NUMERICAL MODELLING OF AKARPILES USING PLAXIS 2D

A

PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degree

of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision

of

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(ASSOCIATE PROFESSOR)

by

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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

WAKNAGHAT SOLAN-173234

HIMACHAL PRADESH INDIA

OCTOBER, 2024

DECLARATION

I hereby declare that the work presented in the Project report entitled **"NUMERICAL MODELLING OF AKARPILES USING PLAXIS 2D"** submitted for partial fulfillment of the requirements for the degree of Bachelor of Technology in Civil Engineering at the **Jaypee University of Information Technology, Waknaghat** is an authentic record of my work carried out under the supervision of **Dr. Saurabh Rawat.** This work has not been submitted elsewhere for the reward of any other degree/diploma. I am fully responsible for the contents of my project report.

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"NUMERICAL MODELLING OF AKARPILES USING PLAXIS 2D"** in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering submitted to the Department of Civil Engineering, **Jaypee University of Information Technology, Waknaghat** is an authentic record of work carried out by **Pradyumn Sharma (201609)** during a period from January 2024 to October 2024 under the supervision of **Dr. Saurabh Rawat**, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best of our knowledge.

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ABSTRACT

A clear understanding regarding the pile behavior and prediction of the pile capacity under the application of uplift load are very important and crucial aspects of foundation design. This thesis focuses on the numerical modeling of single piles and pile arrangements subjected to uplift loading, which primarily depends on the ratio of embedment-depth of the pile to the diameter and also the properties of the soil surrounding the pile. Our research on AKARPILES presents a very promising solution for stabilization of the slope alongwith a significantly reduced impact on the environment.

AKARPILES feature holes along their shafts, allowing grout to be pumped inside after installation. This process creates finger-like extensions that harden and enhance the pile's resistance to uplift loads from various sources. Once the piles are installed and reach the slip plane, grout is injected through the holes, filling the pores in the soil with a very random flow happening inside the slip-zone. The resulting extensions further increase the friction which exists between the soil-pile interface.

The uplift capacity of the pile or piles (T_{ult}) and it can be defined as the net uplift load value when the displacement becomes unlimited, indicating that the load approaches an asymptote along the displacement axis.

The experimental model was constructed using perspex sheets and iron angles to form a box. A hydraulic jack along with a load cell were used to apply the load. The box was filled with nine layers of sand, each 10 cm thick, and the (relative density) of the sand was measured. The pile was installed at an angle in the sand, and grout was poured inside. Using the hydraulic jack and load cell, we recorded the behavior of the pile in the inclined position along with its vertical displacement. Results

The numerical modelling was performed using PLAXIS 2D. We have used axis-symmetery model type for modelling the piles in PLAXIS. The results from PLAXIS and the physical experiment it can be seen that piles when placed in groups perform exceptionally better as they are getting less displaced at the same loading condition when compared with singular piles

The conclusions drawn from the comparison of the values from PLAXIS and the physical experimentation are as follows:-

- The pile modelled using PLAXIS shows lesser displacements at the same load when compared with the displacements obtained from the physical experimentation.
- How efficiently a pile group performs under uplift loading is directly proportional to the increase in the relative density of the soil.
- The response pertaining to the load vs the displacement of single piles under uplift loading conditions is easy to be predicted if we use a load-transfer approach. The following method basically considers the geometrical as well as the material properties of the pile which results in predictions that are very closely aligned with the data observed in the field.

Keywords: Akarpiles; uplift; PLAXIS; displacement; load-transfer; relative density.

CHAPTER 1
INTRODUCTION

1.1. General

Pile foundations are designed to transfer loads from the superstructure to deeper soil layers, particularly when shallow foundations are inadequate due to weak or compressible soil conditions. They effectively transmit these loads to more stable subsurface layers. Uplift forces can arise from activities of seismic origin, overturning moments, or water (hydrostatic) pressure. Additionally, pile foundations support heavy structures and serve a dual purpose: they carry the loads to the deeper, stronger layers while also reinforcing the surrounding soil. The ability of pile foundations to resist lateral loads is crucial for designing structures subjected to forces from earthquakes, soil movement, waves, and other factors. Piles that are driven are installed in the soil by driving them into the soil, while the creation of bored piles is through the drilling into the layer of sand then filling the boreholes with concrete or maybe grout and such identical materials.

1.2. Need of Study

For the approximation of complex mathematical processes, numerical modelling of AKARPILES in this geotechnical analysis has allowed us to approximate the intricate mathematical processes which are lacking analytical solutions. Numerical techniques aid us in finding close approximations. Detailed analysis of pile behavior in soil involves solving a large set of simultaneous equations, which is infeasible using manual methods. Calculation by hand is laborious, but numerical methods employed with the help of software such as [PLAXIS 2D] is necessary for efficient handling of such calculations. This research has made use of numerical simulations to model and analyze complex soil systems. These models predict behavior under different conditions which have enabled exploration and theory testing without costly experiments. PLAXIS 2D simulates conditions close to the exact ones which allows us to quantify the associated error. Knowledge of the accuracy of an approximation is crucial for practical applications.

1.3. Factors Affecting Uplift Capacity Of Piles

Soil Characteristics:-

Soil properties such as the amount of cohesion and the angle of friction significantly affect the uplift capacity of the pile.

Pile Geometry:-

The shape and size of pile influence its uplift capacity. Longer piles have a larger surface area which in turn increase the resistance against uplift forces. Pile diameter and shape can affect the distribution of uplift forces.

Pile Material:-

Steel piles are preferred due to their high strength and ductility but the resistance against environmental and soil factors plays a very big role in the degree of corrosion of the pile.

Groundwater Conditions:-

The level of ground-water impacts the total uplift capacity of the piles to a great extent. Presence of water will contribute to the reduction of effective stress in the soil which reduces the resistance to uplift loading on the pile.

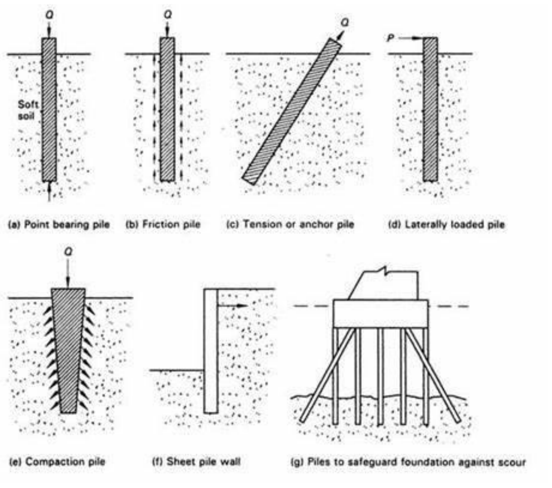


Figure 1.1 Different types of piles

1.4. AKARPILE

The concept of AKARPILES is inspired by the tree structural frame-work for slope stabilization. After the installation of the piles on the incline leading to blocking of the slip plane, grout is poured inside and the grout comes out through the openings once the pile volume is filled. With ongoing developments and rapid societal advancements, we have witnessed numerous incidents of landslides, revealing various cases of slope instability that pose risks and challenges to the public. A key feature of AKARPILES for any slope stabilization efforts is the specially designed root-structured pile that secures the soil on slopes.

This paper aims to plan and analyze the dimensions and configurations of AKARPILES, as well as to identify their mechanisms for the stabilization of the slope. This research focuses on the application of the AKARPILES in resisting inclined uplift loading. The paper also introduces innovative establishment ideas and strategies to streamline the slope stabilization process. Additionally, AKARPILES are designed to be lightweight, reducing transportation costs compared to traditional driven piles. Construction companies can stabilize slopes with less labor and equipment. The tools for installing AKARPILES are straightforward, aiming for the reduction in risks of the failure of the slope and enhancement in the safety of naturally occuring and human constructed slopes.

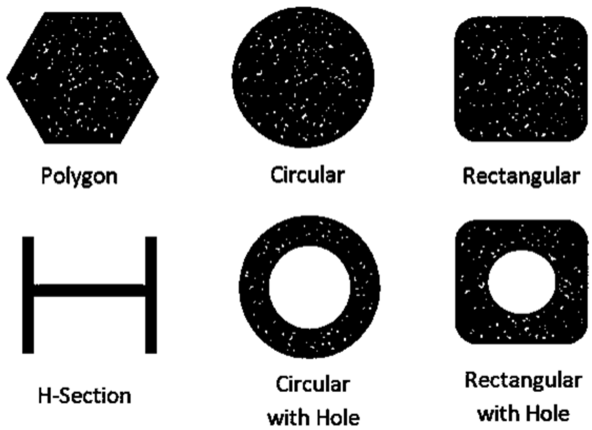


Figure 1.2 Common shapes of Piles

1.5. Interaction between the pile and the soil

The shape of piles significantly influences their response behavior. Square piles offer greater resistance to loads lateral in nature compared to circular piles which due to their larger contact-surface area with the surrounding soil. Calculating the pile-load capacity is essential for determining the ultimate load that the pile foundation is able to withstand under service conditions. The described capacity is known as the bearing capacity of the piles.

Piles may be installed either as singular units otherwise in groups, and the load calculations differ for each arrangement. The efficiency factor can be defined as the ultimate capacity of the group / the total of the ultimate capacities of each singular pile within that group. Grouping piles allows for the support of heavier loads while also reducing the size and cost of the pile cap, making it both safe & easily viable economically.

