EVALUATION OF FAILURE MECHANISM OF PILE UNDER PULLOUT TEST IN LOOSE SAND BY PIV METHOD

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A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Geotechnics)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2013

This work is dedicated to my beloved father and mother

ACKNOWLEDGEMENT

I wish to express my sincere appreciation to my thesis supervisor, Assoc. Prof. Ir. Dr. Ramli Nazir, and my thesis Co-supervisor, Dr.Ahmad Safuan Bin A.Rashid for encouragement, guidance and constructive critics conveyed to me in preparing this thesis. Without them continued support and interest, this thesis would not have been the same as presented here.

My sincere appreciation also extends to all my friends who have provided assistance during experimental set-up. I cannot even start the tests without their help. Their opinions and advices are useful indeed. I am grateful to all my family members for their endless supports.

ABSTRACT

In order to ensure safe design of structures we need to study on behavior of structure's components before and after failing. Consequences effects of failing are important in some structural cases. For instance, piles as a member of structures can be failed because of structural collapses or soil's body failure. Extensive experimental investigations have been carried out to study the behavior of failure mechanism of piles in sand subjected to axial compressive, inclined, or lateral loads. However, studies regarding piles subjected to uplift load are limited. This study reports a series of small scale physical modeling test designed to investigate the uplift resistance of piles with diameter of 5cm and with slenderness ratio L/D=1,2,3 and 4 in loose sand with unit weight of 14.2 kN/m^2. A close photogrammetric technique and Particle Image Velocimetry (PIV) were employed to observe the failure patterns due to uplift force on pre formed concrete piles with a different slenderness ratio. The results from the laboratory tests were verified with a Finite Element Method software (PLAXIS 2D and 3D) and analytical method proposed by B. C. Chattopadhyay1et.al (1986). It was found that, the depth of the failure surface increases with the increase of the slenderness ratio. An acceptable agreement has been observed between the measured and predicted values of uplift capacities (PLAXIS 2D and 3D).

ABSTRAK

Untuk memastikan rekabentuk struktur dalam keadaan selamat, kita perlu mengetahui sifat komponen struktur sebelum dan selepas struktur gagal. Kesan akibat kegagalan amat penting dalam sesuatu kes struktur. Sebagai contoh, cerucuk merupakan anggota struktur yang gagal disebabkan rutuhnya struktur ataupun kegagalan dalam tanah itu sendiri. Pelbagai ujian telah dilaksanakan untuk mengetahui sifat kegagalan cerucuk di dalam pasir, dibawah pengaruh daya mampatan, bersudut ataupun tekanan sisi. Bagaimanapun, kajian berdasarkan cerucuk di bawah pengaruh daya terangkat sangat terhad. Kajian ini mengenai beberapa model berskala kecil diuji untuk menyiasat pengaruh tekanan rintangan terangkat di dalam tanah pasir. Kaedah fotogramatrik dan Gambaran Isipadu Zarah (PIV) digunakan untuk menyelidik paten kegagalan di bawah pengaruh daya terangkat pada pra pembetukan cerucuk konkrit dengan pelbagai nisbah kelangsingan. Keputusan daripada ujian makmal kemudiannya disahkan dengan perisan komputer kaedah Elemen Tak Terhingga (PLAXIS 2D and 3D) dan kaedah analisis yang dicadangkan oleh B.C. Chattopadhyayl dan et al (1986). Didapati bahawa, kedalaman kegagalan permukaan meningkat dengan peningkatan nisbah kelangsingan. Keputusan ujian di mamal menunjukan nilai yang hampir sama dan boleh diterima pakai dengan nilai kapasiti daya terangkat ramalan (PLAXIS 2D dan 3D).

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LIST OF ABBREVIATIONS

PIV	Particle Image Velocimetry
FEM	Finite Element Method

LIST OF SYMBOLS

L	Embedment Depth of Pile
D	Pile Diameter
γ	Unit Weight of Soil
ϕ	Angle of Friction of Soil
ψ	Dilatancy Angle
T_{ug}	Gross Uplift Capacity
T_{un}	Net Uplift Capacity
W	Effective weight of Pile
P_{av}	Average Skin Friction
K_s	Coefficient of Earth Pressure

δ	Pile Friction Angle
λ	Slenderness Ratio of Pile
I_D	Relative Density of Sand
D_{50}	Average Particle Size
σ_V'	Effective Vertical Stress at Depth Z
x	Extent of Failure Surface from Center of Pile

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Long and slender members are the components of structure called pile foundations, used to transfer structure load through unstable ground to a solid stratum. They are also used in action to resist uplift forces or in poor soil condition to resist lateral forces. Piles may be found in variety sizes and shapes. Most are constructed out of different material but most of them made from wood, steel and concrete. Piles are generally driven into the ground in situ; other deep foundations are typically put in place using excavation and drilling.

Pile foundations generally act as compressive loads in superstructure by transferring loads through the lower bearing capacity to deeper soil or rock with high bearing capacity, but action from horizontal forces on the structures and the behavior of piles under these loads are much less well documented. Some structures such as tall chimneys, transmission towers and jetty structures are subjected to overturning loads imposed by wind. In such cases, piles are required to resist uplift forces which are much greater than the weight of the structure itself.

