COMPARATIVE STUDY ON LATERAL CAPACITY OF UNDERREAMED MONOPILE IN COHESIONLESS SOIL

THESIS REPORT

Submitted by

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TKM21CESC13
to

the A P J Abdul Kalam Technological University

in partial fulfillment of the requirements for the award of the Degree of

Master of Technology

in

Structural Engineering & Construction Management

DEPARTMENT OF CIVIL ENGINEERING

T.K.M. College of Engineering, Kollam

July 2023

DECLARATION

I undersigned hereby declare that the project report, **“Comparative Study On Lateral Capacity Of Underreamed Monopile In Cohesionless Soil”**, submitted for partial fulfilment of the requirements for the award of degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of **Dr. Rekha Ambi,** Assistant Professor of Department of Civil Engineering. This submission represents my ideas in my own words and where ideas or words of others have been included. I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated anydata or idea or fact or source in my submission. I understand that any violation of the above will because for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permissionhas not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Place: Kollam **RAMU RADHAKRISHNAN**

Date: 11-07-2023

DEPARTMENT OF CIVIL ENGINEERING

T.K.M. COLLEGE OF ENGINEERING, KOLLAM

CERTIFICATE

Certified that this report entitled **‘COMPARATIVE STUDY ON LATERAL CAPACITY OF UNDERREAMED MONOPILE IN COHESSIONLESS SOIL’** is the report of the project presented by **RAMU RADHAKRISHANAN, TKM21CESC13** during **2022-2023** in partial fulfillment of the requirements for the award of the Degree of Master of Technology in Structural Engineering & Construction Management of the A P J Abdul Kalam Technological University.

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ACKNOWLEDGEMENT

I take this opportunity to express my deep sense of gratitude and sincere thanks to all who helped me to complete the project successfully.

I am deeply indebted to my guide, **Dr. Rekha Ambi**, Assistant Professor, Department of Civil Engineering for his excellent guidance, positive criticism and valuable comments.

I am thankful to my project coordinator, **Dr. Kavitha Madhu**, Associate Professor, Department of Civil Engineering for their constant supervision as well as for providing necessary information regarding the project.

I am greatly thankful to **Dr. Sajeeb R**, Professor and Head of the Department of Civil Engineering, for his kind support.

Finally, I thank my parents and friends who directly and indirectly contributed to the successful completion of my project.

RAMU RADHAKRISHNAN

ABSTRACT

The loads of the structures are transferred to the soil by foundation. Foundations of structures are subjected to different modes of loading. For weak soil and heavy construction of structures pile foundation are better choices. Pile foundations are usually used in harbor structures, bridges, high rise structures and chimneys where both axial and lateral loads are expected to act on the foundation. For the improvement of lateral capacity, many researchers have developed different techniques. The new improvement techniques have been found costly. Under-reamed piles have mechanically formed enlarged base that forms an inverted cone and can only be formed in stable soils. They are used in normal ground condition also where economics are favorable. Under-reamed piles having one or more bulbs at specified locations along their depths have been extensively used in India to support a wide variety of structures in almost all types of soil strata. In many situations, these piles are also required to resist considerable amount of lateral loads besides vertical compressive and uplift loads. However, the behaviour of these piles under lateral loads has not been properly investigated Used to increase the load-carrying capacity of pile foundation under compression, tension, and lateral loading with least deflection compared to other piles.

This thesis work is to study the behavior of under-reamed piles under cyclic loading. The numerical analysis is done by PLAXIS-3D software. The analysis is done on under-r-eamed piles in sand. The study focuses on the lateral capacity of under-reamed pile under the influence of different size and geometry of under-ream. The study is done under lateral loading condition on under-reamed piles in sand.

Keywords: Under-reamed piles, lateral loading, sand, PLAXIS-3D.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The function of a Foundation is to transfer the structural loads from a building safely into the ground. The structural loads include the dead, superimposed and wind loads. To perform the function, the foundation must be properly designed and constructed. Its stability depends upon the behavior under load of the soil on which it resists and this is affected partly by the design of the foundation and partly by the characteristics of the soil.

It is necessary in the design and construction of foundation to pay attention to the nature and strength of the materials to be used for the foundations as well as the likely behavior under load of the soils on which the foundation rests.

1.2 GEOMETRY OF PILES

Geometry of pile foundation has been modified to increase load-carrying capacity

i. **Tapered piles**: Pile whose shaft diameter reduces as the length of the pile increases. Tapered pile enhance the pile capacity under compression and lateral loading

ii. **Screw piles**: Screw piles are a steel screw-in piling and ground anchoring system used for building deep foundations. Screw piles are typically manufactured from high-strength steel using varying sizes of tubular hollow sections for the pile or anchors shaft. Preferred for increasing pile capacity under tension.

iii. **Finned piles**: Finned pile is an emerging form of pile foundation that is capable of resisting large lateral displacements. Finned piles, which consist of fins attached to the pile shaft, are usually used to increase the lateral load-carrying capacity of piles.

iv. **Under-reamed piles**: Under-reamed piles have mechanically formed enlarged base that forms an inverted cone and can only be formed in stable soils. The larger base diameter allows greater bearing capacity than a straight-shaft pile.These piles are suited for expansive soils which are often subjected to seasonal moisture variations, or for loose or soft strata. They are used in normal ground condition also where economics are favorable. Used to increase the load-carrying capacity of pile foundation under compression, tension, and lateral loading.

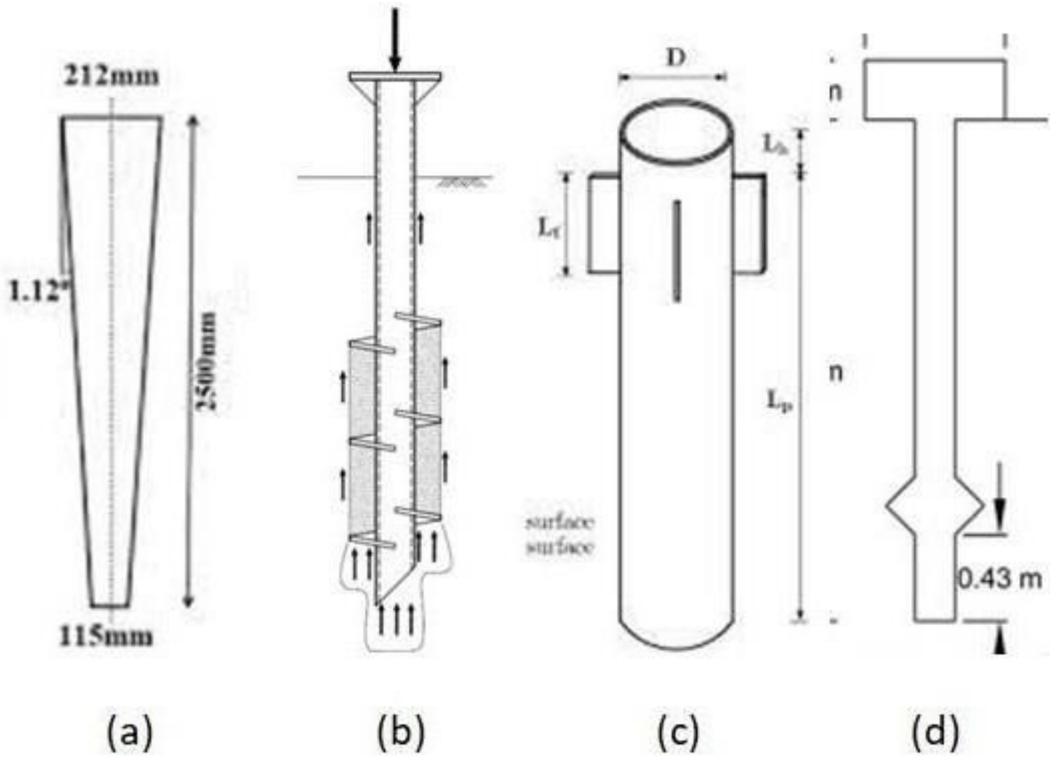


Figure 1.1 Different types of pile foundation (a) Tapered pile; (b) Screw pile;(c) Finned pile; (d)Under-reamed pile(Source: civilknowledge.com)

1.3 UNDERREAMED PILE

A cast-in-situ solid pile with an expanded base called bulb (bulb has shape of triangle) at the base made by one or the other removing or digging soil or by some other appropriate method is called Underreamed Pile. Another name for under-Reamed Piles is bored cast-in-situ concrete piles.The larger base diameter allows greater bearing capacity than a straight-shaft pile. These piles are suited for expansive soils which are often subjected to seasonal moisture variations, or for loose or soft strata. They are used in normal ground condition also where economics are favorable. These piles are most relevant in soils where strong ground developments happen because of occasional varieties or delicate soil layers. Under reamed pile is a simple concrete pile that has one or more bulbs at the lower end. This bulb is named under-ream, which will be used to increase the lateral load-carrying capacity of pile foundation under compression, tension, and lateral loading.

When just a single bulb is given at the lower part of the pile, it is known as a single Under-Reamed Pile establishment. When at least two bulbs are given at the lower part of the heap, it is known as multiple bulbs Under-Reamed Pile establishment. The use of multiple bulbs enhances the weight-bearing capability of the Foundation.

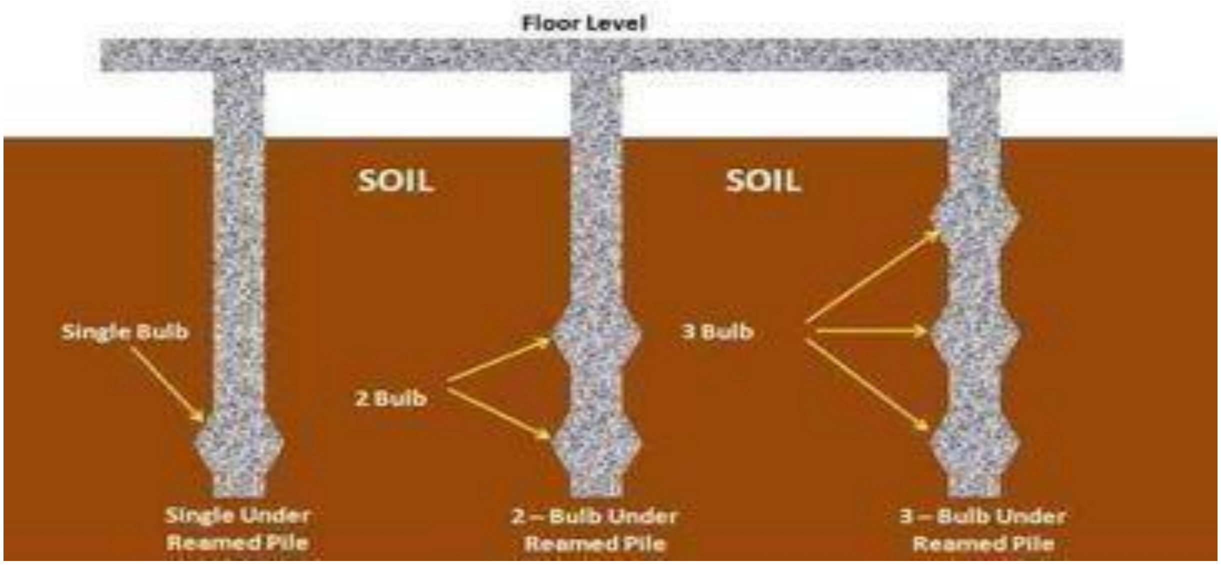


Figure 1.2 Under-reamed piles (Source: https://expertcivil.com/under-reamed-pile/)

1.3.1 Application of Under-reamed Pile

Under-Reamed Piles Foundation is an answer in zones where dark cotton soil could cause primary insecurity. Commonly, soils go through volumetric changes because of the dampness variety under the ground surface. This development and shrinkage can cause disastrous trouble, especially when there is a question about the Foundation’s bearing. The truth is that Under Reamed Piles are considered generally protected establishments for such dark cotton soils or sweeping soils.

1.3.2 Under-reamed Pile Construction

The under-reamed pile utilizes a spiral auger to the ground’s opening, with a unique sharp edge used to burrow the dirt at the lower end of the drill. Furthermore, a basket is hanged for filling the exhumed soil underneath the two cutters. Auger is introduced in the part of the earth to be bored and rotated by hand. When spirals get full of soil auger is taken out. This process is continued until the required depth is achieved. Under-reamer is a rotatory cutting device used for boring. It has cutters that can be extended or shrunk by mechanical methods or by hand and are used to develop or ream a borehole underneath. Under-reaming is a method of widening thebottom area of a drilled hole and thus increasing load-bearing capacity.

The width of the under-reamed bulbs might be 2 to 3 times the width of the stem. The distance between bulbs is 1.25 to 1.5 times the stem breadth. The top most bulb’s distance from the surface should not be less than 2 to 3 times the bulb’s diameter.

Under-reamed piles diminish the vertical settlement and furthermore differential settlement. It is utilized when soil expands because of the dampness variety or sweeping nature of the dirt. Thearrangement of under-reams or bulbs has the upside of expanding the bearing and inspire limits. When the quantity of bulbs is expanded from one to two, the pile conveying limit of the Under- Reamed Pile is expanded. The arrangement of bulbs is of unique benefit in Under-Reamed Piles to oppose uplift, and they can be utilized as anchors.

Foundations of many structures such as high-rise buildings, transmission towers, chimneys, water tanks, bridges, etc., may be subjected to compressive, tensile, and lateral loading together. Therefore, under-reamed piles can be the best suited foundations for these types of structures. Under-Reamed Piles are cheaper comparatively because less amount of concrete is required to fill the excavated area. Lateral resistance of under-reamed pile increases for an increase in embedment length, shaft diameter, number of bulbs, and bulb position from base (Soneja & Garg)

CHAPTER 2

LITERATURE REVIEW

2.1. GENERAL

For the last few decades, the geometry of the pile foundation has been modified to increase the load-carrying capacity. Piles with gradually increasing cross-section towards the top, also known as tapered piles, are generally used to enhance the pile capacity under compression and lateral loading (El Naggar and Wei, 1999; Khan et al., 2008; Liu et al., 2012; Singh and Patra, 2020). Screw piles which consist of blades attached with steel pile shaft, are mostly preferred for increasing the pile capacity under tension (Ghaly et al., 1991; Rao and Prasad, 1993; Tsuha and Aoki, 2010; Nait-Rabah et al., 2021). Finned piles, which consist of fins attached to the pile shaft, are usually used toincrease the lateral load-carrying capacity of piles (Peng et al., 2010; Nasr, 2014; Albusoda et al., 2018; Sakr et al., 2020). Under-reamed piles which have bulb-like projected area are used to increase the load-carrying capacity of pile foundation under compression, tension, and lateral loading (Cooke and Whitaker, 1961; Prakash and Ramakrishna, 2004; Peter et al., 2006; Khatri et al., 2019; Kumar et al., 2020, 2021; Majumder and Chakraborty, 2021a, 2021b, 2021c, 2021d).

2.2 UNDER-REAMED PILE

Foundations of many structures such as high-rise buildings, transmission towers, chimneys, water tanks, bridges, etc., may be subjected to compressive, tensile, and lateral loading together. Therefore, under-reamed piles can be the best suited foundations for these types of structures. Although the bearing and uplift capacities of under-reamed piles have been thoroughly studied (Cooke and Whitaker, 1961; Martin and DeStephen, 1983; Prakash and Ramakrishna, 2004; Peter et al., 2006; Kong et al., 2013; Golait et al., 2018; Vali et al., 2019; Khatri et al., 2019; Kumar et al., 2020, 2021; Majumder and Chakraborty, 2021); limited studies have been conducted on the lateral response of under-reamed pile.

Kong et al. (2019) studied lateral resistance of belled wedge single and group pile based on model tests in sand. Amaresha et al. (2020) conducted small scale model tests on belled piles in sand. They found that belled piles give maximum lateral capacity at a bell angle of 45◦. This bell angle of 45° is used in the modeling of the under reamed pile for the project studies and also the 45° angle gives maximum lateral resistance and more stability compared to other acute angles considered.

2.3 SOIL-PILE MODEL

Following Comodromos and Papadopoulou (2012) and Vali et al. (2019), the under-reamed pile is modeled as linearly elastic material, and soil is modeled as elastic-perfectly plastic material using Mohr-Coulomb yield criteria. The soil parameters mainly the index properties and engineering properties including the Young's modulus, Poisson's ratio, and dilation angle of medium dense sand are assumed as 35 MPa, 0.25, and 6°, respectively, the properties of soil (sand) are taken from Kumar et al. (2021). Table 2.1 shows the properties of soil used in the numerical analysis.