To maintain the undisturbed bearing capacity and ensure the conditions necessary for proper driving, it is essential to provide a minimum clear distance between piles, typically equal to twice the pile diameter (D). This setup enables coherent analyses and quantitative assessments of how parameters such as the length-to-breadth ratio, pile friction angle, and shear resistance angle impact the ultimate uplift capacity and overall values of skin friction.

Research has shown that the installation depth at which skin friction stabilizes depends on the shear resistance angle of sand and also majorly on the friction angle of the pile. The following study offers reasonable estimates for the ultimate resistance to uplift loading and the average of the skin friction, validated through detailed analysis with detailed test results. The load capacity of the pile and the calculation determines the ultimate load capacity of piles, ensuring that the pile foundation can support the loading conditions under service loads which is known as the bearing capacity of the piles being talked about. Piles can be installed either as singular units or in groups, and the load calculations differ for each arrangement based on specific load conditions and foundation sizes.

The efficiency factor (E_g) is defined as (the ultimate capacity of the pile group / the toal of the ultimate capacities of the each of the piles within that group). This factor finds its use primarily used for the evaluation of considerations pertaining to ultimate load.

To effectively support the loads heavy in nature, it is advantageous to arrange piles in groups. Grouping allows for a reduction in the size and cost of the pile cap, making construction both safe as well as economically viable. Achievement of the undisturbed bearing capacity and optimal driving conditions, a minimum clear distance between the piles is required, typically equal to twice the pile diameter (D). This approach enables coherent analyses and quantitative assessments of the effects of factors such as length-to-breadth ratio, the friction angle of the pile, and shear resistance angle on the ultimate uplift capacity and overall skin friction values.

1.7. Organization of Thesis

- Chapter 1 primarily deals with the principal section which illustrates the pull-out behavior of slanted AKARPILES. In this model, we applied inclined uplift loads on three different pile lengths and two arrangements: a triangular layout and a square layout.

- Chapter 2 provides an overview of various parametric investigations and analyses conducted, focusing on the behavior of the piles and predicting their capacity under uplift loads—key topics in foundation design.

- Chapter 3 outlines the methodology for the arrangement, detailing how various piles of different lengths are created to assess the uplift behavior of both single and grouped piles, along with the simulation process in PLAXIS 2D.

- Chapter 4 presents the results obtained from both the PLAXIS 2D numerical modeling tests and physical modeling. Load-displacement graphs are plotted, and this section includes a comparison and validation of the results from the physical modeling against those from the numerical simulations.

- Chapter 5 pertains to the conclusions which have been drawn from the whole reseearch that has been conducted and presents critical observations and the scope of future work related to the current project.

CHAPTER 2
LITERATURE REVIEW

2.1. General

The behavior of the pile and the prediction of the pile capacity under uplift loading are important considerations in designs pertaining to foundations. Model tests experimental in nature were conducted on singular piles and various arrangements of multiple piles in pile groups embedded in sandy soil, subjected to inclined uplift loading using a hydraulic jack fitted in a test frame with a load cell. The tests focused on vertical steel piles with straight shafts, 26 mm in diameter, placed in a steel container. The piles used for the modelling had (L/d) ratios of (15, 22, and 25). The sand box had been prepared at three distinct relative densities: 77/100, 87/100, and 97/100. The study included tests on three piles singularly as well as pile groups with 3, 4, and 6 piles installed in the soil sandy in nature.

2.2. Literature Review

Rahman and Sengupta [1] elaborated that although previous studies have investigated inclined piles without underream bulbs, there is limited information available on estimating the uplift capacity of inclined underreamed piles. In this study, laboratory experiments were conducted on model piles subjected to vertical uplift loads. These piles were tested with no underream, one underream, and two underreams, and were inclined at angles of θ = 0°, 10°, 20°, and 30° relative to the vertical. The piles were placed in locally available sand, and three different pile stem diameters (D = 20, 25, and 35 mm) were used. The results showed that for inclined piles, increasing the number of underream bulbs from 0 to 2 significantly improved the uplift resistance, particularly for piles with a length-to-diameter ratio (l/D) of 10. The decrease in uplift capacity due to increased inclination was more pronounced for piles with two underreams.

The load-displacement response and ultimate uplift resistance of piles in sand are predicted using the load transfer approach by **Goel and Patra [2].** In this method, the pile is divided into segments, with each segment assigned specific geometric and material properties that reflect the actual soil-pile interaction. The shaft resistance is calculated analytically based on established studies. The proposed method incorporates key factors such as the pile's length, diameter, surface characteristics, and soil properties. The load-displacement behavior and uplift capacity of vertical piles, as observed in field tests, have been successfully predicted. The predicted uplift capacities show reasonable agreement with the observed values, and the load transfer mechanism effectively captures the nonlinear load-displacement response of the piles.

The use of helical pile foundations has increased, but predicting their uplift load-displacement behavior for service-level displacements remains challenging. This study by **Mosquera, Tshua and Beck [3]** applies a probabilistic power law model to characterize the nonlinear uplift load-displacement relationship of deep helical piles, with model parameters derived from 30 uplift tests on helical piles in Brazil. A structural reliability approach is then used to demonstrate the model's application for evaluating the serviceability limit state (SLS) of a transmission tower foundation. The analysis considers uncertainties in three factors: the load-displacement curve parameter, the empirical correlation between pile capacity and installation torque, and wind loading on transmission line foundations.

Singh, Pal and Arora [4] proposed a testing program of 250 oblique pullout tests was conducted to study the pullout capacity of batter pile groups in sand. Five pile groups made of aluminum with lengths of 0.40, 0.60, and 0.90 m were tested at two unit weights (16.28 and 15.79 kN/m^3). The angle of oblique load was varied (0°, 10°, 20°, 30°, 45°). Results show that increasing pile length, sand unit weight, and surface roughness enhances pullout capacity. The pullout capacity also increases with the oblique load angle, though the difference is more pronounced at higher angles. ANOVA analysis indicates that pile length, unit weight, and oblique load angle significantly affect pullout capacity, while pile surface roughness does not.

PLAXIS 2D was employed alongside 2 model conditions—one with a project pertaining to deep excavation and one without—utilizing two types of constitutive models: the Hardening Soil model with small-strain stiffness (HSS) and UBC3D-PLM by **Mulyadi, Li and Lastiasih [5].** This approach facilitated a series of multiple numerical analysis aimed at predicting the potential for liquefaction.

Ye and He [6] conside that the primary concern in this study is the effect of surcharge load on the stability of retaining pile walls. Surcharge loads refer to additional loads applied to the ground surface, which can arise from various sources, such as construction activities or nearby buildings. The paper highlights that few studies have adequately explored how these loads affect the structural integrity of retaining walls.

2.3. Summary of Literature Review

- In most of the researches regarding pile foundations, axial compression and straight pull-out capacity of piles were tested but none included the inclined uplift forces acting on certain structures where piles have been utilised or have the potential of being utilized increases the need for such a detailed analysis.

- Investigation pertaining to the factors which are responsible for affecting the (pile) behaviors such as the spacing ratios, and the post grouting at the tip is profitable for the better understanding of these sort of piles.

- Efficiency of the (FRP) composite piles is clearly visible thorugh the optimization of their configuration by the use of taper piles.

- A structure in the form of a pile-anchor can reduce the incurred deformation of the structures in a supporting role by the application of force a prestress with benefits of economic and technical origin [8].

2.4. Objectives

- To perform the numerical modelling of AKARPILES using the various empirical relations of soil parameters with the help of PLAXIS 2D.

- Performing physical modelling of the project described above and comparing the results.

- Investigation of the behaviour of the (akarpile) under an inclined uplift pullout load successively at an inclination of 30°.

- Analysis of the uplift capacity, total displacements, total strain of non-uniform length piles individually and in different arrangements.

CHAPTER - 3
METHODOLOGY

3.1 General

A tank for the physical modelling measuring 850 mm x 750 mm x 870 mm has been constructed using (0.25 cm) thick perspex fiber sheets. The tank is filled with ten layers of soil, each (100 mm) thick, up to a height of (800 mm). Prior to the last testing in the simulated model, several tests are going to be conducted in the soil to study the physical properties.

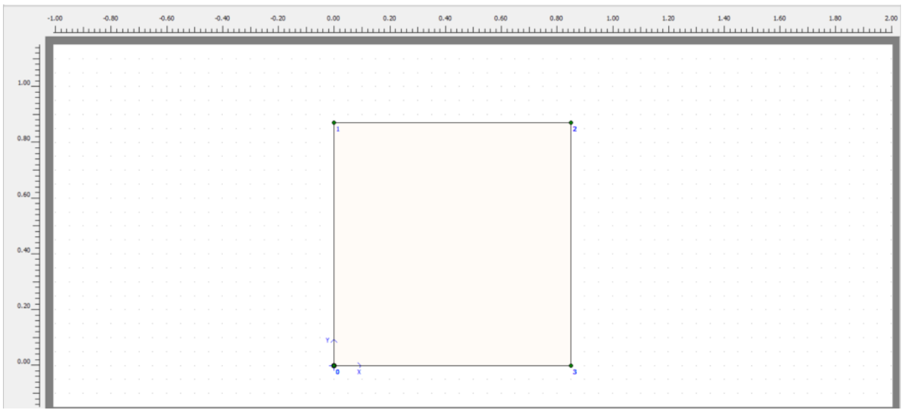


Figure 3.1 Soil Model in PLAXIS 2D

Figure 3.2 Soil model used for physical modelling

3.2 Materials Used

3.2.1 Black soil

In soils such as 'black' soil and various problematic soil types, structural cracking occurs because of differential ground movements which are being caused due to the alternating swelling and shrinkage of the soil proportional to the change in moisture content.

