SINGLE PILE SUBJECTED TO LATERAL LOADS

MAJOR PROJECT – I REPORT

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Submitted by

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CANDIDATE'S DECLARATION

I, **DIBYANSH TRIPATHI**, M.Tech, Geotechnical Engineering, roll no. 2k19/GTE/05, hereby declare that the Dissertation titled "**Single Pile Subjected to Lateral Load**" that I submitted to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the Master of Technology is original and has not been copied from any source. In the past, this work has never been used to confer a degree, diploma, fellowship, or any other equivalent title or honour.

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Date: 16/12/2020

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Single Pile subjected to Lateral Load**," submitted by Dibyansh Tripathi, roll no. 2k19/GTE/05 (Civil Engineering), Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of a Master of Technology degree, is a record of the project work completed by the student under my supervision. To the best of my knowledge, this work has not been submitted in part or in full for any degree or diploma at this University or elsewhere. .

Place: Delhi **(Prof. Ashutosh Trivedi)**

Dated: 16/12/2020 **SUPERVISOR**

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This project report on "**Single Pile subjected to lateral load**" is dedicated to Prof. Ashutosh Trivedi, Department of Civil Engineering, Delhi Technological University, whose support and encouragement have been instrumental in helping me complete it. I was guided through the project by him while he kept an eye on it and offered helpful ideas.

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I'd want to express my gratitude to my parents for their never-ending encouragement and role as my rock throughout this project.

Dibyansh Tripathi
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ABSTRACT

Piles are frequently anticipated to allow lateral loads to be transmitted into the ground in addition to axial stresses. They are subjected to bending moments and shearing forces. As a result of this the pile safety against structure failure has been assessed. The 3D finite element analysis has been used to model a single pile and the mechanism of lateral loading is investigated. The work presents an analysis of load displacement relation of a laterally loaded pile. Numerical method is carried out in this analysis. The Mohr-Coulomb criteria is used for numerical calculation of stress and for physical parameters such as angle of friction and cohesion value. The hollow pile section with varying thickness have been studied with the application of lateral loads. The soil properties namely modulus of elasticity of soil and soil density have been varied to the application of lateral load on single pile. The findings shows that the higher elastic soil offers more resistance to the displacement at a given load and the thicker the pile smaller is the displacement. The change in the density of the soil does not offer subsequent change in the load and displacement analysis.

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CHAPTER 1 - INTRODUCTION

1.1 ESTABLISHMENT OF NEED FOR A PILE FOUNDATION

Determining whether piles are required for a foundation design is difficult for a foundation designer. Examples of situations where heaps might be required are shown in Figure 1. It's more likely that this will happen if the soil on top is too brittle or compressible to hold up under the weight of the superstructure. In this situation, piles are utilised as piers or extensions of columns to carry loads to a deep, unyielding layer, such as rock (Fig 1a). A stiff stratum must be found if the weights are to be evenly dispersed along a pile shaft, mostly by friction (Fig. 1b). Piles are required because shallow footings cannot transmit inclined, horizontal or uplift stresses and overturning moments. Designing structures that can withstand high winds and earthquakes is common in earth-retaining structures and taller constructions. Upward forces are resisted by negative friction around pile shafts (Fig. 1c). If the vertical piles are bent (Fig. 1d) or in a group, all the piles in the group are integrated, they can withstand horizontal stresses by acting as one structural system (Fig. le). In addition to becoming more popular, piling foundations are typically associated with the presence of weak soil strata. Piles are usually required when erosion can be caused by scouring around footings despite the presence of a solid, incompressible layer (sand or gravel) below a certain depth. Even if the dirt around the piles' base is washed away by the currents, piles nevertheless carry the foundation's burden to the earth (Fig. 1f). Similar piles are commonly employed in urban areas since deep foundations can provide considerable obstacles to future construction activities for the proposed structure. It may be a good idea to use piles to transport foundation loads below the predicted excavation level in the case of (Figure 1g). As a result, further underpinning may be avoided, saving money. If collapsible soils extend to a substantial depth below the soil's surface, foundations must be safeguarded from movement. Piles are used to move foundation loads such as uplift forces or down pull from collapsible soil (Fig. 1h) to an area where moisture change does not impact the soil, as a result.