Table 2.1 Properties of Sand

Soil type	**Friction angle(φ) (°)**	**Dilation angle (°)**	**Cohesion C (kPa)**	**Young's Modulus, E_s (MPa)**	**Poisson's ratio**	**Unit weight (kN/m^3)**
Loose sand	30	0	0	20	0.20	13.5
Medium sand	35	5	0	35	0.25	15.5
Dense sand	40	10	0	52	0.30	17.5

Among the above properties from the table properties of medium sand from Kumar et al. (2021) wereconsidered for the sand profile. While the concrete parameters in the cast of pile including Young's modulus (Ep), Poisson's ratio (ν_p), and unit weight (γ_p) of the reinforced concrete pile are considered as 3.2×10^7 kPa, 0.2, and 25 kN/m^3 , respectively, following Comodromos and Papadopoulou (2012) and Majumder and Chakraborty (2021a). Above concrete properties where resulted in from the mix design from Comodromos and Papadopoulou (2012) . A fully rough interface is assumed between the under-reamed pile and soil following Kumar et al. (2021). For a rough interface, interface friction angle (φ_i) is considered as the friction angle of soil (φ), as per IS: 2911-Part III.

2.4. PILE AND UNDER-REAMING

For generalized safe loads based on field load tests have been suggested for single and double underreamed piles of shaft diameters of 200 mm to 500 mm with bulb diameter of 2.5 times the shaft diameter and lengths of 3.5 m. Further, it has been suggested that due to the presence of bulbs, underreamed piles of short lengths tend to behave more as rigid piles and the analysis can be done on rigid pole basis,bulb may be neglected, which is an assumption on the conservative side. Normally reinforced long single bulb piles, which are not rigid, may be analyzed using the approach given by Matlock and Reese (1960) and Broms (1964a) for clayey soils. Shrivastava et al. (1972) have attempted to analyze single as well as group of one-bulb piles using Hrennikoff's approach (1949) involving pile constants related with soil properties. The pile has been assumed to behave as a rigid pole and to rotate about the centre of underream (bulb) and the soil has been idealized as nonlinearly deforming springs. The soil above the bulb is assumed to be pushed up on one side and pressed down on the other side forming a couple. Based on a few field tests on R.C.C. piles in sandy soils and model tests on timber piles, Soneja and Garg (1980) have concluded that the provision of first bulb increases the load capacity to a great extent.

2.5 FINITE ELEMENT METHOD

The finite element method (FEM) is a numerical method for finding fairly accurate solutions of partial differential equations as well as integral equations. The solution approach is based either on eliminating the differential equation completely (steady state problems), or rendering the PDE into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method. For carrying out linear elastic analysis in this project, commercially available geotechnical software PLAXIS 3D is being used which uses Finite Element Analysis (FEA) for simulation of model.

2.5.1. PLAXIS 3D

PLAXIS 3D is a powerful user-friendly finite element package intended for two dimensional analysis of deformation and stability in geotechnical engineering and rock mechanics. It is used worldwide by top engineering companies and institutions in the civil engineering and geotechnical engineering industries. The increased output tools allow a thorough presentation of computational findings, and the easy graphical input processes enable the speedy development of complicated finite element models. The actual computation is totally automated and is based on reliable numerical techniquesApplications range from excavation,embankment and foundation to tunneling,mining and reservoir geo-mechanics. PLAXIS is equipped with broad range of advanced feature in model a diverse range of geotechnical problems, all from within a single integrated software package.

2.6 GAP IDENTIFIED

- Studies on the influence of lateral forces on piles are limited
- Few studies on relevance of the position of under reams to resist lateral thrust
- Less studies on the effect of under-reamed piles in cohesionless soil

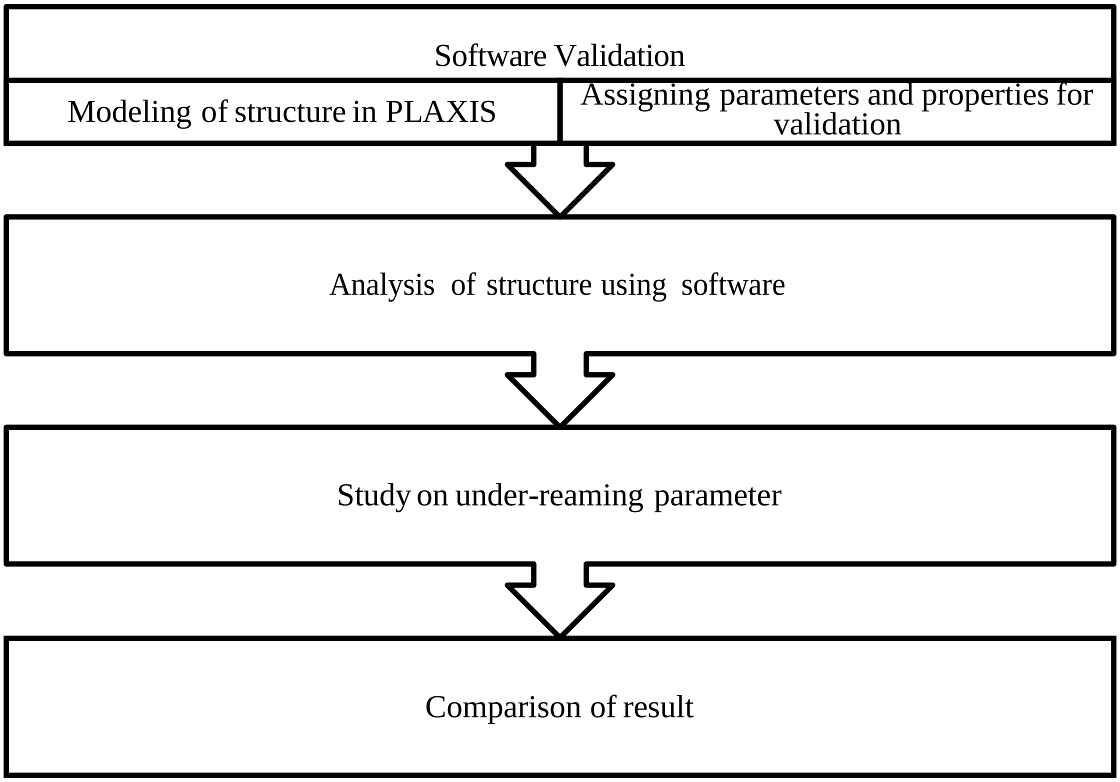
2.7 OBJECTIVES OF THE STUDY

- To study influence of under-reaming positions in the lateral capacity of under-reamed piles under lateral loading
- To quantify the improvement in the lateral capacity of under-reamed piles with different diameters and lengths under loading
- To investigate behavior of under-reamed piles in cohesionless soil under lateral loading

CHAPTER 3

METHODOLOGY

3.1 GENERAL



Under-reamed piles under cyclic loading condition is taken in the analysis. The software used for the numerical analysis is PLAXIS 3D. PLAXIS 3D is a finite element software used for modelling and analysis of mechanical components that performs finite element analyses (FEA) within the realm of geotechnical engineering, including deformation, stability and water flow. The input procedures enable the enhanced output facilities provide a detailed presentation of computational results. It is a non-linear three dimensional software. PLAXIS 3D has been widely used for the analysis of engineering problems due to its accuracy level in analysis results.

Analysis in PLAXIS 3D involves three main stages. Modelling is the first stage that include creating new parts, defining their material properties, assembly parts are defined, defining boundary conditions and meshing. Second stage is the analysis of model which includes providing the loading condition and analysis type. Final stage is visualization that includes the graphical display of the FE model and its results.

3.2 MODELLING

Piles of shaft diameter 0.3m to 0.5m were considered for modeling, the under-reaming provided were of 2.5D i.e the under-reaming diameter ranges from 0.75m to 1.5m. The under-reaming or the bulb were positioned mainly along the length of the pile from the ground surface i.e at l/3, l/2 and 2l/3, where l is the length of the pile measured from the ground surface.

Table 3.1 Positioning of under-reaming of under-reamed pile from ground surface

	Position of Under-ream		
	l/3	l/2	2l/3
Length of Pile (m)			
3	1.00	1.50	2.00
4	1.33	2.00	2.67
5	1.67	2.50	3.33

`

Sand volume were determined based on the diameter and length of the pile considered i.e the plan area of sand profile were 50D X 25D where D is the diameter of the shaft of the pile. Depth of the sand profile considered is Lu+20D where Lu is the length of the under-reamed pile. As L_u/D is considered equal to 10, the length of under reamed pile is 10D in the overall modeling of the structure.

Table 3.2 Geometric parameter of sand- pile profile

Pile			Sand		
Shaft Diameter D (m)	Under-reaming Diameter 2.5D (m)	Length of Pile Lu= 10D (m)	Length L= 50D (m)	Breadth B=25D (m)	Depth D= L_u+20D (m)
0.3	0.75	3	15	7.5	9
0.4	1	4	20	10	12
0.5	1.25	5	25	12.5	15

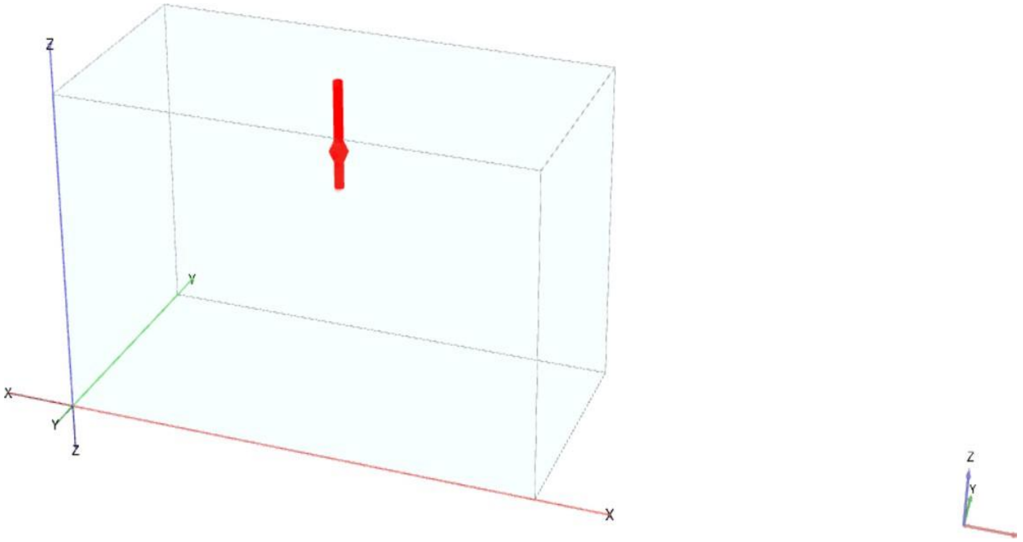


Figure 3.1: Sand- Pile Model

In modeling each part is created separately, initially sand is constructed and then pile. Sand was initially drawn in 2D sketch with its depth and length after that it was extruded symmetricaly with half of the width about the central axis. Later the pile were drawn in 2D, then it was revolved using the revolve function and made it into a 3D model. Both sand and pile are bonded together using Boolean function so, it act as a single material. After the modeling face completes material properties were applied to the completed model before the loading and meshing face starts. The properties of soil and pile considered in the study are taken from literature.

Table 3.3 Material properties of the Sand

Material model	Mohr-Coulomb
Type of material behavior	Drained
Soil unit weight above phreatic level γ_{unsat}	16.5 kN/m3
Soil unit weight below phreatic level γ_{sat}	21.5 kN/m3
Permeability in horizontal direction k_x	1
Permeability in vertical direction k_y	1
Young's modulus	35
Poisson's ratio	0.25
Cohesion	0
Friction Angle φ	36
Dilatancy Angle ψ	5

Table 3.4 Material Properties of Pile

Material model	Linear- Elastic
Type of material behavior	Non-porous
Soil unit weight above phreatic level γ_{unsat}	25kN/m3
Soil unit weight below phreatic level γsat	25kN/m3
Young's modulus	22650 Mpa
Poisson's ratio	0.3
Friction Angle	36
Dilatancy Angle	0

Prior to the loading stage the pile was made to decompose into separate surfaces, so that a single surface can be selected and lateral load could be applied. Meshing is important in engineering simulation because it splits complex geometries into simple parts that can be employed as different local approximations of the wider domain. A model's mesh arrangement affects the simulation's accuracy, convergence, and speed. The meshing method takes up a large amount of time while obtaining simulation results. Fine element distribution of meshing is applied over the soil –pile model. Various element distribution of meshing including very coarse, coarse, medium, fine and very fine meshing of element distribution are available in the PLAXIS 3D software of which fine meshing was selected.

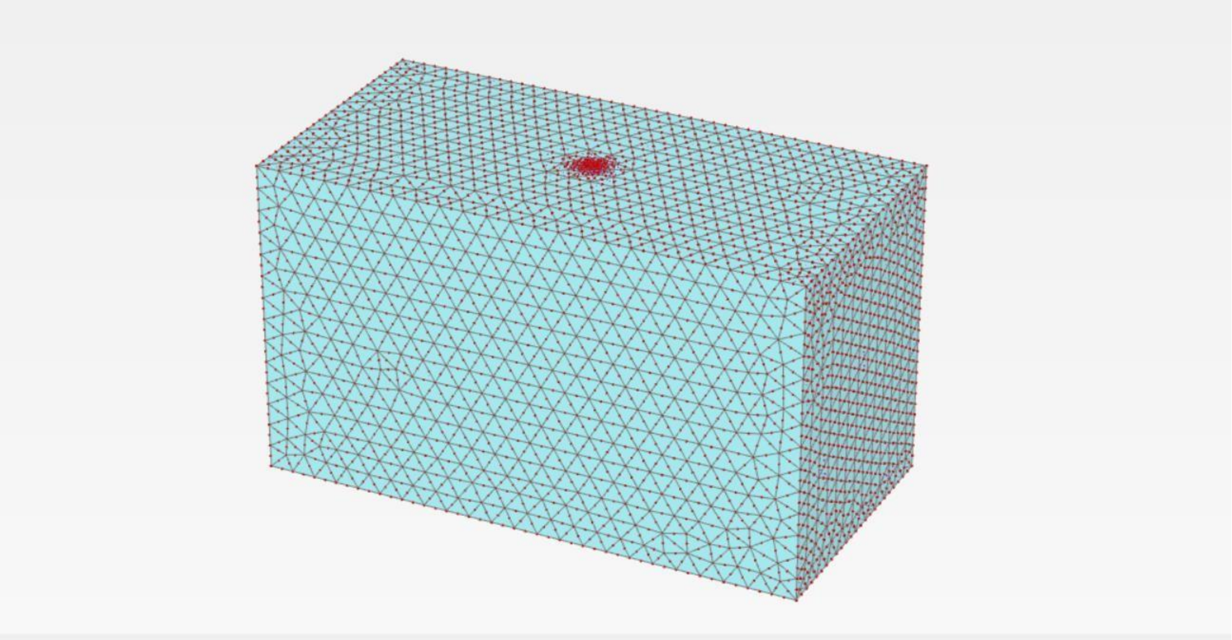


Figure 3.2 Meshed model of Sand

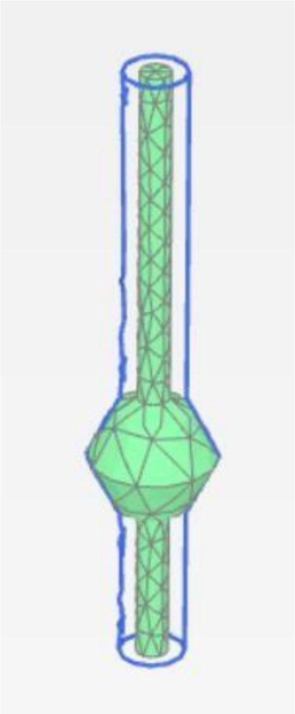


Figure 3.3 Meshed model of under-ream pile

Boundary conditions were given after meshing, fixed end support condition was given to the bottom face while roller supports were given to the lateral faces respectively. The effectiveness of the stresses by the introduction of lateral load to the pile is within the boundary limit of sand profile created. Thus the analysis of the load induced over sand pile model is fully calculated After completion of the staged constructions output were collected including the deformations figures, load-deflection graphs from which the performance comparison could be studied further based on the position and size of under-ream. The ultimate load carrying capacity of pile is considered as the load corresponding to 5mm deflection or pile deflection that corresponds to 10% pile diameter.