The volcanic soil is high in the content of montmorillonite and is very clayey in texture, deep, and an impermeable type of soil. These soils swell and become sticky in nature during the rainy season and contract in the dry season, leading to significant cracking. Chemically the volcanic soil is rich in iron, lime, magnesium, alumina, and potash, but are deficient in nitrogen and phosphorus. Their water-retaining capacity makes them suitable for cotton cultivation, which is why they are referred to as black cotton soil. These soils are characterized by their dark color.

Figure 3.3 Black Soil in natural form

Black cotton soil can expand in volume by 20% to 30% of its original volume, exerting pressure in the process. This upward pressure can become so significant that it tends to lift the foundation. This upward force on the foundation leads to cracks in the walls above. The cracks are narrower at the base and widen as they extend upward.

In such soils, an effective foundation construction technique is essential. In black cotton and other expansive soil types, structures can crack due to differential ground movements caused by the alternating swelling and shrinkage of the soil as its moisture content changes.

To effectively mitigate these movements, the approach best in nature is to anchor the structure at a depth where volumetric changes in the soil due to seasonal fluctuations and other variations are minimal. This can be achieved economically in both shallow and deep layers of expansive soil by using under-reamed piles.

Figure 3.4 A sample of black soil (oven dried)

3.2.2 Sand

The piles for the physical modelling have been installed in dry & siliceous sand with particle sizes ranging from medium to fine. All tests conducted during the physical modeling adhered to the relevant ASTM standard testing procedures. The sand used in the Perspex sheet box was selected to achieve a relative density of 87%. Controlled pouring and appropriate packing methods were employed to create a uniform layer of sand. The quantity of sand for each of the layer was measured and weighed with an accuracy of (0.11 Newton) before being placed in the soil container and compacted. The layers of sand were added to the container to achieve the desired thickness within a tolerance of ± (0.2 cm), ensuring the relative density which is required.

Figure 3.5 Sample of the sand used in physical modelling

3.2.3 Model Piles and Pile Caps

The pile caps have been created using smoothened, very delicate steel tubes with a 2.6 cm outer diameter and 0.3 cm thick. A machined cap of steel was added to seal the ending part of each pile. The pile lengths examined were 364, 520, and 676 mm, corresponding to length-to-diameter (L/d) ratios of (14, 20, and 26) respectively. The caps were crafted from 30 mm thick steel plates, machined to precise dimensions within ±2 mm.

Additionally, various pile group arrangements were utilized to assess soil stability under different conditions. We implemented triangular and square arrangements for inclined pile installations, using two distinct pile lengths: 52 cm and 64.6 cm.

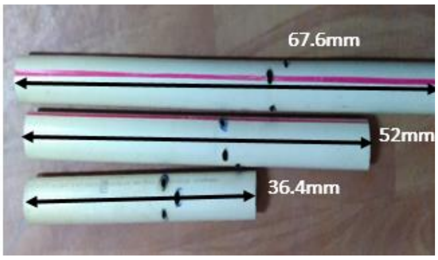


Figure 3.6 (a) Longitudinal View of PVC pile

Figure 3.6 (b) Plan View of the PVC pile

Figure 3.7 Pile cap for single pile

Figure 3.8 Pile cap for group of three piles

Figure 3.9 (a) Four Pile Cap

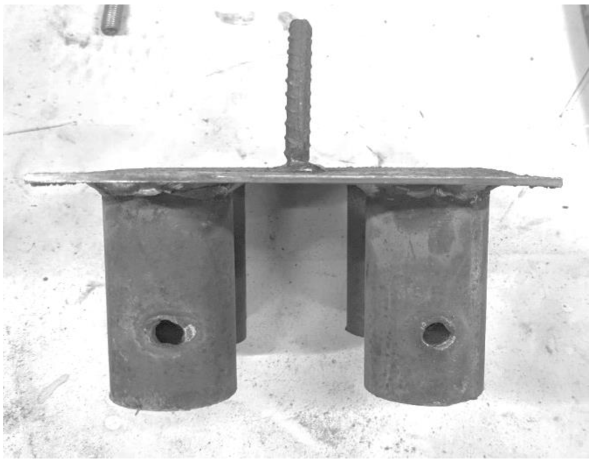


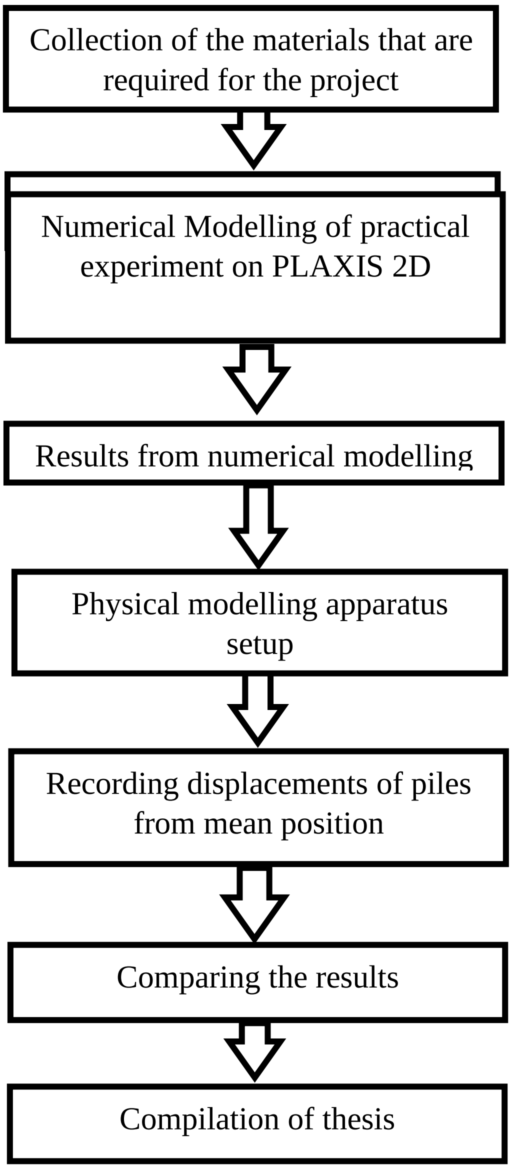
Figure 3.9 (b) Pile Cap for four pile arrangement

The primary function of a pile cap is to transfer the loads from the structure to the piles beneath it, ensuring that the piles work together to resist these forces. The cap also provides a stable base for the superstructure, allowing for efficient load transfer and reducing the potential for differential settlement between piles.

Pile caps are commonly used in foundation systems where deep foundations (piles) are required, such as in areas with weak soil or high load demands.

Steel pile caps are an alternative to traditional reinforced concrete pile caps and are used in situations where a steel foundation system is required or preferred. These caps are typically made of steel plates or steel beams and are used to transfer the loads from the superstructure to the piles below.

3.3 Methodology



3.4 Sand Tank

The tests were conducted on PVC (model) piles within a constructed sand tank measuring 850 mm x 750 mm x 870 mm. The tank that has been built is shown below. Materials used for the construction were as following:

a) **Perspex Sheet** – Polymethyl Methacrylate (PMMA), commonly known as plexiglass, Lucite, acrylate, or Perspex, is a thermoplastic material. It is often used as a lightweight, shatter-resistant sheet and is incorporated in inks and various applications, serving as a glass alternative. This synthetic polymer of methyl methacrylate has a thickness of 0.25 cm. Acrylic is a versatile synthetic fiber that can be molded into numerous shapes and is resistant to outdoor conditions. Many people choose acrylic sheets for various reasons; products made from acrylic are generally more flexible than glass and less likely to break. Additionally, acrylic cases weigh less and more durable.

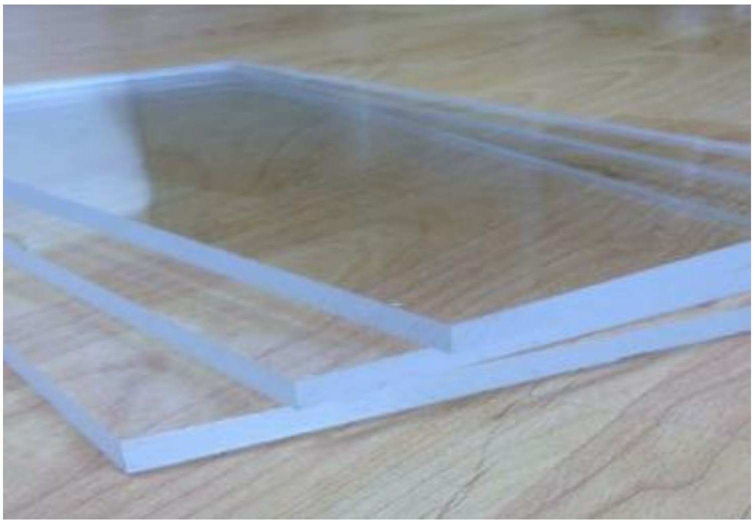


Figure 3.10 Perspex fiber Sheet (0.25 cm)

b) **Steel Bars**

An iron or steel bar, used as a brace/cleat, is shaped like an angle, featuring a cross-section that resembles the letter "L."

