VISVESVARAYA TECHNOLOGICAL UNIVERSITY
"Jnana Sangama", Belgaum-590 014

A Dissertation Project Report on

"PERFORMANCE ANALYSIS OF OPEN ENDED DRIVEN PILES IN COHESIVE SOIL AND ITS PLUGGING ESTIMATION USING IMAGE ANALYSIS AND ANALYTICAL METHODS"

Submitted in partial fulfilment for the award of the degree of

BACHELOR OF ENGINEERING IN

CIVIL ENGINEERING

BY

ANIL KUMAR M	1CR17CV400
VALERIE ANITA JOSEPH	1CR16CV070
VAISHNAVI KM	1CR16CV069
VENKATESH REDDY J	1CR17CV423

Under the guidance of

Mrs. Sreelakshmi Gopalakrishnan

DEPARTMENT OF CIVIL ENGINEERING

CMR INSTITUTE OF TECHNOLOGY

ITPL MAIN ROAD BENGALURU-560 037

2019-2020

C.M.R. INSTITUTE OF TECHNOLOGY

(#32, AECS Layout, IT Park Road, Bengaluru-560 037)

Department of Civil Engineering

DECLARATION

We, Mr. Venkatesh reddy J, Ms. Vaishnavi KM, Ms. Valerie Anita Joseph , Mr. Anil Kumar M bonafide students of CMR Institute of Technology, Bangalore, hereby declare that dissertation entitled "Performance analysis of open ended driven pies in cohesive soil and its plugging estimation using Image analysis and Analytical methods" has been carried out by us under the guidance of Mrs. Sreelakshmi. G (Assistant Professor), Department of Civil Engineering, CMR Institute of Technology, Bangalore, in partial fulfilment of the requirement for the award of degree of Bachelor of Engineering in Civil Engineering of the Visvesvaraya Technological University, Belgaum during the academic year 2019-2020. The work done in this dissertation report is original and it has not been submitted for any other degree in any university.

VENKATESH REDDY J (1CR16CV423)
VAISHNAVI KM (1CR16CV069)
VALERIE ANITA JOSEPH (1CR16CV070)
ANIL KUMAR M (1CR17CV400)

ABSTRACT

The behaviour of piles under axial loading and impact loading has been challenging for engineers as the design philosophy of this system is mainly based on concepts of conventional design without giving consideration to deformation at pile soil interface surface. This is mainly due to complexity in theoretical modelling of interface region. When a small displacement (open-ended) pile is driven into the ground, a soil plug may develop within the pile during driving, which may prevent or partially restrict additional soil from entering the pile. It is known that the driving resistance and the bearing capacity of open-ended piles are governed to a large extent by this plugging effect.

Particle image velocimetry is an optical method, which helps us to track movement of particles and capture its instantaneous deformations. Recently, Image-based analysis techniques are adopted in laboratory investigation of the pile penetration process in particulate media. After image processing, the displacement field within the soil mass is obtained at different stages of the penetration or loading process that can be correlated with bearing capacity.

Analytical methods used here is ADONIS, a new software tool for computational geomechanics. ADONIS's newly developed pre- and postprocessors enable the user to set up finite element models for different type of geometries and support a wide range of material types. Employing several easy-to-use features in ADONIS such as viewing options, meshing capabilities, and dialogue windows allows engineers to create geotechnical models in a shorter amount of time and reduce the probability of making errors. The facilities included in ADONIS make the modelling process more transparent for engineers, which can significantly contribute to acceptance and utilization of the analysis program.

CONTENTS

CHAPTER 1: INTRODUCTION

1.1 General

Infrastructure sector plays an important role in growth and development of country's economy. Skyscrapers, road and rail transport system, bridges and ports forms the baseline for all services and deep foundations are essential to support such constructions. Pile foundations are generally used to transmit the loads from the superstructure into a hard stratum. To accomplish this function, piles must be designed with sufficient bearing capacity to sustain the loads from the superstructures and should not undergo excessive settlement by causing structural damage. Currently, deep foundation industry provides a wide range of pile systems for different loading conditions. The piles can be large displacement piles made of solid or hollow sections with a closed end or small displacement pile with rolled steel section with an open end allowing soil infiltration during pile driving. The selection of displacement type piles depends on location and type of structure, ground conditions and durability criteria. Usually displacement piles are preferred in urban areas (where it is desired to avoid ground heave, noise and vibration), coastal areas, shallow water, and deep water or for marine structures.