3.3 PARAMETRIC STUDY

Parametric study is conducted to investigate the maximum lateral resistance offered by the under-reamed pile by altering the position of under-ream along its length and by varying the diameter of the pile. Three different diameters as well as three varying positions were included in this project so a combition set of nine different under-reamed pile models are used in this project study.

3.4 COMPARATIVE STUDY

The load-deformation graphs of under-reamed and tubular piles were compared under similar loading conditions and the results were analyzed. In addition with the comparison with the tubular pile models, a study was conducted to understand the ideal position of under-ream which offers maximum lateral resistance, by shifting the position of under-ream along its length in each model and also by varying the shaft and under-ream diameters.

CHAPTER 4

VALIDATION

4.1 MODEL

Three-dimensional numerical analysis was carried out using commercial geotechnical software PLAXIS 3D. Stone column diameter, d of 1.0 m was installed in the soft clay. The column length is determined to be 5.0 m. The horizontal and vertical boundary were set to be far enough to have caused no infuence on the numerical results. A rigid footing of the same diameter as the stone column was placed on the column head.

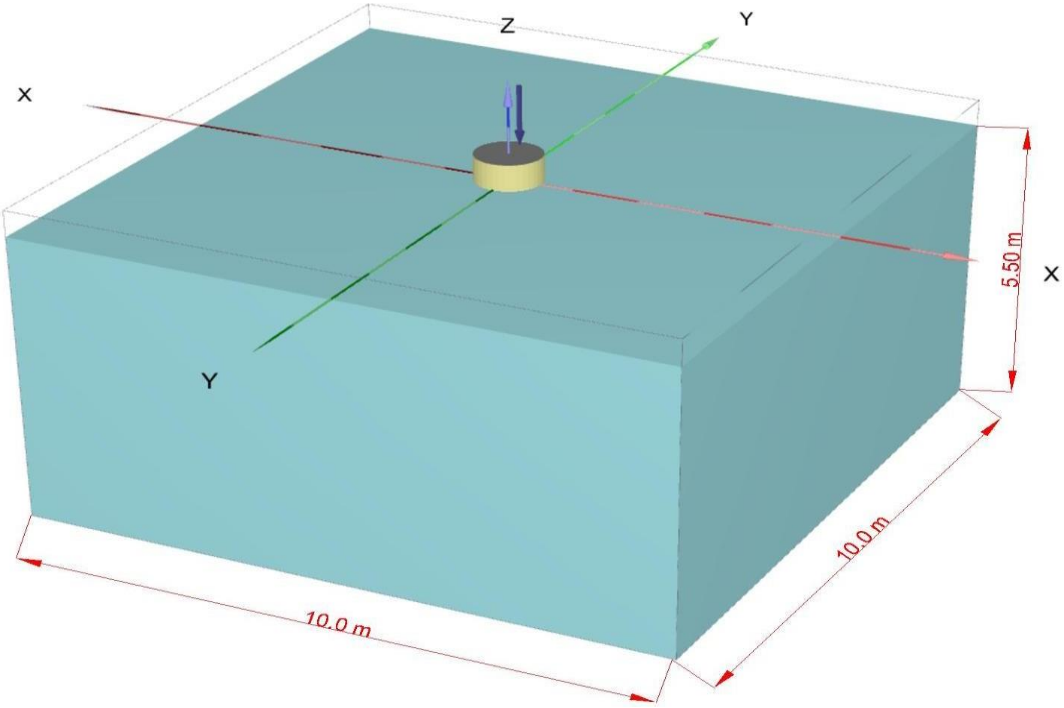


Figure 4.1 Stone column- sand model

In the validation study, both stone column and soft soil were modelled as Mohr Coulomb (MC) soil model under undrained condition. The undrained strength of the soft soil, C_u 40 kPa and the efective friction angle for the column material, φ_c' of 40° is adopted. The Young’s modulus of the surrounding soil, E_s is determined to be 150 times the undrained shear strength. The modular ratio, $m=E_c/E_s$ is taken as 10 which is within the typical range; where E_c is the Young's modulus of column material.

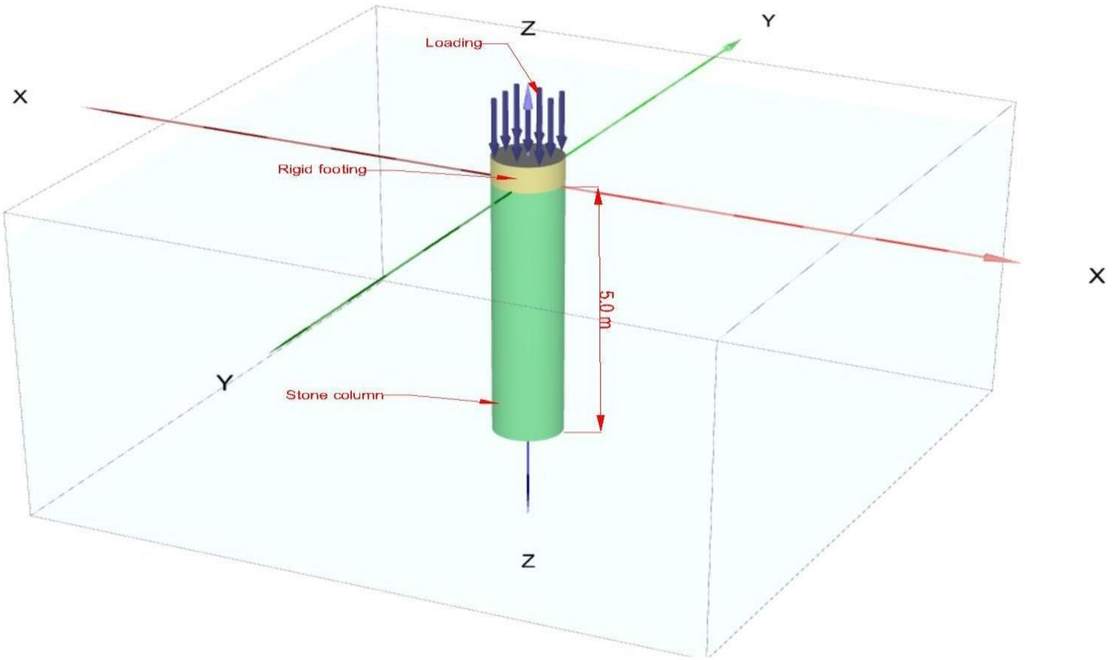


Figure 4.2 Stone Column

Initial stresses were generated by K_o procedure with the proposed value of lateral earth pressure, K=1.0 for both the column and the soil refecting wish-in-place approach was adopted in the model. The staged construction with the prescribed displacement approach was adopted to obtain the load that has caused the footing to deform 0.2 m vertically. Thus, the ultimate bearing capacity in this study is determined to be the pressure that has caused 20% strain relative to the column diameter.

4.2 MESHING

Fine element distribution of meshing is applied over the soil –pile model. Various element distribution of meshing including very coarse, coarse, medium, fine and very fine meshing of element distribution were performed in the PLAXIS 3D software. Ultimate load of 1104.346kN/m^2 was resulted when meshing of finite element distribution was selected which is more closer to the base journal and is within the limit of percentage error or percentage deviation.

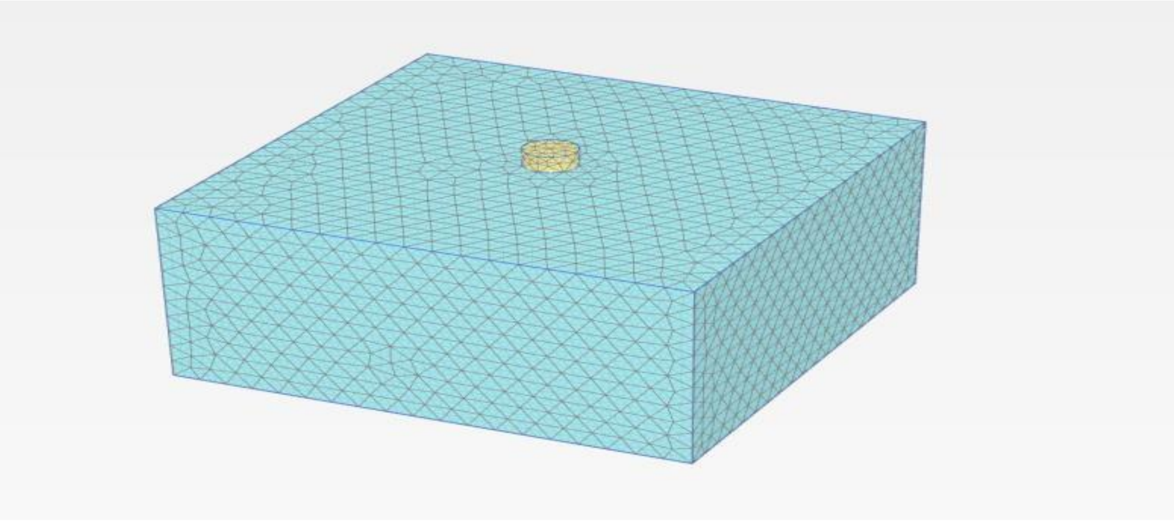


Figure 4.3. Meshed soil-pile geometry

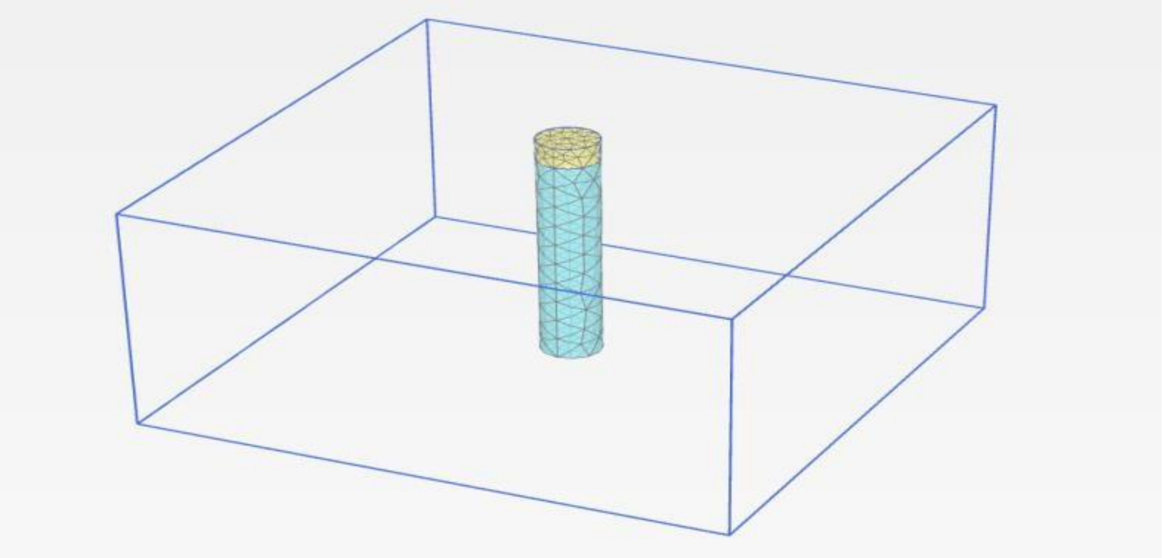


Figure 4.4. Meshed pile geometry

Table 4.1 Mesh Comparison

	VERY COARSE	COARSE	MEDIUM	FINE	VERY FINE
MAX DEFLECTION in m	0.09	0.06	0.16	0.2	0.4
FAILURE LOAD	1106.85	2019.412	1106.85	1104.346	226.5531
LOAD (kN/m^2) @ 0.20m DEFLECTION	1621.729	1106.85	1184.142	1104.346	423.1931

4.3. FAILURE MECHANISM

In the analysis, the case with Cu of 30 kN/m^2 , E_c/E_s of 10 and φ_c'=40° is taken as the base case. Figure shows the failure mechanism in the base case. Bulging is observed, and the maximum lateral displacement occurred at about one column diameter below the ground surface. Similar observation on a field load test was also being made. The bulging is noticed up to the depth of 3.5d. The toe penetration of the column is insignificant.

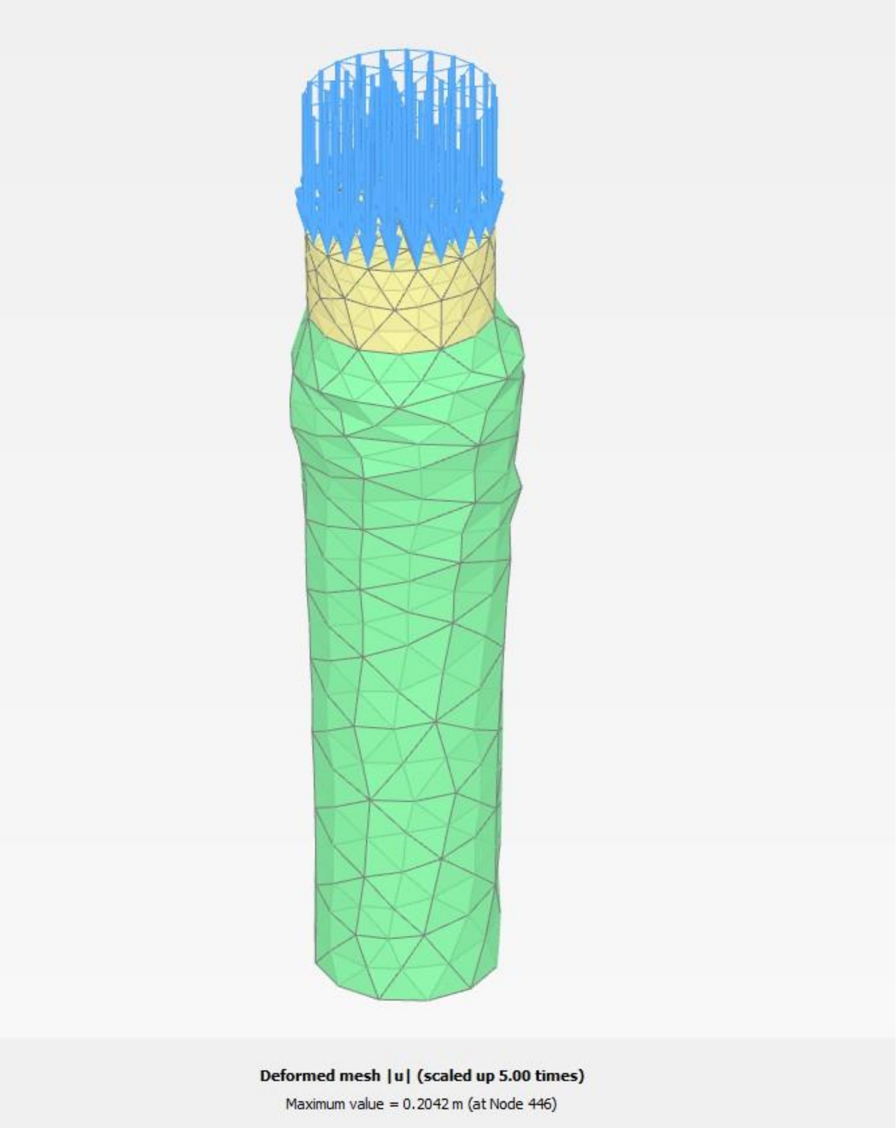


Figure 4.5. Deformed pile

The ultimate load was recorded as 1104.346 kN/m^2 with a deflection of 0.2m was obtained as the validation result, which was almost matching with the base journal data i.e in the base journal the ultimate load of 1020 kN/m^{2}with deflection 0.20m . Thus the percentage error as per validation with the reference base journal is about 8.27% which is within the allowable limit.

