STUDY OF PULLOUT BEHAVIOUR OF FIBRE REINFORCED PILES

A THESIS

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

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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to

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"STUDY OF PULLOUT BEHAVIOUR OF FRP PILES"** in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by ***Aditya Bansal (141671), Anirudh Gupta (141672), Sumit Sohal (141682)*** during a period from June 2017 to May 2018 under the supervision of **Dr. Saurabh Rawat**, Assistant Professor, 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

Pile foundations are frequently used to transmit the superstructure loads to deeper strata, if the subsurface soil is of inadequate strength. In cohesion less soils, the shaft resistance is an important source of pile capacity under axial loading, especially when the pile is subjected to uplift loading. The objective of this report is to find the load-displacement behaviour, failure mechanism generated during uplift of single and group of FRP piles under vertical uplift. Upliftment of piles due to wind effects, seismic events, wave actions or ship impacts causes overturning of structures. Hence to minimize this effect upliftment of pile under various load condition. Filling of Frustum with soil using suitable method, arrangement of Gauges, insertion of pile in to the soil, Upliftment of pile through pulley with help of weights, noting the reading dial gauges analysis of result, analysis of numerical result comparison and validification of results & publishing papers. To find the load displacement behaviour of single piles and group of FRP piles during vertical uplift. To study the failure mechanism of single piles and group piles during vertical uplift.

Keywords: Boundary effect; Uplift apparatus; Fibre reinforced pile (FRP); load bearing capacity; finite element method; Plaxis 2D

CHAPTER 1
INTRODUCTION

1.1 General

The introduction chapter is divided into four section. The first section introduces types and use of foundation. The statement of problem for this study. The objective and scope of work. The last section of this chapter proposed organization of study.

1.2 Type and Use of foundation

The supporting ground is soil which is weaker than any structure material. To transfer the heavier load from super structure to ground in such a way that the supporting soil is not overstressed and not undergo excessive settlement. There are 2 types of foundation.

1. Shallow Foundation
2. Deep foundation

Shallow foundation are used where structural loads are less or soil has high bearing capacity. Deep foundations are used where soil has low bearing capacity, deep foundation such as pile foundation have D_f/B ratio is greater than 15.

1.3 Statement of the Problem

Piles are made of steel, timber, concrete. These traditional piles have been used from long time. Organic soil & marine environments deteriorate these traditional piles. These traditional material have limited life and high maintenance cost in harsh environments.

Chemicals present is soils deteriorate concrete by Alkali aggregate reaction, which further causes cracks in concrete and then further leads to corrosion of reinforcement. In marine environment due to high velocity of wind and impact of waves piles get subjected to uplift loads.

Figure 1.1 - Degradation of piles

(1)

Problems associated with the use of traditional pile materials include steel corrosion and concrete deterioration. Fibre reinforced piles (FRP) represents an alternative construction material that have the potential to eliminate the durability concerns.

FRP materials are considered as an option for deep foundations due to its properties such as light weight, durability and high specific strength. The use of FRP is limited because high initial cost, lack of database, insufficient knowledge for these use in harsh environment.

Our study aims in developing geotechnical properties of FRP under uplift load.

Studying the behaviour of piles under vertical loads as well as the parameters affecting the uplift capacity of piles is one of the most important and interesting areas of research in geotechnical engineering. FRP is generally used in the maintenance work and now there is a emerging scope about the use of FRP as driven piles because of its huge benefits in terms of durability and strength increment.

1.4 Fibre Reinforces Fibre (FRP)

Fibre reinforced polymer (FRP) points out to composite materials consisting of two phases; the reinforcing phase and the matrix phase as shown in Figure 1.2. The reinforcing phase is usually continuous fibre reinforcement, which is the major load carrying element in FRP and regulates its stiffness and strength. The matrix phase provides protection and support for sensitive fibres and also allows local stress transfer from one fibre to another. The matrix may have the form of polyester, vinyl ester, epoxy, phenolic, thermoplastic, etc. The reinforcement fibres are merged with the resin matrix material in a variety of forms to create the laminate. The reinforcement fibres can be made of carbon, glass, aramid, etc. Other terminology for composites include fibre reinforced polymer (FRP), glass fibre reinforced polymer (GFRP), carbon fibre reinforced polymer (CFRP), Aramid fibre reinforced polymer (AFRP), and others. The mechanical properties of FRP composites depend on several factors including the types of fibre and resin matrix, fibre orientation and volume of fibres. That is, mechanical properties such as strength are direction dependent and will differ in the fibre direction and the transverse direction.

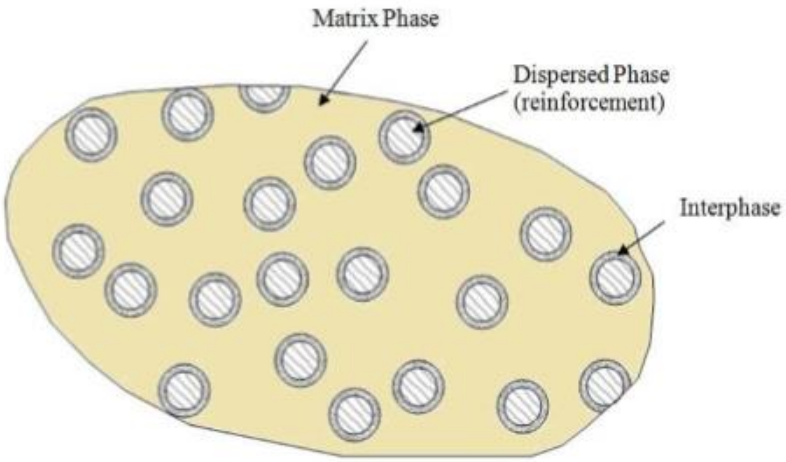


Figure 1.2 - Phases of FRP Composite Material

(1)

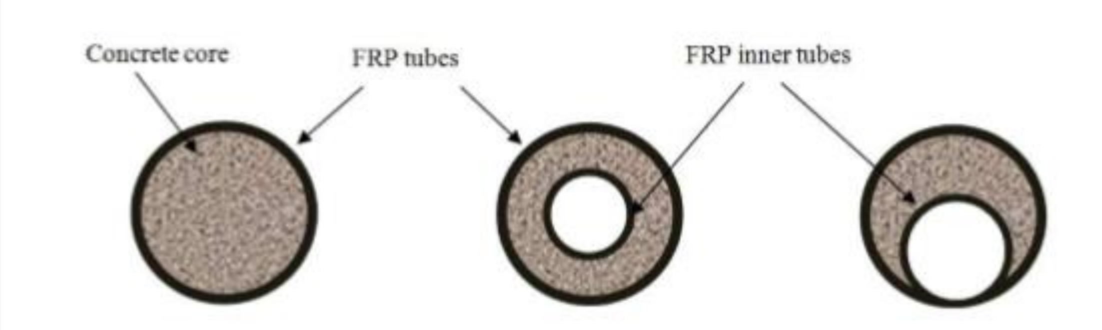


Figure 1.3 – Different configuration of FRP tube confined with concrete

(1)

1.4.1 FRP in Civil engineering

The technology of composites has seen boom from past two decades. The construction industry has started using FRP's. Their specific strength and high resistance to corrosion & electro chemical reactions have made them suitable for use.

The fast deterioration of concrete and corrosion of steel, especially in aggressive environments, such as marine areas, decreases the designed service life of the bridge structure. The use of the same materials to repair or rehabilitate the structure will not resolve.

The use of fibre reinforced polymer composites (FRP's) to replace the traditional materials in rehabilitating old and building new structures is becoming more common.

This system consists of FRP round tube totally or partially filled with concrete as shown in Figure 1.3 The concrete is protected from severe environmental effects and deterioration resulting from freeze-thaw cycles.

Figure 1.4 shows the other potential applications of FRP tubes confined concrete including marine piles, overhead sign structures, poles and posts bridge columns and piers, girders, large pipes and tunnels. The main focus of the present study is on FRP tube confined concrete used in piling foundation system. FRP show great enhancement in strength and stiffness properties (Keller, 2003).Table describes an example of comparison of typical ranges of FRP composite characteristics with those of traditional steel material. These characteristics are gradually being used in the building construction industry for infrastructure applications.

The combination of high specific mechanical characteristics such as strength and stiffness make the designers be able to develop the construction at lower weights and thicknesses. Furthermore, these characteristics enable civil engineers to consider new design concepts that would be limited by the specific properties of other construction materials.

FRP is composed of two materials namely matrix phase and fibre phase. Fibre phase provides the strength to FRP along both tensile and compressive strength and matrix phase is helpful in providing the support to fibre phase by keeping the fibres along fixed alignment. This gives the view that fibre act as a skeleton and matrix phase act as a supporting part.

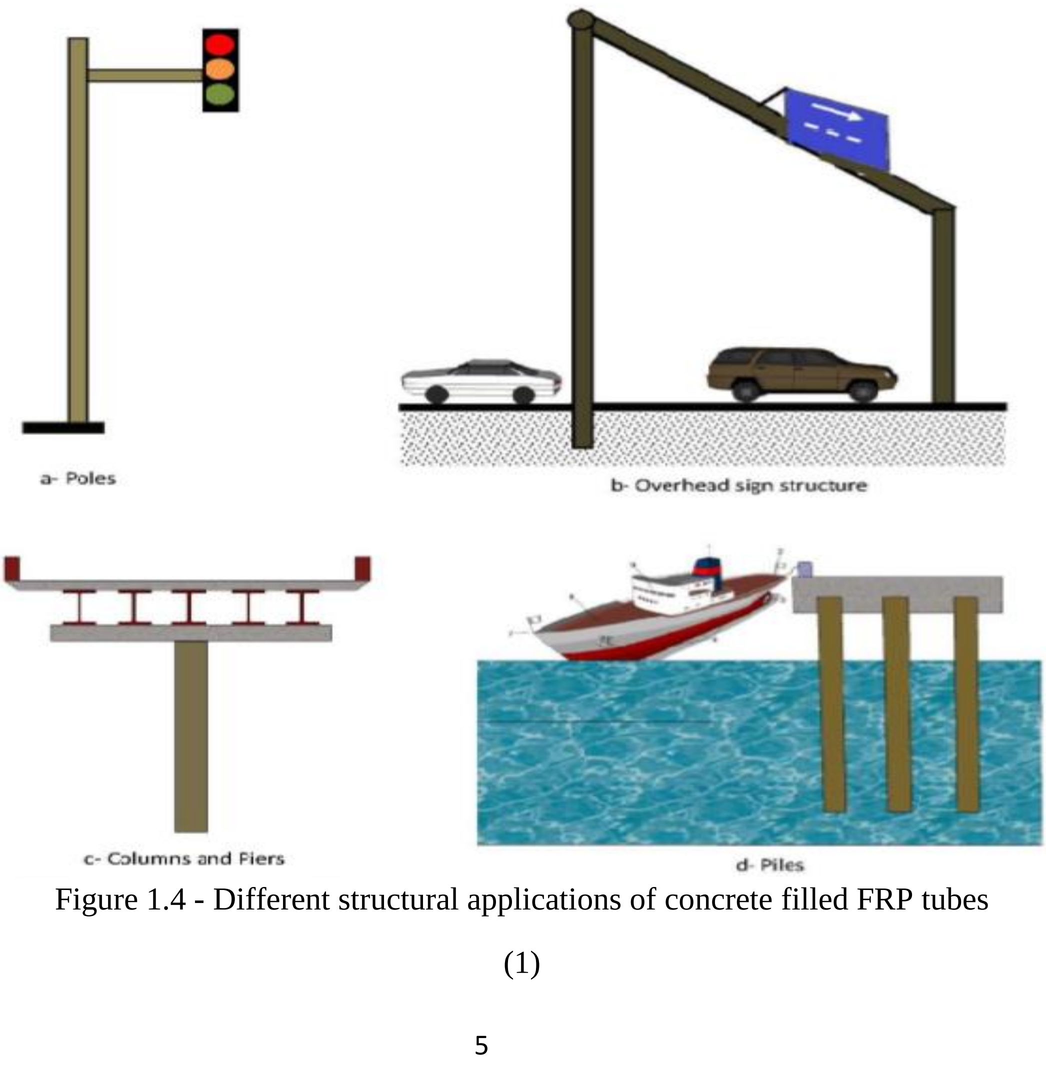


Figure 1.4 - Different structural applications of concrete filled FRP tubes

(1)

Table 1.1 - Comparison between FRP and steel (4)

Property	Merit/Advantage (Rating)		Rating Scale
	FRP	Steel	
Strength/ Stiffness	4-5	4	1. Very low
Weight	5	2	2. Low
Environment Durability	4-5	3	3. Medium
Ease of Field Construction	5	3-4	4. High
Ease of Field Repair	4-5	3-5	5. Very high
Fire	3-5	4	
Transportation/Handling	5	3	
Toughness	4	4	
Acceptance	2-3	5	
Maintenance	5	3	

1.5 Thesis Organisation

Chapter 2 gives detailed information of FRP composite materials in general and special focus on piling materials. This chapter provides you the details of experimental setup, shape of tank, type of pile used, numerical modelling, summary of Literature review and objectives and scope of work.