1.2 Introduction to pile foundation

A driven pile usually have long and slender column like structure made of predefined material and have a predetermined shape and size. Such piles are installed by impact hammering, vibration or by pushing it into the ground to a design depth or resistance. They are classified into a) large displacement piles comprising solid-section piles or hollow-section piles with a closed end. b) Small-displacement piles with rolled steel H or I-sections, pipe or box sections having a relatively small cross-sectional area driven with an open end such that the soil enters the hollow section. (Tomlinson, 1994). Large displacement piles are generally preferred in loose cohesion less soil and develop greater shaft bearing capacities with tapered sections. Small displacement piles have been frequently used in the foundations of urban and coastal structures such as harbour terminals, long-span bridges and offshore wind power structures. The pile load carrying capacity depends on friction along pile length, end bearing resistance and soil conditions. The response of piles to loading also depends on the installation or construction methods employed.

1.3 Problem statement

Pile foundations are used to transfer loads from a superstructure, through weak, compressible strata or water onto stronger, more compact, less compressible, and stiffer soil or rock at depth. There are many examples where, the structures with pile foundations have failed. For example, Mexico city pile foundation collapse (1985), 13 storeyed building collapse in Shangai (2009), Delhi Metro pillar collapse (2009), Wilmington Bridge pile foundation settlement (2014) are some of the cases of pile foundation failures. Failure of a pile can be due to different conditions such as collapse of pile during driving itself, failure due to buckling or due to excessive settlements that surpass the serviceability criteria, shear failure of piles, tilting of piles or due to rotational failure of piles. The different loading conditions that initiate such failures are sudden loading, gradual loading and lateral loading due to wind and earthquake forces. A pile-soil interaction problem is complicated since this phenomenon is a function of pile material, pile dimensions, geometry of pile group, soil-pile interfacial friction, method of installation, end conditions, soil characteristics, plugging behaviour, location of water table and type of loading.

1.4 Objectives

Keeping in view of the above, the present research is envisaged with the following objectives.

- Develop a laboratory experimental model to investigate pile soil interaction under sustained and impact loading
- Study the deformation patterns in soil surrounding the driven piles and at the pile-soil interface using the principles of particle image velocimetry.
- Estimate and compare the bearing resistances of driven piles (both open ended and solid piles) at different in-situ densities.
- Develop modified equation to estimate the pile capacity of open ended piles by incorporating plug density, infiltration rate, plug length and pile penetration.

1.5 Summary

This section gave a brief description about circumstances under which pile foundation is adopted, types of piles, selection of suitable piles and different loading conditions that result in failure of pile foundation, followed by objectives developed for the proposed study.

1.6. Circumstances under which pile foundation is adopted :

A pile foundation is needed for the following circumstances-

- When top layers of soil are highly compressible for it to support structural loads through shallow foundations.
- Rock level is shallow enough for end bearing piles foundations provide a more economical design.
- Lateral forces are relatively prominent.
- In presence of expansive and collapsible soils at the site.
- Offshore structure
- Strong uplift forces on shallow foundations due to shallow water table can be partly transmitted to piles.
- For structures near flowing water (bridge abutments etc.) to avoid the problems due to erosion.

Pile foundation has large bearing capacity, great stability and small differential settlement compared to other foundation types. Pile foundation is widely used deep foundation for complex geologic conditions with different kinds of load conditions, especially for soft soils. Fig. 1.1 shows the pile foundation for a transmission tower.