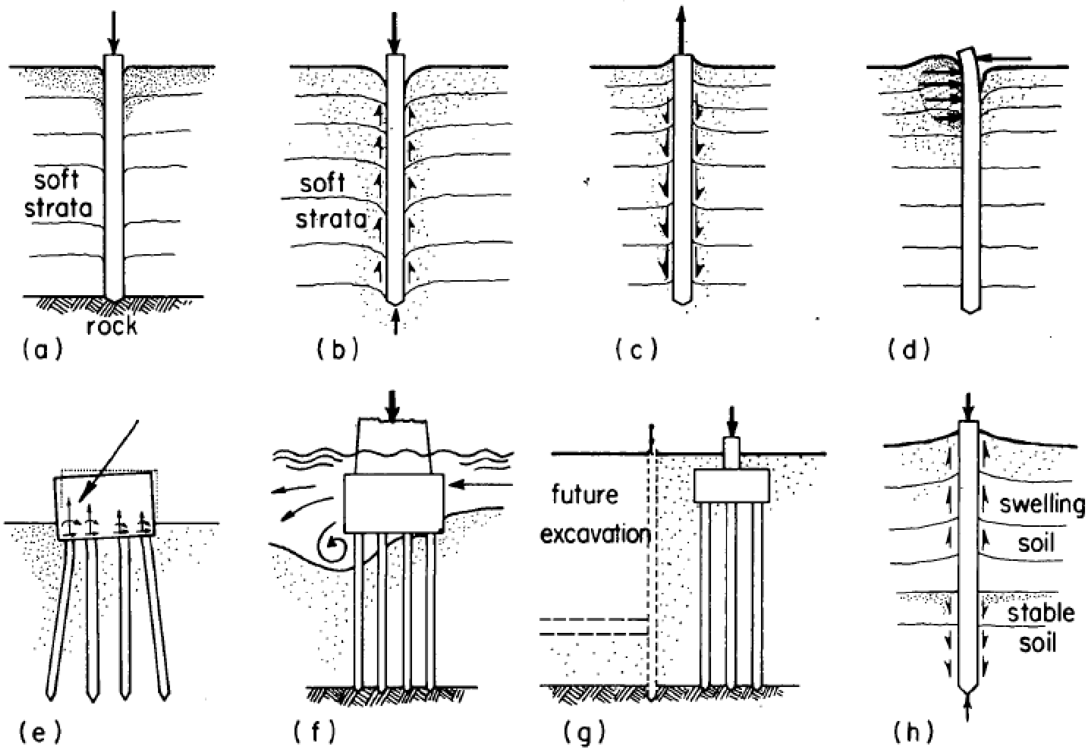

Figure 1- Conditions in which piles are needed (Rajapakse, 2008)

1.2 LATERAL LOADING

1.2.1 Single Pile under Lateral Loads

In addition to axial strains, piles are usually expected to carry lateral loads into the ground. Thus, they are subjected to bending moments and shear stresses that must be calculated to assure the safety of the pile. To determine the supporting structure's lateral displacement and tilt, lateral deflections and a piling axis slope are needed simultaneously.

1.2.2 Winkler's Hypothesis

Assumption: The soil medium is represented by independent elastic springs that are closely spaced. Laterally loaded piles embedded in soil present a similar difficulty to beams with a flexible foundation when external loads or moments are applied to the ground's surface or above it. 1867(Winkler). The nature of the pile after it has been laterally loaded is depicted in the next illustration.

The deformation qualities of the soil are represented by the non-linear springs. The following assumptions underpin the laterally loaded single pile.

1. Laterally loaded piles act as a flexible member, whilst supporting soil acts as an ideal elastic member.
2. The subgrade response theory can be used in this situation.
3. There is no axial force.

In practice, two sorts of piles are encountered:

1. Long Pile: long flexible pile.
2. Short Pile: Rigid member which rotates as a unit.

There are three different types of problems depend upon the load applied in the pile head:

1. The pile head can spin at or above ground level, and the lateral load can act at or above ground level in a free head pile.
2. Fixed head pile: Only pile displacement is permitted; rotation is strictly prohibited.
3. Head pile that is somewhat restrained: The head moves and rotates while it is restricted. On offshore drilling sites, this is a common occurrence.

1.2.3 Solution for Laterally Loaded Piles

Accordingly, the pile's underlying issue can be expressed as follows. See Figure 3 for further information. Deeper than D is known in a known soil a single B-diameter EI-strength pile. The pile at the ground is subjected to a transverse load (P) and a moment (M). There must be a thorough evaluation of the location and magnitude of the pile's greatest bending moment, as well as the pile's horizontal displacement (u) and pile axis gradient (0) at the surface of the soil.