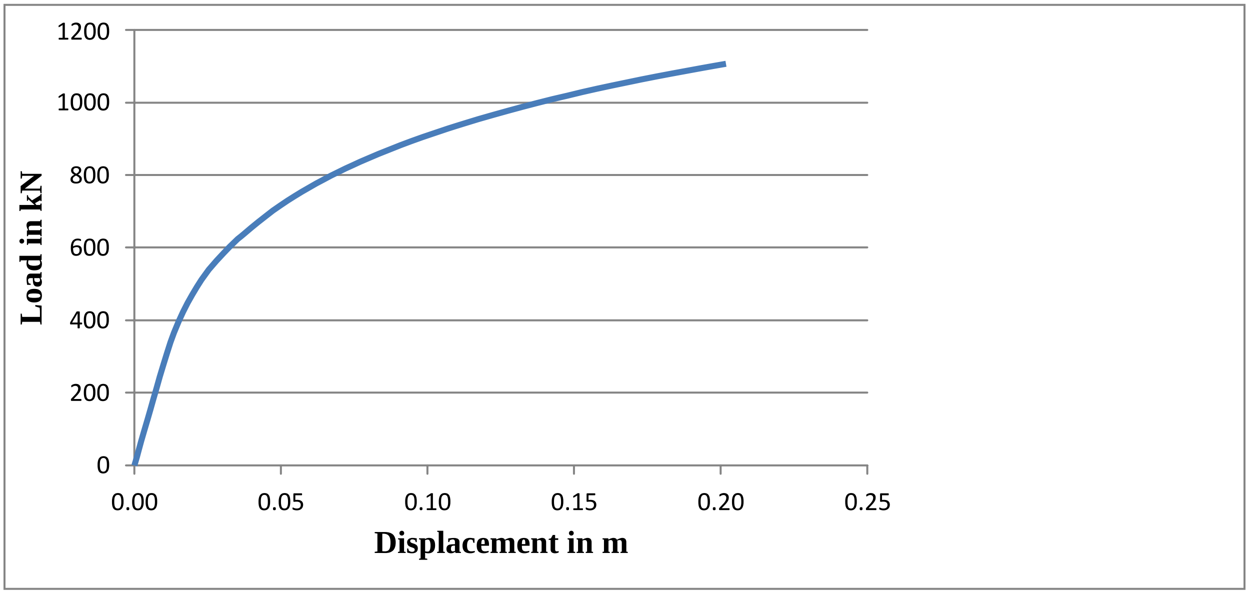


Figure 4.6 Load vs Displacement using finite element analysis

Table 4.2 Comparison of Ultimate load and displacement based on experimental and finite element analysis

Model	Ultimate Load (kN)	Total Deformation in m
C_u=30 kPa. E_c/E_s=10	1020	0.2
As per validation	1104.346	0.2
Percentage of Error	8.27	

Parity Curve is plotted for the ultimate load is within a 10% variation as shown in Fig 4.6

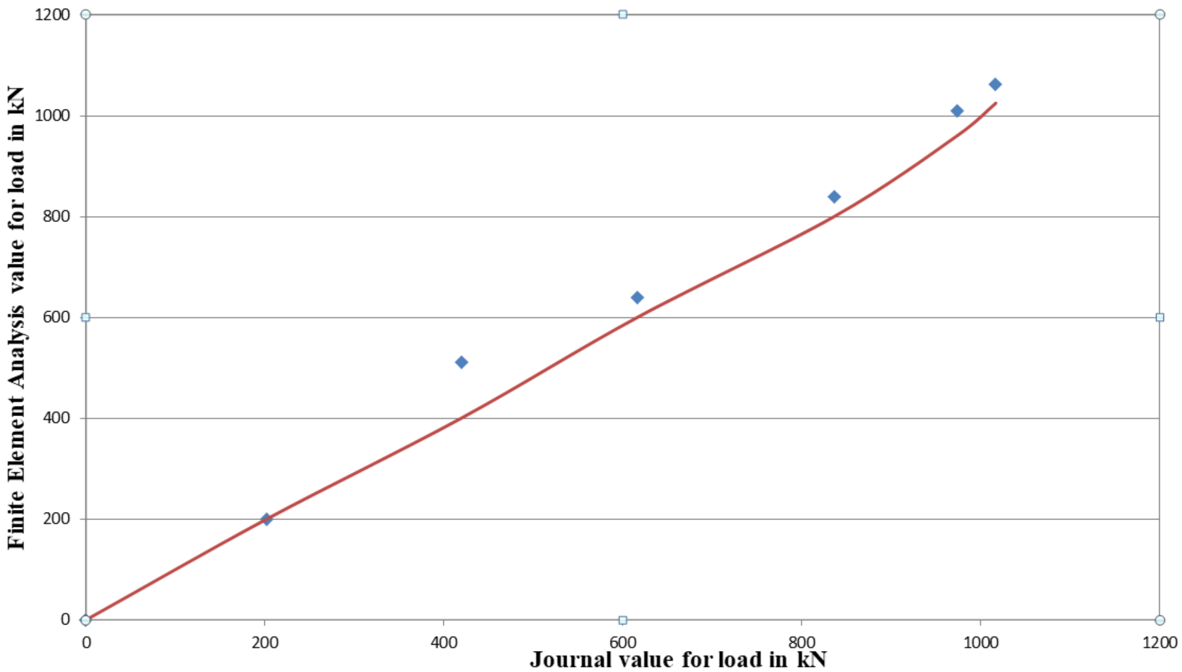


Figure 4.7 Parity curve for load

CHAPTER 5

RESULT AND DISCUSSIONS

5.1 GENERAL

The numerical analysis on under-reamed pile was performed to evaluate the improvement in lateral load resistance by providing under-reaming and comparing the effectiveness by comparing it with tubular pile and also by varying diameter and also by varying the position of under-ream at l/3, l/2 and 2l/3 from the ground surface along the length of the pile were studied and the results are discussed in the following sections.

In order to study the effect of under-ream on the lateral resistance of under reamed pile, various diameters such as 0.3m,0.4m and 0.5m of length 3m, 4m and 5m were considered as Lu/D =10 is used in this project. The performance of the varying diameter under reamed pile is compared with the same diameter of tubular pile and then the improvement were analysed.

5.2 0.3m DIAMETER PILE

Firstly 0.3m diameter tubular pile is compared with the same diameter under-reamed pile having the under-reaming at various 3 positions such as l/3, l/2 and 2l/3 from the ground surface is studied. There is an increase of 22.97%- 33.58% in lateral resistance when an under reaming was introduced to the pile with very low deflection compared to the tubular pile. As in tubular pile of 0.3m diameter the deflection was observed to be 4.69mm with an ultimate load of 32.96kN while in under reamed pile maximum deflection was 0.7353mm with ultimate load of 44.03 kN which is about 33.58% increase in lateral resistance. The maximum lateral resistance is offered by the under-reaming positioned at l/2 from surface and minimum at l/3 length from the surface i.e there is trend on increasing the lateral resistance by positioning the under reaming away from the surface towards the middle of the pile length and then the lateral resistance decreases proportionally when it is positioned away from the middle length towards the bottom as the lateral resistance offered by the under-ream position at 2l/3 is 41.05kN with 0.649mm which is lesser compared with the one positioned at the l/2 length from the ground surface.

