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Performance of single vertical helical anchor embedded in dry sand

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ABSTRACT

An investigation into the uplift behavior of single vertical helical anchor embedded in dry sand presented. A series of laboratory tests have been conducted to determine the effect of the embedment ratio, shaft diameter ratio and sand density against the uplift capacity of helical anchor. The laboratory tests were conducted in a small scale model in loose and dense sand. A sand placement technique was utilized over the testing program to achieve the predetermined depth. In this testing program, the uplift load and uplift displacement have measured. The observation of failure mechanism and the measurement of pullout load and the vertical displacement analyzed and discussed. A number of graphs will be plot between the uplift capacity and the factors to obtain their relationships. From the analysis, the uplift capacity is increase with the increase of embedment ratio and sand density however the shaft diameter ratio is not significantly influent to the uplift capacity. In the observation of failure mechanism, the failure surface proposed for the helical anchor embedded in loose and dense sand. For loose sand package, local failure surface observed however for dense sand package, a truncated cone shape failure surface was observed. From the analysis, an empirical model was proposed. The proposed empirical model compared with the experiment result and existing theories to verify the validity of the empirical model.

1. Introduction

Slim high-rise structures such as the electric transmission tower, telecommunication tower, street lamp have always being subjected by a high lateral forces especially from wind load. This lateral load will generate an overturning force to rotate the foundation and affect the stability of structures. During slim high-rise structure failure, the overturning force always higher than the weight of the structure. Therefore, the lateral loading is the major factor that must be considered during design. In the design for the slim high-rise structures, the traditional method is by using the massive foundation to resist the overturning forces due to wind load. However, it is very heavy, large and expensive to construct, which not effective in terms of cost and time. To overcome the problem, Engineers have recommended a new construction method by using ground anchor systems to enhance the structure stability. Over the years, many types of anchor have been developed and used in the construction of slim high-rise structure. Helical anchor is one of the anchor that is always used in this type of construction. Helical anchor consist of some steel shafts with a series of helical steel plates welded on a pitch. During installation, helical anchor was screwed into the ground by using a standard truck or trailer mounted augering equipment. The equipment will apply a rotating moment to the steel shafts to screw the anchors into ground. The torque resistance of the anchor will be monitoring along the installation. When the torque resistance achieved its designed values, it verified the capacity of anchor achieved. It was thought that the working helical anchor can provide compression and uplift resistance of foundation between 100 kN and 400 kN depending on size of helixes, number of helix and the type of soils

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encountered. Therefore, when the friction angle of soil, size and number of helix increases, the capacity of uplift and compression will also increase. Helical anchor system is a cost, time effective system for the foundation of slim high-rise structure because this system can be installed rapidly, with immediate anchor capacity verification and easily installed. Currently the helical anchor system is not widely used as foundation in construction industry and just limited for a transmission tower and pipelines. This is due to the lacking of a rational and reliable analytical technique to carry out its uplift behavior and failure mechanism. Many theories have been developed to describe the uplift behavior and failure mode of helical anchor. Inevitably, there are many variations among the theories due to different assumption adopted. To produce an effective design which with respect to cost and time, the verification of these design methods and a further understanding of the uplift behavior of failure mechanism of helical anchor in sand are needed.

2. Early background history of helical anchor

The earliest usage history of helical anchor was applied by a blind English brick maker names Alexander Mitchell. In 1833, he use the helical anchor to design a foundation support for a lighthouse. This concept of "screw pile" was very successful in the design application but the development of helical plate foundation was not in further progress [1]. Until 1950s, a power-installed screw anchor for resisting tension load was used in United States and this type of anchor begins its popularity and widely used in construction site. The helical anchor was formed by a steel shaft where one or more helical plates welded to the shaft to create a "screw anchor". Helical anchors are primarily designed and constructed to provide the uplift resistance to the foundation of a structure. However, helical anchor system can also provide the compression support to the structure. Generally, helical anchor can be dividing to two types namely single helix anchor and multi helix anchor. Mitsch and Clemence [6] proposed a semi empirical solution to predict the ultimate uplift capacity of multi helical anchor in sand. They introduced values for coefficient of lateral earth pressure as a function of embedded ratio, H/D and relative density. Their values were 30–40% less in comparison with those proposed by [5]. They indicated that the reduction is due to shearing disturbance of the soil during anchor installation. Clemence and Pepe [2] studied the effect of installation and pullout of multi helix anchors to lateral stress in the sand layer. The values of lateral earth pressure were measured before and after the installation of anchor continuously during the application of the uplift loads until it failed. From the test, it was indicated that the installation of helical anchors in dry sand causes an increase in lateral earth pressure around the anchor and the pressure was significantly increase in dense sand. They concluded that the increase of lateral earth pressure was due to the relative density of sand and the embedment ratio (H/D_h). Ghaly and Hanna [4] finding shows that there are three components mainly contribute to the uplift capacity of shallow anchor, which are the selfweight of anchor, weight of sand within the failure surface and the friction along the failure surface. From the experiment result, a theoretical model was developed by using the limit equilibrium technique and Kotter's differential equation. In this model, they assume the failure surface to be a log-spiral shape. In their model, the complexity of model has been reduced by developing the weight and shear factors for shallow and deep anchors. The uplift capacity of helical anchors in sand have been studied by numerous researchers such as Mitsch and Clemence [6] and Ghaly et al. [3] although some researchers such as [7,8] evaluated the uplift capacity of shallow horizontal strip anchor in cohesionless soils. Mitsch and Clemence [6] have proposed a semi empirical solution to predict the ultimate uplift capacity for multi helical anchor in sand. Based on Laboratory and Field Tests, they have recommended the bearing resistance of top helix, frictional cylindrical resistance and friction on the anchor's shaft for a multi helical anchor. Based on laboratory tests, Ghaly et al. [3] suggested a similar solution with the Mitsch and Clemence [6] for the pullout resistance of single helical anchors in sand. Nevertheless, in their solution, the effect of friction of anchor's shaft in the uplift resistance has been ignored.

3. Test program

Verification of the previous theories with a series of modelling in laboratory will be highlighted in this paper. Through the laboratory test, the failure mechanism and uplift behavior of helical anchor in sand can be carry out to produce a better reference in the designing the helical anchor system in sand. Results analyzed will be focus on the physical modelling in the laboratory. Four major variables have been focused for a small model of helical anchor tested in laboratory. The sand used in the laboratory test is in dry condition; single helical anchor will be used to studied and tested in the work; limited to vertical pullout capacity of single helical anchor only; the study is limited to the shallow embedment ratio between 1 and 5. In this laboratory test, the main parameters such as embedment ratio and relative density will tested to obtain the effects and relationships to the uplift capacity of helical anchor in sand.

4. Physical modelling uplift test set-up

In this experimental work, both full and a half-cut model of single pitch helical anchor will be prepared. The dimensions of the anchor's shaft diameter ranged between 300 mm and 500 mm with helical diameter of 100 mm as shown in Figs. 1 and 2.

Pullout test will be conducted in a bigger glass container with dimension length 650 mm, 650 mm width and 1000 mm depth. The glass frame was build using steel angle 50 mm × 50 mm × 6 mm and placed using C channel at a height of 250 mm above floor level to avoid any humidity transfer from the base. An electrical motor gearing is placed on the top of the frame. The pulling arm, the load cell and Linear Variable Displacement Transducer