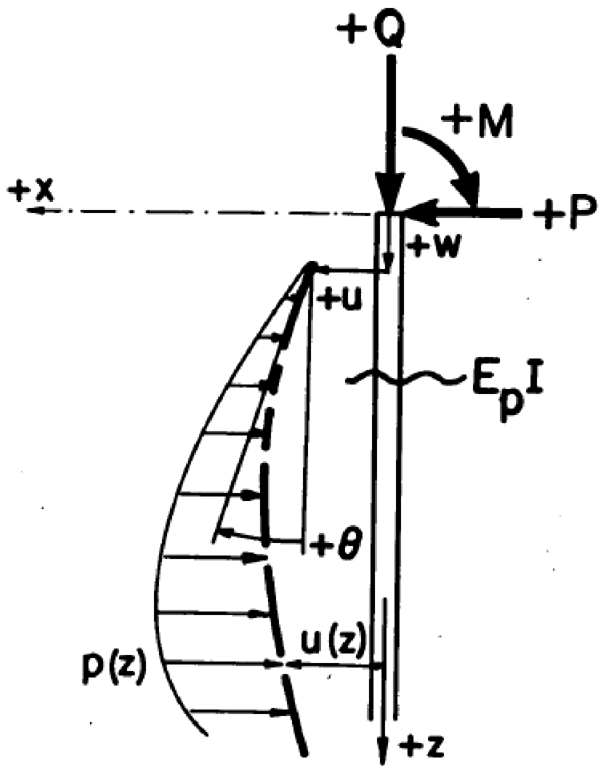

Figure 2- Lateraly loaded pile (VESIC, 1977)

A pile's small diameter and lengthy length make it a good candidate for using the well-known differential equation of bending to compute statistical influences along the pile:

$$\epsilon_p I \frac{d^4u}{dz^4} = -p(z) \tag{1}$$

Reactive soil pressure against the pile, given in force-per-length units such as kN/m, is represented by p(z). Any point on the pile's intricate pressure-to-deflection distribution (pa to u) and the nearby soil's stress-strain parameters are known or presumed. This problem can be solved rather easily by using an assumption similar to that used in the theory of beams and slabs resting on soil, namely that the ratio of pressure (p_z) to deflection (u) at any point of the pile, called soil response modulus, is known. For example,

$$\frac{p_u}{z} = k_h = constant = n_h z \tag{2}$$

in which n_h represents an empirical quantity called the coefficient of soil reaction. The resulting differential equation has a solution in the form of an infinite series, however, it also can be easily integrated by using the method of finite differences.

$$u = \frac{2.43}{n_h T^2} P - \frac{1.62}{n_h T^3} M \quad (3)$$

$$\theta = -\frac{1.62}{n_h T^3} P + \frac{1.75}{n_h T^4} M \quad (4)$$

in which T represents the characteristic length of the pile system defined by:

$$T = \sqrt[5]{\frac{\epsilon_p I}{n_h}} \quad (5)$$

1.3 OBJECTIVE

1. To create a soil pile model with dimensions of 4m*4m*10m and a length of 10m.
2. A lateral load is applied to the pile.
3. The effect of lateral loading on the pile with different pile thicknesses was investigated.
4. To investigate the impact of loading soil with a varying modulus of elasticity.
5. To investigate the impact of loads on different soil densities.
6. To compare the outcomes of different pile thicknesses .

CHAPTER 2 - LITERATURE REVIEW

Three-dimensional finite-element study on pile groups subject to combined axial and torsional loads in the flow-controlled geomaterial was performed using a computational software using a numerical technique. The flow potential for yielding the geomaterial with flow control is determined by a smooth elliptic function in the deviatoric stress plane and a hyperbolic stress function in the meridional stress plane. This study used experimental pile load tests and literature numerical findings to compare the load–displacement relationships of a large-diameter pile (LDP) with pile groups (1*12 and 2*2). Torsional stress causes a significant increase in displacement for both the LDP and the piling groups. In relation to the axial force, the twist increases dramatically. The plastic strain and dilation angle of the geomaterial were used to classify the displacement and twist features.

The lateral response of a single pile under pure lateral load was studied by Abbas et al. (2018) using a three-dimensional finite element technique. The main goal of this research is to find out how the slenderness ratio of a pile affects the lateral behaviour of that pile. By considering the influence of lateral load magnitudes, cross-sectional form, and pile flexural rigidity on modified p-y curves for lateral single-pile responses, the results were further improved. Large weights can be handled by a pile submerged in non-cohesive soil rather than an intermediate one.