Two major sources raise pullout capacity, skin friction between pile and soil and suction generated at the base of the piles as movement occurs. The gross uplift resistance of the pile subjected to uplift forces shown in Figure 1.1.

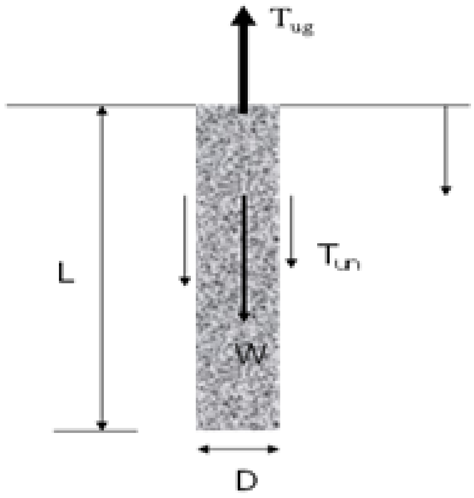

Figure 1.1: Pile subjected to uplift forces

$T_{ug} = T_{un} + W$

Where

T_{ug} : Gross uplift capacity
T_{un} : Net uplift capacity
W : Effective weight of pile

The uplift capacity of a buried concrete pile essentially come from the weight of soil within the failure zone and skin friction between pile and soil.

Interpretation of the load test results rely on predicting the failure load or limit load by applying mathematical or graphical techniques is important in geotechnical engineering field in order to applying a proper factor of safety to get the pile working load. Hence, it is important to determine the ultimate or limit load as accurately as possible, so reliable assessment of soil behavior in element tests or physical models requires accurate measurement of deformation and strains.

Figure 1.2. presents the strain ranges typically experienced during a variety of geotechnical processes.

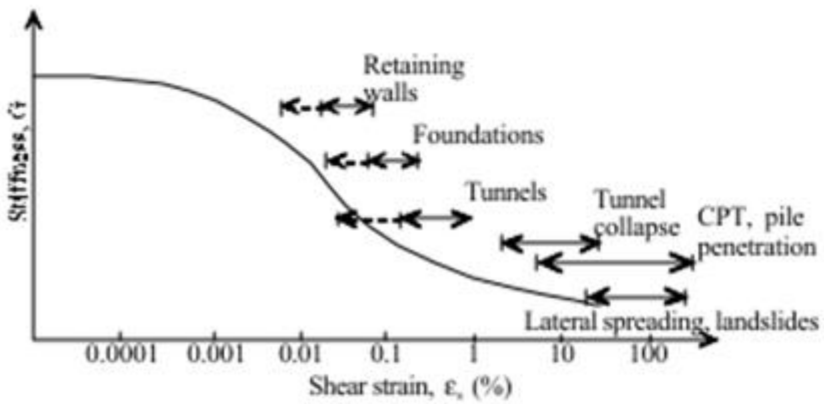

Figure 1.2: Typical strain ranges in geotechnics (after Mair, 1993)

Regarding to above figure, if element tests and physical models are to capture the relevant behaviour, they must be equipped with a deformation measurement system which can detect pre-failure strains of the order of 0.01%. In a typical element test, this strain level corresponds to a displacement of 5 µ m.

Uplift resistance of a circular vertical pile embedded in sand can be evaluated by determination of failure zone. For evaluation of failure mechanism in this case deformation shape should be visualized.

Observation of Pile-Soil Interaction during Cyclic Axial Loading or displacement and load controlled under lateral loading using PIV studied by many researchers. However, studies regarding the influence of slenderness ratio of concrete pile on the failure mechanism in sand by PIV are limited.

The uplift capacity of a buried pile essentially comes from the weight of soil within the failure zone above the base, the frictional resistance along the failure surface and the self-weight of the foundation. The required pullout resistance can be achieved by increasing sand density, diameter of pile and the depth of embedment. The influence of slenderness ratio on the failure mechanism of soil has been investigated by PIV in this research.

The testing described in this research extents this work by considering circle concrete pile with 4 different ratio (1,2,3,4,). The testing was carried out in a box model based on half circle concrete pile to comparing the results.

Furthermore plane strain and axisymmetric packages are most commonly used in analytical modeling. However here a modified axisymmetric package was required as shown schematiccaly in Figure1.3. So, the testing was carried out for 4 samples based on half circle concrete pile to comparing the results by FEM and theoretical results.