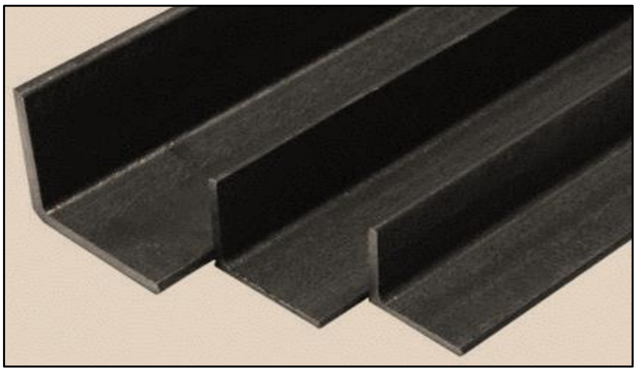


Figure 3.11 Iron L-Bars

c) Nuts/Bolts

Figure 3.12 Nut-Bolt

d) In-extensible wire

These inextensible wires is composed of 2 components: an inner cable made of stainless steel wire in a braided fashion with an outer cable housing. They function by transmission of the force through a combination of tension in the inner cable with compression in the outer housing.

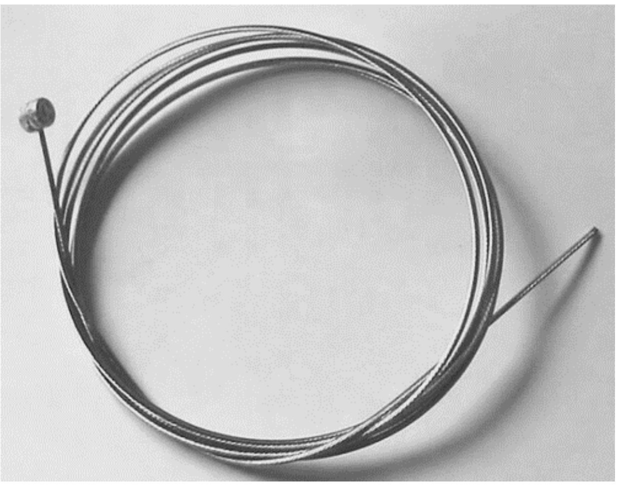


Figure 3.13 In-extensible wire used for the experiment

e) Hydraulic jack

The hydraulic jack operates on Pascal's law, which states that the pressure being applied to a fluid at rest is transmitted uniformly in all directions. A hydraulic jack is a mechanical device used to lift heavy loads using hydraulic force. It operates based on the principles of Pascal's Law, which states that pressure applied to a confined fluid is transmitted equally and undiminished in all directions. Hydraulic jacks are commonly used in automotive repairs, construction, and other industries where heavy lifting or load-bearing is required.

Figure 3.14 Hydraulic jack used for physical modelling

Figure 3.15 Casing welded for placing the Jack

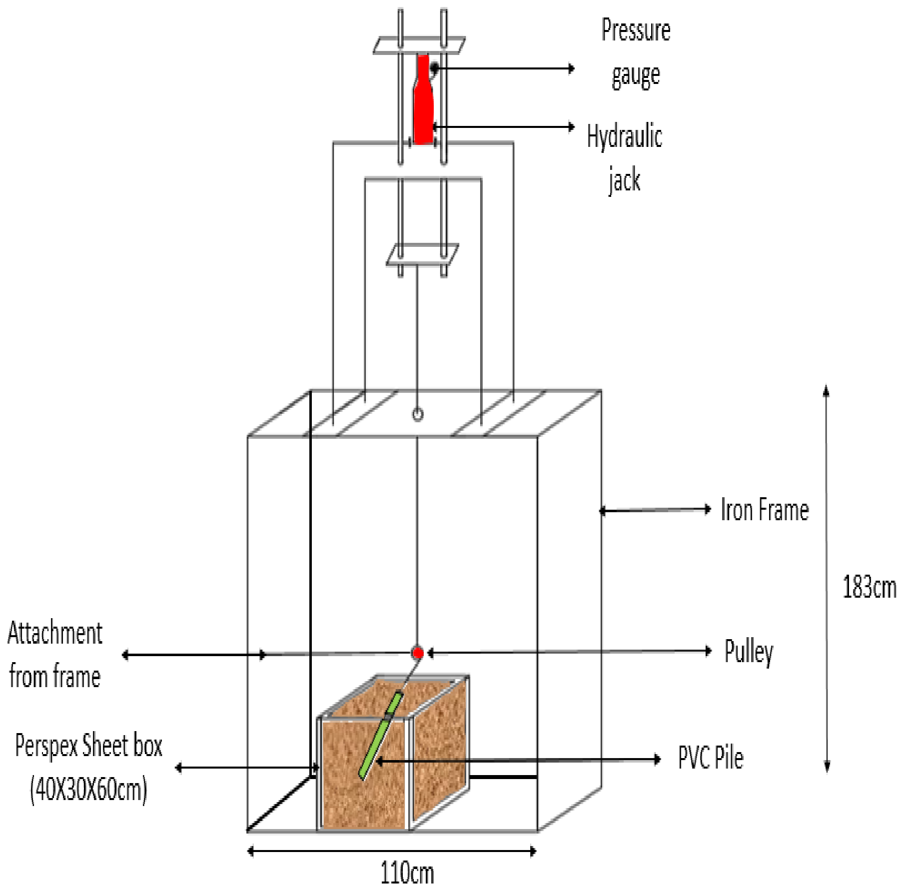


Fig. 3.16 AUTOCAD model of the
physical model constructed

The figure above depicts the model created during the physical modeling of AKARPILES, which has been simulated in AutoCAD. The model tank was constructed using iron angles and Perspex sheets, with dimensions of 85 x 75 x 87 cm. A hydraulic jack was used to apply an uplift force on the AKARPILES, which varied in length and were embedded at a 30-degree angle into the sand layers.

Figure 3.17 Model Tank used for physical modelling

The hydraulic jack will exert pressure on the frame which has the clutch wire connected to it which is going through 2 pulleys in such a way that the pile installed in the sand box will experience inclined uplift on the pile at 30 degrees. The hydralic jack also has a load cell fitted on it which gives the load applied magnitude.

Fig. 3.18 Model Sand Tank

3.5 Sand Layer Preparation

A model sand tank with dimensions amounting to 850 mm x 750 mm x 870 mm has been built using 0.25 cm thick Perspex sheets. Eight layers of sand, each 10 cm thick, were added to the tank amounting to a height of 800 mm. Controlled pouring alonside proper tamping techniques have been employed for ensuring a uniform layer of the sand. The layers of sand in the soil box were placed to reach a target thickness within ±0.2 cm, resulting in a height of 70 cm. Sand has been deposited in seven layers, each 10 cm deep, with relative densities of 77/100, 87/100, and 97/100.

3.6 Preparing Grout

The preparation of the BCS (black cotton soil) grout, intended for use in the model test, involves mixing black cotton soil, siliceous sand, and water in a ratio of (1:3:4). The sand is to be dried properly and also sieveing is necessary prior to mixing. This grout fills the pores in the soil with a very random flow usually inside the slip-zone. It is a liquid having a thick consistency used for filling voids or reinforce existing structures, forming finger-like extensions that fill gaps and anchor the piles more securely. Grout typically consists of water, cement, and sand blended together in a mix and is commonly used for apllications such as pressure-grouting, installation of rebar in masonry walls, developing connections between sections of precast concrete, filling voids, and reparation of joints.

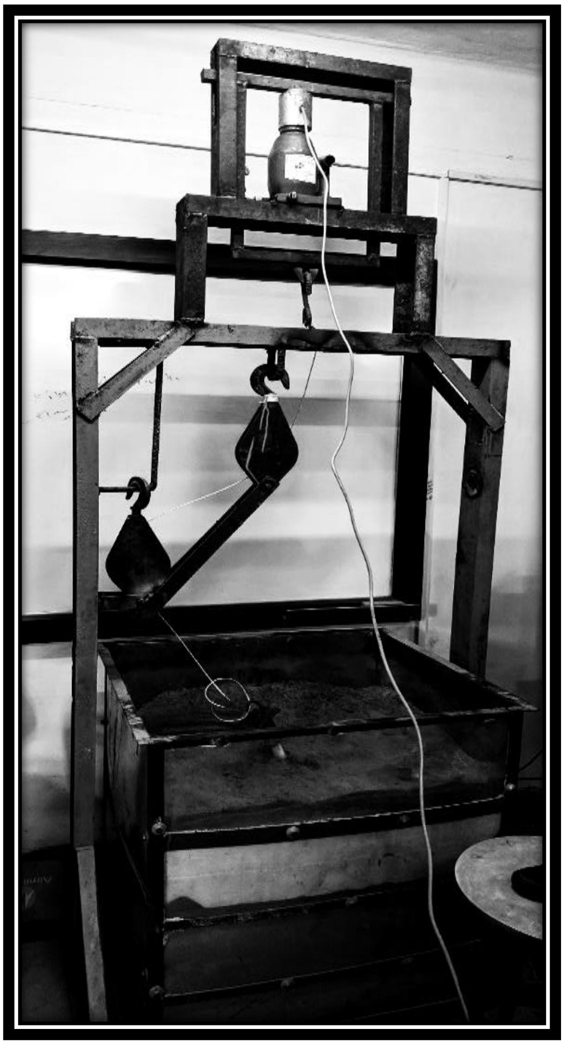


Figure 3.19 Hydraulic Jack alongwith load cell on test frame

3.7 MATERIAL PROPERTIES (PLAXIS 2D)

PARAMETER	NAME	VALUE	UNIT
Material Model	Model	Mohr-Coulomb	-
Type of material behaviour	Type	Drained	-
Soil unit wt. above phreatic level	γ_{unsat}	17	kN/m^3
Soil unit wt. below phreatic level	γ_{sat}	20	kN/m^3
Permeability in horizontal direction	k_x	1	m/day
Permeability in vertical direction	k_y	1	m/day
Young's Modulus (constant)	E_{ref}	8000	kN/m^2
Poisson's Ratio	ν	0.3	-
Cohesion (constant)	c_{ref}	1	kN/m^2
Friction Angle	φ	34	degrees
Dilatancy Angle	Ψ	0	degrees

