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Investigation on Pull-Out Capacity of Helical Piles in Sand

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Abstract: Helical piles are increasingly adopted where foundations must resist uplift while permitting rapid installation and immediate loading. This paper presents a laboratory investigation of the pull-out response of model helical piles installed in sand, with emphasis on helix number, embedment ratio, and soil compaction. Four 700-mm-long mild-steel model piles were examined: a plain shaft (P) and piles with one, two, and three helices (P1–P3). The shaft diameter was 15 mm, helix diameter 75 mm, helix thickness 2 mm, pitch 15 mm, and helix spacing 100 mm. Pull-out tests were performed in a 750 mm × 1000 mm × 1000 mm tank using a rope-and-pulley loading arrangement and a dial gauge of 0.02 mm resolution. The sand had a reported specific gravity of 2.54. At $H/D=2.5$ in loose sand, ultimate loads for P, P1, P2, and P3 were 2.873, 8.681, 17.238, and 20.731 kg. Increasing embedment to $H/D=3.5$ raised the corresponding capacities to 3.442, 16.105, 20.734, and 28.171 kg. Under compacted sand at $H/D=2.5$, P1–P3 reached 13.259, 39.883, and 45.535 kg. The results show that additional helices, greater embedment, and increased soil density substantially enhance uplift resistance in the tested model system.

Index Terms—helical pile, screw pile, pull-out capacity, uplift resistance, sand, embedment ratio, compaction

I. Introduction

Helical piles, also referred to as screw piles or helical anchors, consist of a central steel shaft fitted with one or more helical plates. They can transfer axial compression and tension to surrounding soil and are particularly attractive for applications in which uplift actions govern. Their response depends on soil strength and density, shaft and helix geometry, installation depth, and helix spacing. Established research on cohesionless soils shows that uplift resistance may be mobilized through helix bearing, shear between adjacent helices, and shaft resistance [1]–[5].

Design methods commonly idealize either individual helix bearing or cylindrical shear, with the controlling mechanism depending on pile geometry and soil state [6]–[8]. The source project examined these effects using four model piles in a laboratory tank. Its objectives were to quantify pull-out capacity, evaluate one to three helices, compare embedment ratios $H/D=2.5$ and 3.5, and examine the influence of compaction. The reported load unit is retained as kilograms so that the converted paper does not silently alter the original dataset.

II. Experimental Program

2.1 Sand Characterization

The test medium was clean, dry sand. Particle-size distribution was determined by sieve analysis and specific gravity by pycnometer. The reported specific gravity was 2.54. The measured percent passing values were 83.606% at 0.60 mm, 69.142% at 0.425 mm, 47.532% at 0.30 mm, 24.954% at 0.212 mm, 10.644% at 0.15 mm, and 1.992% at 0.075 mm. The resulting gradation curve is shown in Fig. 1.

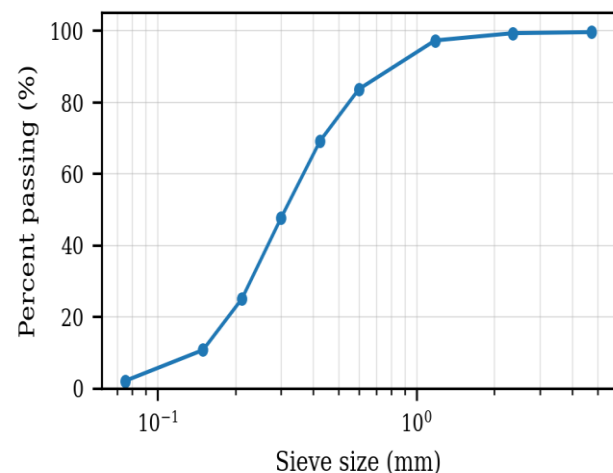


Figure 1. Particle-size distribution of the test sand.

2.2 Model Piles

The piles were fabricated from solid mild-steel rods with welded helical plates. Total length was 700 mm, shaft diameter 15 mm, helix diameter 75 mm, helix thickness 2 mm, and helix pitch 15 mm. Four configurations were used: P without a helix, P1 with one helix, P2 with two helices, and P3 with three helices. Multi-helix specimens used a reported helix spacing of 100 mm. The model geometries are shown in Fig. 2.

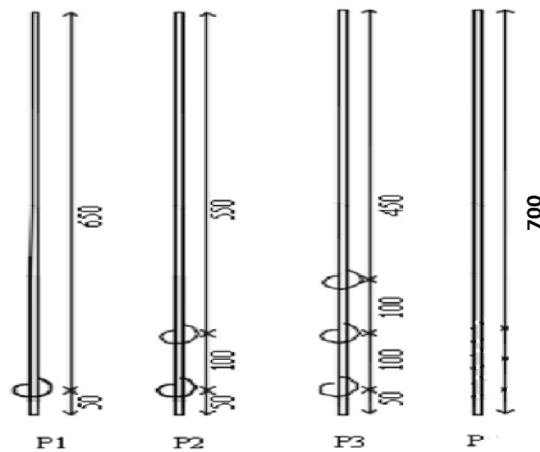


Figure 2. Model pile geometries (P, P1, P2, and P3).