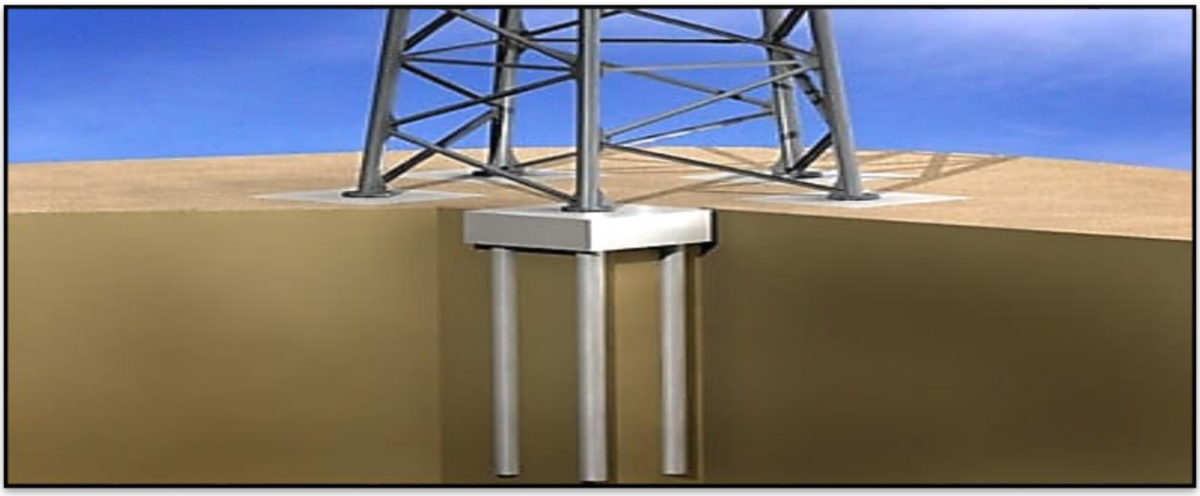

Fig 1.1. Pile foundation

Nevertheless, pile foundations may also be damaged and fail specially during earthquakes as shown in Fig 1.2. Therefore, many challenges are involved in the design and construction of pile foundations.

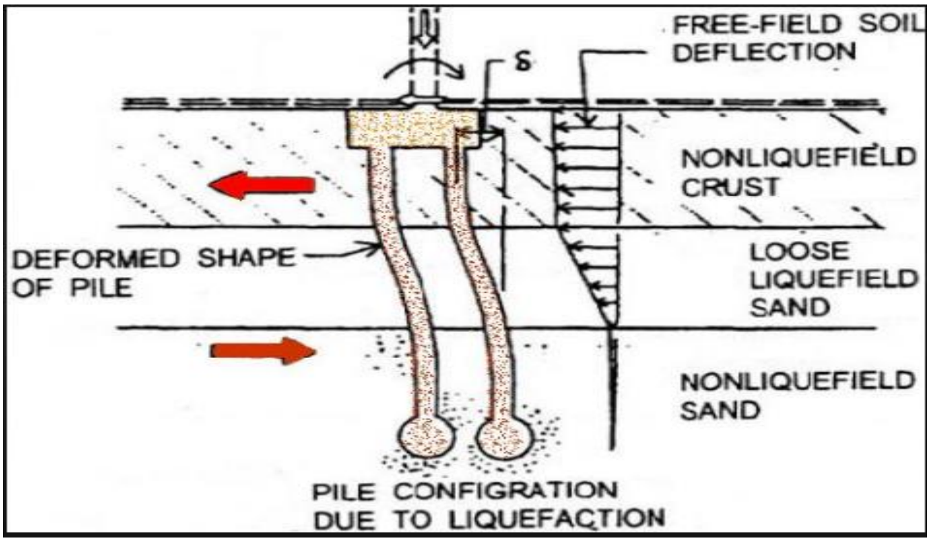

Fig 1.2. Pile foundation failure

The failure of the pile foundation may result from any of the following causes:

- Lack of adequate boring
- Inaccurate soil classification
- Soft strata under tip of pile
- Inadequate driving formula (wrong data)

- Improper size of hammer cause insufficient penetration, too light or damaged if too heavy
- Misinterpretation of load
- Damaged of encased piles
- Buckling of piles
- Breaking of piles
- Vibration that cause lateral or vertical movement
- Flowing strata caused by adjacent excavation or bank sloughing
- Tension failure of concrete pile for lack of reinforcement
- Eccentricity due to bowing or falling out of plumb
- Decay due to lower ground water level
- Insect and marine borer attack and corrosion
- Disintegration of concrete due to poor quality of concrete or reactive aggregate
- Collapse of the thin shell of the piles
- Overweight due to earth fill.

CHAPTER 2: LITERATURE SURVEY

2.1 Premeable

In this chapter a comprehensive review of literatures related to theoretical, numerical and experimental approaches developed to analyze behaviour of piles under different types of loading is explained in following sections. The outcome of the literatures is listed and has been used to derive methodology for this project. Finally the use of these concepts in the current study has been summarized at the end of each section.

