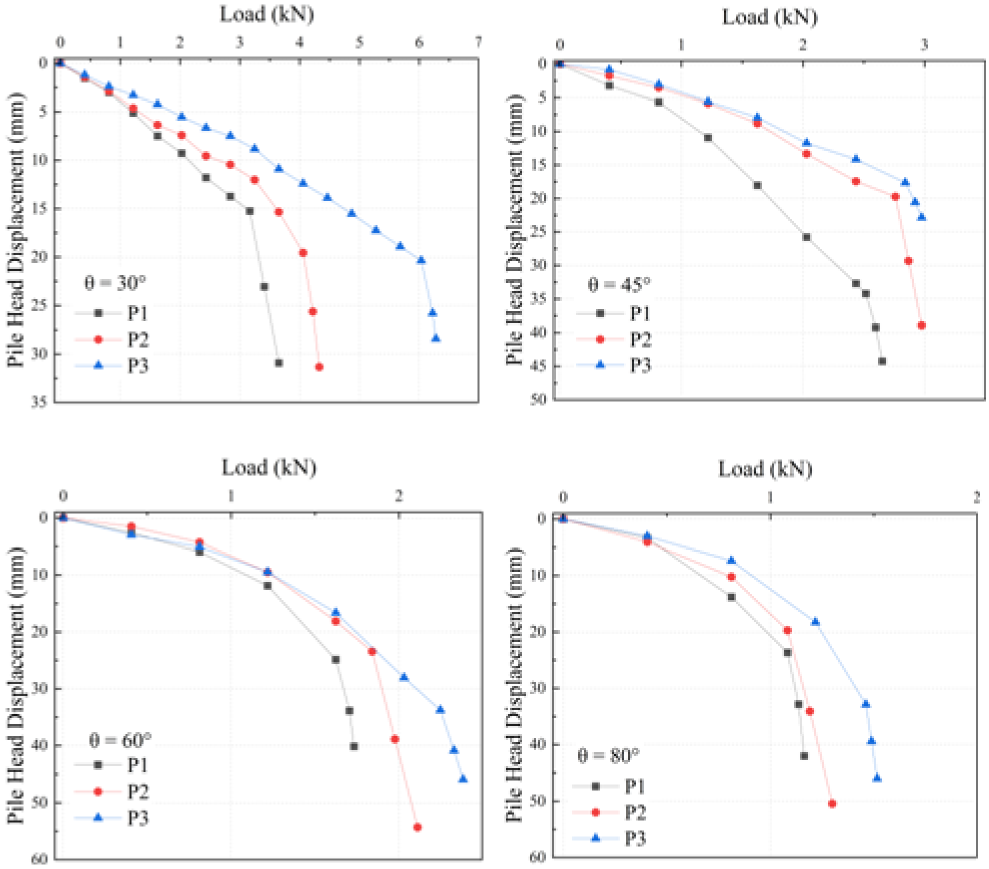


Figure 11Load vs Pile head displacement in the direction of load for P1, P2 and P3piles at different load inclination with vertical

The ultimate load capacity

The ultimate load capacity of a screw pile refers to the maximum load it can sustain before failure or excessive displacement occurs. It is a crucial parameter for analysis and design, determining the pile's carrying capacity. In load settlement curves, the ultimate load is represented by the peak load achieved during the test or maximum load before significant settlement occurs, indicating the pile's maximum load-carrying capacity as shown in Figure 12. The curve plots applied load against settlement, allowing engineers to observe pile behaviour and identify the point of significant settlement or failure. The effect of inclination and helix diameter on ultimate load of screw pile are presented in Figures 13-14.