Using a model pile with a diameter of 16 mm and a length of 600 mm, Mahmood et al. (2018) evaluated the impact of unsaturated sandy soil. The pile was put to the test in a variety of saturation scenarios (dry, saturated, and unsaturated). The pile head received lateral loads from a static lateral load setup device until the pile's maximum lateral capacity was attained. When the soil is unsaturated, the pile resists lateral displacement and bending moments less than when it is dry or saturated for the same relative density. This reduction occurs because unsaturated soil has a suction effect.

With the help of three-dimensional finite element modelling, Elhakim et al. (2019) analysed the major parameters that govern the response of laterally loaded pile groups (spacings of 2.5 D, 5 D, and 8 D) and the position of the piles within the groupThe load–

displacement under lateral loading is influenced by the pile head's fixity. Depending on whether the pile head is permitted to rotate, it is either uncontrolled (free) or constrained (fixed). Both free and fixed head scenarios were tested.

Foundation design for seismic stress in Hungary has been researched by Ray R.P. and Wolf (2013). An overview of foundation modelling alternatives is provided during the design phase of a superstructure, as well as the Hungarian practise (fix support, linear elastic support, non-linear elastic support). It is found that the bearing forces and stresses in a typical reinforced concrete office building are affected by the support mechanisms used, and this is explored using SAP2000 finite element software. The results of the calculation are compared to the moment, deflection, and reaction of the column.

In a detailed three-dimensional finite element formulation for the study of laterally loaded piles in sloping terrain, Sawant V. and Shukla S.(2012) investigated the 18 node triangular prism elements. The numerical formulation has been proved to be applicable to the pile at the hill's crest as well as the pile at a distance from the crest. The examples show that the displacement and bending moment increase with increasing slope of the ground while decreasing with increasing edge distance at any given depth.

It was found that the lateral reaction of piles differed depending on whether the soil was cohesive or not (Abbas et al., 2010). Design quantities such as lateral displacement and soil stress, as well as how they fluctuate over time in the case of piles can be determined by using the full geotechnical model The model has been validated by comparing it to published case studies, and the results are very similar. According to the findings, the pile in a cohesionless soil is more resistant to fast loading but less resilient to long-term loading. Cohesive soil that's been piled on top of itself, on the other hand, takes the opposite behaviour.

Researchers discovered that the final lateral capacity of individual heaps and pile groups varied depending on the method utilised to strengthen the sand surrounding the heaps. Bahloul and Magdy(2011) carried out research on these differences. Various slenderness (L/D) ratios were tested on single piles and pile groups in sand with varying densities

(Dr=25%, 45%, and 68%) in the surrounding soil. a fixed head spacing of three diameters was used for the testing on pile groups of 2x1 and 2x3, and the results showed that (3D). The numerical and experimental results agreed when comparing F.E.M. results with those obtained through experimentation.

The piling foundation for the earthquake was examined by Mahalakshmi and Arulsurya(2021). The piles are modelled in Solid Works and evaluated in ANSYS workstation. Solid Works is utilised for both. Loads are applied vertically and laterally to long and short piles. Massive overturning and displacement in the long pile were induced by the lateral force impact, along with smaller ground displacements. There was extensive ground displacement as well as short pile settlement.

An research was carried out by Abbas and associates (2017) to see how axial load intensities impact different pile slenderness ratios. The entire geotechnical system was simulated using a three-dimensional finite element model. As for simulating the pile-soil interaction, a Mohr-Coulomb model was employed to represent the soil around it and a linear elastic model to represent the pile. Increasing the axial load also increased the lateral deflection in cohesionless soils, it was discovered. However, in cohesive soil, a minor axial stress reduces the lateral pile displacement.

According to Karthigeyan and Rajagopal (2009), the vertical load has a numerical effect on the lateral capacity of a 2x2 pile group in homogeneous sand. The lateral reaction of pile groups under combined loads was studied using the GEOFEM-3D technique, which relies on 3-D finite elements. An idealised stress-strain behaviour of the soil is used to model the pile's elastoplastic stress-strain behaviour in the analysis. The influence of connected loads on the piling group's lateral capacity improves numerically as a result of research.

The influence of the surcharge load on the pile was studied by Jegatheeswaran and Muthkkumaran(2012) and the surcharge load was kept at two different locations. One is located closer to the pile than the other (as a result of an active wedge interaction) (without interaction of active wedge). Consequently, in this research, it is necessary to investigate the impact of the surcharge load on the active wedge formation. This study investigates the pile's behaviour and deformations when subjected to these loads. This study was done on perfectly flat ground. Additionally, a variety of sandy soil types with varying relative densities (such as 30%, 45%), 50%, and 70% are considered.