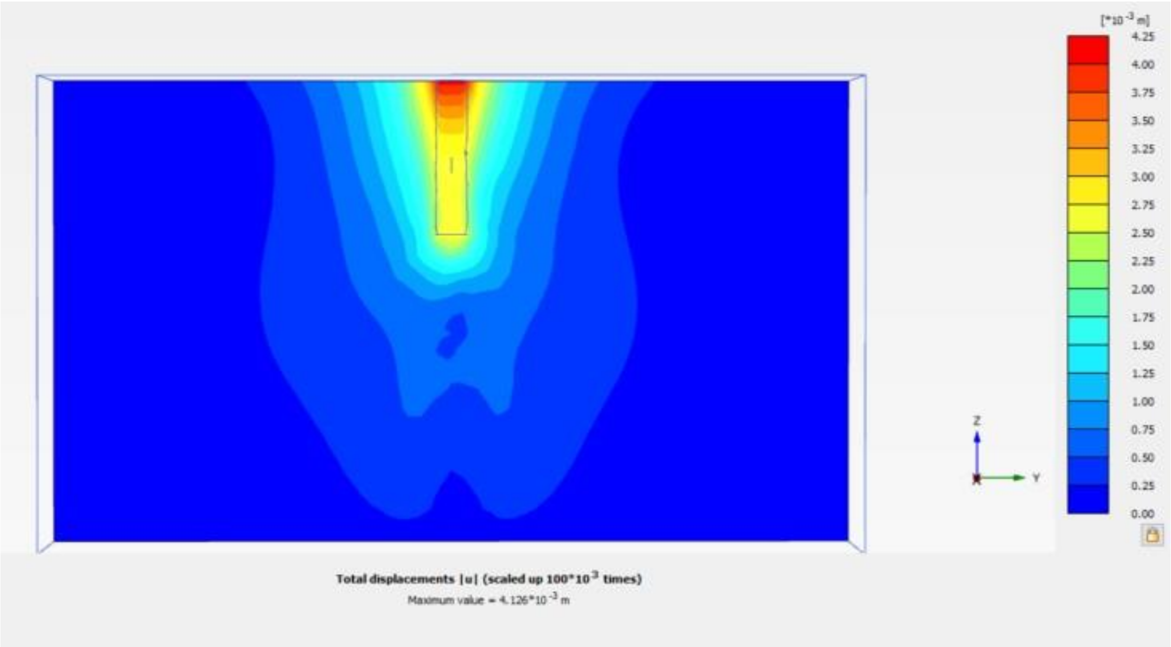


Figure5.1 Total displacement of 0.3 Tubular Pile

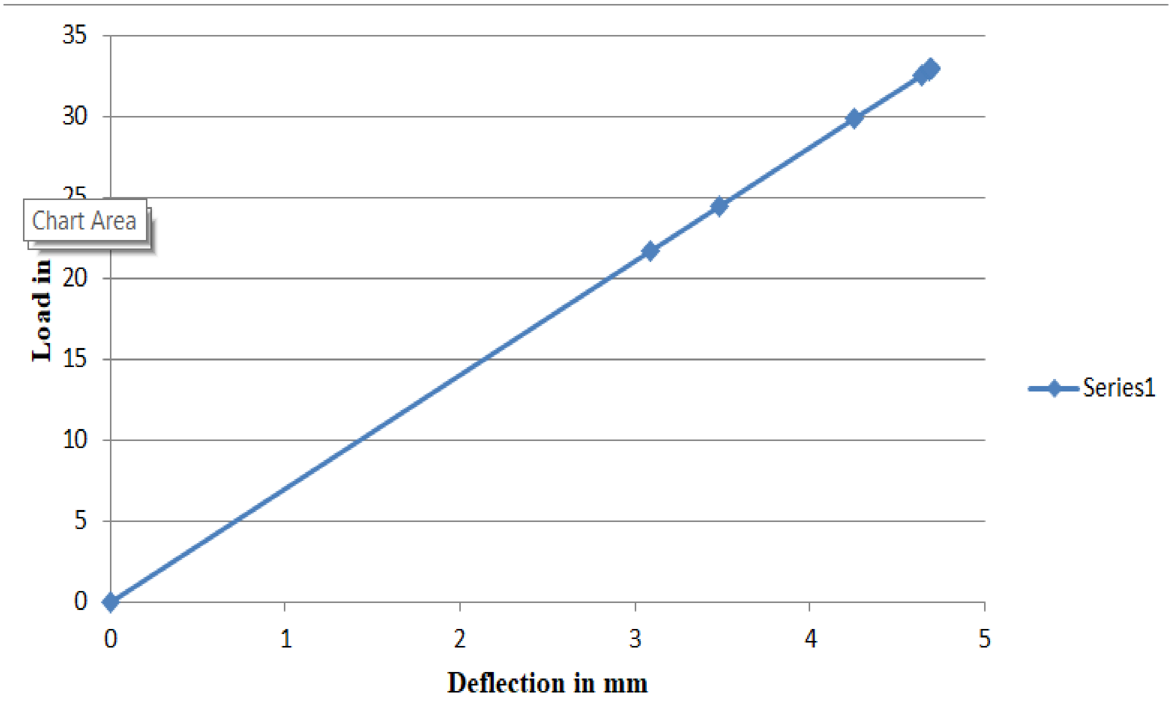


Figure 5.2 Load vs Deflection of 0.3m diameter tubular pile

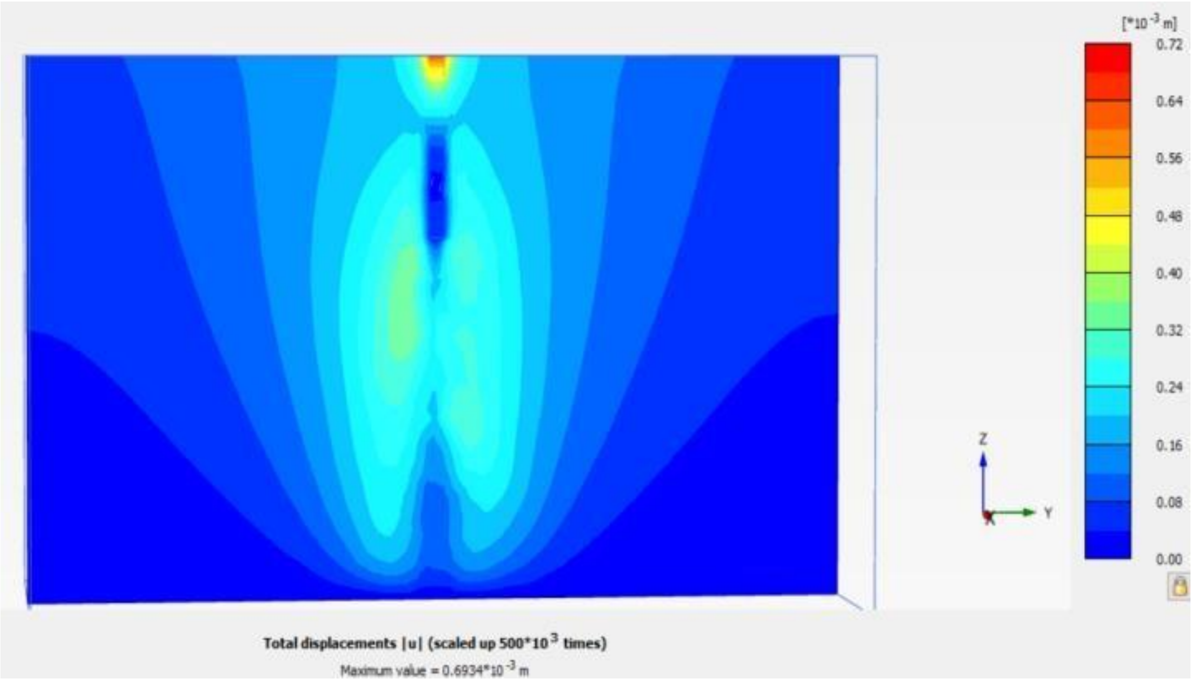


Figure 5.3 Total displacement of 0.3m under reamed pile positioned at l/3

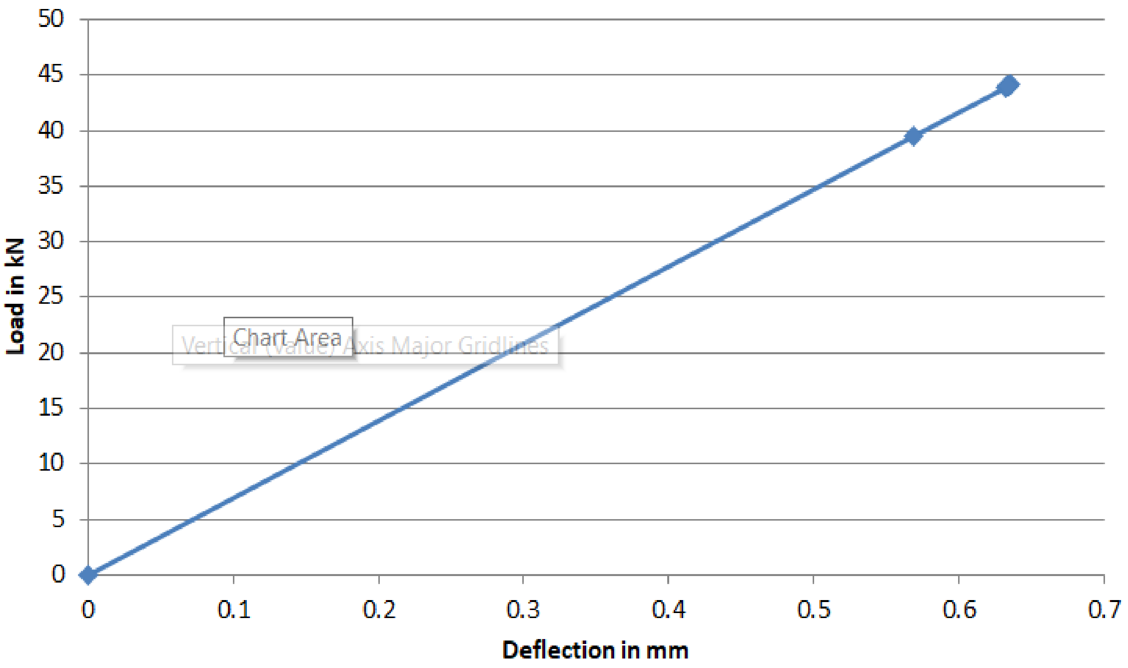


Figure 5.4 Load vs Deflection of 0.3m under-reamed pile positioned at l/3

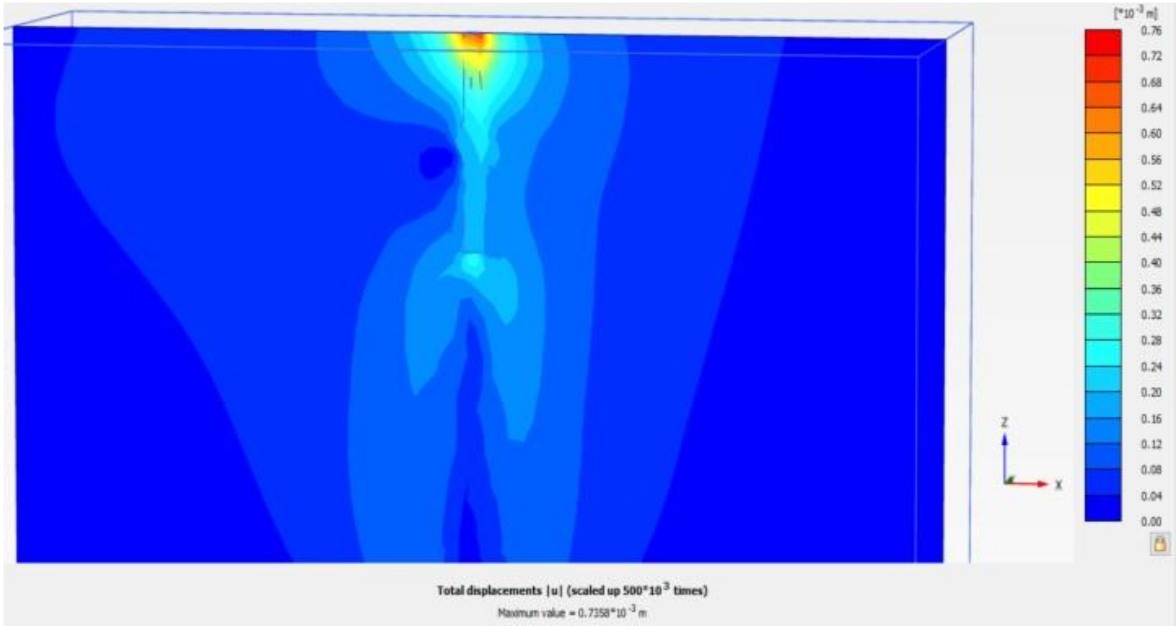


Figure 5.5 Total displacement of 0.3m under-ream pile positioned at l/2

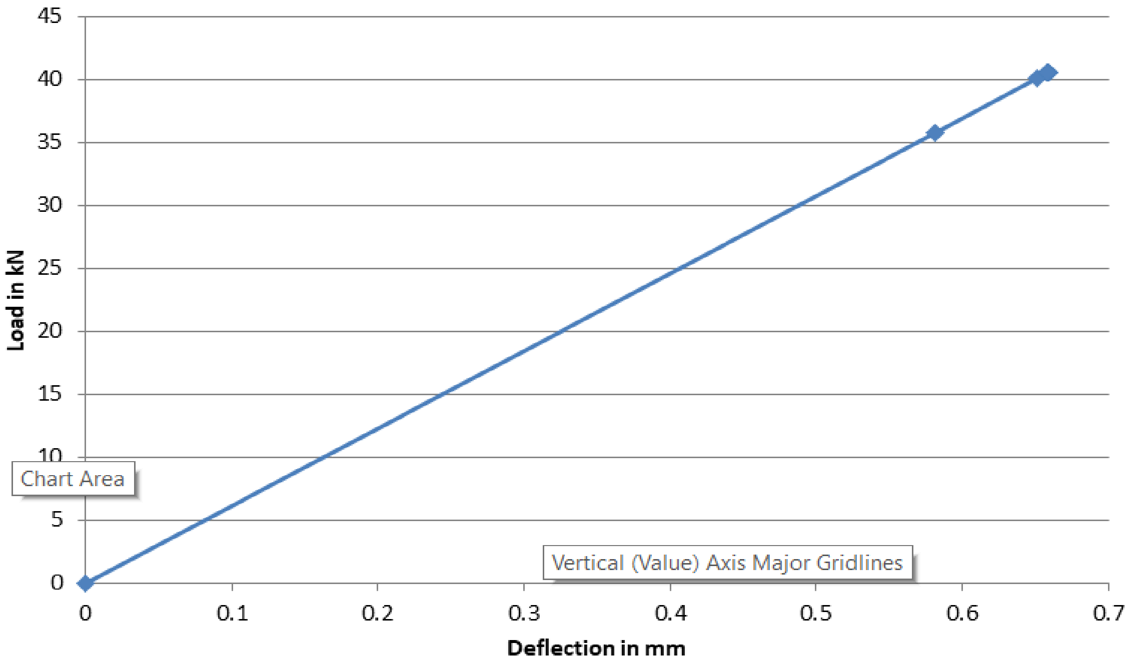


Figure 5.6 Load vs Deflection of 0.3m under-reamed pile positioned at l/2

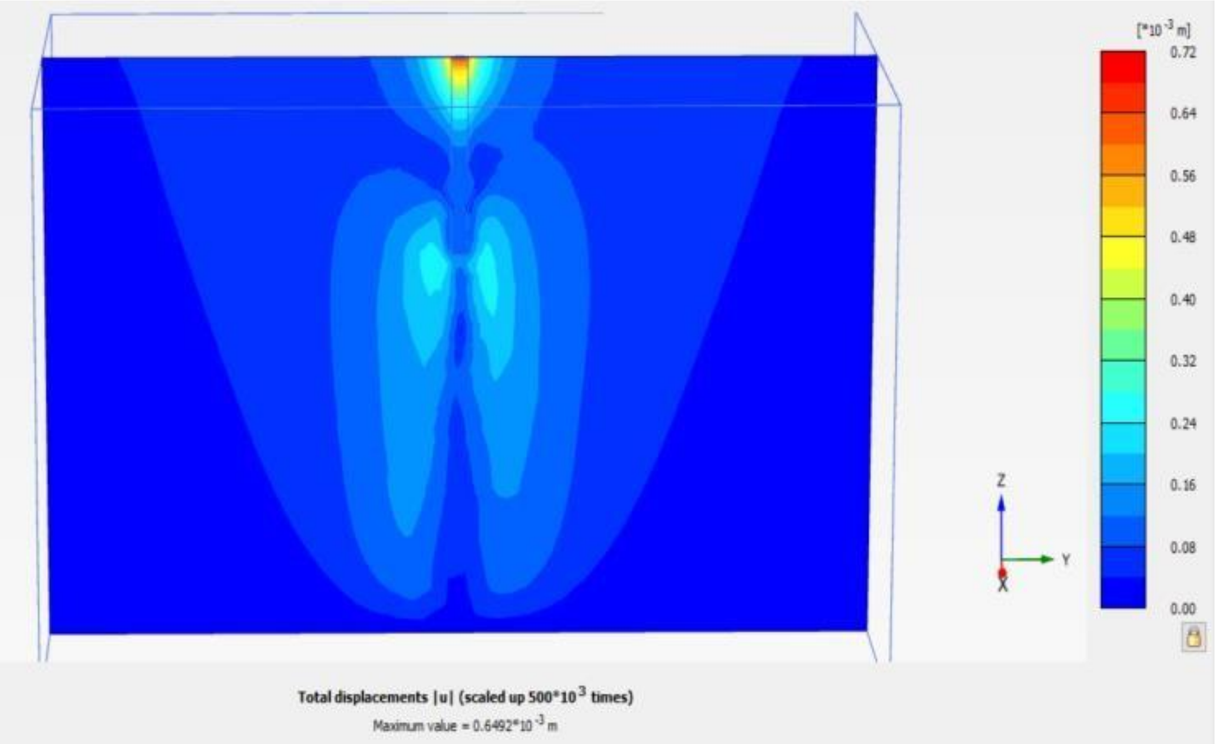


Figure 5.7 Total displacement of 0.3m under-ream pile positioned at 2l/3

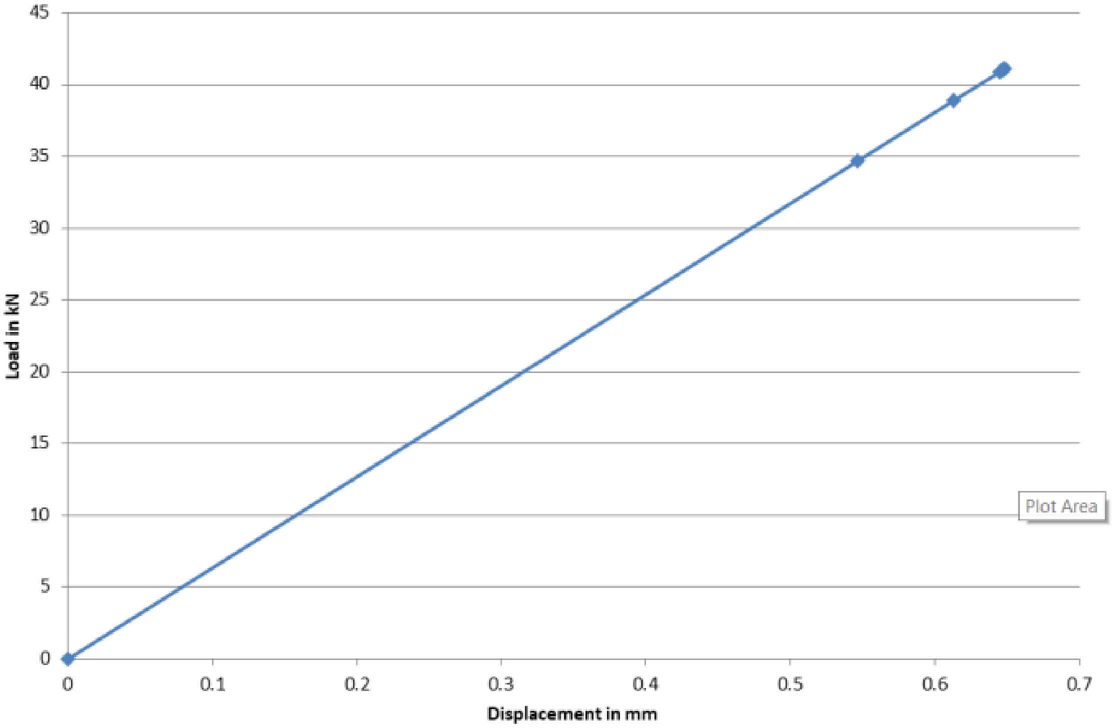


Figure 5.8: Load vs Deflection of 0.3m under-reamed pile positioned at 2l/3

5.3 0.4m DIAMETER PILE

On coming to 0.4m diameter models there are 4 different pile models including one tubular pile and three under-reamed piles having under-reaming monopiles at three different positions along the length such as l/3, l/2 and 2l/3 from the ground surface is studied. There is an increase of in lateral resistance of 14.21% to 57.14% when an under reaming was introduced with the pile with very low deflection compared to the tubular pile. In tubular pile loading of 46.30kN was found corresponding to the 5 mm deflection as we are concerned load corresponding to 5mm deflection or corresponds to 10% pile diameter, while in under reamed pile maximum deflection was 1.561mm with ultimate load of 72.757kN which is about 57.14% increase in lateral resistance. The maximum lateral resistance is offered by the under-reaming positioned at l/2 from surface and minimum at l/3 length from the surface i.e there is trend on increasing the lateral resistance by positioning the under reaming away from the surface towards the middle of the pile length and then the lateral resistance decreases proportionally when it is positioned away from the middle length towards the bottom as the lateral resistance offered by the under-ream position at 2l/3 is 56.307kN with 1.527mm which is lesser compared with the one positioned at the l/2 length from the ground surface.

