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論文の内容の要旨

A screw pile is one of the old piling systems that have regained its importance due to the development in hydraulic motors. These piles have edge over other steel pile systems due to its quick installation mechanism, high end bearing, uplift and lateral resistance, noise reduction and minimum involvement of man power during pile installation. Its use is increasing rapidly as a foundation for transmission towers, elevators, buildings and many other civil structures. Generally, it consists of cylindrical steel shaft with one or more helices at various length of the shaft. They are usually considered as end bearing piles because pile tip holds majority of the structural load. (Pile tip includes helix and tip of central shaft).

It is always desirable to utilize the maximum available bearing capacity of the ground through any type of piling system. However, the available ground capacity is often reduced due to soil disturbance during pile installation or deformation of the pile itself. Similarly, like other piling systems, screw piles can also disturb the ground conditions and reduce the bearing capacity of the ground if torque and pushing force is not properly monitored and controlled. However, end-bearing capacity still can be reduced even if the installation of screw pile is done properly without any serious soil disturbance or pile deformation. This reduction in bearing capacity of the ground is due to the bending deflection of helix during the loading phase. Therefore, larger ratios of helix to shaft diameters are usually discouraged by the engineers to overcome helix bending.

In this study, the effect of helix bending deflection on load settlement behaviour in dense sand was investigated to estimate the critical helix bending deflection (helix bending deflection beyond which it starts affecting the load settlement behaviour). The effect of increasing stress level (overburden pressure) on load settlement behaviour and critical helix bending deflection was also considered. This study also investigated the effectiveness of simple extrapolation methods such as Chin-Kondner and Decourt to estimate the ultimate screw pile capacity, when the available load test data is limited (not up to failure). The comparison of end bearing capacity of screw and straight pipe piles under similar pile tip area and ground conditions were also studied in this research. The effect of increasing overburden pressure on the end bearing capacity of screw and straight pipe piles was also considered in this study.

Model scale of pile load testing was used to achieve the set objectives. A cylindrical steel container was used to prepare the model ground. The size of the container was according to the previous studies to avoid any boundary effect on the pile load test results. Pressure transducers were also fixed on the wall and floor of the container to measure the boundary pressure during the pile load test. Model screw pile having single helix and closed shaft end was used in this study. The helices were modeled as a flat circular plate with silt so that helices with various diameters (43, 55, 60 and 89 mm) can be used with the central shaft (21.7 mm). Close-ended straight pipe piles (21.7, 43, 60 and 89 mm) were also used to compare the end bearing capacity with the screw pile having similar pile tip area. The material of the model piles was according to STK400 and SS400 steel standards.

Dry Toyoura sand was used to develop the model ground. The soil was compacted in 6 layers, each having a thickness of 100 mm. The relative density of the ground was set around 70, 80 and 92 %. The model piles were placed after the compaction up to the 4th layer. The remaining two layers were compacted around the pile. Four rubber tubes with different diameters were used to simulate the effect of stress level (overburden) on the surface of model ground. The tubes were covered with circular steel plate, which was clamped with container so that the supplied air pressure in the tubes directly transferred to the surface of the model ground.

The experimental results indicated that if the bending deflection of helix is more than critical helix bending deflection it will start affecting the load settlement behaviour and will reduce the available bearing capacity of the ground. The range of estimated critical helix bending deflection based on experimental results is 0.41 – 1.2 mm (with and without the effect of increasing stress level). It is also observed that the downward movement of the central shaft has a direct relationship with the bending deflection of the helix and it is due to the fixed boundary condition at the outer edge of the helix. It is presumed that the change in load settlement behaviour and reduction of ultimate end bearing capacity is due to radial outward movement of the soil as the central shaft of the screw pile moves downward. An equation is proposed based on the critical helix bending deflection (bending deflection of helix that has no effect on the load settlement behavior) to estimate the critical thickness of helix with respect to ground strength.

The prediction analysis of simple extrapolation methods (Chin-Kondner and Decourt) indicated that both methods overestimate the ultimate pile capacity at plunging resistance state. However, the prediction analysis showed better agreement with the load test data if the ultimate pile capacity is selected from the predicted model curve at settlement equals to 10% of helix plate diameter (indicates full mobilization of end bearing). Therefore, it is better to consider the ultimate end bearing capacity at settlement equals to 10% of helix diameter from the model curve if limited load test data is available. A reduction factor based on pile load test results in dense fine sand is proposed to control the over prediction of Chin-Kondner and Decourt methods at settlement equals to 10 % of helix diameter. It is also observed that the Decourt method of plotting can indicate the helix plate deformation during the pile load test that affects the ultimate pile capacity of the ground. It is observed from the test results that the straight-line portion transformed to convex downward curve as the deformation of the helix plate start affecting the load settlement behavior of the ground. The helix plate limit load that affects the load settlement behaviour can be estimated if tangents are plotted on the convex downward curve.

The comparison of end bearing capacity of screw pile with straight pipe pile under similar pile tip area and ground conditions showed that the screw pile end bearing capacity is 16.25 % average (with and without the effect of increasing stress level) less. Based on the test results in dense fine sand, shape reduction factor is proposed for the estimation of the end bearing capacity of screw pile. However, the screw piles having helix to shaft diameter ratio of 2 – 4.1 showed 2.5 – 12 times higher end bearing capacity than straight pipe piles with similar pile shaft diameter. It is also observed, in case of straight pile, the load settlement curve plunges downward without increase in load around settlement equals to 10% of pile tip diameter (D_s), whereas, in case of screw pile the load settlement curve plunges around settlement equals to 15% of pile tip diameter (D_H).