Chapter 3 describes the methodology and and experimental program carried out on FRP piles. The details of properties of materials, specimen preparations, and fabrications of pullout apparatus, instrumentation, soil properties and testing procedure were presented in this chapter.

Chapter 4 describes the analysis of results using finite element method and provides a information on numerical modelling.

Chapter 5 Provides the results and discussions, experimental results of single and group of piles, result discussion of theoretical value coming from Plaxis 3D, validation of experimental with numerical and failure pattern

.

Chapter 6 provides the summary and conclusions of this paper, recommendations and scope of future work are also given in this chapter.

CHAPTER 2
LITERATURE REVIEW

2.1 General

1. Pile foundations are used to transmit the superstructure loads to deeper strata if the subsurface soil is of inadequate bearing capacity. In cohesion less soils, the shaft resistance i.e. frictional resistance offered by the surface of pile is an principal source of pile capacity under axial loading, especially when the pile is subjected to uplift loading.

2. Uplift forces act on the supporting piles if structures such as basements, dry docks, and pumping stations are constructed below the water table. Additionally, Electric and mobile towers, tall chimneys, submerged platforms, jetting structures, and similar constructions on pile foundations are usually subjected to overturning moments due to wind effects, seismic events, wave actions or ship impacts.

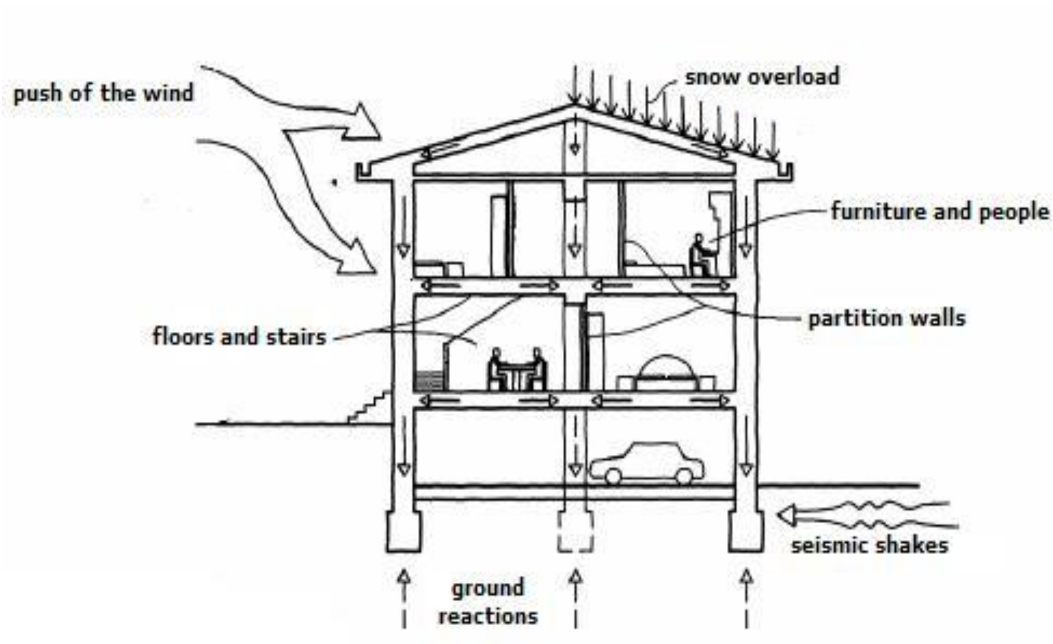


Figure 2.1 - Factors which causes uplift of piles

(1)

3. In such structures, the induced overturning moments gets transferred to the piles supporting the structure in the form of compression in some piles which concrete piles can bear and pull out on others causes problem as concrete is weak in tension. Moreover, uplift forces may be exerted on piles due to swelling of the surrounding soils.

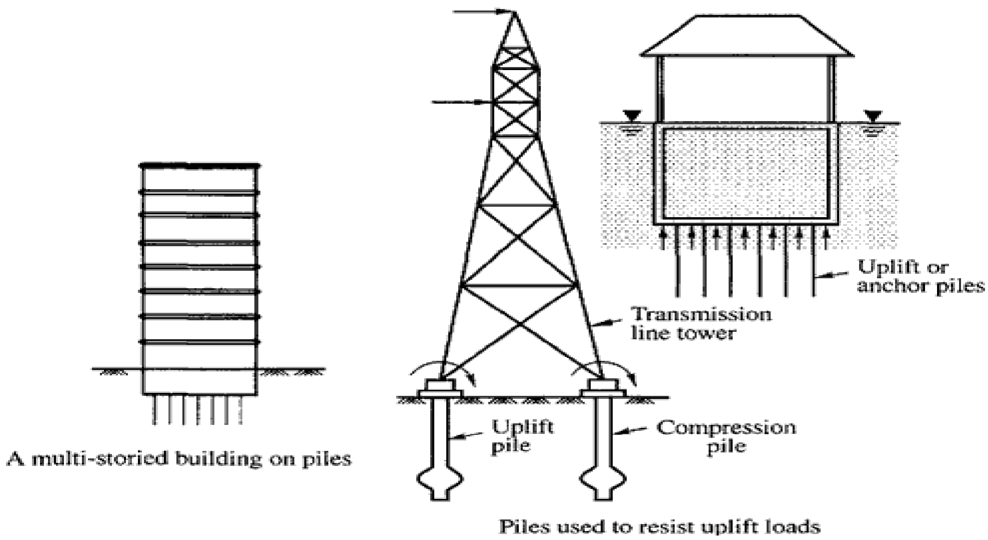


Figure 2.2 - Due to wind load a part of pile is under tension

(1)

4. Moreover, uplift forces may be increase on piles due to swelling of the surrounding soils by the variation of water table. Most studies were done on axial compressive load but less research work was conducted on pile response under uplift forces especially on FRP piles which ensures durability under adverse conditions.

2.2 Literature Review

1. **Hussein A. Shaia (2013)**

   Hussein studied both numerical and experimental behaviour of FRP composite piles under uplift and he laid emphasis on the use of FRP piles under severe soil condition to increase a durability of pile , thus increasing the life span of structure.

FRP are generally used in a maintenance work that is curing of deteriorated piles but he laid emphasis on increasing research on use of FRP as deep foundation material.

Initial installation cost of FRP is high but it proved to be economical in the long span.

Figure 2.3 - Maintenance work

(1)

The interface friction study was conducted between FRP and particulate materials. The interface tests were carried out using a direct shear test. In this, soil is placed in the direct shear box and then FRP pile (surface plane) is placed above soil and then shear test is performed. The shear value gives the roughness of pile. The roughness of pile depends the asperity height and the spatial distribution of them across the surface.

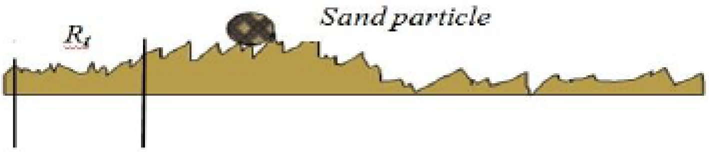


Figure 2.4 - Surface Roughness

(1)

The only disadvantage of FRP is that it is less resistance to heat conditions that is it is less compatible to fire resistance. Stress- Strain behaviour of FRP of considered to be linear elastic of Young modulus of elasticity ranges between 120-580GPA.

In our project, used FRP is characterised as polypropylene random copolymer. It has a life span of about 100 years and have high resistance against sulphates attack in soil and chlorides attack in sea shore environment.

The interaction between the surface of pile and soil mainly depends on:

1. Angle of friction between the pile and the soil.
2. Average effective overburden pressure over the embedded length of pile.
3. For clayey soil, adhesion factor and cohesion in the embedded length of pile

In this paper numerical modelling is done to verify the experimental results. His analysis about pile/soil behaviour using finite element method. Plaxis 3D and ABAQUS are the software which run on finite element method.

2. Khaled E. Gaaver (2013)

Gaaver studied uplift capacity of single and pile groups embedded in cohesion less soil. He tested piles have embedment depth-to-diameter ratios (L/d) of 14, 20, and 26. The sand model is prepared at three different values of relative density of 75%, 85%, and 95%. From this paper, it can be concluded that the influence of pile embedment depth, relative density of soil, and arrangement of piles in a group signifies the uplift capacity of piles.

The study revealed that the behaviour of single piles under uplift loading depends mainly on both the pile embedment depth-to-diameter ratio and the soil properties. He further concluded that the group efficiency under uplift loading improved with an increase in the relative density of soil that more compact the soil, more resistance against uplift loading whereas it decreased with an increase in the pile embedment depth-to-diameter ratio.

From this paper we get a detailed information about our experimental setup and placement of soil. The placement of soil is done by rainfall technique to obtain the desire relative density.

From this, each increment of the load was kept constant till no significant change occurred in displacement, i.e., the difference between two successive readings was less than 0.01 mm per 5 min for consecutive readings.

Experimental setup is made on the basis on the boundary effect. For single pile of known diameter "d", the radius of influence of single pile is ten times of pile diameter from the centre of pile.

For the pile group, the uplift load increases for the closely spaced pile group due to interaction effects between piles.

3. Robert G. Horvath and Dieter Stolle (1996)

He uses a frustum confining vessel for testing piles. The reason behind this is that frustum depicts the actual site conditions of soil that is variation of effective stress in situ is similar to soil confining in frustum.