2.1.1 Pile soil interaction studies

The response of frames/ buildings resting on pile foundations is dependent upon pile-soil interaction. The work on frame structures supported on pile foundations was first started by Buragohain (1977). Here the space frames resting on pile foundation were evaluated by means of stiffness matrix method in order to quantify the effect of soil-structure interaction using simplified assumptions. Since then many researchers have carried out simulation studies to perform interactive analysis on build frames resting on pile foundations (Cai, 2000; Deepa and Nandakumar, 2012; Chore et al., 2013). However main drawback of these analytical/ simulation methods is that nonlinearity of material or soil properties is not taken into account. Experimental research on model piles under controlled conditions can be used to resolve some of the important design uncertainties.

Laboratory scale model tests are always preferred in any analysis since they replicate in-situ conditions. However integrity of experimental results depends on scaling relationship between model and prototype. Experimental studies were carried out on pile groups of different materials and sizes to determine its lateral capacity, group efficiency and critical spacing of piles by few researchers *viz.*, Lemnitzer et al.(2008); Chandrasekaran et al.(2009). From the studies it has been observed that the group interaction increases the bending moment of the pile group and for a 3×3 pile group, piles in the front row experience maximum bending moment and the piles in the middle row experience the least. Ismael (2002) studied the behavior of bored pile groups (reinforced concrete piles) in cemented sand by conducting axial load tests under tension and compression loads. Test results on single pile indicated that 70% of the ultimate load was transmitted in side friction and that was uniform along the pile shafts. Also it has been reported that the load-deflection behavior of a single pile in sand under combined uplift and lateral load was non-linear (Reddy and Ayothiraman, 2015). From the experimental studies carried out on short displacement piles by Martinkus et al.(2013) it has been reported that the shear stress increased near the pile tip due to changes in state of stress in the soil adjacent to it during its installation and loading process. Though few researches has been carried out towards estimating the pile capacity under different loading conditions, the stress and displacement condition at the tip of the pile remains unexplored. Since the pile tip remains embedded in soil, novel methods and techniques are required for visualisation of the same.

Geo-PIVwas used to collect information from the images. Geo-PIV is a Mat Lab module which implements Particle Image Velocimetry (PIV) in a manner suited to geotechnical testing given by Cambridge University Engineering Department by D.J. White & W.A. Take in October 2002 . It describes the practical details of using Geo-PIV to measure displacement fields from digital images.

In the study of effect of different parameters on bearing Capacity of soil researched by
Dixit et al soil is considered by the engineer as a complex material produced by weathering of the solid rock. The bearing capacity of soil to support the load coming over its unit area is very important. There are various methods for calculation of bearing capacity of soil put forth by scientists like Prandtl, Terzaghi, Meyerhoff, Hansen, Vesic and others. With the study of effect of shape of footing on bearing capacity of soil. Similarly the effect of depth of footing on bearing capacity of soil is studied.

In the research paper, “Application of particle image velocimetry to study Pile soil interaction”. The behaviour of pile foundations under different loading conditions has been a challenge for engineers as the design philosophy of these systems are based on the principles of elastic theory and do not consider soil deformations at soil-pile interface. In this paper attempts are made to investigate soil-pile interaction through PIV (Particle image velocimetry) technique. The experimental studies are carried out in a steel tank of dimensions 450 mm × 200 mm in plan and

450 mm deep. The front side of the steel tank is made of perspex to facilitate image capture. Two half section aluminum piles of hollow and solid sections with same flexural rigidity are used in experiments. Wood's scaling law is employed to model pile dimensions. The infill material has an average size of 3.8 mm and experimental studies are carried out at a uniform density. Under axi-symmetric conditions, the piles are driven at a uniform rate and the deformations of the infill, surrounding the pile are seized using a high resolution digital camera. The images are used as inputs in Geo-PIV software, and analysis is performed using MAT LAB code to capture soil-pile interaction.

2.1.2 Estimation of bearing capacity of pile

There exists few methods for the estimation of ultimate capacity of the pile and many of the codal procedures, design hollow piles as solid piles itself and do not consider the effect of soil plugging. The ultimate capacity of the pile estimated from the modified equation is compared with the capacity of pile determined by three other methods *viz*., IS code method (IS 2911, Part 1/Sec 2, 2010), American Petroleum Institute Recommended Practice API RP 2A, and SPT based design approach. A brief overview of the different design methods is presented here.