Table 1 – Material properties of sand

PARAMETER	NAME	VALUE	UNIT
Normal Stiffness	EA	5000000	kN/m
Flexural Rigidity	EI	8500	kNm^2/m
Equivalent Thickness	d	0.143	m
Weight	w	0	kN/m/m
Poisson's Ratio	υ	0.25	-

Table 2 – Material properties of pile

3.8 MODEL GENERATION IN PLAXIS 2D

- The model pile is represented as a plate element in PLAXIS and is visible in the figure below in colour 'blue' . The material properties of the plate input in the software are similar to the material properties of the pile. The inclined uplift loading has been applied on the soil model which can be seen in the form of an upward inclined arrow. The scale of the soil model has been set such that it resembles the dimensions of the soil model which has been utilised in the physical modelling of the akarpiles.

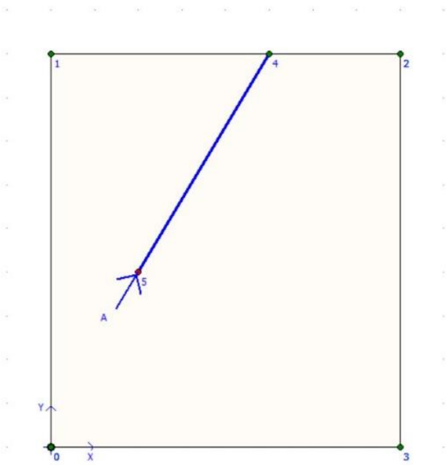


Figure 3.20 Soil model in Plaxis

- In the second step the material set for the soil will be defined and the soil parameters are input followed by conducting a Triaxial and an Oedometer test in the software itself.

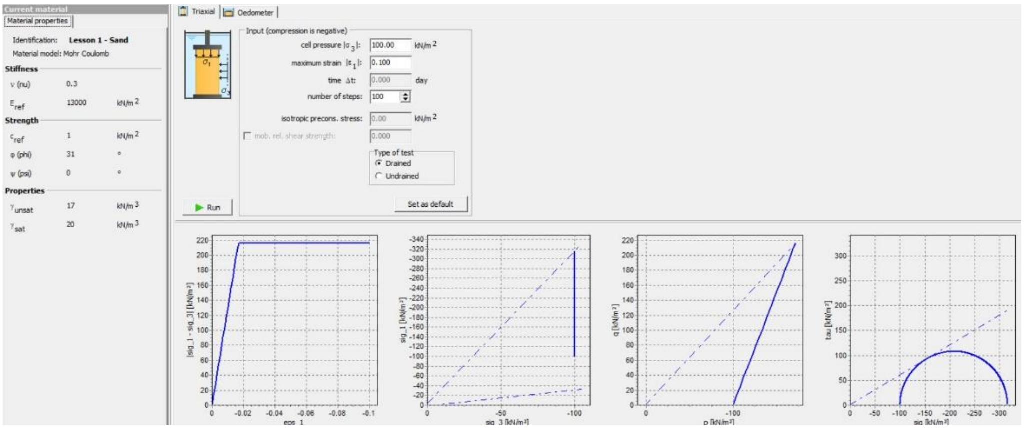


Figure 3.21 Triaxial test

The Triaxial Test in PLAXIS 2D is used to simulate the behavior of soils under controlled stress conditions, replicating laboratory triaxial testing. This type of analysis helps in understanding the soil's shear strength, stress-strain behavior, and deformation under both drained and undrained conditions, which is critical for geotechnical engineering projects like foundation design, slope stability, and tunnel construction.

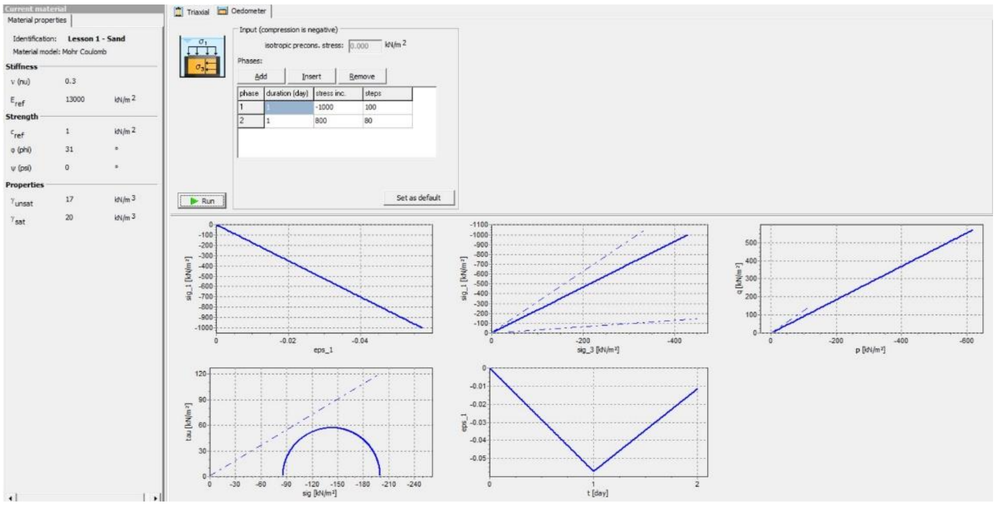


Figure 3.22 Oedometer test

The Oedometer Test (also known as a one-dimensional consolidation test) in PLAXIS 2D can be simulated to study the consolidation behavior of soils under vertical loading. The test is typically used to evaluate how a soil will compress over time due to an applied vertical load (such as a foundation or embankment) and how pore water pressure dissipates, leading to settlement. In PLAXIS 2D, you can model this test using finite element analysis (FEA) to understand the time-dependent behavior of soil under loading and pore pressure dissipation.

- After conducting the soil test in the software we define the material properties of the pile as previously discussed in the previous part of this chapter. The standard fixities for the soil model is also set. After assigning the material properties necessary, and the standard fixities, a 'mesh' is generated.

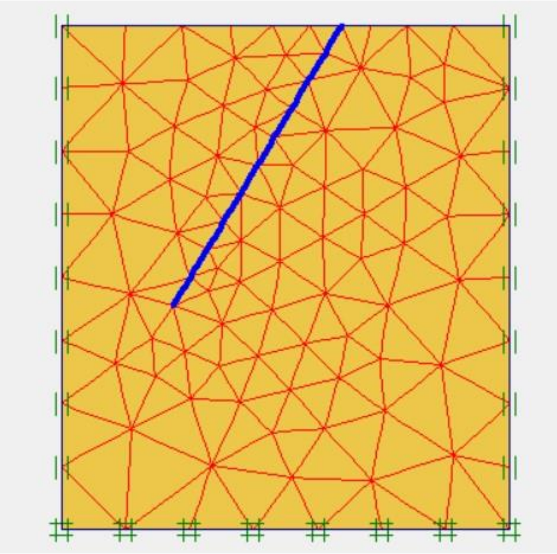


Figure 3.23 Mesh in Soil model

- After generating the mesh and standard fixities for the model, the result program is run which gives the results for the calculations. The calculation program gives the output for the model.

3.9 Experimental Steps In Physical Modelling

- Filling of perspex sheet box with required amount of sand.
- Setting up of the hydraulic jack alongwith the load cell over the constructed frame.
- Preparing black soil grout.
- Inserting pile in the sand inclined with the surface at an angle of 30 degrees.
- Setting up of the dial gauges.
- Uplifting of the pile via pressure through the hydraulic jack.
- Uplift applied on single and group of piles.
- Recording the reading of the load cell and dial gauges.
- Deep analysis of the result.
- Comparison alongside finalisation of the results.

CHAPTER - 4

RESULTS

4.1. General

Test results have been organized into two categories: the behavior of singular;y placed piles and the performance of two distinct pile groups under the application of inclined uplift loading.

4.2. Single pile under Uplift Loading

In the following experiment, we used single piles of varying lengths (364 mm, 520 mm, and 646 mm). The piles were placed in the tank containing sand, and black cotton soil grout was poured inside each pile, allowing it to set for 48 hours.