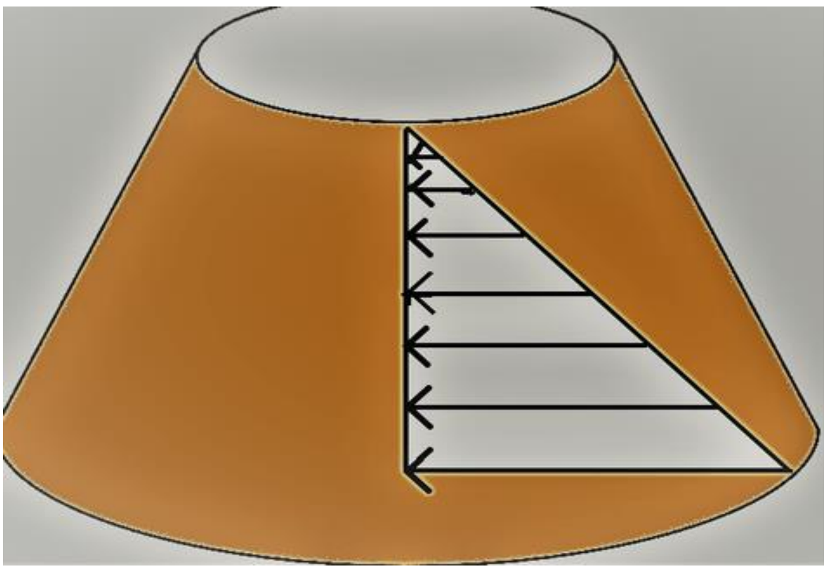


Figure 2.5 - Frustum showing a variation of effective stress

From the figure above it can be concluded that in actual site conditions stress increases with depth is a triangular manner and frustum provides use the real site conditions.

4. K. Faizi, R. Kalatehjari, R. Nazir, A. S. A. Rashid (2015)

Pile slenderness ratio is notable factor for the uplift capacity of pile. The uplift resistance of pile increases with the increase of slenderness ratio. This is generally due to a larger skin contact surface of the pile.

They verify their experimental result from by PLAXIS 2D and 3D finite element method software. It was also observed that that the depth and width of the failure surface increase with the increment of the slenderness ratio. A fine conclusion was observed among the measured bearing capacity of soil and obtained failure surface of the model sand the results of numerical modelling.

Identification of pile failure mechanism is done by plotting graphs of load-shear, load-displacement, strain curve and deformation mesh. From their results, it was concluded that the shear stress area could provide a good prediction for the maximum displacement zone.

5. Leland M. Kraft Jr. (1991)

This paper helps in estimation of boundary effect in case of group pile, thus providing a view in designing a experimental setup of pullout of pile. The lateral boundaries of containers affect the stress and displacement pattern of pile uplift. Friction between the container wall and soil can result vertical stress being transferred to wall. So to erase this issue, the inner surface of container should be painted.

The radius of influence of a loaded pile is 0.9-1.4 times the pile length, depending upon the poisson's ratio. It was concluded that when the pile to diameter ratio equal or exceeds about 0.45 times chamber to pile diameter ratio, the zone of influence reached the wall chamber. Driven piles have large zone of influence than bore piles.

6. Ramli Nazir et al (2014)

Ramli Nazir concluded that the limiting uplift load capacity of the enlarged base pier was influenced by the embedment ratio, the pile diameter, the base diameter, the base angle and the soil relative density. Increasing the base of pile increases the uplift load of pile embedded in soil. Thus under reamed piles have high uplift capacity due to increase weight and surface friction.

7. Gary L. Henderson (2006)

The engineering conclusion is that FRP piles can be used effectively as load-bearing pile sand represents an alternative for deep foundation construction, especially in seashore environments and aggressive soils.

The concluded that FRP piles are good in handling the negative moment induced while pile is subjected to vertical loads.

8. J. R. Compton and W. E. Strohm, Jr.(1968)

This paper laid emphasis that compaction of sand is done by watering method. Since sand bulge due to capillarity at particular water content, to ensure maximum compaction, watering should be done in such a way that it capillarity breaks and it attains maximum density.

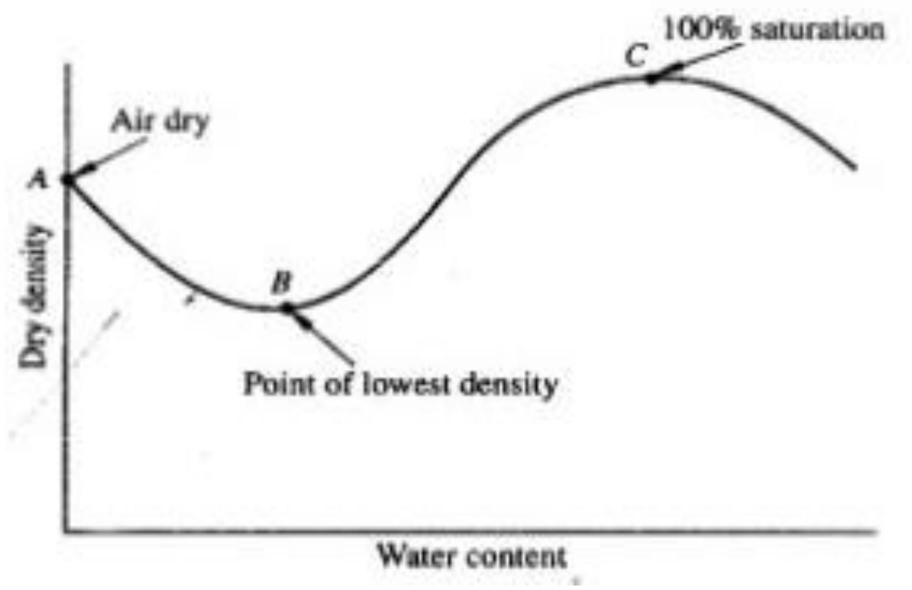


Figure 2.6 – Compaction curve for sand (Ranjan and Rao)

9. W. R. Azzam; and A. Z. Elwakil (2016)

They concluded that there is a considerable increase in uplift capacity of the piles when using fins at the end of the piles. Uplift capacity depends upon length to diameter ratio but upto a certain depth known as a critical depth. After this effective stress calculation remains to be constant. For sand length to depth ratio is 15.

10. IS: 2911 part 1 (2010)

A minimum number of three piles is used under a column in a triangular pattern. When the number of piles required is more than three, the piles are so arranged that they are symmetrical with respect to the load.

The load is transferred to the piles in the group through a reinforced slab called pile cap.

IS: 2911 recommends minimum spacing of 2.5 times the shaft diameter for point bearing piles, 3 times the shaft diameter for friction piles.

11. A.K. Verma, Ronak K. Joshi (2010)

This paper provides us the theoretical uplift capacity of single and group pile and coefficient of earth pressure for the FRP piles. The ultimate uplift capacity of piles under uplift load is determined from the uplift load v/s uplift axial displacement response. The ultimate load is taken as the load corresponding to the point where the pile (or pile group) fails to the load i.e. pile came out of sand bed.

12. Qin Yue et al (2014)

They observed that the displacement increases with the uplift force in a two-phase rule transformation of pile-sand friction which changes from static friction (or rolling friction) to sliding friction is the first phase and particle breakage of sand is the second phase.

13. Jian-Gu Qian et al (2016)

This paper laid emphasis on the shear behaviour of pile. Pull-out resistance and displacement of the piles revealed that the resistance varies with rib spacing and is at a maximum when the ratio of rib spacing to pile diameter is 1, and the resistance is twice that of a smooth pile with the same outer diameter.

14. Nihar Ranjan Patra (2004)

The pile groups were subjected to oblique pulling loads at angles 0, 30, 60 and 90 degrees with the vertical central axis of the groups. They reported the inclinations of the load, at which maximum oblique resistance for the group pile and single pile.

15. Mohammad Zarrabi and Abolfazl Eslami (2016) This paper describes the behaviour of piles under different installation by physical modelling. Modification of installation results in changes in soil–pile interaction, surrounding soil stress states and densities, and lateral earth pressure coefficients.

2.3 Objectives

1. To find the load-displacement behavior of single and group of FRP piles under uplift load.The concrete is filled in the FRP piles and then they are inserted into the soil so that it can settle with the soil conditions after this the vertical load is applied to FRP piles and lifted and through the dial gauges we able to get the reading of displacement.
2. To study the failure mechanism of single and group of FRP piles during vertical uplift.The pile are lifted with help of vertical load and up to a specific point, the failure point is where the pile is totally uplifted from the soil load and displacement reading is noted down.

CHAPTER 3
METHODOLOGY

3.1 General

The first section of this chapter gives the description about type and properties of material used. Further second section gives information about the fabrication process of apparatus designed for the experimental procedure. Third section deals with the instrumentation process and the last gives the detailed information about testing process.

3.2 Materials

3.2.1 Soil

Sand was used as an embedment medium in this work. The dense packing was achieved through compaction through 12.5 kg hammer. Sand is procured from nearby site.

Table 3.1 - Geotechnical properties of sand used in test

Parameters	Value
Percentage of fine material	2.4 (Poorly Graded)
Specific gravity of soil	2.67
Max dry unit weight	20 kN/m^3
Optimum moisture content	16 %
Angle of internal friction	30^0
Uniformity coefficient	2.63
Coefficient of curvature	1.44
Minimum void ratio e_{min}	0.52
Maximum void ratio e_{max}	0.75
Natural Void ratio e	0.59
Relative Density	70%

3.3 Fabrication

3.3.1 Fabrication of Pullout Apparatus

Apparatus was designed in following tool and most of the waste material is used for fabrication process as shown in Figure 3.4. Some of material is procured from the local market of Solan H.P.

Channel sections, angle section, steel plate, flexible steel wire, steel pulleys etc are used. The height of stand is 1.86m as shown in Figure 3.7 with working space of 0.95m*0.76m as shown in Figure 3.5 and elongated arm on the top of length 1.60m to support weighing apparatus as shown in Figure 3.7. A square plate of 0.46m*0.46m was designed as shown in Figure 3.6.

3.3.2 Soil Bin

A frustum shaped soil bin was used to ensure that the upliftment of piles under stressed conditions are closely related to actual site condition. The experiment was performed on model piles in a steel soil frustum.

The frustum bin has a 0.47m upper internal diameter and 0.73m lower internal diameter 710mm depth as shown in Figure 3.3 & 3.1. The base of bin was perforated, to control drain and undrained conditions as shown in Figure 3.2.

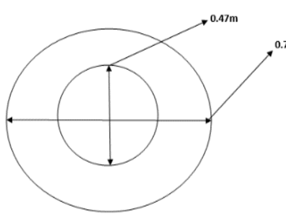


Figure 3.3 - Inner outer diameter

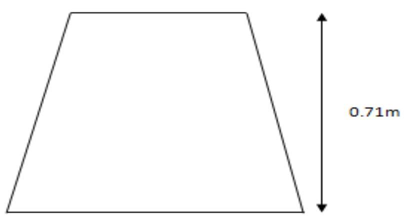


Figure 3.1 - Frustum

Figure 3.2 - Perforations

Figure 3.4 - Fabrication of pullout stand

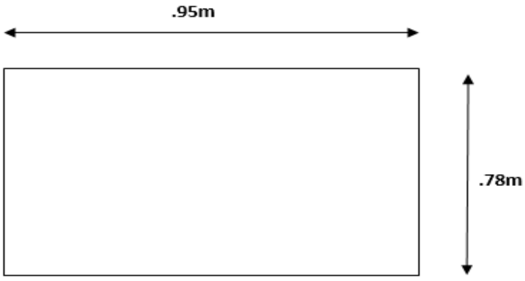


Figure 3.5 - Working space

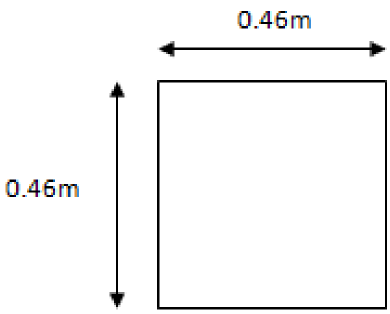


Figure 3.6 - Weighing plate

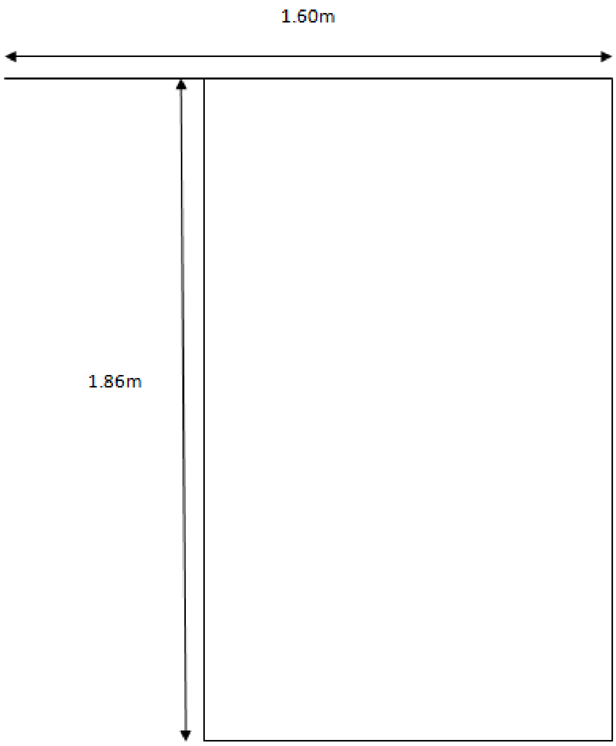


Figure 3.7 - Pullout stand

3.3.3 Pile Cap

Pile cap is used to distribute a single load equally over the pile group and thus over a greater area of bearing potential and to laterally stabilize individual piles thus increasing overall stability of the group. Both single and group of pile was fabricated. Pile caps are thick slabs used to tie a group of piles together to support and transmit column loads to the piles.