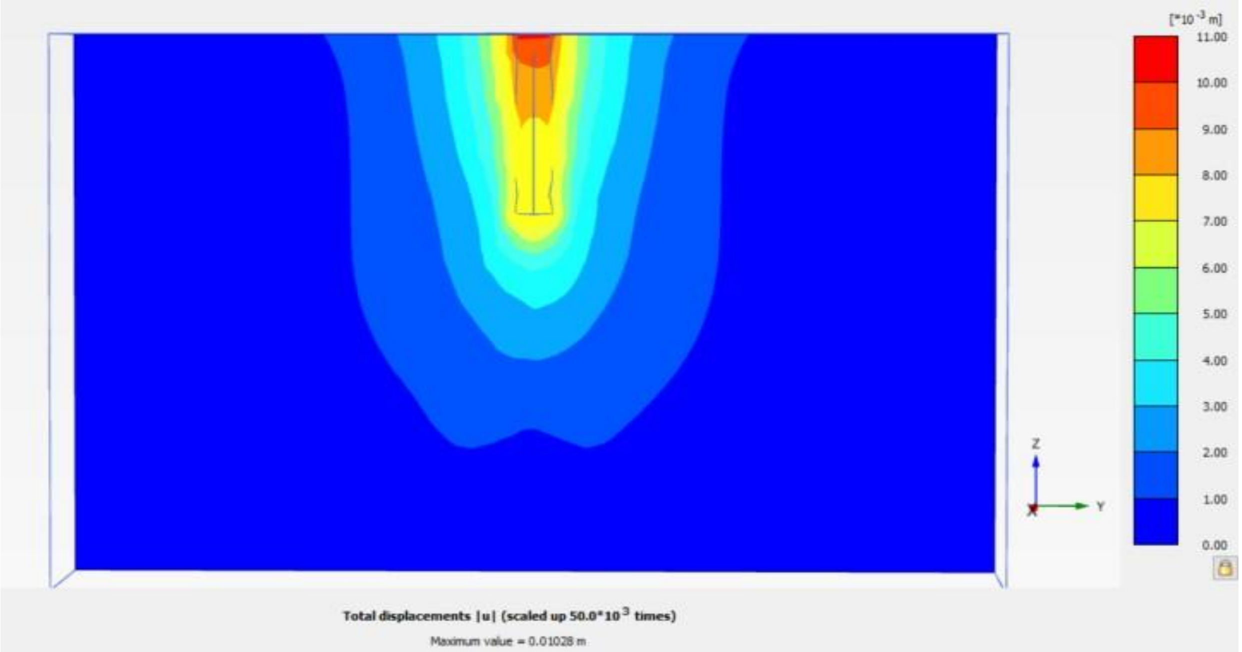


Figure5.9 Total displacement of 0.4m Tubular Pile

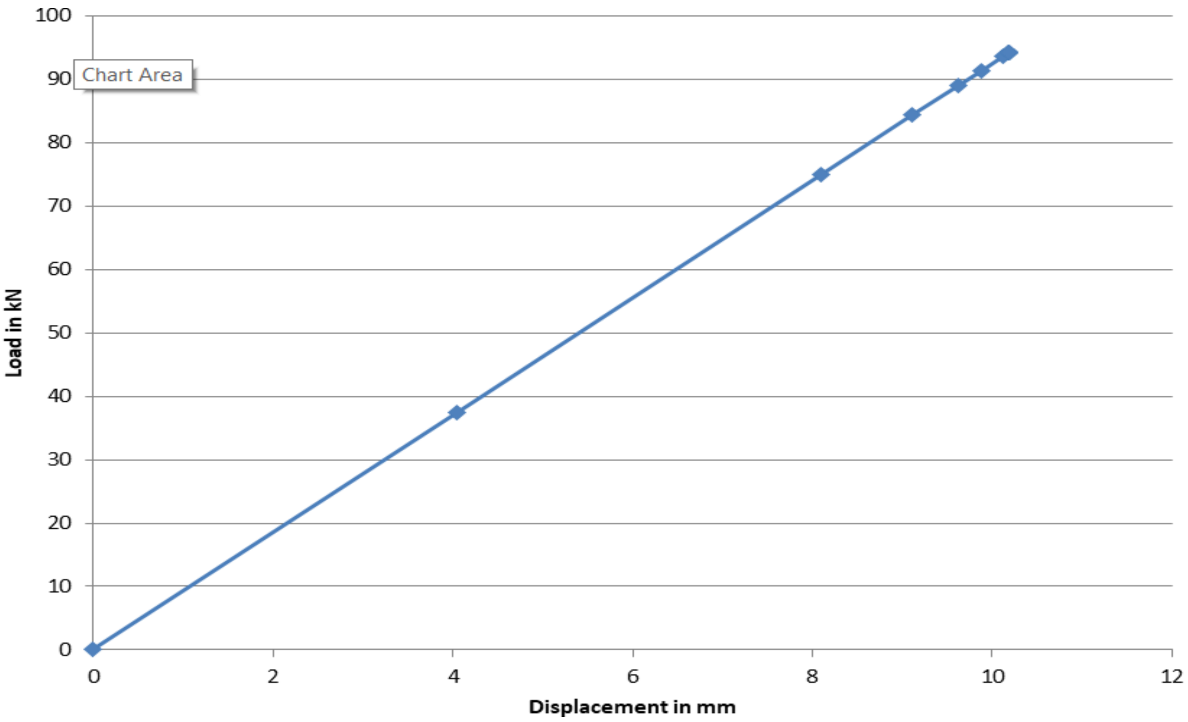
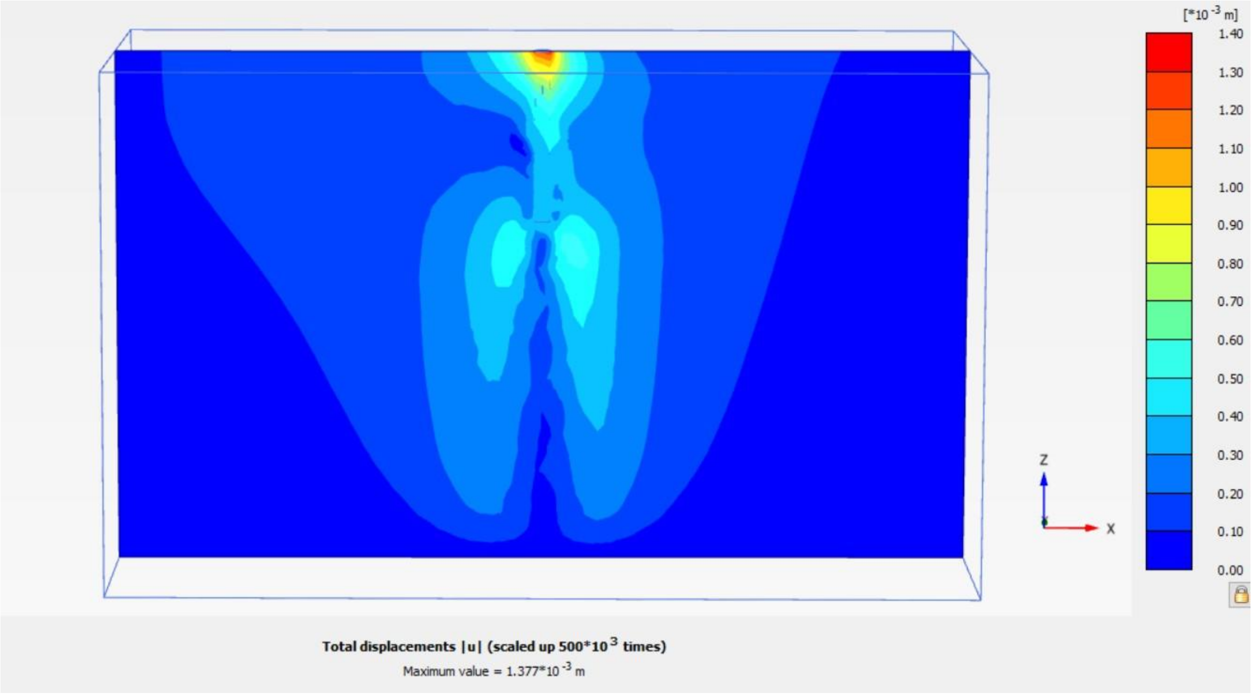


Figure 5.10 Load vs Deflection of 0.4m diameter tubular pile



Total displacements |u| (scaled up 500*10^{3} times)