4.2.1 L-D Curve for the 520 mm pile

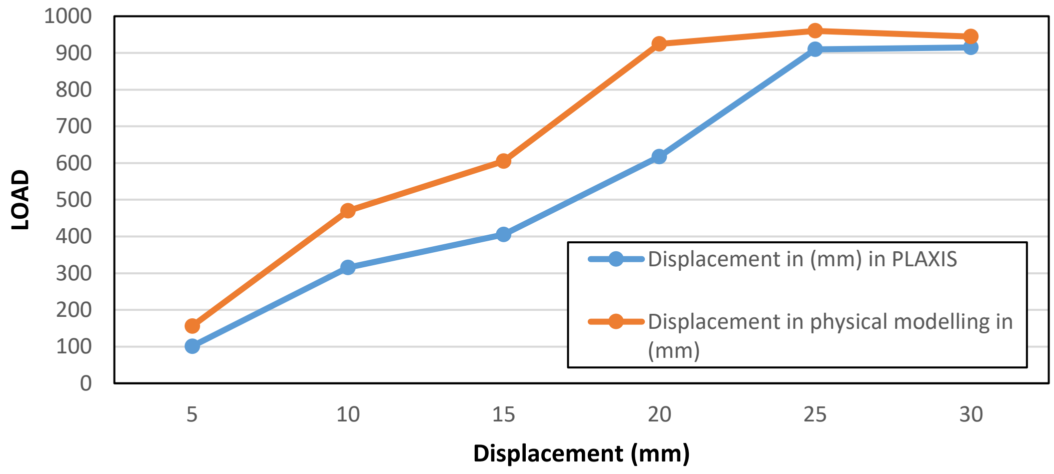


Figure 4.1 L-D curve for 520 mm Pile

4.2.2 L-D curve for the 364 mm pile length

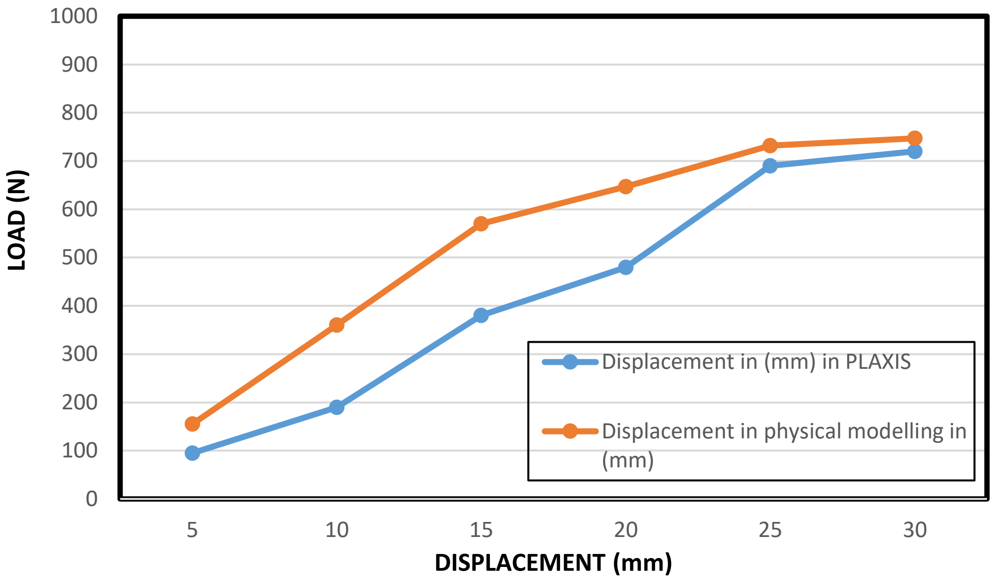


Figure 4.2 L-D curve for 364 mm Pile

4.2.3 L-D curve for the 646 mm pile length

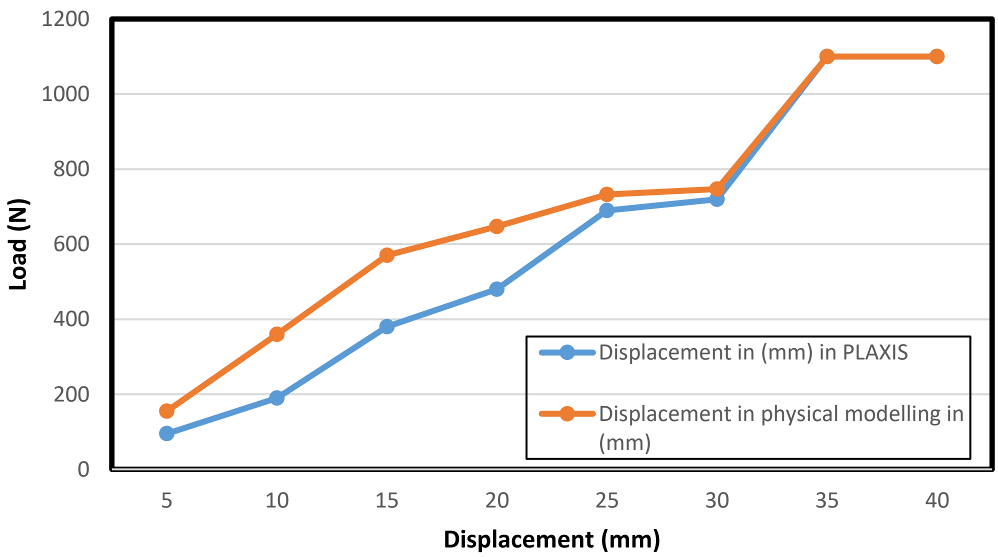


Figure 4.3 L-D curve for 646 mm Pile

4.3. Pile groups under Uplift loading

In the following experiment, we conducted uplift tests on pile groups arranged in both triangular and square formations. The uplift was achieved using a specialized setup that included a jack operating on Pascal's Law, a load cell, and a strain gauge. This test aimed to determine the uplift load, the uplift capacity, and pile displacement. For both the triangular and square arrangements, we created a pile cap that securely held the piles, allowing them to be pulled out. Inside each pile, we poured grout made from black soil, sand, and water in a ratio of (1:3:4) and is let to set for 48 hours. The pile group was then extracted using the specialized arrangement.

4.3.1 3 Pile Arrangement

In this setup, the piles have been arranged in a formation that is triangular in shape with 0.5 cm spacing in between them. A pile-cap has been built for this arrangement to facilitate th 31 -out of the pile arrangement. Grout is pumped inside the piles and then allowed to set for 48 hours. This process enables us to determine firstly the total uplift capacity of the pile and pile displacement. We first conducted the test using three piles of 646 mm length, followed by tests with three piles of 520 mm length.

- **L-D Curve for the 520 mm pile**

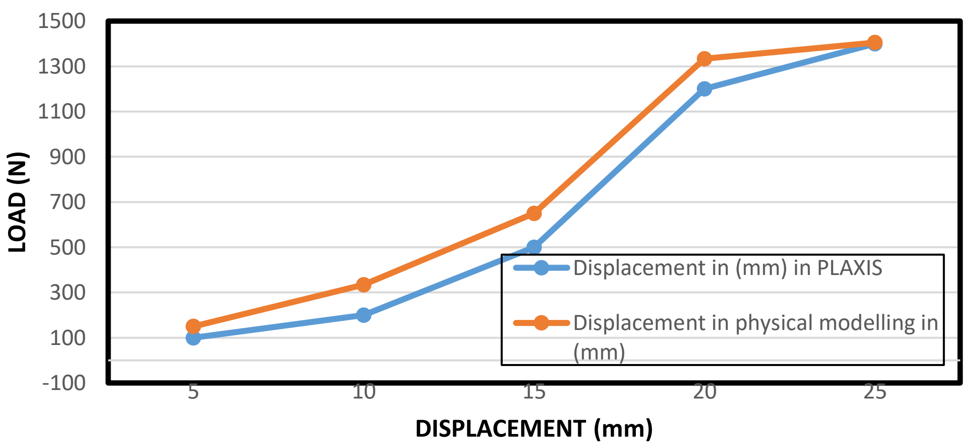


Figure 4.4 L-D curve for three 520 mm Piles

- **L-D curve for the 646 mm pile**

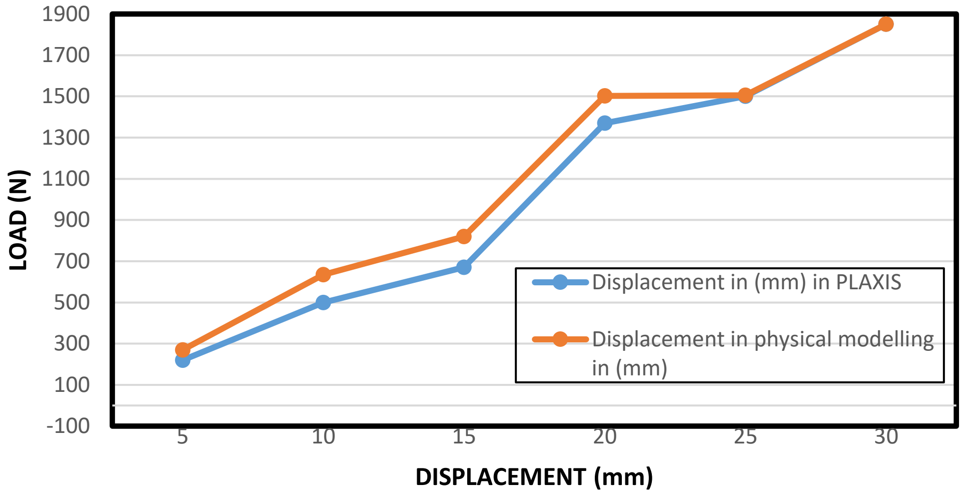


Figure. 4.5 L-D curve for three 646 mm Piles

4.3.2 4 Pile Arrangement

In the current setup, the piles have been arranged in a formation that is square in shape with 0.5 cm spacing between them. A cap for the pile is constructed for this arrangement for facilitating the pull-out of the piles. Grout is poured inside the piles and allowed to set for 48 hours. This process allows us to determine both the uplift capacity and pile displacement. We first conducted the test using four piles of 64.6 cm length, followed by tests with four piles of 520 mm length.