The pile cap fabricated for the single pile was 0.20m in length and 0.030m in breadth as shown in Figure 3.9. The square plate pile cap of dimension 0.20m*0.20m was also fabricated so that the piles can be supported into it as shown in Figure 3.10. This pile cap was fabricated to support the 4 piles in square cross section.

transmitted from the structure to the group of piles. In the case of presence of neighbours, piles should be away from the property line by a distance not less than *D* or as the pile installation method requires. The projection of the pile cap should be 10-15 cm.

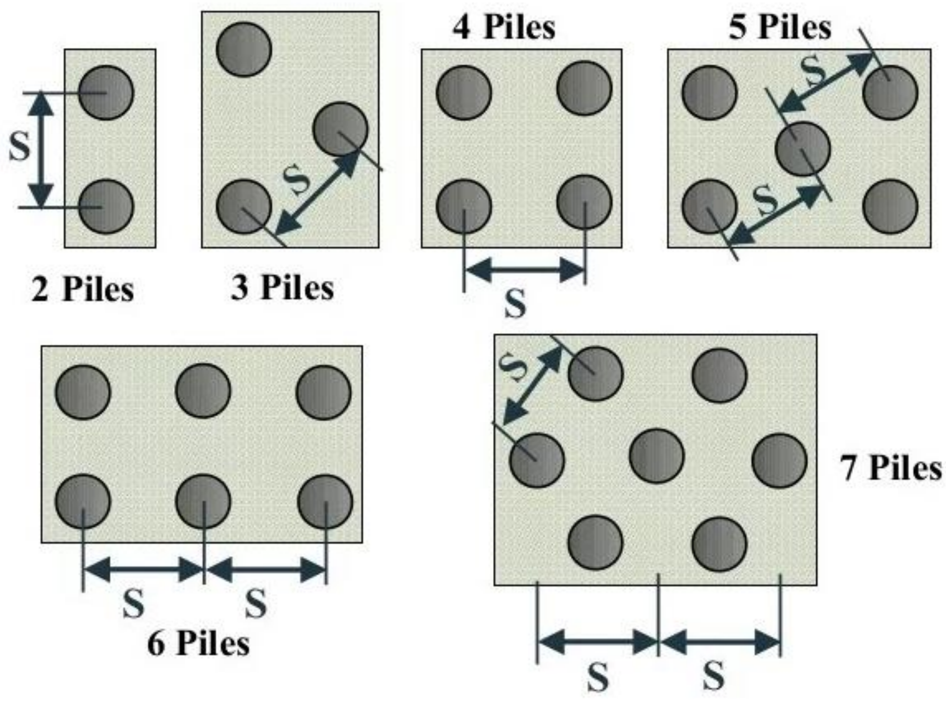


Figure 3.8 - Different Pile Spacing (Ranjan and Rao)

Figure 3.9 - Single pile cap

Figure 3.10 - Group pile cap

3.3.4 Roughness of piles

Skin friction is the main factor governing the uplift load on pile. The behaviour, of an interface shear friction depends not only on the surface roughness of the material surface but also on the grain size of the soil in contact with it. So in order to increase skin friction, pile was circularly grooved through knife as shown in Figure 3.11.

Roughness is one of main criteria in governing the uplift capacity of piles because more the soil and pile interface bonding, it tends to increase the capacity of piles in both bearing capacity under superstructure loads and also uplift loads. Roughness of pile surface is measured by direct shear test. Roughness is also measured by profile roughness device. It is the most popular method of making profile roughness measurement

.

Figure 3.11 - Grooved piles

3.4 Instrumentation

3.4.1 Proving ring

The proving ring is device to measure the force. It consists of elastic ring of known diameter with a measuring device located in the center of ring. The least count of proving ring is 0.01mm and maximum bearing load is 250 Kg as shown in Figure 3.13.

3.4.2 Linear Variable Differential Transformer (LVDT)

LVDT is used for measuring displacement, it is a passive transducer, the supply is provided in the middle coil and outputs are engaged across the other two coils. Unlike most position sensor LVDT have no moving electronic contacts which will eventually wear out or corrode.

Typical LVDT measurement ranges are ±0.25mm up to ±600mm as shown in Figure 3.14. LVDT used in project has maximum displacement of 45mm.

3.4.3 Dial Gauge

A test indicator measures the deflection, the probe does not pull back but swings in an arc around its hinge point. The lever may be interchanged for length or ball diameter, and permits measurements to be taken in narrow grooves and small bores where the body of a probe type may not reach as shown in Figure 3.12.

3.4.4 Pulleys

A pulley is a wheel on an axle or shaft that is designed to support movement and change of direction of a cable or belt or transfer of power between the shaft and cable. A pulley may have a groove between flanges around its circumference to locate the cable or belt. A gun tackle arrangement was used in experiment. It works on the mechanism of weight balancing.

Figure 3.13: Dial gauge

Figure 3.12:Proving ring

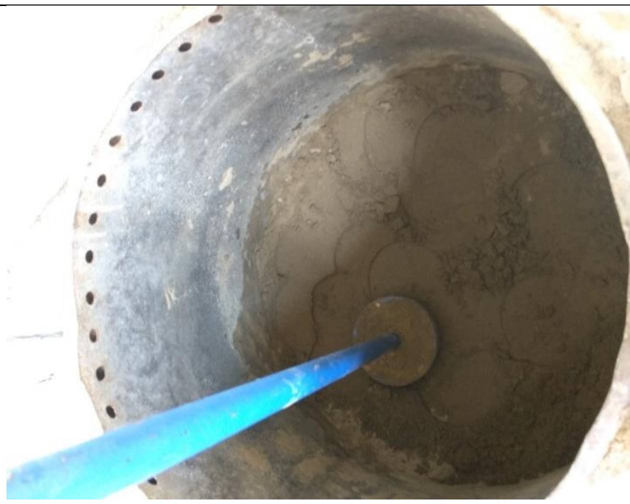
Figure 3.14:LVDT

3.5 Testing Process

3.5.1 Installation Process

1. To increase the surface roughness, single and group piles, pile was grooved.
2. The sand was sieved through 4.75 mm sieve and filled in the empty soil bin in 6 layers of 115 mm each as shown in Figure 3.15.1.
3. Each layer was tempted with the hammer of 12.5Kg with 25 blows as shown in Figure 3.15.2 such that to attain relative density of 70%.
4. Pile was suspended centrally and vertically in the soil bin after laying 2 layers of soil as shown in Figure 3.15.3 & 3.15.4.
5. Soil bin was filled by laying each soil layer and tamping it simultaneously.

1.Sieving of soil



2.Tamping

3.Installing single Pile

4.Installing group of Piles

Figure 3.15 - Installation of pile

3.5.2 Testing Procedure

1. After installation of pile both in single and group of piles, it was left for one to two days to allow sand to form bond with pile.

2. Proper set up was assembled for practical analysis by setting up proving ring, dial gauges and LVDT as shown in Figure 3.16 & 3.17.

3. Experiment was carried out by applying incremental increasing load as shown in Figure 3.16 when pile displacement is less than 0.1mm/hr in digital displacement meter.

4. Proving ring and dial gauge reading were taken on increment of every successive load.

5. When dial gauge reading becomes constant, this stage shows our net uplift load at which the pile fails.

Figure 3.16 - Upliftment of group pile

Figure 3.17 - Set up for single pile

Figure 3.18 - Set up for pile group

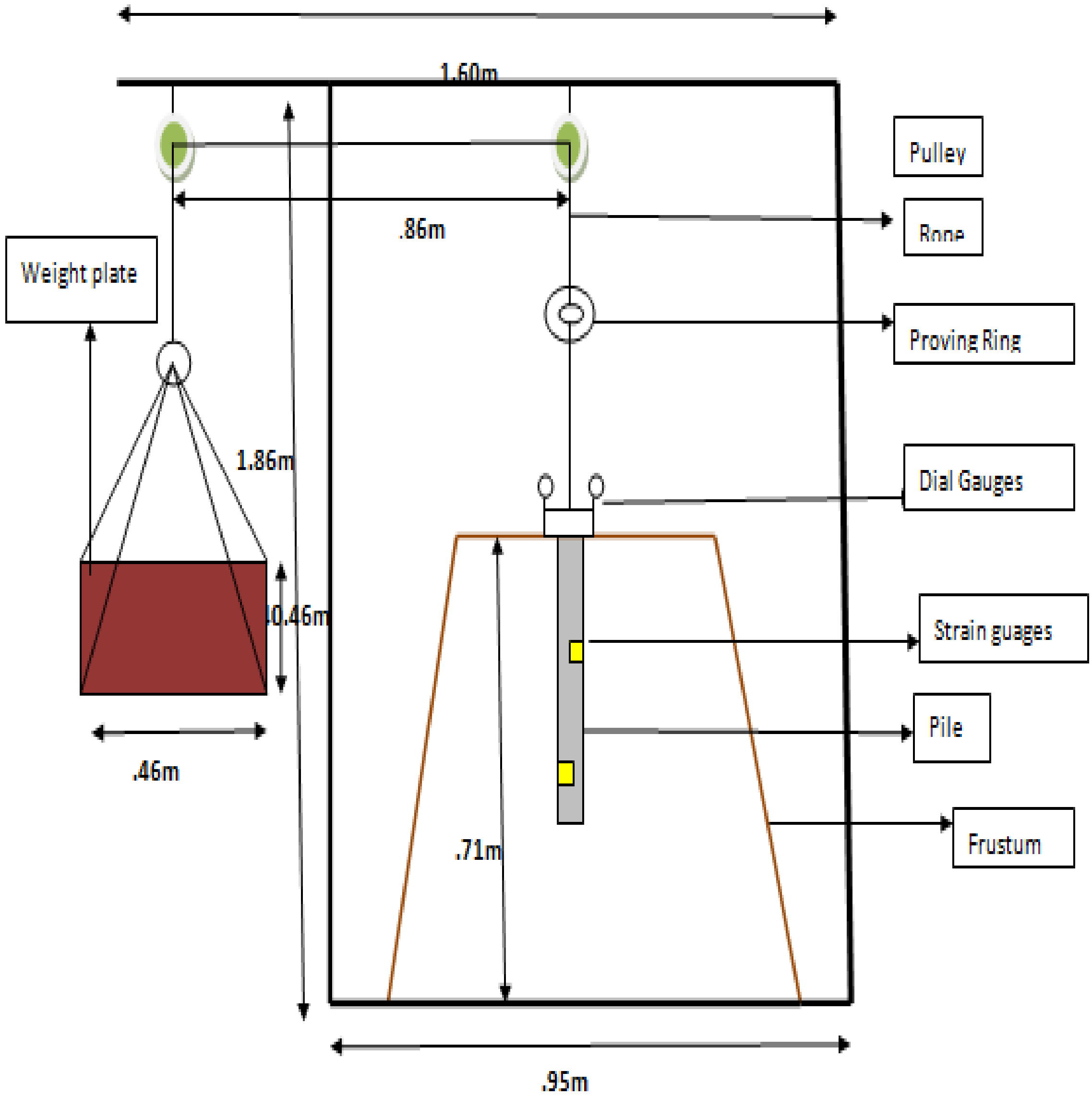


Figure 3.19 - Line diagram of apparatus

Our fabricated model of uplift was tested by applying uniform load with the help of a plate in contact with a surcharge plate. The uniform loading was done in regular intervals in order to give ample time for the various values being noted to become constant.