2.1.3 Indian standard code for pile foundation design

IS 2911 (Part 1/Sec 1) (2010) followed (Meyerhof 1956) correlations of using standard penetration resistance, N in saturated cohesion less soil to estimate the ultimate load capacity of bored pile (Q_u).

2.1.4 Full scale and prototype model experimental study on single piles

Studies of the behaviour of bored pile groups in cemented sand by the field testing program in Kuwait is done. Axial load tests were carried out on single bored pile in tension and compression on two pile groups each consisting of five groups. Test results on single pile indicated that 70% of the ultimate load was transmitted in side friction that was uniform along the pile shafts. The calculated pile group efficiencies were 1.22 and 1.93 for a pile spacing of two and three diameters, respectively.

CHAPTER 3: METHODOLOGY

3.1 General

This chapter describes the methodologies that may be adopted to execute the study in order to attain the objectives.

3.2 Methodology for experimental studies carried out in stages

To understand and analyse the pile soil interaction problem, accurate simulation of pile drivability conditions is very important to predict mechanical behavior around the pile soil interface. In the experimental studies to scale the prototype scaling laws proposed by Wood et al. (2002) has been used.

The methodology proposed for the experimental study involves three stages:

1. Half section model pile tests using image analysis: This involves
    - Characterization of infill material.
    - Fabrication of steel tank in accordance with Parkin et al. (1982).
    - Image acquisition using high resolution digital camera and obtain soil deformation profiles using Geo-PIV software.
    - Assessment and comparison of pile drivability, plug density and soil plug length for different infill densities using ADONIS and Geo-PIV software.

2. Laboratory model tests on full section piles to determine the plug density: This involves
    - Sample preparation by pluviation technique.
    - Model tests to estimate density of plugged soil in the model pile.

3. Estimation of bearing capacity using different methods
    - The output from stage 2 is analysed and modified skin friction resistance is calculated by incorporating soil plug length.
    - Comparison of bearing capacity values with the different methods.

CHAPTER 4: MATERIALS AND METHODS USED IN PILOT STUDIES

4.1 Preamble

Model experiments were carried out in the laboratory to measure the pile behaviour under impact and sustained loads. Models are properly scaled down so that the response measured from the small-scale models can be used to interpret the behaviour of prototype pile foundations. Experiments were carried out on a model single pile embedded in locally available aggregates. Details of experiments conducted are discussed in the following sections.

4.2 Methodology in brief from start to end

The following brief methodology is proposed for the experimental study:

- Installation of Geo-PIV and ADONIS software.
- Collection of clay and its characterization.
- Fabrication of steel tank.
- Filling tank with infill material of uniform density.
- Selection of pile dimensions after scaling. Both hollow and solid piles under axis-symmetric conditions will be tested.
- Driving of piles by impact loading and the deformations of the infill surrounding the pile were seized using a high resolution digital camera.
- Images captured were used as an input in Geo-PIV software to study the soil-pile interaction for solid and hollow single piles for L/D ratios =10
- Perform the analysis using Geo-PIV and ADONIS software to understand the deformation patterns and stress contours under different conditions of the soil layers.

4.3 Pile Modeling criteria

Physical modeling is performed in order to study particular aspects of behavior of prototypes. However, modeling of soil structure interaction requires scale factors for structural elements (Wood's *et al* (2002)). An aluminium tube with an outer diameter of 16 mm and inner diameter of 12 mm and solid pile of 14mm diameter is selected as the model pile with a length scaling factor of 1/10.This is used to simulate the prototype pile of350-mm-diameter solid section made of reinforced concrete. The range of prototype dimensions represented by the model pile for different scale factors is calculated

Table 2: Scaling factors for pile flexure rigidity

Variable	**Length**	**Density**	**Stiffness**	**Stress**	**Strain**	**Force**
Scaling Factors	**1/10**	**1**	**1/10**	**1/10**	**1**	**$1/10^3$**

$$\frac{E_m I_m}{E_p I_p} = \frac{1}{n^5}$$

Where

E_m and E_p are the moduli of elasticity of model and prototype respectively.

I_m and I_p are the moment of inertia of model and prototype respectively.