Table 1: Model Pile And Test Parameters

Parameter	P	P1	P2	P3
No. of helices	0	1	2	3
Shaft dia. (mm)	15	15	15	15
Helix dia. (mm)	-	75	75	75
Thickness (mm)	-	2	2	2
Pitch (mm)	-	15	15	15
Helix spacing (mm)	-	-	100	100
Pile length (mm)	700	700	700	700

2.3 Tank and Loading Arrangement

The iron test tank measured 750 mm × 1000 mm × 1000 mm. A steel wire rope connected the pile head to a load hanger through a two-pulley arrangement. Load was increased incrementally until pull-out, while vertical displacement was monitored with a dial gauge of 0.02 mm resolution. The methodology states that each increment was maintained until displacement stabilized before the next increment. The setup is shown in Fig. 3.



Figure 3. Laboratory pull-out test tank and loading arrangement.

Loose-sand tests were performed at $H/D=2.5$ and 3.5 , where H denotes embedment depth and D the helix diameter. A further series at $H/D=2.5$ was conducted after compaction. For each

condition, the ultimate capacity was the applied load at which the pile was reported to pull out of the soil bed.

III. Results and Discussion

3.1 Effect of Number of Helices at $H/D=2.5$

In loose sand at $H/D=2.5$, the plain pile P reached 2.873 kg. $P1$ reached 8.681 kg, about 3.02 times the baseline; $P2$ reached 17.238 kg, approximately six times the baseline; and $P3$ reached 20.731 kg, about 7.21 times the baseline. Thus, additional helices consistently increased pull-out resistance. The incremental gain from $P2$ to $P3$ was smaller than that from $P1$ to $P2$, showing that capacity did not increase linearly with helix count in this configuration. This trend agrees qualitatively with bearing and shear interpretations reported for helical anchors in sand [1], [2], [6].

3.2 Effect of Embedment Ratio

At $H/D=3.5$, the ultimate capacities of P , $P1$, $P2$, and $P3$ were 3.442, 16.105, 20.734, and 28.171 kg. Relative to loose sand at $H/D=2.5$, the increases were approximately 19.8%, 85.5%, 20.3%, and 35.9%, respectively. The largest proportional embedment benefit occurred for $P1$. For $P3$, increasing H/D from 2.5 to 3.5 raised capacity from 20.731 to 28.171 kg. Greater embedment increases confinement and the soil mass involved during upward movement; earlier investigations likewise identify installation depth as an important control on uplift capacity [2], [4].

3.3 Effect of Compaction

The compacted-sand series at $H/D=2.5$ produced 2.873 kg for P , 13.259 kg for $P1$, 39.883 kg for $P2$, and 45.535 kg for $P3$. Relative to loose sand at the same embedment ratio, $P1$ increased by 52.7%, $P2$ by 131.4%, and $P3$ by 119.6%. The unchanged value reported for P is retained exactly from the project dataset. For the compacted condition, $P1$, $P2$, and $P3$ provided approximately 4.6, 13.88, and 15.85 times the plain-pile capacity. The large gains for $P2$ and $P3$ indicate that denser sand can allow multiple helices to mobilize substantially greater uplift resistance [5], [7], [8].

Table 2: Ultimate Pull-Out Capacities Reported in The Tests

Pile	$H/D=2.5$ loose (kg)	$H/D=3.5$ loose (kg)	$H/D=2.5$ compacted (kg)
P	2.873	3.442	2.873
P1	8.681	16.105	13.259
P2	17.238	20.734	39.883
P3	20.731	28.171	45.535

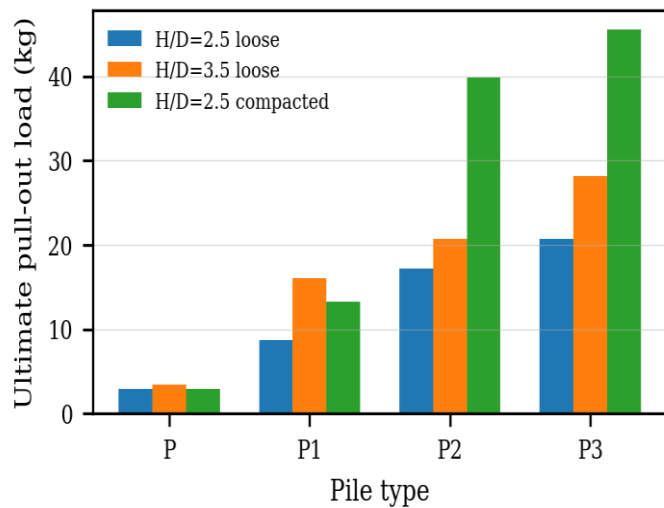


Figure 4. Ultimate pull-out capacity under the three reported conditions.