論文の審査結果の要旨

羽根付き杭は軸の先端に螺旋状の羽根を付けた杭を回転貫入させるもので、少ない鋼材量で高い支持力が期待できる。この形式の杭は以前から存在していたが、油圧モーターの開発とともに普及が進んだ。貫入速度の向上、高い支持力、引抜き力及び横方向力への高い抵抗性、騒音の軽減、省力化、など多くの利点が挙げられる。通常は杭軸と羽根部の先端支持力を最も期待する。本論文は、密な砂地盤中の羽根付き杭の荷重沈下挙動に羽根の曲げ変形が及ぼす影響について、室内試験及び解析を通して検討を行っている。

本論文は、研究成果を８章に分けて記述している。

第１章では、羽根付き杭について、その概要を述べるとともに、羽根変形が荷重～沈下関係に及ぼす影響を調べる、簡易な外挿法を用いて羽根変形の有無を検討する、太さが一様な直杭と羽根付き杭の支持力特性を比較する、など研究目的を述べている。

第２章では、羽根付き杭の歴史、挿入メカニズムや支持力・引抜き抵抗などの挙動に関するこれまでの知見、支持力が発揮されるメカニズム、支持力に関する提案式、などの既往の研究について述べている。

第３章では、模型杭、試験土槽、地盤材料、計測システム、上載圧載荷システム、などの試験装置や試験手順を説明している。

第４章では、密な砂地盤における羽根付き杭の種々の載荷試験から得られた荷重～沈下関係に及ぼす羽根変形の影響について検討し、羽根変形が 0.4 ～ 0.8mm を超えると支持力特性に大きく影響を与えることを示している。羽根径や羽根厚を変えた実験結果から得られた荷重～沈下関係を比較し、さらに双曲線関数近似における Chin-Kondner の方法と Decourt の方法を比較検討し、後者の方が羽根変形の影響を的確に捉えることができることを示すとともに、羽根変形を生じる限界荷重の評価法を提案している。また、実際の現場では載荷能力の限界などから、直接的に支持力値を求めることが難しいことから、羽根径の 2.5%から 15%までの数段階の沈下量まで載荷試験が行われたと仮定した上で、Chin-Kondner の方法と Decourt の方法を用いて極限支持力を推定した上で模型実験により得られた値と比較し、使用可能なデータ範囲に応じた低減係数を提案している。さらに、羽根と杭軸や羽根周辺部との境界条件を種々仮定した Roak の解析解と実験結果を比較し、適切な境界条件を提案している。さらに羽根変形量の実測値と解析値を比較し、荷重～沈下関係に影響を及ぼす羽根変形を生じる羽根厚と羽根径（支持力）の境界を解析的に求め、実験結果と適切に対応していることを示した。

第５章では、羽根付き杭の荷重～沈下関係に上載荷重が及ぼす影響について検討している。模型地盤の表面にゴム袋を設置し、空気圧により上載圧を載荷できるように装置の改良を行った。最初に地盤厚を段階的に変えて土槽底面に作用する土圧を計測することで、土槽側壁の摩擦の影響を検討し、杭先端部に作用する鉛直圧を適切に評価した。然る後に上載圧を種々変化させ、載荷試験を行った。上載圧が載荷された場合についても、第４章と同様な検討を行い、羽根変形の荷重～沈下曲線への影響、影響を与える限界羽根厚の評価が、上載圧の無い場合と同様に適切に行えることを示した。

第６章では、羽根付き杭の支持力特性を、羽根を有さず先端まで太さが一定である直杭と比較している。直杭の荷重～沈下曲線は羽根付き杭のものとほぼ同様な形を示すが、当然のことながら羽根変形の影響は受けない。両者の極限支持力は先端部面積にほぼ比例して増加し、地盤密度によらず羽根付き杭の支持力は直杭の約 83.5%となった。

第７章では、羽根付き杭と直杭の支持力特性に及ぼす上載圧の影響を検討している。第６章と同様の実験条件で上載圧を変えた場合も、羽根付き杭の支持力は直杭の約 83.7%となり、上載圧の影響は非常に小さかっ

た。従って、密な砂地盤における羽根付き杭の支持力式は、同様な条件の直杭について提案されている試機に対し、0.835という補正係数を掛けることで得られることが示された。

第８章では、本研究により得られた結論を述べている。

本研究では、これまで実務ではかなり用いられているものの、あまり系統的に研究が行われてこなかった羽根付き杭の支持力特性について、精密な室内試験により羽根変形の影響、地盤密度、上載荷重の影響を緻密に調べるとともに、解析解についても検討し、羽根変形の影響を生じさせない条件などを示している。さらに直杭との比較を通し、極限支持力式の補正法を提案している。その点で、研究の独創性、新規性、発展性が大きい。また、結論に至る種々の検討における厳密性も高く評価される。それらの点を総合的に判断して、博士の学位論文として合格と判定した。