4.3.1 Fabrication of model pile and pile cap

Aluminium pipe is cut into the required length for simulating the desired length-to diameter ratio of model pile. Chandrasekaran et. al (2010*)* proved that larger spacing of pile groups helps in increasing lateral load capacity due to the reduction in the overlap of stress zones. In the present study, pile groups are provided with a spacing of 5D (where D is the diameter of the pile) and length to diameter (L/D) ratio of 10, 15 respectively. A sufficient free standing length of 50 mm is maintained from the bottom of the pile cap to the top of the soil bed to avoid contact of pile cap with soil (Chandrasekaran et al (2010).

Gradual load is applied on the pile cap and the penetration of the pile and the deformations of the surrounding soil are captured as a video using high resolution cameras which are later converted to images. These images are used as inputs to GeoPIV software for capturing displacement profiles of founded soil.

4.4 Model pile design

Aluminium pipe is cut into the required length for simulating the desired length-diameter ratio of model pile. The pile length includes the embedment length required for a particular L/D ratio, plus a free-standing length of 50 mm for avoiding contact of the pile tip with the soil. Markings are drawn with 10 mm interval to observe plugging and penetration.

4.5 PIV Technique and its applications

In the recent years, image-based methods such as X-ray, stereo-photogrammetric techniques, digital image correlation techniques (DIC) and computer-based image processing techniques have been applied to measure planar deformation fields in element and model test studies (White et al., 2004). These techniques depend on the presence of targets within the deforming soil to serve as reference points to track the particle displacements. The displacement profiles for any application are obtained by comparing position coordinates of subsequent images. To facilitate this image capture one side of the model test tank will be made of acrylic/perspex sheet. Originally developed in the field of fluid mechanics to measure its velocity, PIV (Particle image velocimetry) is one of the DIC techniques currently used in the field of Civil Engineering. GeoPIV software is a MATLAB based tool developed by White and Take (2002) and it is based on the principles of PIV. In the recent years, many researchers have used this tool to visualize the displacement and deformation of infill materials in various geotechnical processes through digital image correlation.

White and Bolton (2004) used PIV technique to study the resistance offered by sand to the penetration of a pile in plane strain condition. The model studies carried out in a tank of 1000 mm length and 745 mm depth revealed that the image analysis technique offered sufficient precision to measure pre-failure strains and offers the flexibility to capture non-homogenous soil deformations. Tran (2005) investigated the possibility of installing suction caissons in layered deposits and used PIV technique to capture soil deformations within the caisson. Ni et al., (2010) carried out physical modelling to assess the impact of soil disturbance during augered pile installation. A vertical section aligned with the pile centreline was illuminated by a laser light sheet, and a sequence of digital images was recorded. These were analysed using particle image velocimetry, and the complete displacement distribution during the pile installation was obtained. Arshad et al. (2014) adopted image analysis technique to obtain the soil displacement field resulting from deep cone penetration test. Stanier et al., (2015) demonstrated that enhanced measurement precision improves the clarity of the interpretation of all deformation modes, including rigid-body displacements, rotations, and strains. Sreelakshmi et al., (2018) have investigated pile soil interaction behaviour on hollow and solid closed ended single pile and pile groups through image analysis. They stated that surface heave developed around hollow pile under axisymmetric loading was more in hollow pile due to lesser mass density of the same than solid piles. Motamedinia et. al.(2018) carried out DIC measurements on half-cut double-helix anchors in a sand tank. PIV analysis was used to study displacement fields developed around the piles. The failure surfaces were analysed through displacement strain fields and findings indicated that helix spacing had a significant effect on pile soil interface behaviour.

CHAPTER 5 : SOFTWARES USED

5.1 Geo-PIV- Image Analysis Tool

Geo-PIV software is used for measuring the deformation of the soil around the pile. The images captured from the experimental studies are used as inputs to Geo-PIV software and analysis is performed using MATLAB code to capture soil-pile interaction patterns. The displacement vectors and strain contours are analyzed and studied for different tests. For analyzing the image there are two methods in the Geo-PIV Software.

- Control points analysis: In the control point analysis, datasets for a new specific matrix of the XY (object space) or locations of the static control points to be used for image - object space calibration are generated. Here control points are marked on the images with the help of black marker at a spacing of 2cm.
- Mesh point analysis: In this analysis, meshes of 50× 50 pixels subsets are created in known selected area of marked tank chamber.