Figure 4.6 Pull-out test (inclined) performed on 4 PILES

- **L-D curve for the 646 mm pile**

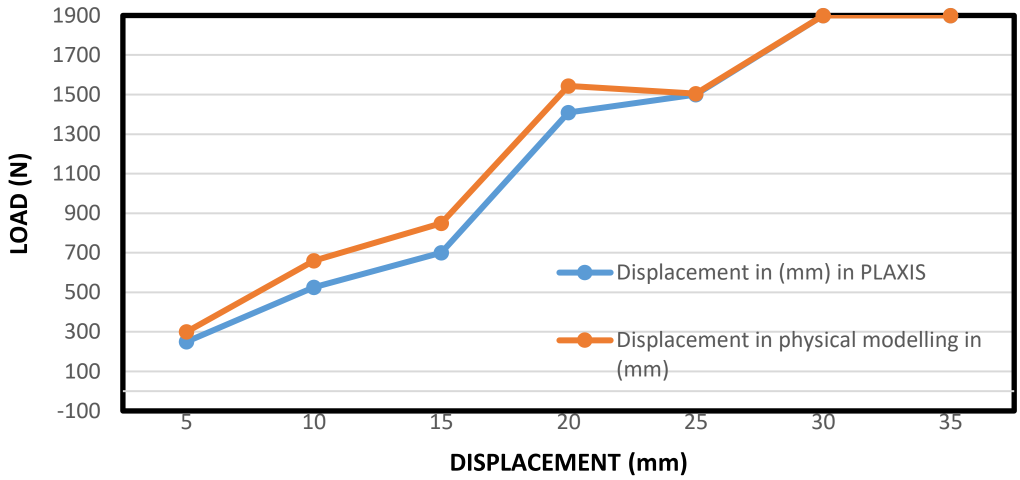


Figure 4.7 L-D curve for four 646 mm Piles

- **L-D curve for Four 520mm Pile**

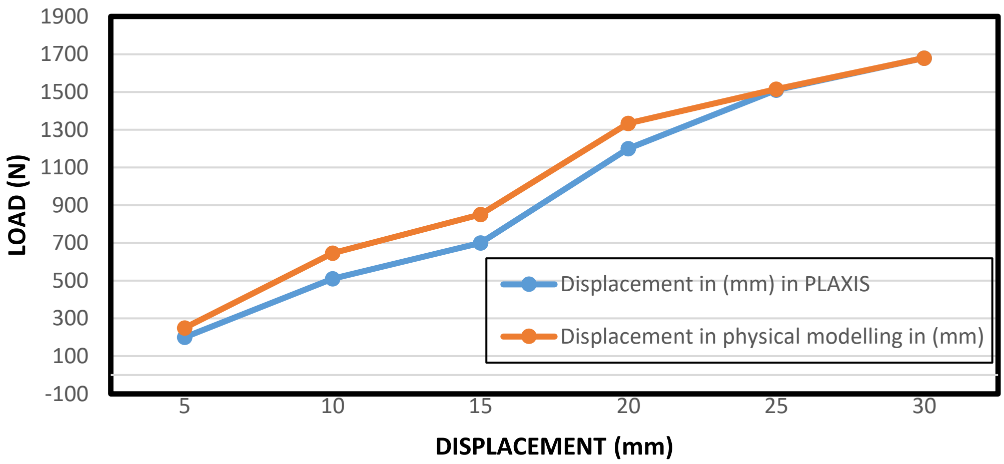


Figure 4.8 L-D curve for four 520 mm Piles

4.4 Discussions

- The response of the single piles under uplift loading is primarily influenced by the (L/d) ratio of the pile and the properties of the surrounding soil. The total uplift capacity of a pile increases to a large extenet with higher values of (L/d) ratio and the relative density of the soil.
- A vertical displacement of approximately (1.5–2.75%) multiplied the pile diameter is necessary for achieveing the uplift capacity for both the singular piles and piles placed in groups. Conversely, a minimal vertical displacement of only (0.5–0.7%) of the pile diameter is sufficient for developing the uplift load which is allowable.
- The pile group is less efficient under uplift loading and the efficiency declines as the number of piles in the group of the piles increases and we see an increase in the pile embedment depth-to-diameter ratio.
- The pile group is more efficient under uplift loading as it increases slightly with higher relative density of the soil.

4.5 Critical Observations In PLAXIS 2D

- The longer the pile length, the larger is the friction between the soil-pile interface which resulting in greater uplift resistance to the uplift loading.
- The ultimate uplift capacity for the 36.4 cm pile is the minimum and of the 64.6 cm pile is the maximum.
- During uplift application of load on the piles, it was observed that even for a constant uplift load the displacement keeps on increasing if the load is constantly applied.
- For the 36.4cm pile the maximum uplift force was around 800N since without any increase in the load there was displacement occuring which suggests failure of the pile.

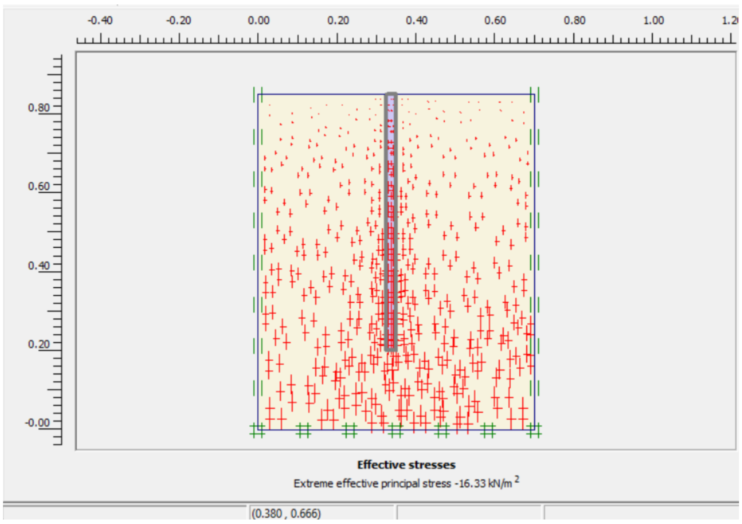


Figure 4.9 Effective Stresses

The effective stress points are seen in the most concentration around the pile and in the soil near to the pile.

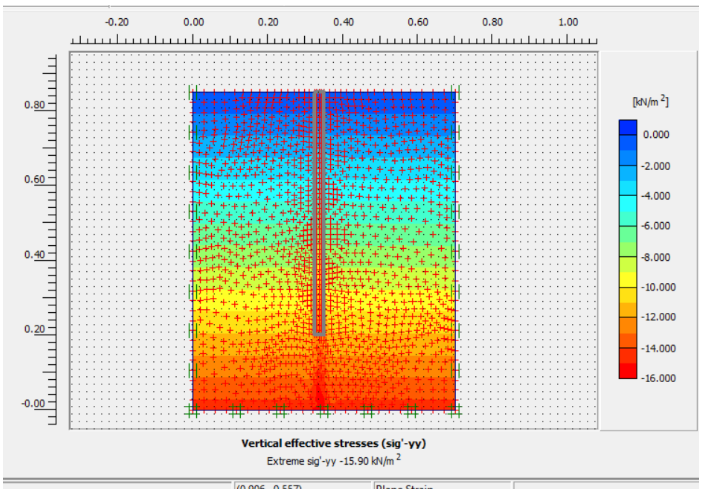


Figure 4.10 Vertical Effective Stresses

Vertical effective stresses refer to the portion of the total vertical stress in the soil that contributes to soil strength and stability. Effective stress is a key concept in soil mechanics.

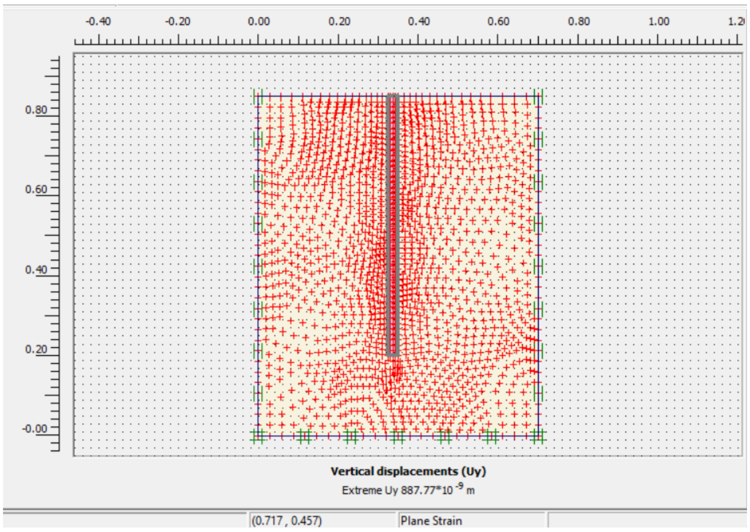


Figure 4.11 Vertical Displacements

Vertical displacements refer to the movement of nodes or points in a model along the vertical axis, caused by applied loads, changes in boundary conditions, or soil behavior. These displacements are essential for analyzing the structural response in soil-structure interactions, evaluating foundation performance, and assessing the stability of slopes and excavations.In the software’s results section, users can visualize these vertical displacements to observe how the ground or structures deform under different loading conditions. Understanding these displacements enables engineers to design safer and more effective structures by predicting their behavior in real-world scenarios.