The model proposed to be fabricated and the actual model fabricated has been depicted in Figure 3.19.

CHAPTER 4
NUMERICAL MODELLING

4.1 GENERAL

Numerical modelling is a technique for providing analytical solution for those models whose solutions are too complex to get generated. A mathematical model is a closed form solution i.e. whose can be described as mathematical analytic function.

A mathematical model can be described in to the form of table, graph and charts. Numerical modelling has been used into rock mechanics, flow of liquid can also be stimulated by numerical models, shows the movement of ground water beneath the soil.

Different types of numerical modelling methods are:

1. Finite element method

2. Spectral method

3. Finite volume method

4. Finite difference method

5. Discrete element method

The method which we are using is Plaxis 3d which is based on finite element method. The finite element method divides object into smaller parts or sub domains so that each part can be analysed separately properly.

This method generate approximate solution over no of discrete no of unknowns. FEM uses variation methods form the calculus variations for generating a approximate solution by minimising the error from it.

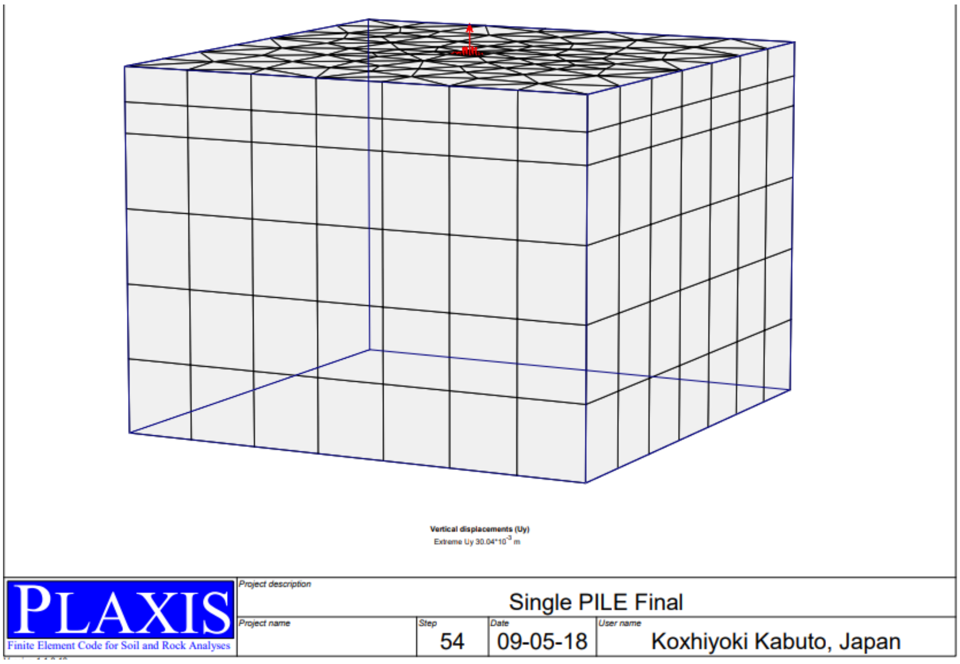


Figure 4.1 – Model Configuration

4.2 Materials

Pile is taken as element and soil is taken as model. In this we massive circular pile is taken of diameter 0.025m and outside clearance of pile is set with soil model. The young modulus of pile is taken as 135000Mpa, Poisson's ratio of pile is taken is as 0.3 and pile is taken as linear elastic in nature. The finite element method is done on Mohr coulomb criteria.

According to Mohr coulomb theory the failure criteria is obtained from the plot between the shear strength and applied normal stress.

4.2.1 Mohr coulomb in Plaxis

The linear elastic perfectly plastic mohr coulomb model works on five input parameters i.e. young modulus E, Poisson's ratio for soil elasticity ,cohesion C, friction angle and dialatancy angle. The Mohr coulomb model gives first order approximation of soil or rock. For each layer a constant stiffness is considered. Due to this constant stiffness the computations or result comes very fast and estimate of deformations can easily be made out.

For a first request estimate of the genuine soil conduct, the Mohr-Coulomb display has been chosen as the material model. For our thought, the model requires 5 input parameters, in particular, Young's modulus E, Poisson's proportion ν, cohesion c, friction angle of soil φ, and a dialatancy angle ψ. While reproducing the drained behaviour, no excess pore water pressures were produced, which is essentially our case. The saturated and unsaturated unit weights, strength parameters of the soil are determined in the lab. The values obtained from the laboratory testing are used for the input in the numerical modelling. In case of Poisson's ratio and dialatancy angle, standard values for sand have been used. The soil parameters have been presented in Table 4.1

Table 4.1 Material Properties Used in Numerical Modelling

Soil Properties

Properties	Values
Mass Density, kg/m^3	1.63
Poisson's Ratio *(v)*	0.30
Friction angle (ϕ), degrees	30
Dilation angle (ψ), degrees	0
Cohesion, kg/cm	0.07
Young's Modulus, KN/m^2	50,000
γ_{unsat}, KN/m^3	17
γ_{sat}, KN/m^3	20

FRP Properties

Properties	Values
Mass per unit area, g/m^2	200
Stiffness, KN/m	150
Modulus of Elasticity (*E*), MPA	135,000
EA, KN/m	75,000
Porosity	Non-porous

CHAPTER 5
RESULTS AND DISCUSSION

5.1 General

This chapter gives you overview about our practical analysis of uplift of single and group piles. The experimental test were conducted on FRP piles with diameter of 25mm in soil bin. The tested piles have embedded depth to diameter ratio (L/d) of 14.

The sand bed was set at relative density of 70%. Single pile and pile groups containing four piles in square manner. The analysis revealed that single piles under uplift loading depends on L/d ratio, shaft friction and soil properties. The load and displacement curves and failure pattern of single and group piles were observed.

5.2 Results from model testing

5.2.1 Single pile under uplift loading

Test was conducted on single pile at L/d ratio of 14 and relative density of 70%. As shown in graph (Figure 5.1) relationship has been derived between uplift load and corresponding displacement of pile embedded in cohesion less soil medium.

From this graph we can easily predict that the pile has failed at a load of 47 kg and uplift displacement observed was 22mm. it can be seen from the graph (Figure 5.1) that the uplift capacity of single pile decreases as the soil becomes denser.

From the graph (Figure 5.1) it was observed that after applying load of 47 kg the displacement has become constant for every increased value of load. From the graph, it can be concluded that firstly small part of pile is mobilising uplift this causes steep rise in curve, after increment of load, whole shaft surface is mobilising uplift, the slope of graph tends to decrease and then after when whole frictional capacity exceeded, pile fails.

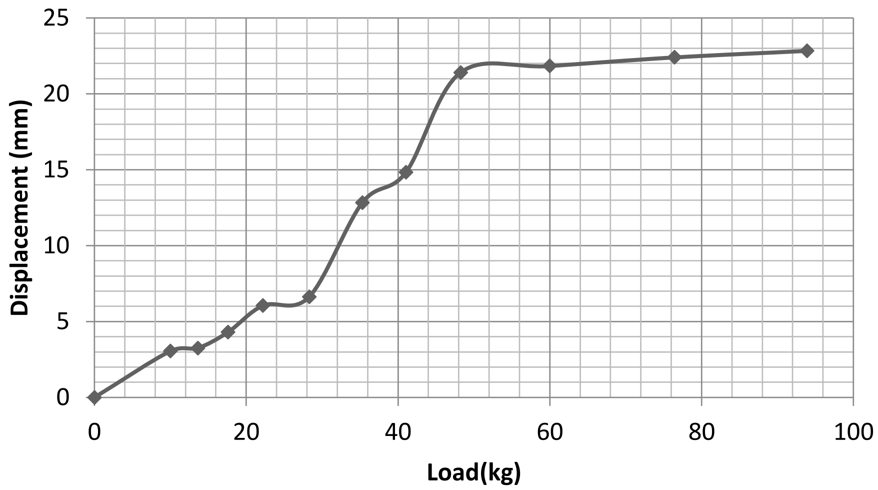


Figure 5.1 – Variation between load and displacement

5.2.2 Theoretical ultimate capacity of single pile.

The theoretical capacity of single pile of diameter d= 25mm and length L= 0.35m is given by

$$Q_u = 0.5K_s\sigma_y tan\delta Z_c + K_s\sigma_y tan\delta\pi(L - Z_c) \quad \text{(Eq-1) (9)}$$

K_S = Coefficient of earth pressure

6_V = Effective Vertical stress at a depth of Z_C

δ = Soil pile friction angle

Z_C= Critical depth of embedment

From equation 1 the theoretical uplift of single pile was calculated to be 36.83 Kg and experimental value was 47 Kg.

5.2.3 Variation of Pressure with depth for single pile

The pressure was calculated at different depths of soil using formula P = k_Aɤh (Ranjan Rao) where k_A is coefficient of earth pressure, ɤ is dry density of soil and h is soil depth. From this graph (Figure 5.2) can see that pressure has increased linearly with depth. Also active pressure applied by soil increases linearly with depth.

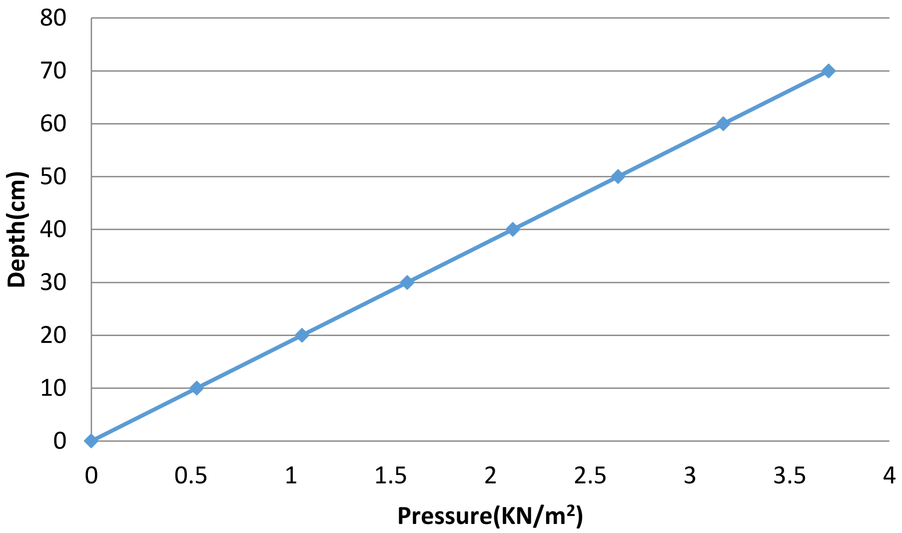


Figure 5.2 – Variation of pressure with depth

5.2.4 Variation of Displacement ratio with load of single pile

The graph was plotted between the load and displacement ratio i.e. ratio of displacement observed to pile diameter, where pile diameter is 25mm. From this graph we can see that at low load the initial stiffness is same at early stage of loading, where as when the load is increased the pile has shown a stiffer response especially at high displacement ratios.