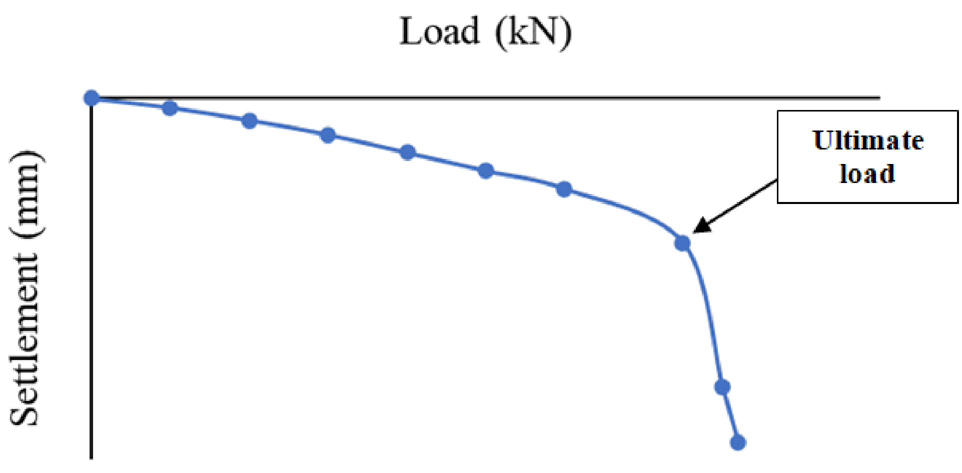


Figure 12 Ultimate load

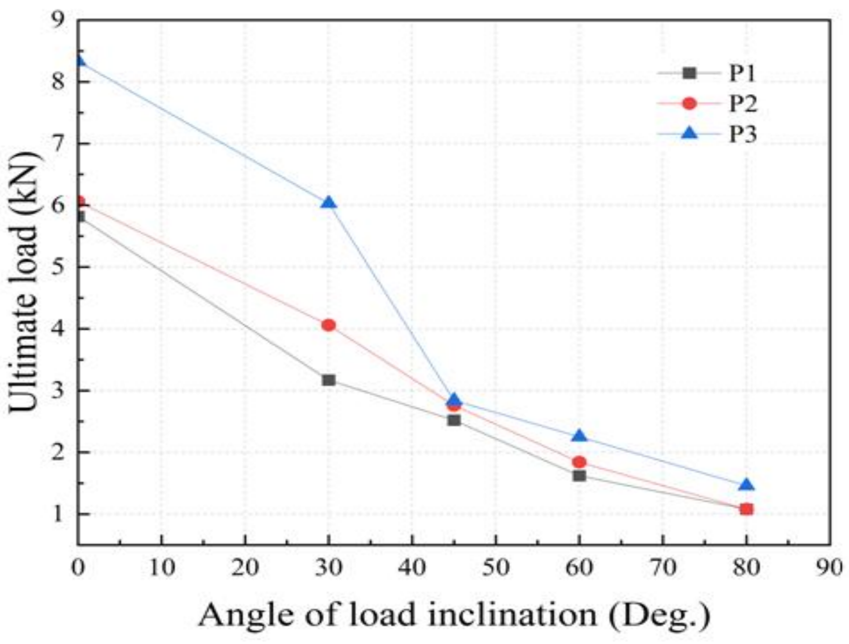


Figure 13 The effect of load inclination on ultimate load of screw pile

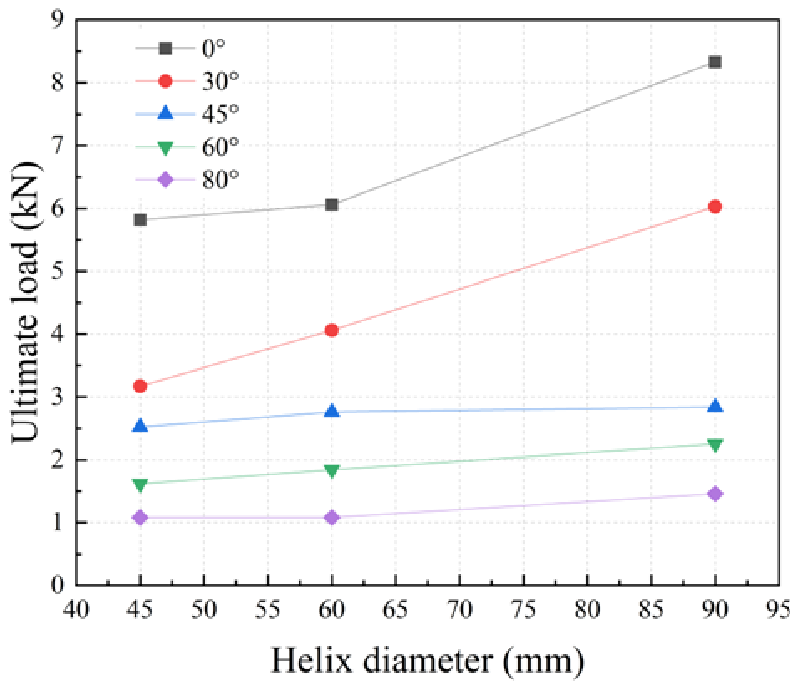


Figure 14 The effect of helix diameter on ultimate load of screw pile

The results shows that the ultimate load capacity of the piles often decreases as the angle of inclination with the vertical axis increases. The ultimate load on the P1 and P2 piles gradually decreases as the load inclination increases. It's interesting to note that for pile P3, the ultimate load value decreases significantly and noticeably from 30° to 45°. This observation highlights the sensitivity of pile P3 to inclined loading conditions. With an increase in helix diameter, the ultimate load increases for 0° to 30° and there is no significant change from 45° to 80°.

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CONCLUSION

In conclusion, the observed relationship between load and displacement in pile foundations indicates that the displacement of the pile top increases with increasing load, initially at a slow rate and then with a higher rate of progressive displacement. Furthermore, the load-carrying capacity of the pile decreases as the load inclination angle deviates from the vertical axis and screw piles with larger helix diameters exhibited higher load-carrying capacities compared to piles with smaller helix diameters. The ultimate load of pile increases with the increase of helix diameter for load inclination of 0° to 30° and there is slight increase for load inclination of 45° to 80°.These findings emphasize the need to consider inclined loading effects and the importance of considering the helix diameter when designing screw pile foundations. It provides valuable insights for optimizing the design and implementation of screw piles to achieve the desired load-carrying capacity in various geotechnical applications.

Further analysis and research can be conducted to investigate the specific mechanisms behind the improved load-carrying capacity associated with larger helix diameters and factors influencing the observed trends in load-displacement behaviour under inclined loading. This can involve investigating the effects of different soil conditions, pile geometries, and installation techniques on the load capacity and displacement characteristics of pile foundations. Such studies would contribute to a deeper understanding of the behaviour of pile foundations and aid in the development of more accurate design methodologies and guidelines.

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Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Pooja J. Bhojani,Ravi V. Jotaniya and Dr. Nitinkumar H. Joshi. The first draft of the manuscript was written by Ravi V. Jotaniya and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability

The data and material generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

DECLARATIONS

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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