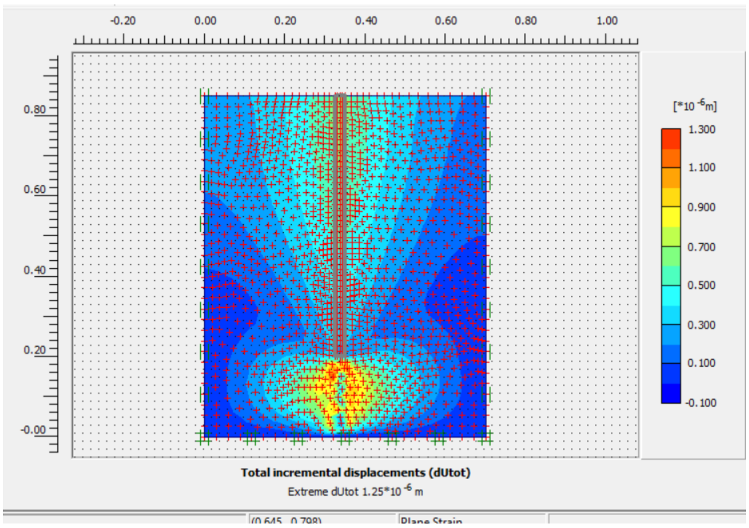


Figure 4.12 Incremental displacements

Incremental displacements are largest at the bottom part of the pile, as shown in the figure above. These displacements provide insights into the potential failure mechanism. When failure occurs, the corresponding strength reduction factor can be viewed as a safety factor regarding soil strength. It can be determined that failure is likely when a minor reduction in strength results in significant changes in strains and displacements.

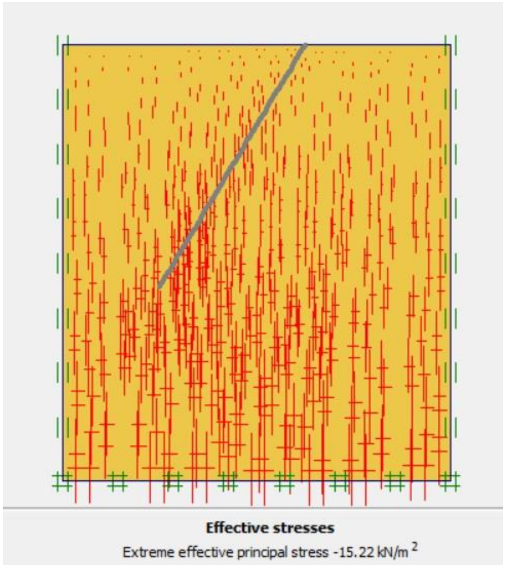


Figure 4.13 Effective Stresses

In PLAXIS 2D, effective stresses refer to the stresses that contribute to strength of the soil and deformation, accounting for the influence of pore water pressure within the soil. The concept is based on Terzaghi's principle of effective stress, which is critical for analyzing soil behavior under various loading conditions.

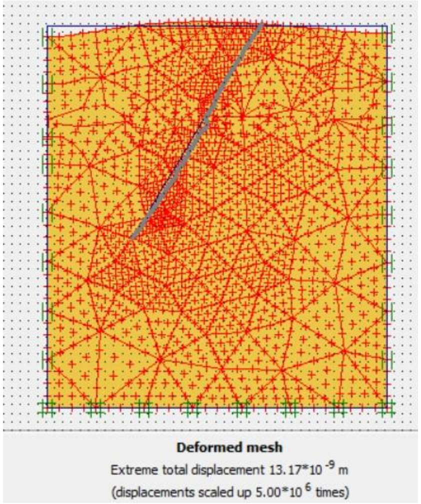


Figure 4.14 Deformed Mesh

Deformed mesh in Plaxis 2D typically refers to the visual representation of how the mesh changes shape or configuration during a simulation, particularly under applied loads or boundary conditions. Deformations in the mesh represent the displacement of nodes and elements due to stress and strain in the materials being modeled.

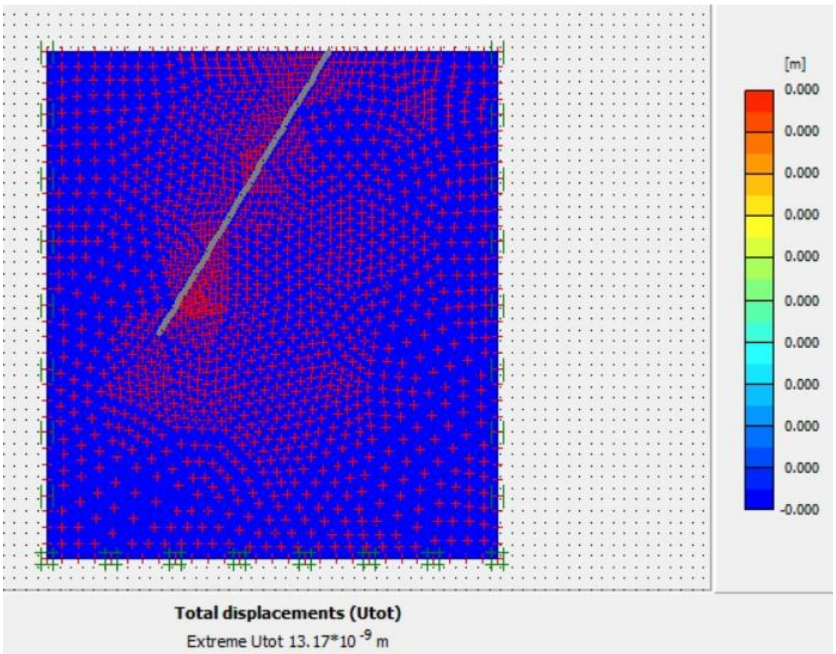


Figure 4.15 Total Displacements

Total displacements refer to the overall movement of nodes in the mesh as a result of applied loads, boundary conditions, and other factors influencing the structure or soil model. Total displacements include both elastic and plastic deformations in the materials.

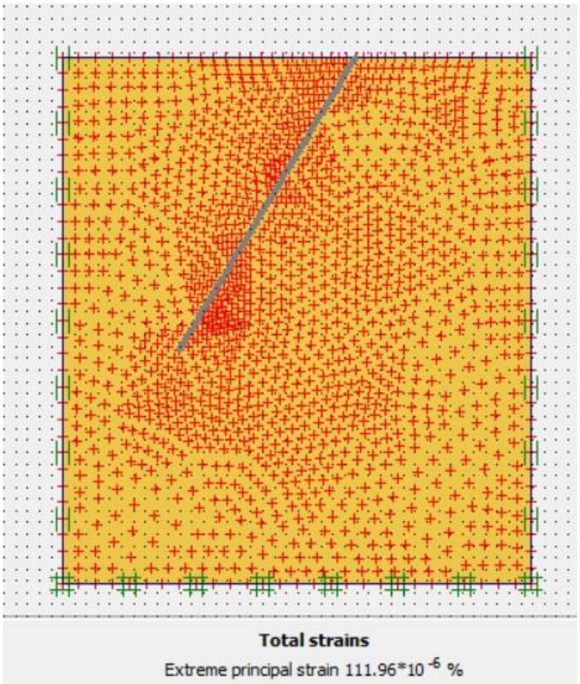


Figure 4.16 Total Strains

Total strains represent the cumulative deformation per unit length that a material undergoes under applied loads. They include both elastic and plastic strains. Strains are typically expressed as a change in length per unit length (dimensionless), often represented as a percentage. PLAXIS allows you to display strains as contour plots or vector plots, which help in assessing the distribution and magnitude of strains across the mesh.

CHAPTER – 5
CONCLUSIONS

5.1. General

Initial tests were conducted on three unique singular pile lengths and two pile groups which contained 3 and 4 pile heaps under inspired stacking. The test results are presented and discussed in the current thesis.

5.2. Conclusions

In lieu of the study and investigation conducted , the following conclusions are drawn:

- How the single piles behave under the application of uplift loading is majorly dependent on firstly (L/d) ratio and the properties of the soil in which the pile is enclosed. The total uplift capacity of a pile is significantly improved by increasing firstly the(L/d) ratio and secondly the relative density of the soil surrounding the pile or the group of piles.

- The upward displacement amounting to about 1.55–2.75% of the pile diameter is necessary for attaining the net uplift capacity for both the singular piles and the pile groups. Quite small upward displacement amounting to 0.5–0.65% of the diameter of the pile, is necessary for developing the allowable load during uplift.

- A pile group which is subject to uplift loading has its efficiency decreasing with an increment in the amount/number of piles in the pile group and with an increment in the ratio of the depth of embedment of the pile to the diameter of the pile.

- How efficiently a pile group performs under uplift loading is directly proportional to the increase in the relative density of the soil.

5.3. Scope of Future Work

The following wide areas related to research are being identified for the investigation regarding how the pile foundations behave when they are subjected to uplift loads at an incline.

- Study of failure systems which includes the surfaces of failure and the mechanism leading to failure.
- Para-metric analysis of (K) which is known as the earth pressure coefficient and also analyzing the adhesion factor.
- Effect or result of particle size distribution of soils and the impact because of size of the piles and the pile groups.
- End states of the piles.

A model that is quite small in scale has been utilized; henceforth, for an analysis which is more comprehensive in the future work, the need for developing a larger scale model arises. Moreover, the study has its focus laid on a model which is static in nature, future research should also be conducted with the inclusion of dynamic modeling.

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