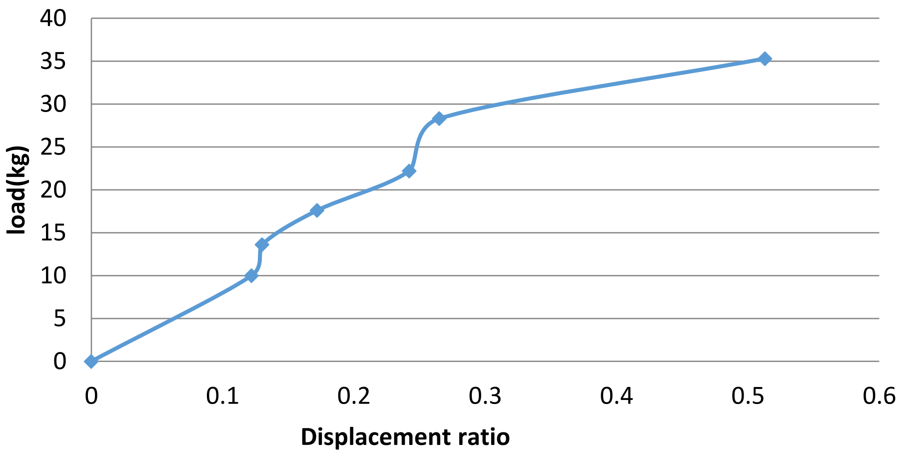


Figure 5.3 – Variation of displacement ratio with load

5.2.5 Pile group under uplift loading

For pile of group four piles were placed in square manner at centre to centre spacing of 3d i.e. 75mm (Rajan Rao). Graph (Figure 5.4) shows the failure pattern of uplift of pile group and load at which failure occurs was 120 Kg and displacement observed was 12.86mm. From this graph (Figure 5.4) we can predict that after applying 120 kg load or above displacement becomes constant, which depicts that failure has occurred.

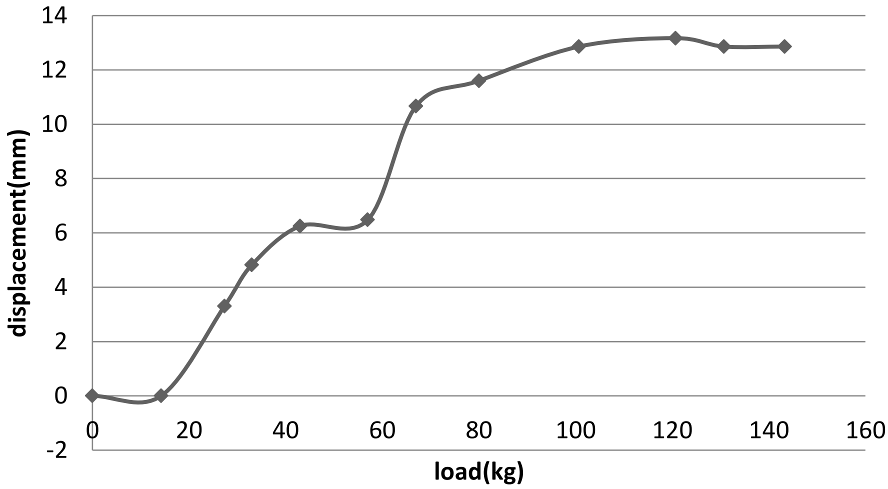


Figure 5.4 –Variation of load displacement of group pile

5.2.6 Theoretical ultimate capacity of Pile group

The theoretical capacity of single pile of diameter d= 25mm and length L= 0.35m is given by

$$Q_u = 0.5K_s\sigma_y tan\delta Z_c + K_s\sigma_y tan\delta\pi(L - Z_c)dN\eta_g \quad \text{(Eq-2) (9)}$$

K_S = Coefficient of earth pressure

6_V = Effective Vertical stress at a depth of Z_C

δ = Soil pile friction angle

Z_C= Critical depth of embedment

N= No of piles

η_g= group efficiency factor

The theoretical capacity of group pile was found to be 147.32 Kg and experimental value was 120 Kg.

5.2.7 Variation of efficiency with displacement for group pile

This is the plot between the efficiency and displacement of group pile. The efficiency can be calculated using formula:

$$\eta = \frac{Q_{ug}}{Q_u} \times n_1 n_2 \qquad \text{(Eq-3) (9)}$$

Q_{ug}=Uplift load capacity of group pile

Q_u= Uplift load capacity of single pile

n_1 = No of piles in rows

n_2= No of piles in column

Efficiency was calculated to 76%.

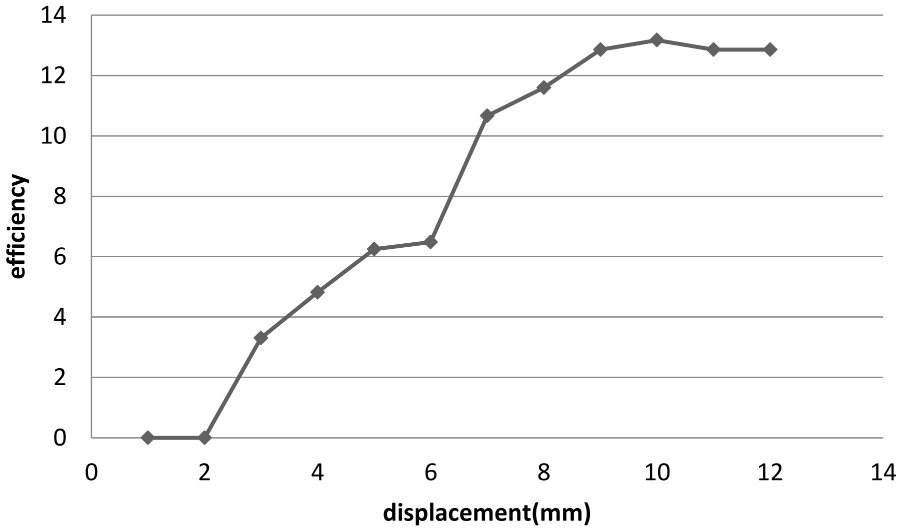


Figure 5.5 – Variation of displacement with efficiency

5.2.8 Variation between load and Displacement ratio for group pile

The graph was plotted between the load and displacement ratio i.e. ratio of displacement observed to pile diameter, where pile diameter is 25mm. From this graph we can see that at low load the initial stiffness is same at early stage of loading, whereas when the load is increased the pile has shown a stiffer response especially at high displacement ratios.

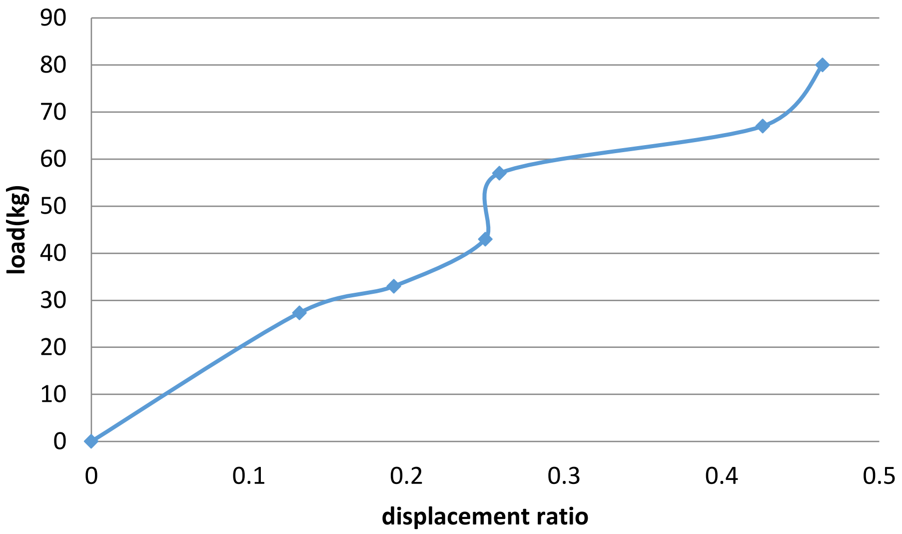


Figure 5.6-Variation of displacement ratio with load for group pile

5.3 Numerical modelling

5.3.1 Single pile

Once the geometry of the model assigned, there occurs a need to divide the geometry into finite elements in order to permit finite element calculations. The organization of finite permits fully automatic mesh generation in majorly these medium, fine and very fine.

The vertical and horizontal boundaries directions were considered to be fixed in their respective directions. The stability of the foundation soil does not form a part of this analysis therefore the bottom boundary of the model has been simulated as a fixed boundary.

Figure 5.7 represents the generated mesh.

Green colour in the mesh shows pile and blue stratum depicts the soil. 3-D modelling delivers much more accurate results but requires a high-end processor for the computation. PLAXIS 3D has been developed as advanced and extended package, including advanced soil models, static elastoplastic deformation,, stability analysis, consolidation, updated mesh analysis and steady-state groundwater flow.

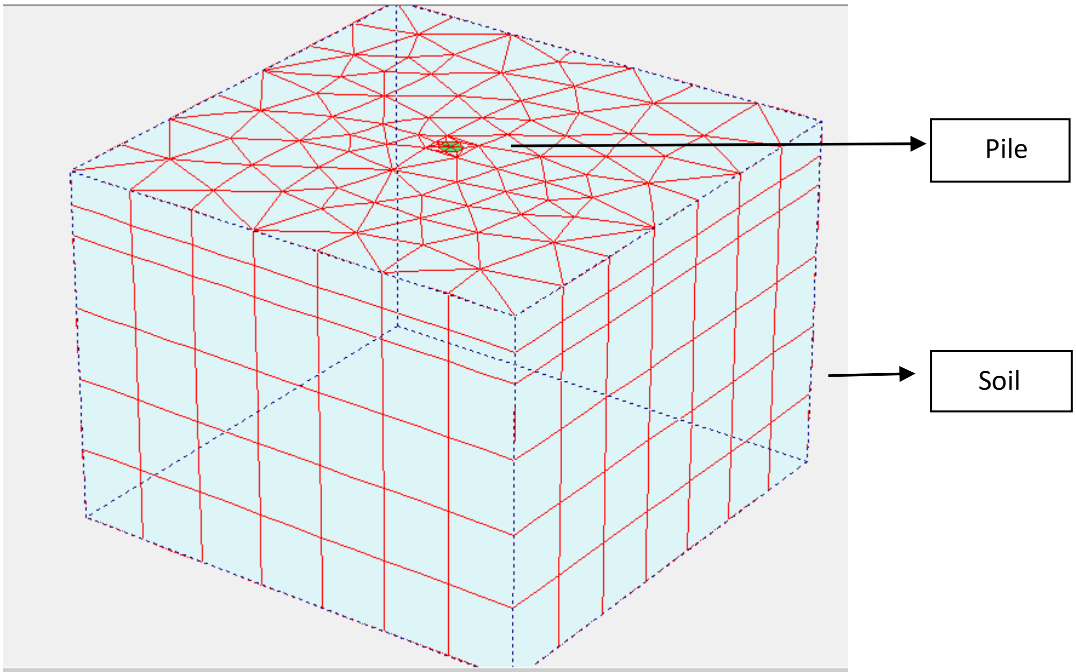


Figure 5.7 - Input after meshing

The parameters affecting the initial stress of a soil mass are its own weight and history of soil formation. In Plaxis, the effective initial stress is analysed by the Ko (at rest) condition.