Maximum value = 1.377*10^{-3} m

Figure 5.11 Total displacement of 0.4m under reamed pile positioned at l/3

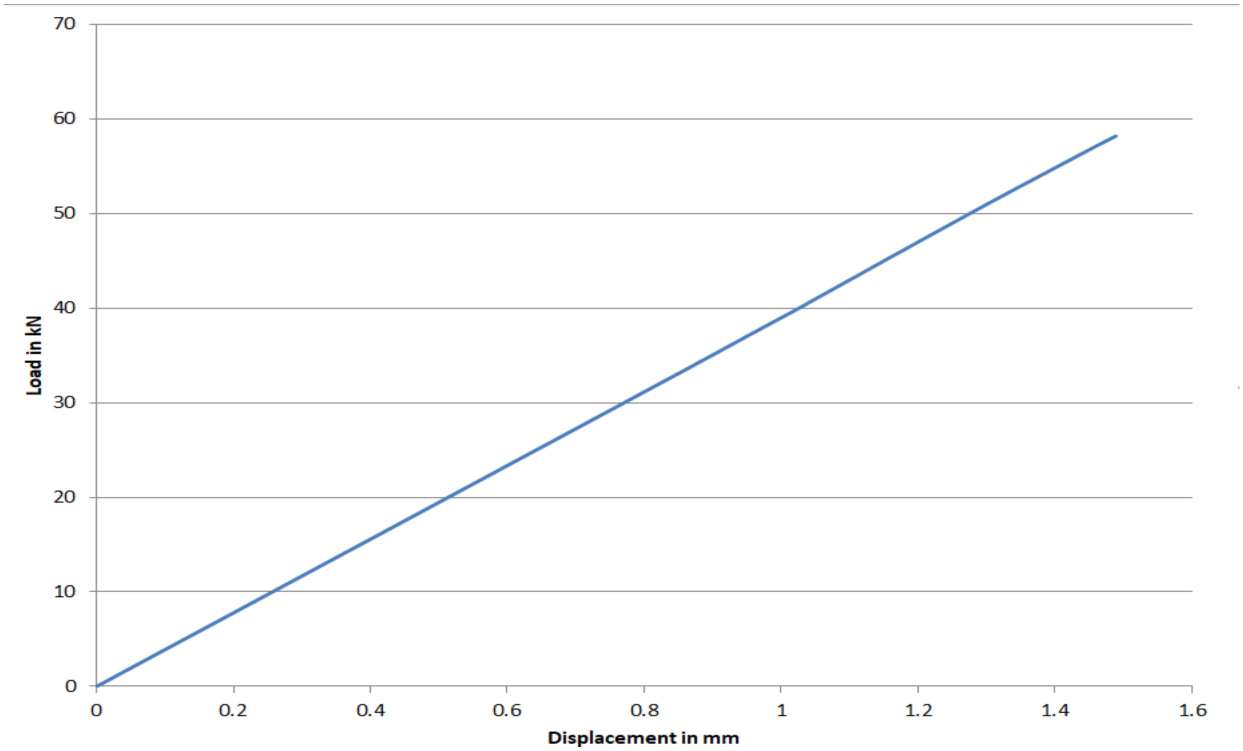


Figure 5.12 Load vs Deflection of 0.4m under-reamed pile positioned at l/3

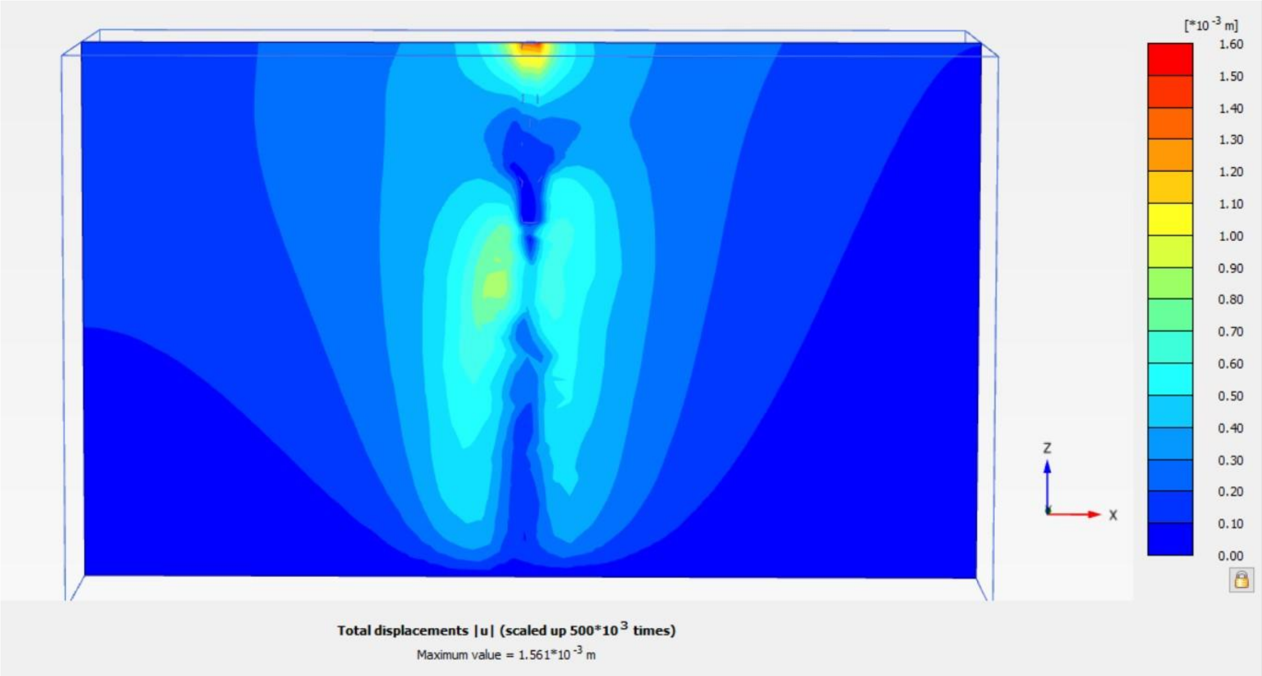


Figure 5.13 Total displacement of 0.4m under-ream pile positioned at l/2

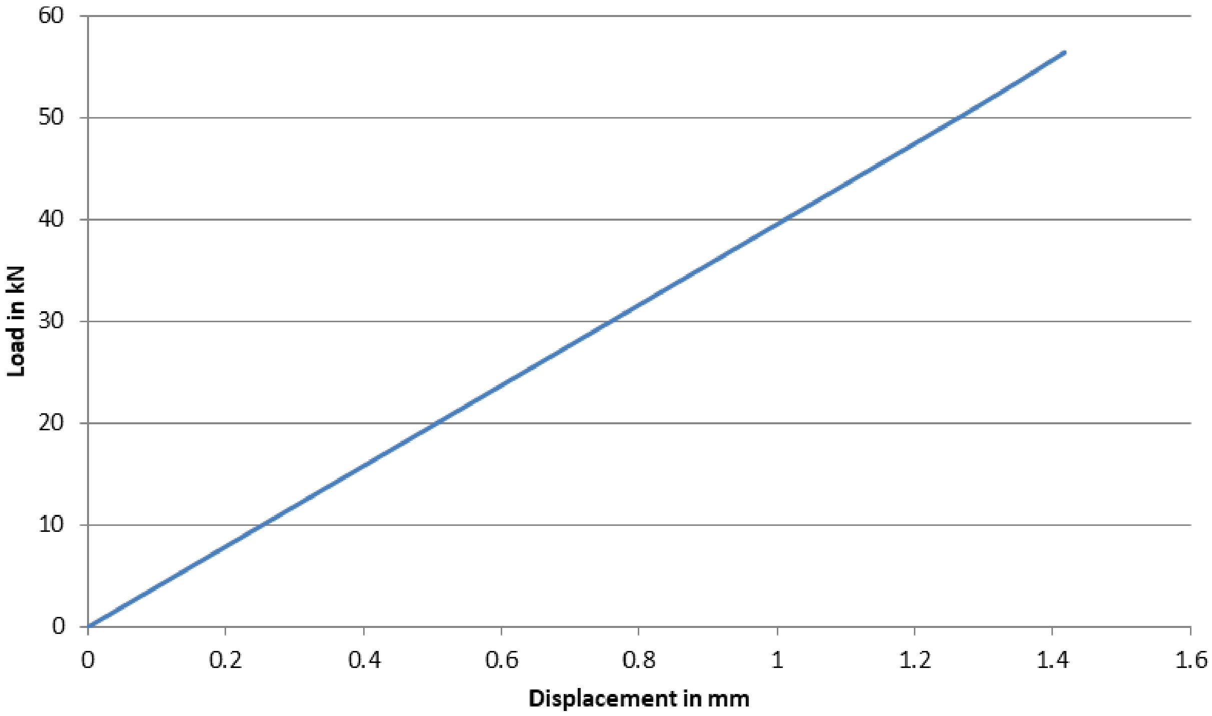


Figure 5.14 Load vs Deflection of 0.4m under-reamed pile positioned at l/2

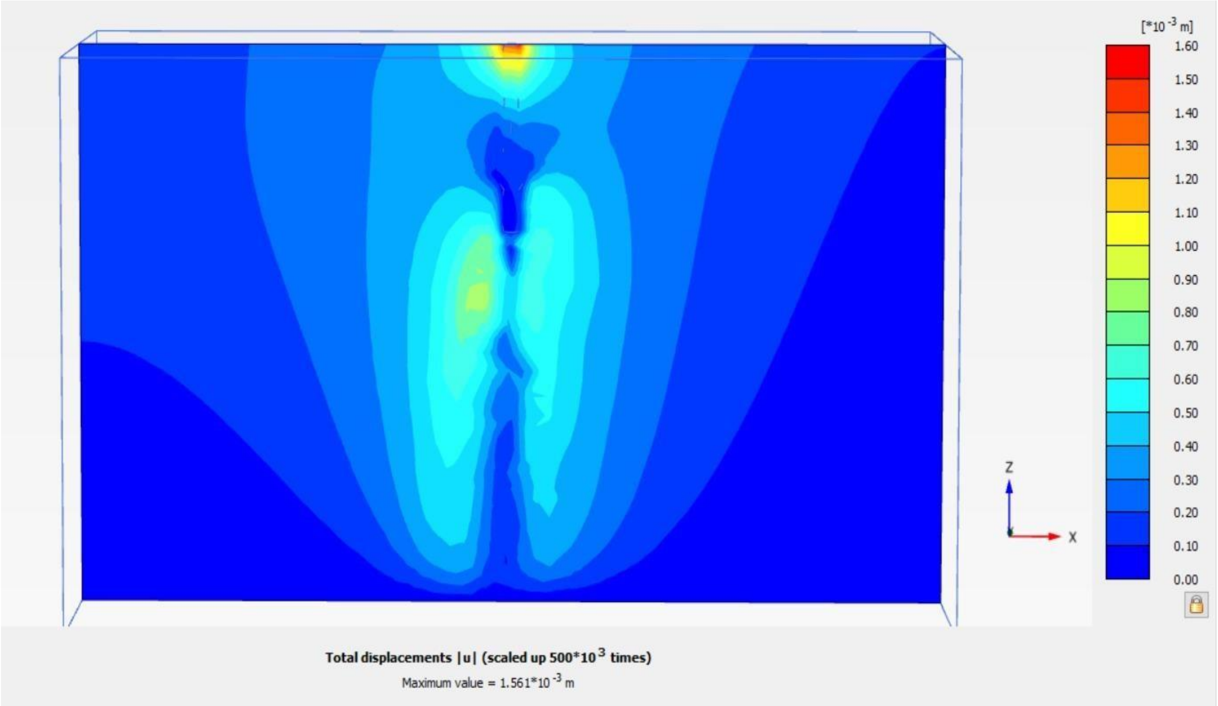


Figure 5.15 Load vs Deflection of 0.4m under-reamed pile positioned at 2l/3

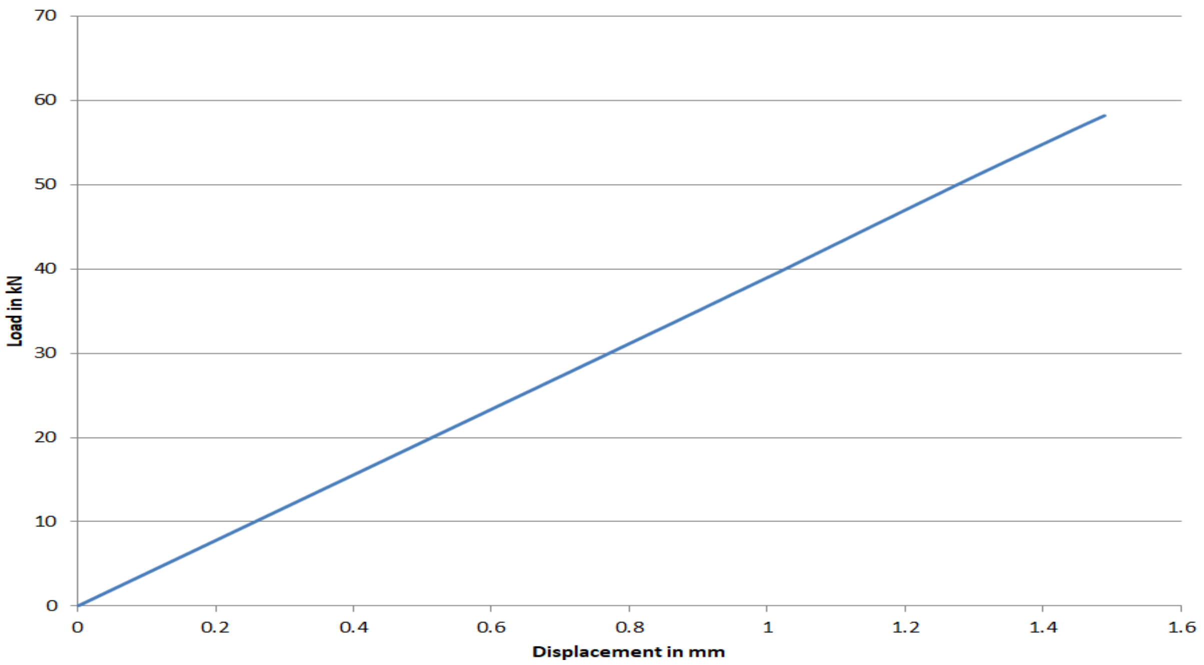


Figure 5.16 Load vs Deflection of 0.4m under-reamed pile positioned at 2l/3

5.4 0.5m DIAMETER PILE

On coming to 0.5m diameter models there are 4 different pile models including one tubular pile and three under-reamed piles having under-reaming monopiles at three different positions along the length such as l/3, l/2 and 2l/3 from the ground surface is studied. There is an increase of in lateral resistance of 32.5% to 59.14% when an under reaming was introduced with the pile with very low deflection compared to the tubular pile. In tubular pile an ultimate load of 294.95 kN was recorded as we are concerned load corresponding to 5mm deflection or corresponds to 10% pile diameter, loading of 48.561 kN was considered corresponding to the 5 mm deflection while in under reamed pile maximum deflection was 2.72mm with ultimate load of 77.289kN which is about 59.14% increase in lateral resistance. The maximum lateral resistance is offered by the under-reaming positioned at l/2 from surface and minimum at l/3 length from the surface of 2.05mm deflection at a load of 64.356kN i.e there is trend on increasing the lateral resistance by positioning the under reaming away from the surface towards the middle of the pile length and then the lateral resistance decreases proportionally when it is positioned away from the middle length towards the bottom as the lateral resistance offered by the under-ream position at 2l/3 is 72.885kNkN with 2.138mm which is lesser compared with the one positioned at the l/2 length from the ground surface.

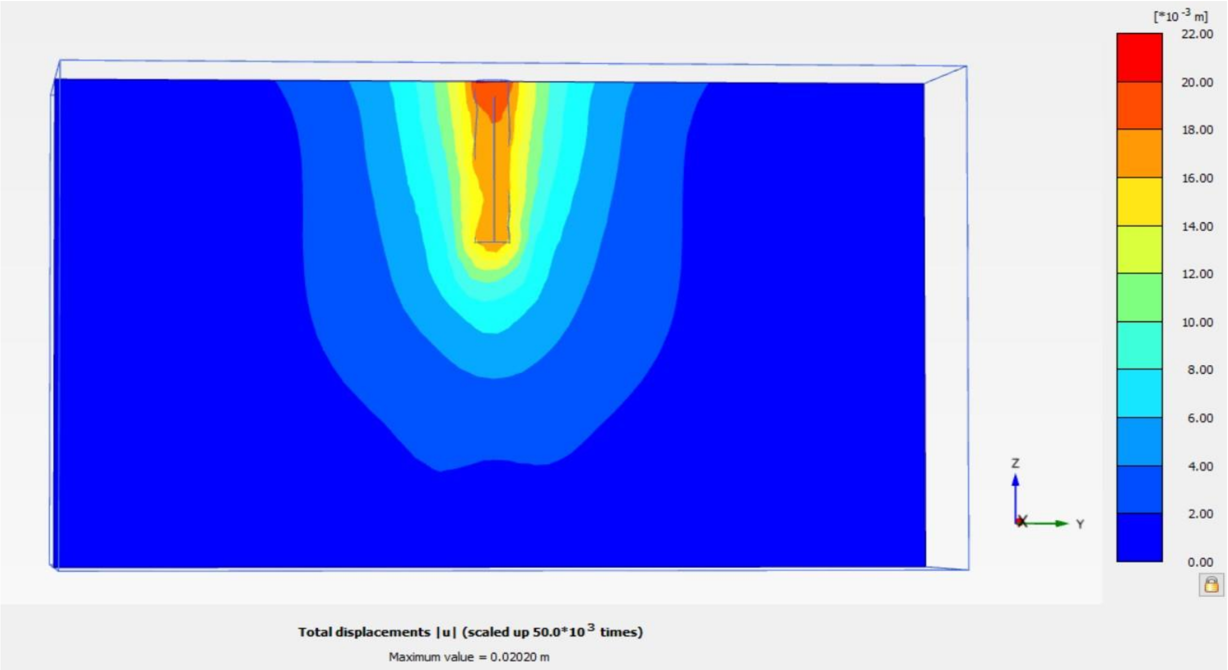


Figure5.17 Total displacement of 0.5m Tubular Pile

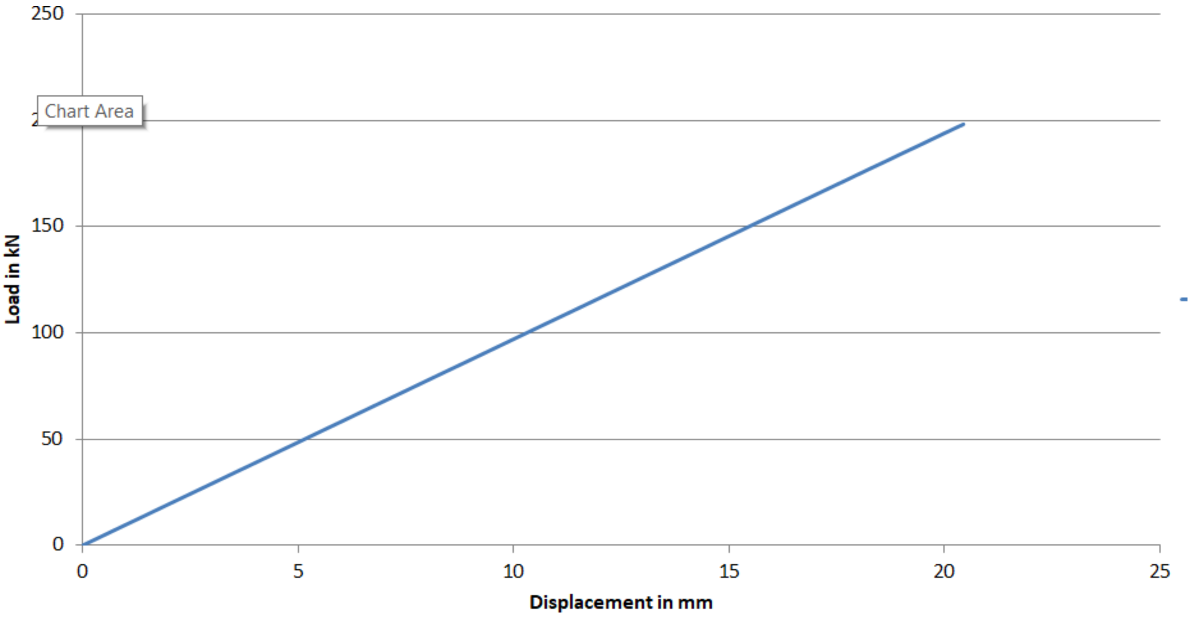


Figure 5.18 Load vs Deflection of 0.5m diameter tubular pile

Figure 5.19 Total displacement of 0.5m under reamed pile positioned at l/3

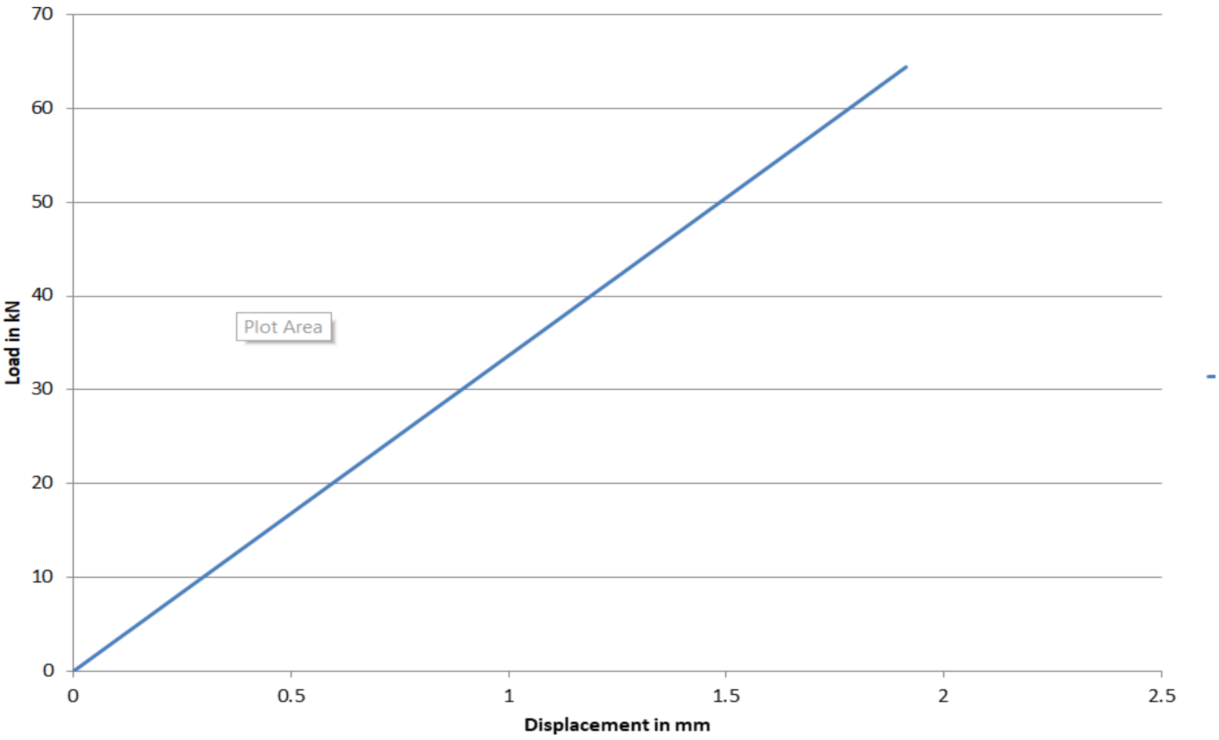


Figure 5.20 Load vs Deflection of 0.5m under-reamed pile positioned at l/3

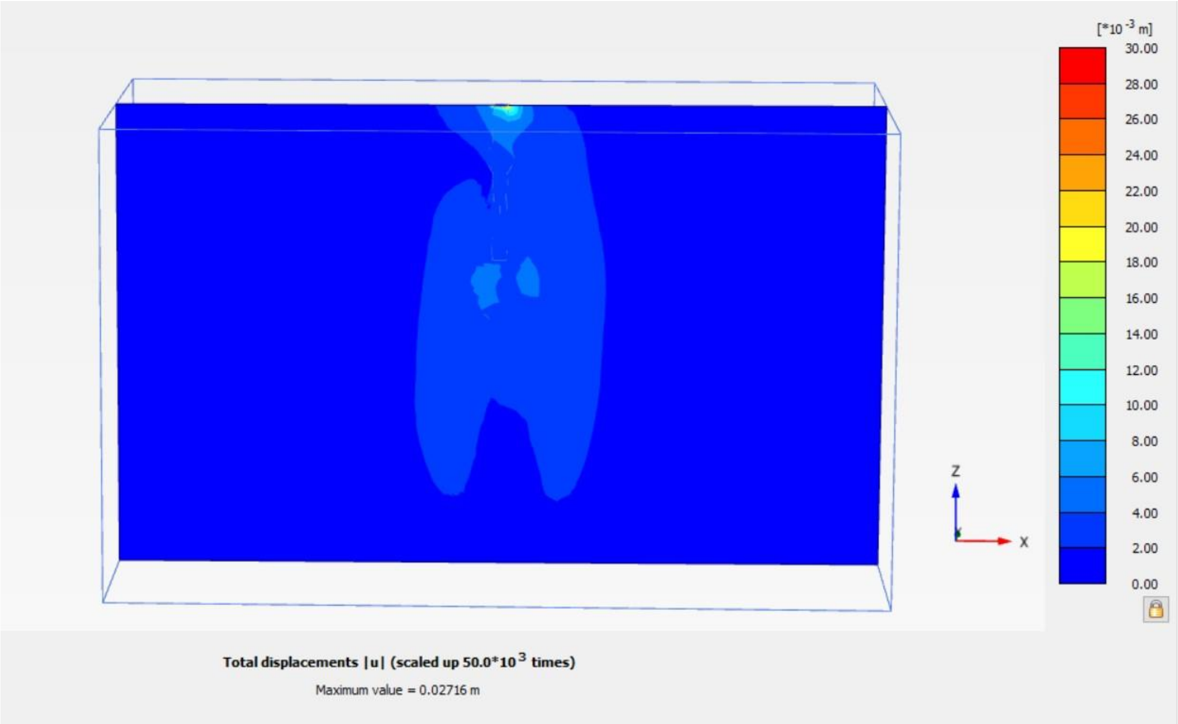


Figure 5.21: Total displacement of 0.5m under reamed pile positioned at l/2

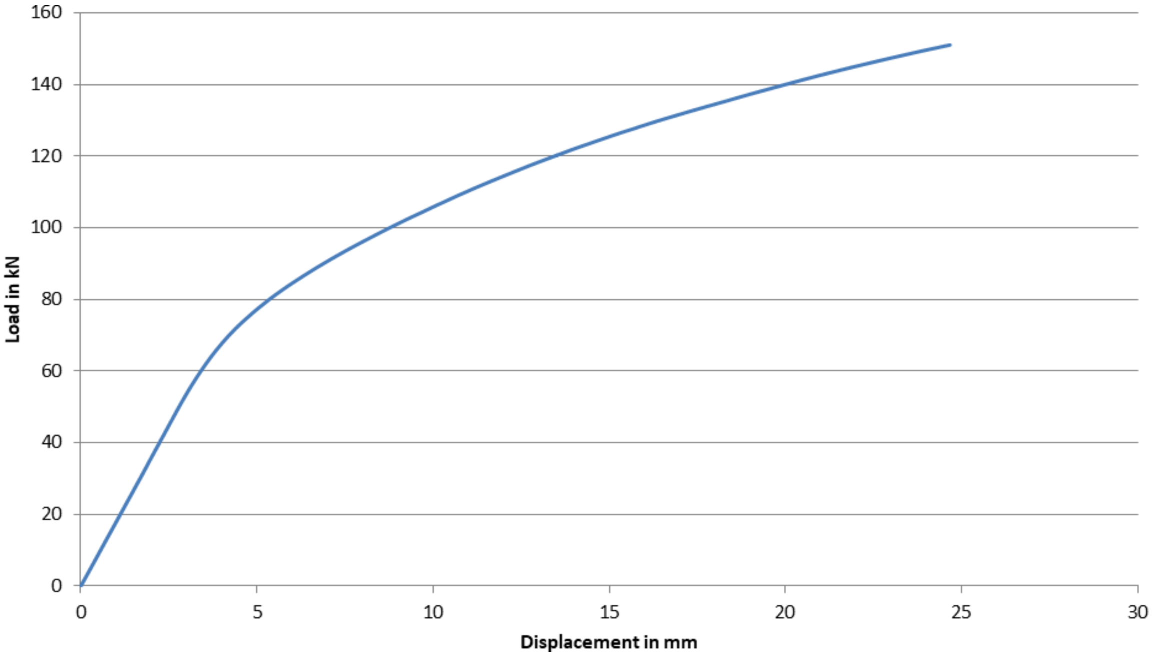
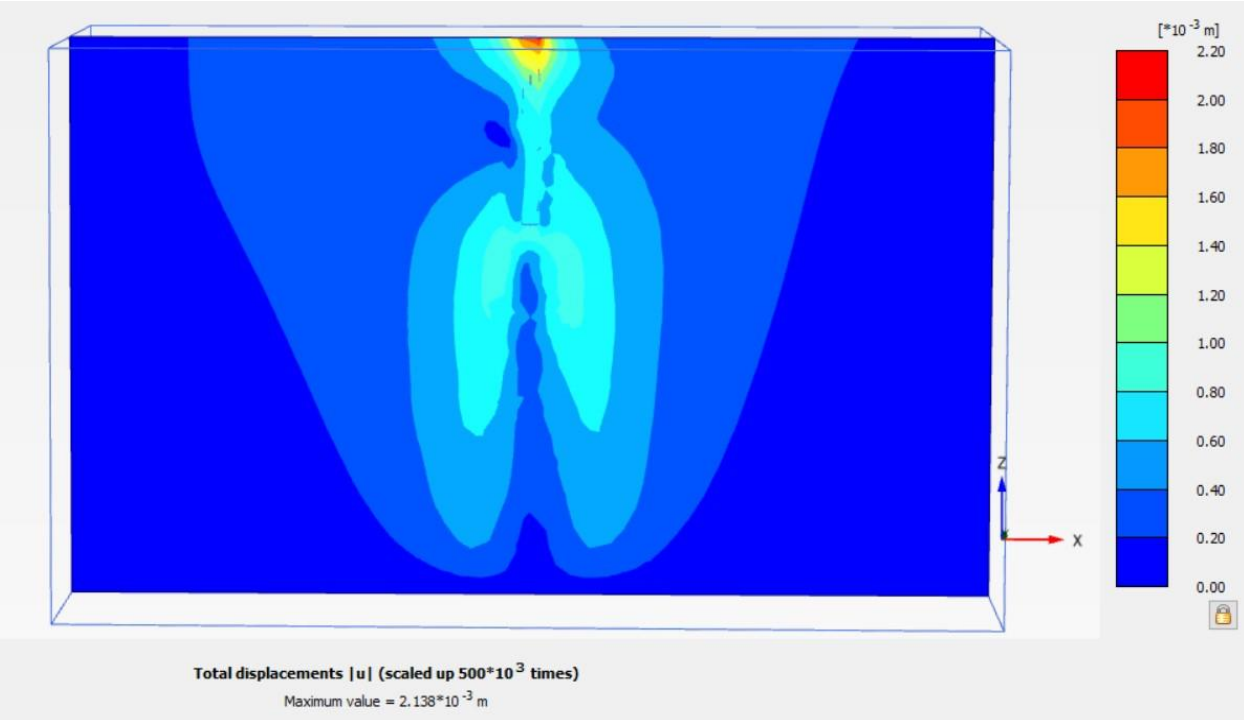