Since images did not have sufficient texture, (low spatial variation in brightness) calibration in the control point analysis is not possible. Hence, for the present experimental studies mesh analysis is performed where the results are shown in pixels. Experimental results are analyzed to compare the displacement vectors and strain contours for hollow and solid pile when placed individually as well as in a group. Comparison of displacement vectors and strain contours for different aspect ratio of piles are also made.

5.2 ADONIS Software

ADONIS is a free finite element program designed to perform deformation and stability analysis of geotechnical structures. It is an easy-to-use program for various geotechnical projects. It features a full graphical interface for pre-processing or post-processing and uses an automated unstructured mesh generator to create complex finite element meshes. The user-friendly interface guides the user throughout the specification of the construction phases. ADONIS supports a wide range of boundary conditions and constitutive models to simulate interactions between materials that are relevant to problems in geoengineering. An embedded scripting language in ADONIS enables the user to interact with and manipulate the models.

Free Software - ADONIS is a free two-dimensional geotechnical finite element program.
User Friendly - The graphical user interface and automatic mesh generator provide pre- and post-processing capabilities for the ADONIS.
Scriptable - Scripting allows users to create their own solutions and customizations based on the core functionality provided by ADONIS.
User Defined Constitutive Model - Users can define their own constitutive model and integrate it into ADONIS by using a dynamic-linking library (dll).

CHAPTER 6: TESTING PHASES

6.1 Initial tests performed

Basic Experiment Conducted:

1. Compaction test - From the standard proctar test, the values obtained were,
- Maximum dry density obtained is 1.4g/cc.
- Optimum moisture content tested is 14 %.
2. Specific Gravity test – The specific gravity was found to be 2.285.
3. Wet sieve analysis using Hydrometer.
4. Liquid limit test by Casagrande's method.
5. Unconfined consolidation test.
6. Small scale experiment to estimate plugging behaviour of soil in hollow open driven pile.

6.2. Basic experiment conducted: small scale experiment to finding plugging effect of soil in open ended driven piles

In recent years, open ended steel piles have been frequently used in the foundation. Because an increasing number of massive structures are being constructed, it is becoming very important to consider the plugging effect of soil. It is not easy to design the bearing capacity of open-ended pile without considering plugging effect. The bearing capacity of open-ended piles is highly affected by the degree of soil plugging.

Numerous studies have been conducted on the plugging effect of open ended piles. Some researchers reported that the plugging effect influenced by the pile driving conditions, pile geometry conditions and soil condition.

Quantitative methods for the plugging effect on open-ended piles:

- Cone penetration test (CPT).
- Standard penetration test (SPT).
- The earth pressure approach (API).
- Plug length ratio method (PLR).

PLUG LENGTH RATIO METHOD:

In our project we conducted Plug length ratio method for finding plugging effect. Plug length ratio (PLR) is defined as the soil plug length per penetration depth at the end of the pile installation. The PLR can be written as

PLR = L_i / D_P .... (1)

Where L_i is the soil plug length and D_p is the penetration depth.

PLR =0 represents that no soil enters the pile during pile installation. The behaviour of open-ended piles in this condition is similar to the behaviour of closed-ended piles. However, PLR =1 represents that soil plug length is equal to pile penetration depth at the end of pile installation. The PLR was measured on open-ended piles to investigate the plugging effect under various condition such as pile driving conditions (hammer weight and height of fall) , soil condition and pile condition (pile length and diameter).

6.3. Experimental procedure

- Fill the mould with clay in three layers by providing 25 no. of blows for each layer.
- Make the top surface level and scale the pile prototype from standard pile dimensions.
- Take three different pile diameters of 1.15, 1.9, and 3.1.
- For pile diameter of 1.15, drive pile up to 4.5cm depth and note down no of blows value.
- Similarly pile diameter of 1.9, depth is 9cm and 3.1 pile diameter, depth is 11cm.
- Now taken out pile from mould and weigh the soil which enter pile and its length.
- By its depth and length, we got plug length ratio.
- From this we get plugging effect of soil in open-ended driven piles.

Fig: 1 and Fig: 2 Small scale experiment using open-driven piles in CBR mould.