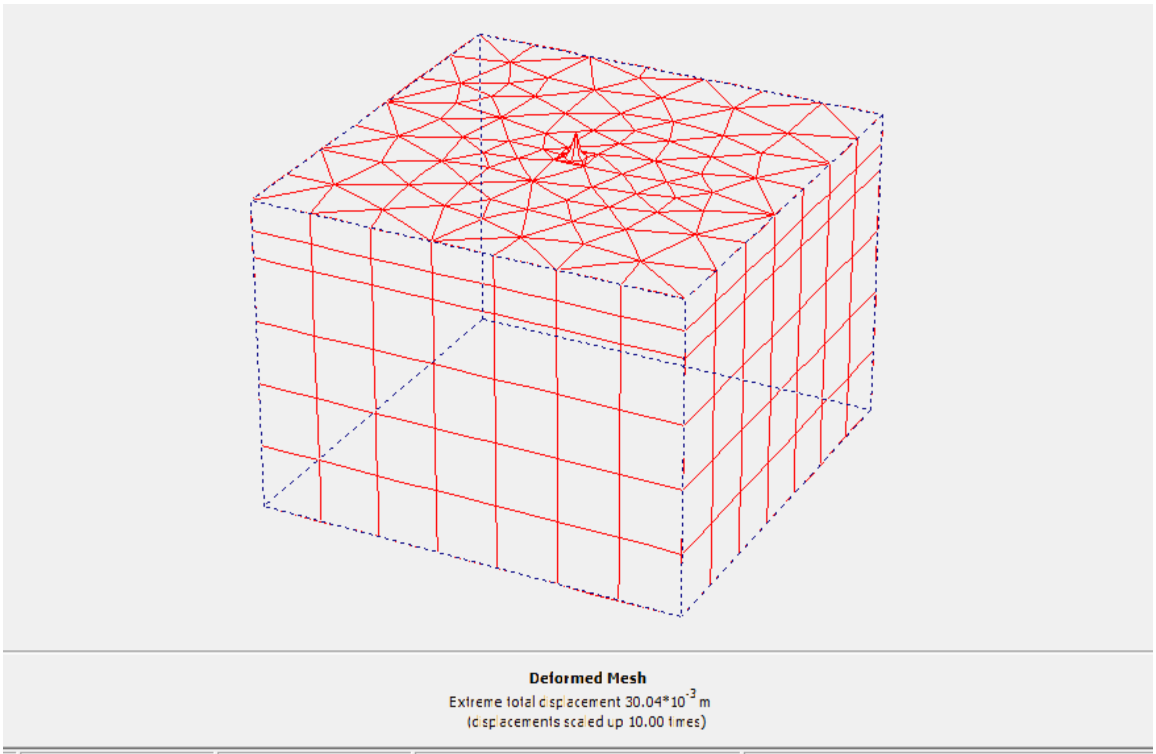


Figure 5.8 - Deformed mesh showing uplift displacement of 30mm

Due to the presence of vertical load, the soil mass undergoes a smaller degree of initial bulging, which consequently results into the vertical movement of pile. The movement of pile, as analysed in Plaxis 3D results in the maximum displacement of 30mm for single pile and 30 mm for pile group.

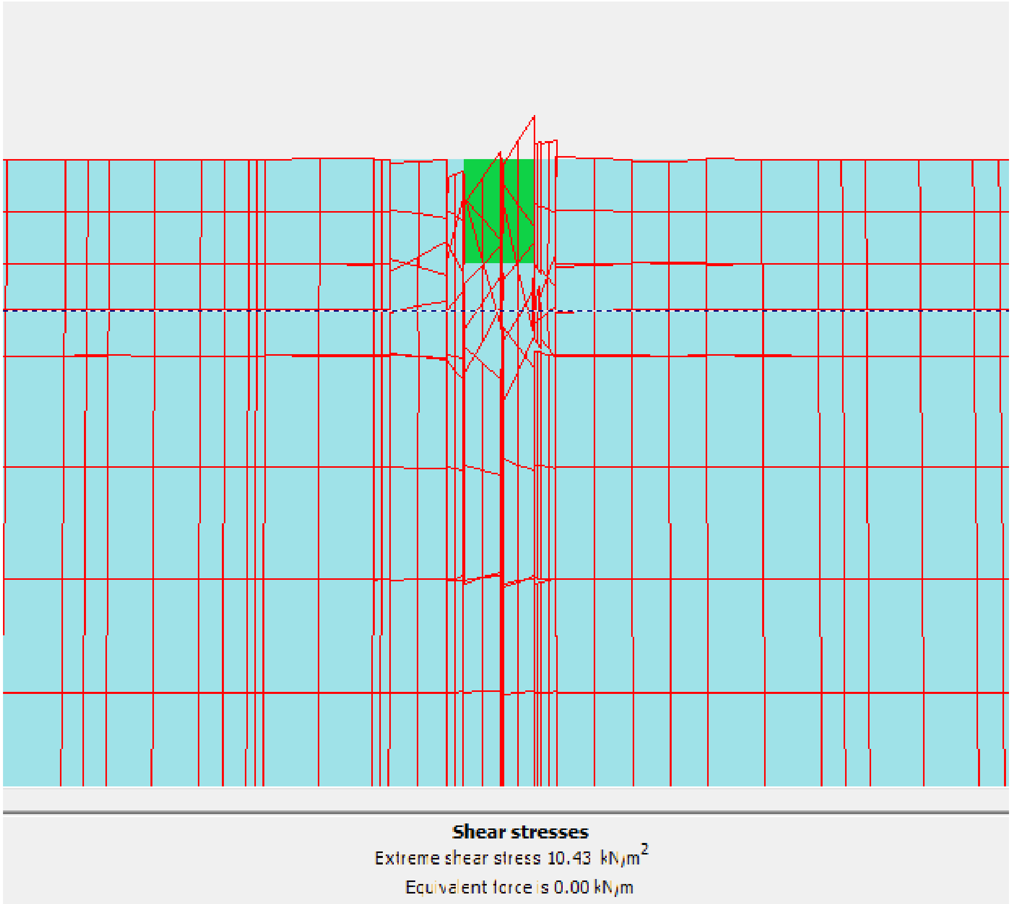


Figure 5.9 - Shear Stress Distribution

The shear stress is developed when the pile is uplifted. The value obtained from Plaxis shows that if we use conventional concrete pile, concrete will fail in shear as it exceeds the shear strength of concrete. General maximum shear strength of concrete for M25 grade is 1.8 N/mm^2.

From the figure it can concluded that the shear stress is generated between the interface of the FRP pile and the soil. From the Plaxis 3D result, the shear stress at the cross section of the centre of pile gives value of 10.43 N/mm^2.