Figure 5.22: Load vs Deflection of 0.5m under-reamed pile positioned at l/2



Total displacements |u| (scaled up $500*10^3$ times)

Maximum value = $2.138*10^{-3}$ m

Figure 5.23: Total displacement of 0.5m under reamed pile positioned at 2l/3

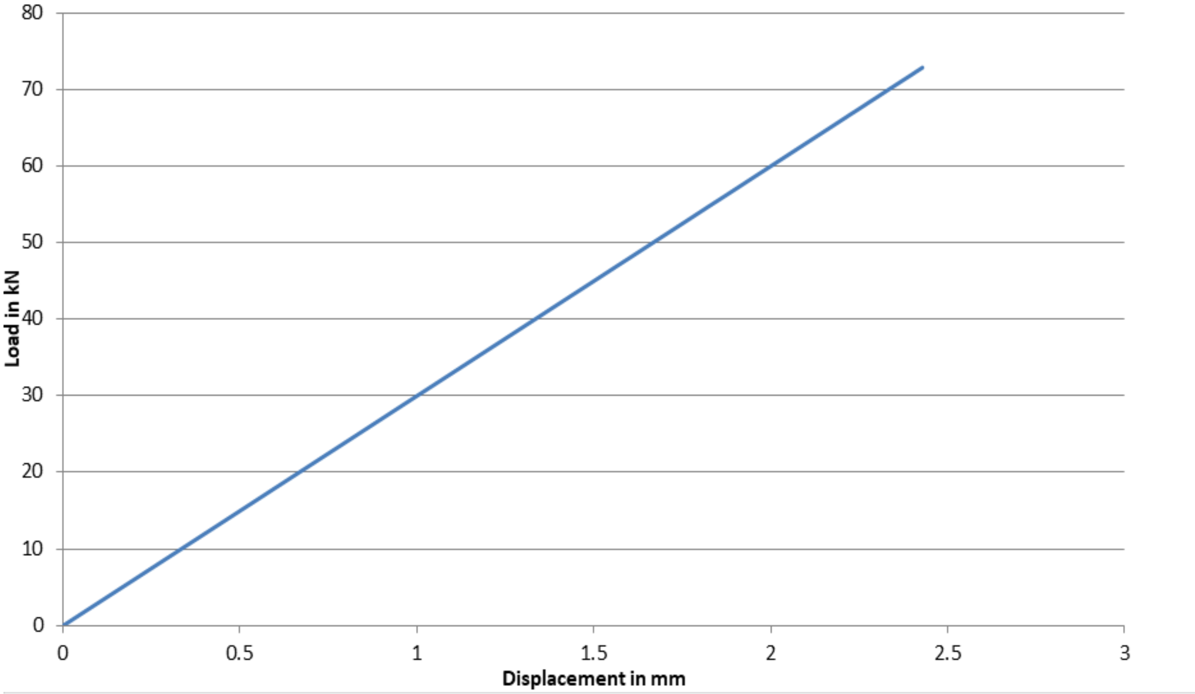


Figure 5.24 Load vs Deflection of 0.5m under-reamed pile positioned at 2l/3

A graph was plotted between ratio of ultimate lateral resistance of under-reamed pile to the tubular pile and ratio of deflection by under-reamed (U.R)pile with the tubular pile. The variation is maximum when the under-reaming is at positioned at mid portion of the pile. In comparison with all the three positions, the position of under-ream at middle of the pile is subjected to maximum deflection and maximum lateral resistance which is shown in the Figure 5.25. As the diameter of the piles increases the crest portion visible in the figure 5.25 gets diminishes and became steeper as seen in figure 5.26 and figure 5.27, this is mainly due to the fact that as the diameter increase the lateral load resisting capacity of the under reamed pile increased tremendously and the displacement due to the loading were also more compared with smaller diameter under-reamed pile but within the permissible limit i.e 5mm or 10% of the diameter of pile whichever is smaller.

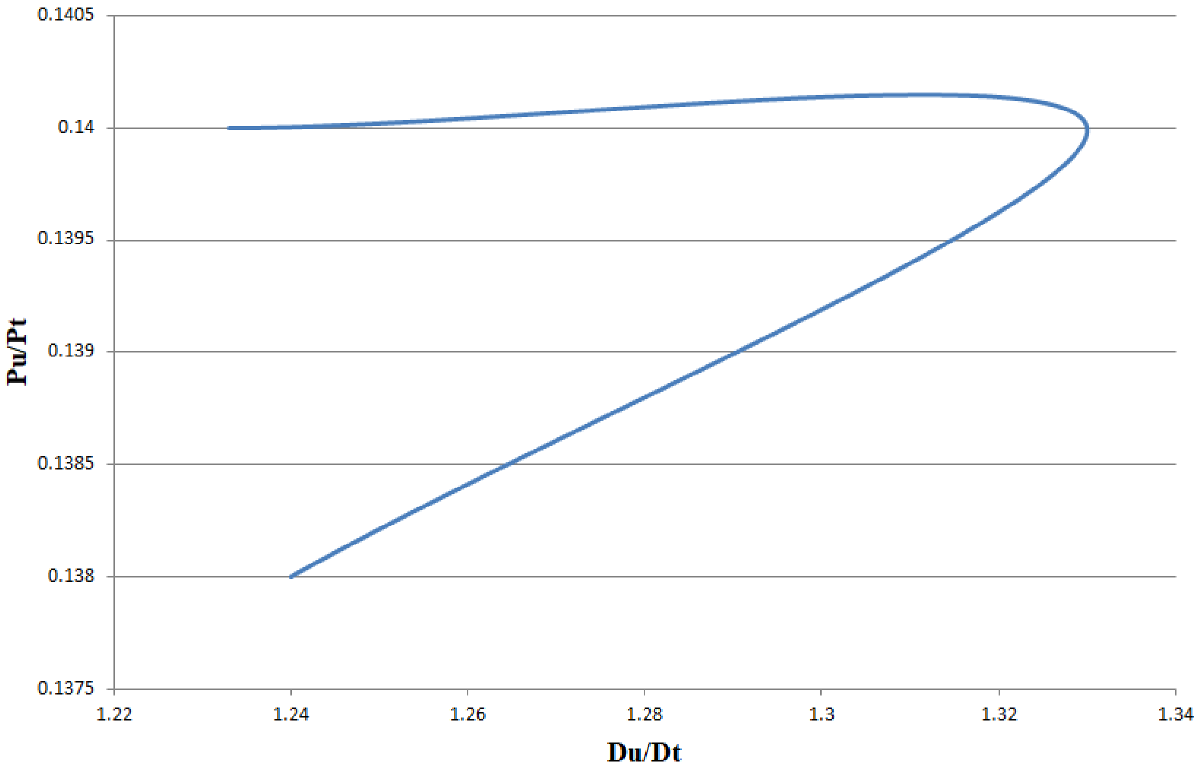


Figure 5.25 Ratio of ultimate lateral resistance by under-reamed pile to the tubular pile and ratio of deflection by under-reamed pile with the tubular pile of 0.3m diameter

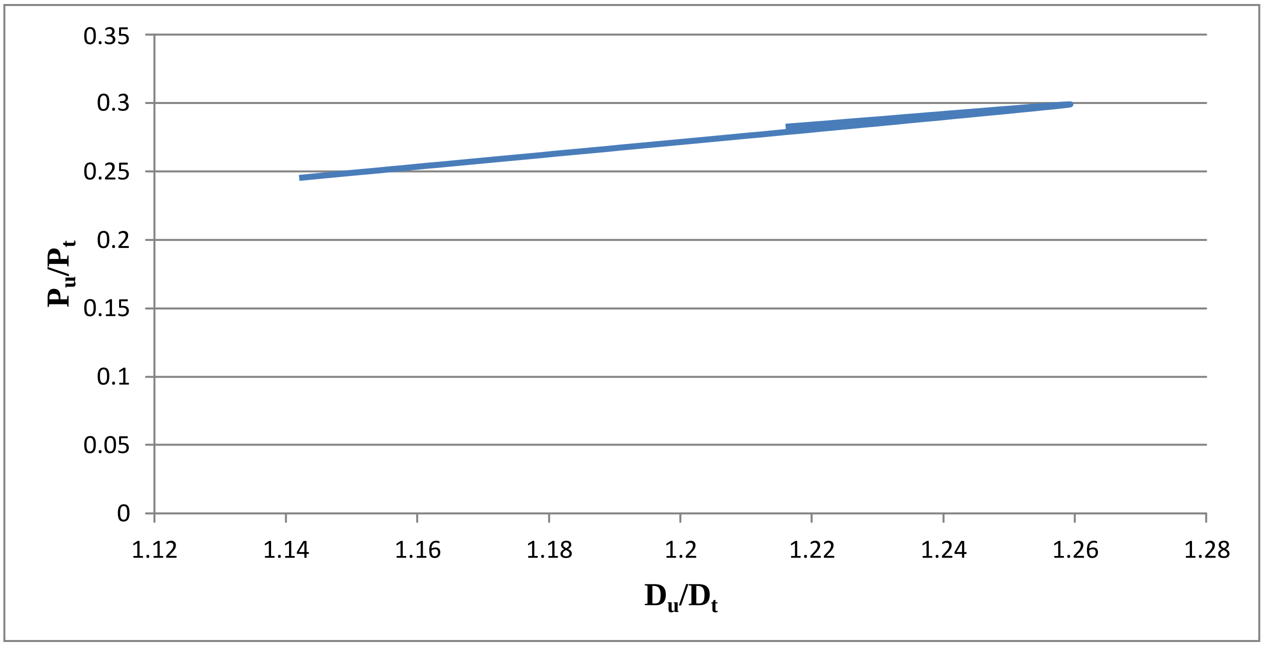


Figure 5.26: Ratio of ultimate lateral resistance by under-reamed pile to the tubular pile and ratio of deflection by under-reamed pile with the tubular pile of 0.4m diameter

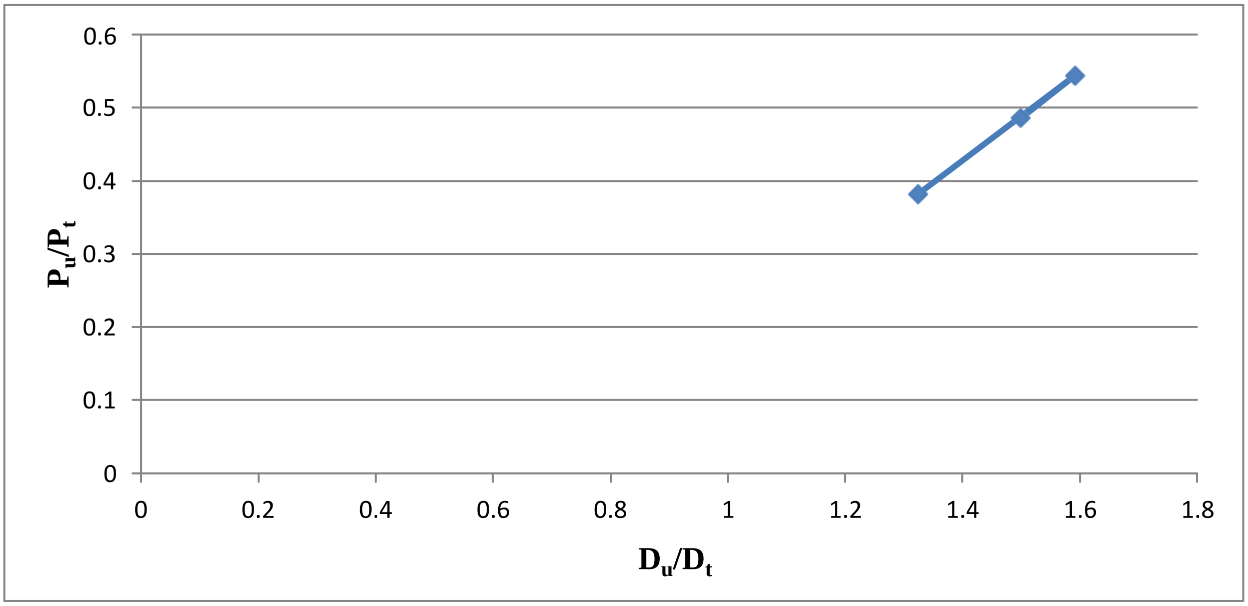


Figure 5.27: Ratio of ultimate lateral resistance by under-reamed pile to the tubular pile and ratio of deflection by under-reamed pile with the tubular pile of 0.5m diameter

CHAPTER 6

CONCLUSION

An analytical procedure to predict the ultimate lateral load capacity of under-reamed piles in cohesionless soil incorporating the influence of diameter, length and position of under-reaming by length to diameter ratio of piles has been presented ground surface. For a mono under-reamed pile, under-reaming located at depths of 0.5 times the length of pile provides the maximum resistance and less deflection compared to the tubular piles.

Under-reamed pile produces a stiffer load-deflection response compared to the pile without under-reaming. The load-deflection response of under-reamed pile is found to be significantly influenced by diameter as well as the position of under-reaming. The lateral capacity at given pile were found to increase remarkably when bulbs are positioned at half length of the pile from ground surface. The lateral resistance increases by about 14.21% to 59.14% by increasing the diameter as well as by positioning the under-reaming. Horizontal stress significantly drops with the introduction of under-reaming to the pile.

As the study conducted on lateral resistance of under-reamed mono pile with the tubular pile shows that the smaller diameter under-reamed pile showed the matched performance- large lateral resistance with the large diameter tubular pile with least deflection. The deflection for under-reamed piles were minimum when under-reaming were at positioned at l/3 and 2l/3 measured from the ground surface. Even with large deflection the pile at under-reaming positioned at l/2 showed were less than 5mm or 10% of diameter of pile shaft except for very large diameter pile.

Provision of under-reaming to the small diameter pile results in very large in the increase of lateral resistance, as the diameter of pile increases the lateral resistance of it also increases with the introduction of under-reaming to the large diameter pile, the deflection of it was reduced considerably. The lateral capacity of under-reamed piles improves significantly with the increase of diameter. Safe lateral loads on the under-reamed piles by adopting a factor of safety of 3.0.

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