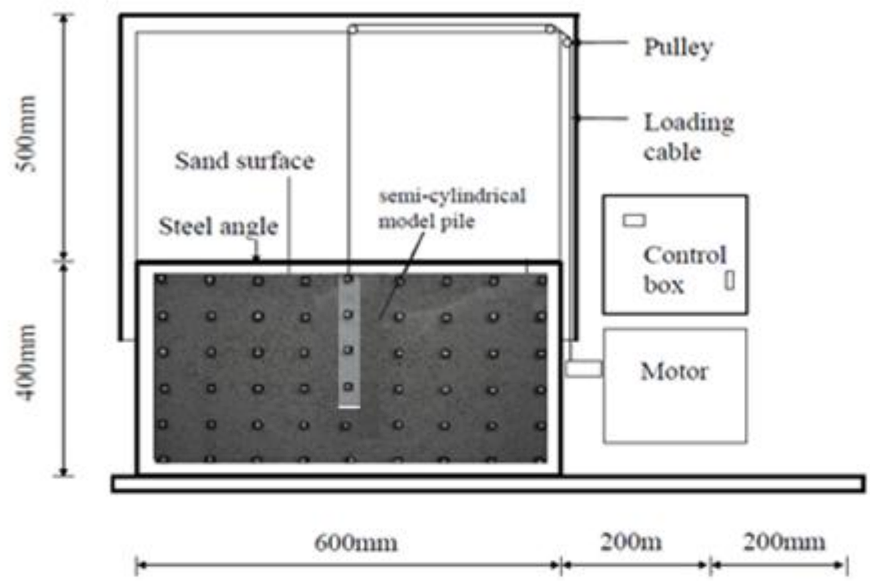

Figure 1.3: Schematic diagram for failure mechanism tests

The type of failure occurring in a laboratory specimen can be used to infer the type of failure that will occur in the field, so long as the laboratory stress path models the in-situ stress path reasonably well and the specimen is representative. When the laboratory specimen exhibits a plastic failure and no failure plane forms for the range of strain applied in the laboratory, then the stress-strain curve will show no peak for that range of strain.

In the field, a very wide failure zone would develop in a mass of such soil. Large deformations would occur in the mass and no distinct failure plane would be observed. Such failures are not catastrophic because the deformations warn of impeding failure. Also, field observations are useful for controlling construction, and one is able to use relatively low factors of safety (high working stress) in design because of the character of the failure in such cases the deformations usually control the design working stress rather than the strength. Obviously, the selection of factor of safety (or working stress) is also a function of the consequence of failure and the reliability of the test data. When a laboratory specimen fails along a narrow zone, the stress-strain curve usually shows a peak.

1.2 Problem Statement

Deep foundations with normal concrete piles are often used to support a variety of land structures such as guyed lattice towers, transmission towers, tension cables for suspension bridges and tent-type roofs and marine structures such as floating platforms, tension leg platforms and guyed towers (Weiwei Liu 2010).

These structures are often subjected to wind loading which cause pullout forces much greater than the weight of the structure itself. In addition to wind, marine structures are also hit by wave forces. Historically there have been many case histories where pile foundations have suffered either total collapse or severe damage during pull out loading. Thus, the investigation of behavior of soil around the pile is important.

Studying on behavior of soil around the pile under pullout loading can leads to prediction of failure mechanism of soils. The measurement of pre-failure strains in a physical model remains a difficult task. Displacement transducers can be placed at the boundary of a physical model, but these do not reveal the deformation pattern within the deforming soil. Also, various image techniques have historically been used for observation of failure mechanisms and preceding displacements such as, Radiography technique, Colored layers /bead-grid, Stereo-photogrammetric method, Laser speckle interferometry technique and Photoelastically sensitive glass particles, but most of the techniques referred above rely on targets (lead shot or beads) within the deforming soil, or use of an artificial material to represent the soil (White et.al, 2003). The reliance on target markers has a number of drawbacks such as, a dense grid of markers can influence the behaviour,a widely spaced grid of markers provides sparse data and markers can become obscured by soil during the course of an experiment (White et.al 2003). White et.al (2003) attempted to overcome these problems by using a novel image-based deformation measurement system based on close-range photogrammetry and PIV. So, an alternative technique for measuring the deformation of soil through a series of digitally captured images is PIV.

1.3 Aims and Objective

- To quantify the uplift resistance under different of slenderness ratio of concrete pile.
- To observe failure pattern around the concrete pile subjected to uplift in loose sand by PIV.

- To compare the uplift resistance and failure pattern with theoretical and FEM results.

1.4 Scope of Study

This research includes experimental and numerical works. The experimental work is devoted to laboratory small size model test. There are two tests that would be carried out, failure mechanism test based on circle concrete pile embedded in the center of the box test and failure mechanism test based on semicircle concrete pile embedded near glass side of box test. Failure mechanism tests for circle concrete piles are conducted to study the behavior of failure mechanism around the model pile subjected to uplift based on the different slenderness ratio. On the other hand, failure mechanism test for semi circle concrete piles are conducted to compare influence of geometric factors on the failure mechanism of piles which obtain in PLAXIS by cross section. Normal concrete piles with circle and semi circle shapes with diameter D = 50mm, and slenderness ratio, $\frac{L}{D} = 1,2,3,4$ will be tested for all test. Both tests are carried out in loose sand having dry unit weight of $14.3 kN/m^3$.

The numerical work is conducted by PLAXIS 2D and 3D to model of small scale pile based on the experimental results. Comparison is made between failure behaviour around circle pile and around semicircle pile. The results obtained from experimental and numerical of these tests will be compared with theoretical equations carried out by other researchers.

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