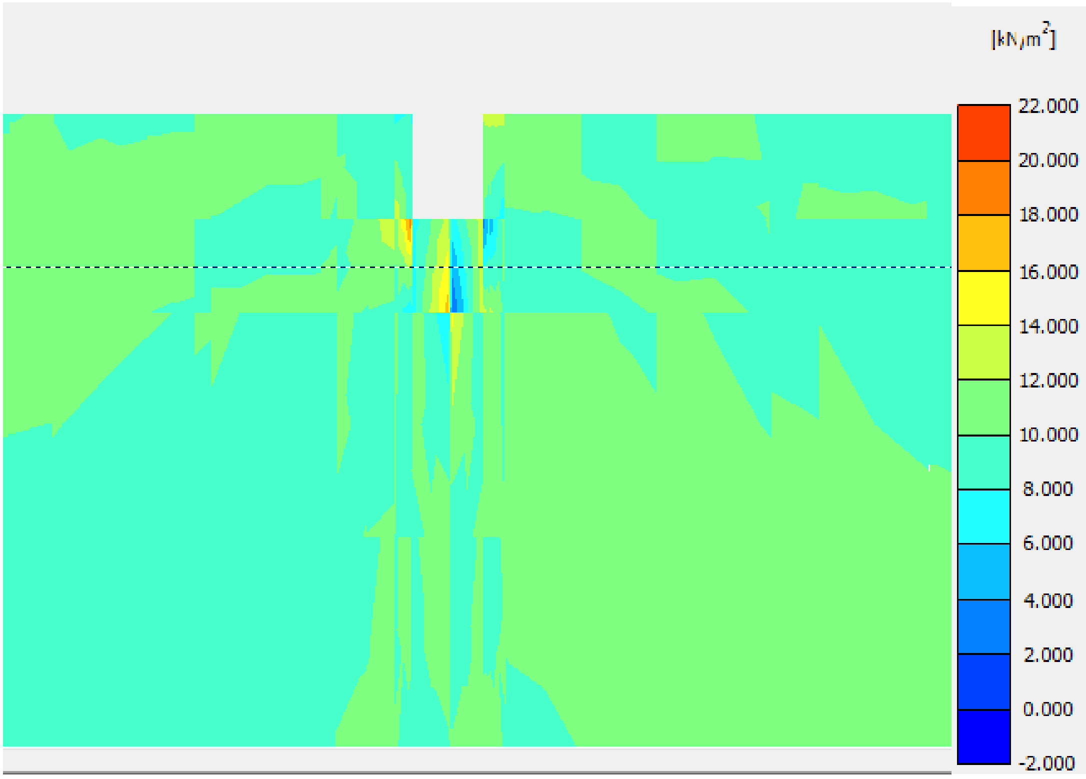


Figure 5.10 - Shear stress Shading

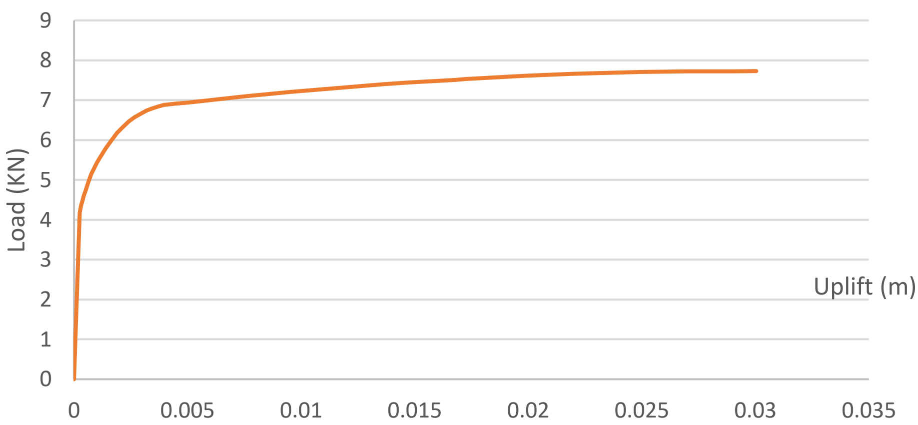


Figure 5.11 - Load-displacement curve in Plaxis 3D

5.3.2 Pile Group

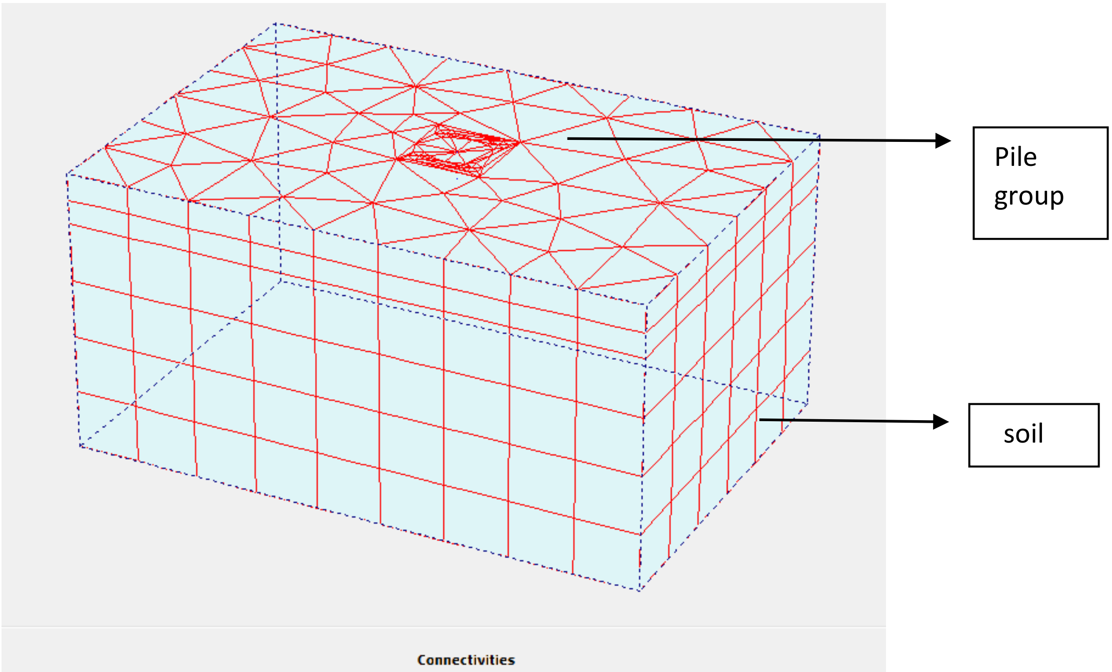


Figure 5.12 - Input after meshing

The maximum deformation in pile group according to Plaxis 3D is 25mm which is lower that single pile uplift.

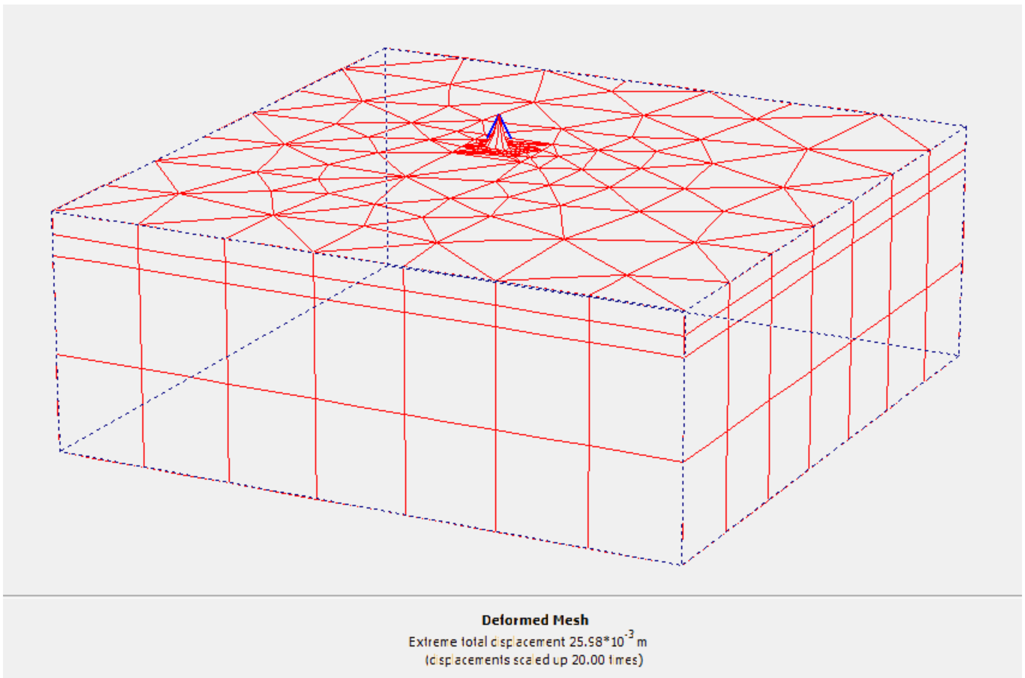


Figure 5.13 - Deformed mesh showing 25mm displacement of pile group

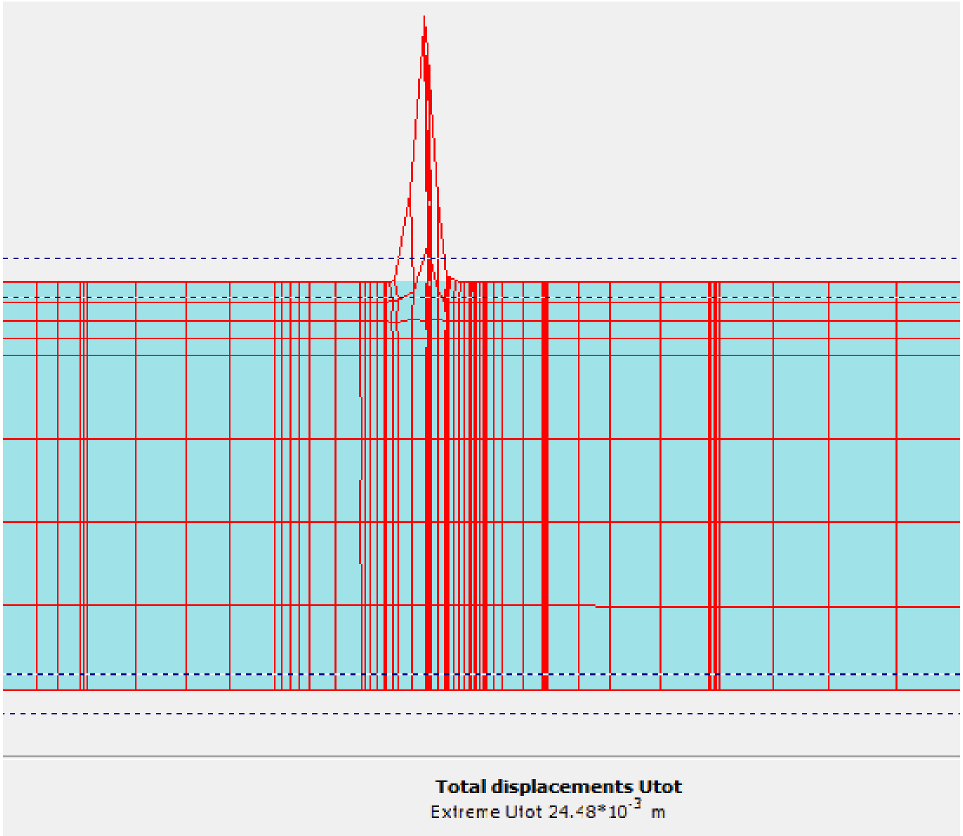


Figure 5.14 - Shear Stress at Pile

Figure 5.15 shows heaving of soil both in model single pile and Plaxis 3D output.

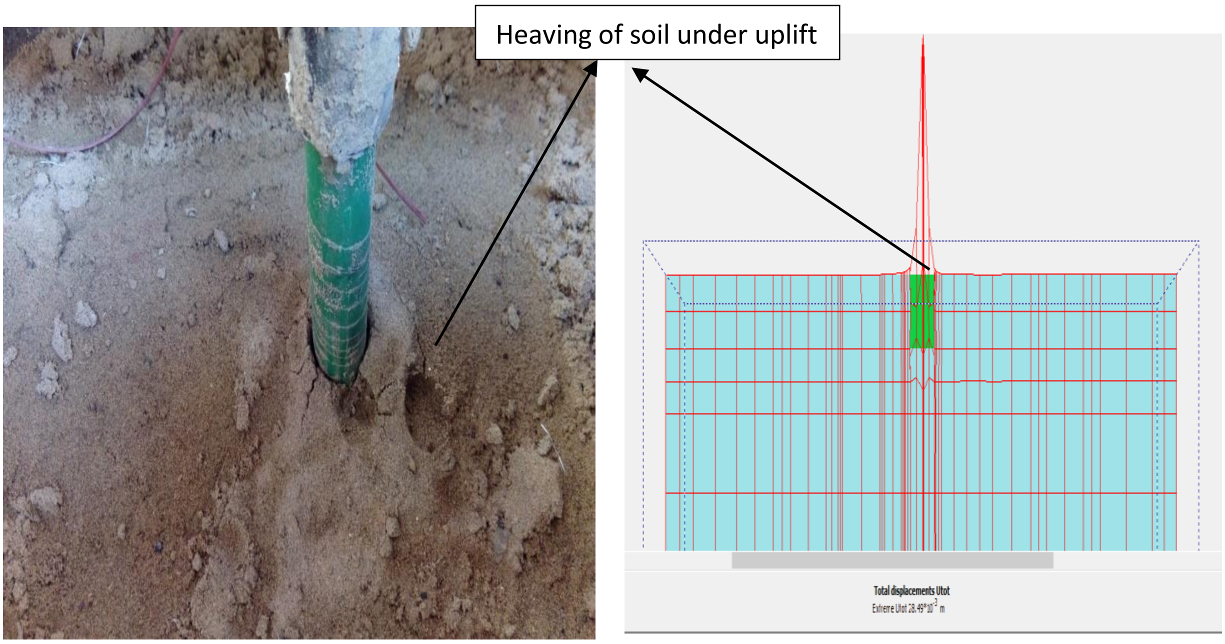


Figure 5.15 - Experimental and numerical using Plaxis 3D

1. Tests were conducted on single and group piles under uplift loading, where the piles have (L/d) of 14. Test were conducted on relative density of 70%. relative density of soil has a significant contribution to both the net uplift capacity and the displacement at the uplift capacity of single piles.
2. Experimentally, the fail of single pile comes in 22mm at 47 kgf and using Plaxis 3D , at that particular load the uplift displacement is found to be 30mm.
3. For the pile group. 12mm was the experimentally and Plaxis 3D provides us the displacement of 25mm.The net uplift capacity increases significantly with an increase of (L/d) ratio.

CHAPTER 6
CONCLUSIONS

6.1 General

We performed the experimental and numerical testing of the FRP uplift. It can be concluded that the technique of soil reinforcement has evolved and contributed to the infrastructure in terms of speed, ease of construction, economy and aesthetics.

6.2 Conclusions

- The behavior of piles under vertical loading depends mainly on both the pile embedment depth-to-diameter ratio (L/d) and the soil properties such as relative density and soil aggregate properties. The net uplift capacity of a pile improves significantly with an increase in both the (L/d) ratio and the relative density of soil.
- The load–displacement behavior of a single pile and group piles embedded in sand under uplift loading shows that pile group has less displacement as compared to single pile upliftment.
- The uplift capacity of group piles increases when piles are closely spaced because closely spaced piles tends to densify the soil with its zone of influence.
- Group efficiency of pile group ranges from 0.76-0.83.

6.3 Scope of future work

Study on FRP piles is limited and needed to enhance research on use of FRP piles in mass construction work. Experiment should be done cohesive soils and also with different soil types.

The response of FRP piles to extreme loading conditions such as impact load and seismic should be evaluated. The response of FRP pile under earthquake should be evaluated.

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