6.4. Test setup

Impact load Test-A rectangular tank of dimension 600x200mm and 450mm depth fabricated with vertical partitions and grid marking was done on perpex sheet is used for experiment. The pile is driven at a uniform rate with the help of SPT model rammer and deformations around the pile were seized with the help of high resolution digital camera.

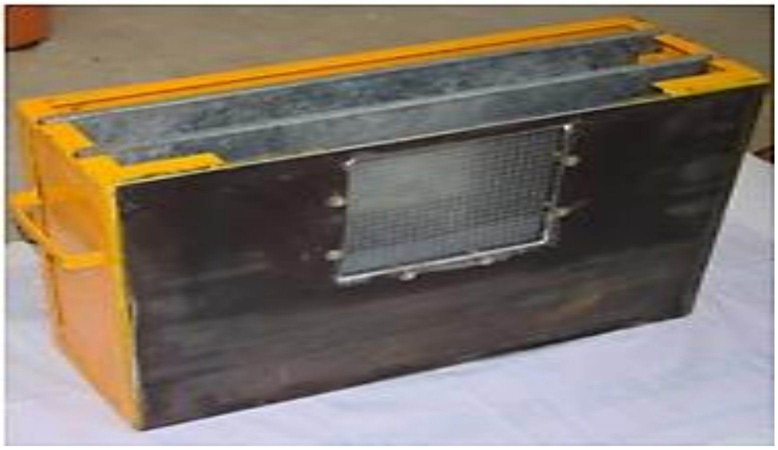

FIG 3: RECTANGULAR TANK TEST SETUP

CHAPTER 7: DISCUSSIONS

Experiments are carried on hollow piles in different densities for clay under impact load and the soil-pile interaction is studied.

8. SCOPE OF WORK

- Pile group interaction in clay can be investigated.
- Bearing capacity and stress around pile can be investigated.
- Variation in length to diameter ratio can be investigated.

9. REFERENCES

1) **Buragohain, D.N., Raghavan, N. and Chandrasekaran, V.S., 1977 Interaction of Frames with Pile Foundation. Proc. Int. Symp. Soil-Structure Interaction, Roorkee, 109-115.**
2) **Cai, Y. X., Gould, P. L. and Desai, C. S., 2000. Nonlinear analysis of 3D seismic interaction of soil pile structure systems and application. Engineering Structures 22, 191-199.**
3) **Chandrasekaran, S.S., Boominathan, A., Dodagoudar, G.R., 2009. Group Interaction Effects on Laterally Loaded Piles in Clay. J. Geotech. Geoenvironmental Eng. 136, 573–582. https://doi.org/10.1061/(asce)gt.1943-5606.0000245**
4) **Wood DM, Crew A, Taylor C (2002) Shaking table testing of geotechnical models. International Journal of Physical Model Geotech, 1:1–13.**
5) **White, D.J., Bolton, M.D., 2004. Displacement and strain paths during plane-strain model pile installation in sand. Geotechnique 54, 375–397. https://doi.org/10.1680/geot.54.6.375.45427**
6) **White, D.J., Take, W. a., 2002. GeoPIV: Particle Image Velocimetry (PIV) software for use in geotechnical testing. Cambridge Univ. Eng. Dep. Tech. Report, D-SOILS-TR 322, 15.**
7) **Wood DM, Crew A, Taylor C (2002) Shaking table testing of geotechnical models. International Journal of Physical Model Geotech, 1:1–13.**
8) **Ameta , "Bearing capacity of foundation", with link** www.ajer.org **, 2017.**
9) **M.S Dixit , K.A patil , "Study of sffect of different parameters on bearing capacity of soil" , Research scholar , government college of Engineering ,M S -431005.**
10) **Suraysah , Sonu kumar, "Application of PIV to investigate pile-soil interaction behaviour", 39S_BE_1414.**
11) **D.J white and W.A Take "Geo PIV: Particle image velocimetry (PIV) software for use in geotechnical testing", CUED/D-SOILS/TR322, OCT 2002.**

12) "ADONIS: A free finite element analysis software with an interactive graphical user interface for geoengineers" given by Roozbeh Geraili Mikola McMillen Jacobs Associates, San Francisco, California, USA.

INDIAN STANDARD CODES REFERRED :

"CODE OF PRACTICE FOR DESIGN AND CONSTRUCTION OF PILE FOUNDATION in IS: 2911 - 2010".