The combined comparison shows that P3 developed the largest ultimate load under every test condition. Increasing embedment improved all four piles in loose sand, while compaction at $H/D=2.5$ produced the most pronounced gains for P2 and P3. The data therefore indicate that helix number, embedment, and soil state should be considered together rather than as independent design variables.

3.4 Load–Displacement Response at $H/D=2.5$

The recorded load–displacement curves provide an additional view of pile performance in loose sand. At an applied load close to 2.87 kg, the plain pile had reached about 2.31 mm displacement, P1 about 1.45 mm, P2 about 0.25 mm, and P3 about 0.13 mm. Thus, in the low-to-intermediate loading range common to all specimens, increasing helix number reduced vertical movement markedly. P2 continued to 15.825 kg with 5.09 mm displacement before the reported failure at 17.238 kg. P3 recorded 3.25 mm at 18.929 kg before the reported failure load of 20.731 kg. P1 reached 8.25 mm at 8.681 kg.

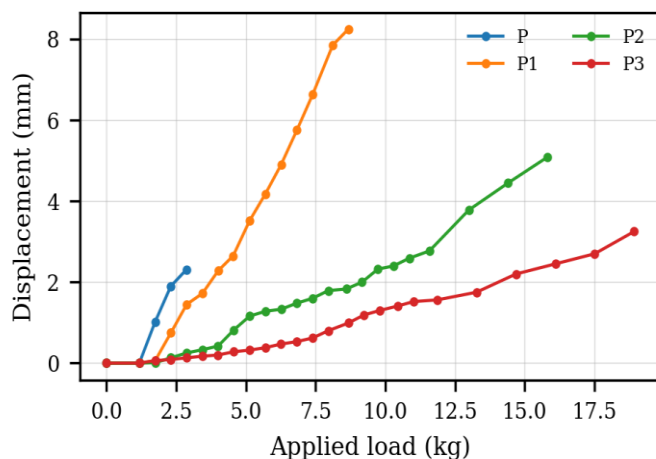


Figure 5. Load–displacement response at $H/D=2.5$ in loose sand.

The curves show that the influence of helices is visible not only in ultimate capacity but also in deformation response. The double- and triple-helix piles remained substantially stiffer than the plain

and single-helix specimens over the shared loading range. Because the project data identify failure as pull-out from the soil bed and do not report post-failure displacement for P2 and P3, Fig. 5 plots only the measured displacement points available before failure.

3.5 Practical Implications of the Test Trends

For the tested model geometry, the data demonstrate that increasing the number of helices was the most direct means of raising uplift resistance, but its benefit depended strongly on the state of the sand. In loose sand at $H/D=2.5$, moving from two to three helices increased capacity from 17.238 to 20.731 kg, whereas after compaction the corresponding increase was from 39.883 to 45.535 kg. This shows that the contribution of an additional helix cannot be treated as a fixed increment independent of soil condition. The designer must consider the ability of the surrounding soil to mobilize resistance around each plate.

Embedment produced a second clear effect. The triple-helix pile increased from 20.731 kg at $H/D=2.5$ to 28.171 kg at $H/D=3.5$ in loose sand, while the single-helix pile showed an even larger proportional increase. In practical terms, this suggests that a deeper installation can improve uplift performance when geometric or site constraints limit helix diameter or helix count. Compaction, where feasible in a model or engineered fill, had the strongest effect on the multi-helix piles. These comparisons reinforce that pile geometry and soil state should be selected together rather than optimized separately.

3.6 Engineering Interpretation and Limitations

The investigation is a model-scale study with a fixed 75-mm helix diameter and 15-mm shaft. Tank boundaries, preparation method, and scale can influence measured behavior. Installation torque was not reported, so a torque-capacity correlation cannot be established. The results are therefore most reliable as comparative laboratory trends. Future work should include controlled relative density measurements, repeated tests, additional helix spacings, instrumented load transfer, and prototype-scale validation.

IV. Conclusion

The laboratory results demonstrate that helical plates substantially improve uplift resistance in sand. In loose sand at $H/D=2.5$, capacity increased from 2.873 kg for the plain shaft to 20.731 kg for P3. At $H/D=3.5$, P3 reached 28.171 kg. Under compacted sand at $H/D=2.5$, P3 reached 45.535 kg, with especially large gains also observed for P2. The results show that helix number, embedment depth, and soil compaction act together to control pull-out capacity. Prototype design should additionally account for installation effects, scale, and site-specific soil properties.

V. References

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