To determine the effect of embedment length-to-diameter ratios L/d = 12 and 38, the researchers used dry Ennore sand from Chennai, India, and applied lateral loads while measuring friction angles of 20° and 31°. The results showed that the pile configurations 1*1, 2*1, 3*1, 2*2, and 3*2 performed well under these conditions. Through quantitative and qualitative analysis of the pile number, the response to load displacement was investigated together with the pile's ultimate resistance as well as its overall group efficiency. The ultimate lateral capacity of individual piles and pile groups has been predicted using analytical approaches. Thus, for example the methodology's friction angle and length-to-diameter ratio are taken into account. These methodologies are excellent for determining piles' lateral capacity when compared to experimental data from the authors and other researchers.

It was found that numerical analysis was utilised to calculate the horizontal modulus of sub-grade response when Bisaws et al.(2015) evaluated model piles (h). Free-headed piles were tested in homogenous and stratified soils to see how they performed. In addition, sand density and slenderness ratio were adjusted, as well as pile embedment ratio (SR). The numerical study was performed using PLAXIS 3D Foundation version 2.1 software and a three-dimensional finite element approach. It was possible to compute h, the horizontal modulus coefficient of the sub-grade reaction, using the deflection profile along the pile depth after the finite element analysis findings were examined. The test circumstances were modelled using a finite element analysis with variables that had the same soil–pile properties as those used in the real investigation. For both long and short sand stacks in homogeneous and stratified situations, numerical results matched up well with experimental ones. The change in h was next examined in light of the soil–pile properties previously indicated. The flexibility ratio, referred to as h, was further studied in relation to various soil–pile characteristics using a normalised form. First, the behaviour of long and short heaps in homogenous and stratified sand differed significantly. H grew when the thickness of the thinner, weaker layer of sand beneath the more robust one dropped. The difference between short and long heaps, on the other hand, was never non-linear. A pile's size and height were inversely related, but for long heaps, the height rose along with the heap's height and declined when that measurement approached 40 feet (h). All changes have an impact on the ultimate lateral load according to this research in soil–pile characteristics as well as coefficient of horizontal modulus of sub-grade reaction (h), the fundamental stiffness parameter that defines one single pile's ultimate lateral load.

By using PLAXIS3D software and numerical analysis, Karthigeyan and Samanta(2011) investigated the impact of surrounding excavations' indirect loading on the lateral response of a pile in sandy soil. It was decided to use an idealised Mohr-Coulomb model to simulate the soil's behaviour because of its similarity to a linear elastic material throughout the numerical study. Excavation depth and pile placement relative to the excavation face affect indirect pile loads. These factors are plotted. The research gives numerical results for pile section lateral deflections and maximum bending moments under direct and indirect loads.

Abbas et al. (2015) used a 3D finite element technique to examine the lateral response of single and many piles under simultaneous vertical and lateral forces. Additionally, this study looked at the p-y curve that goes along with the lateral pile displacement and soil resistance. Due to this discovery, increasing the axial load intensities had a stronger influence on the modified p-y curves for lateral single pile reactions. P-multiplier curve and equation generation for collective action construction is doable using the revised plots. Laterally loaded pile construction may also be done using the revised plots. Three pile group configurations (2*1, 2*2, and 3*2) with four pile spacings (i.e. s = 2D, 4D, 6D, and 8D) were tested for the influence of load combination on lateral pile group response. Consequently, design curves for analysing pile group behaviour with updated p-multipliers were developed and implemented in real-world case studies and other scenarios. they were To analyse the lateral pile group action under consideration of the axial load intensities, a design equation was generated from design curves. With pure lateral animosity, group interaction increased lateral resistance for the group pile. Because of this, if two loads are coupled simultaneously, the p-multiplier will be multiplied by about 100 percent, increasing the group pile capacity. This is known as a large axial load intensity.

Two-way cyclic lateral loading was used on a large number of steel pipe piles and a single pile by Brown et al. (1988). The experiments were done on sand that had been compressed around the piles and then sunk to the bottom. In order to compare the differences in soil resistance among the piles, each one was fitted with a variety of sensors. They also compared the collective response to a single isolated pile. The group's piles lost efficiency mostly as a result of "shadowing" (i.e., the loss of soil resistance of piles in the trailing rows). There was a lot of weight on the piles in the front row, and they behaved like a single isolated pile. Two-way cyclic loading had no effect on the load distribution to the group's piles, although it did tend to densify the sand in the vicinity of the single pile and the group piles.

Researchers used the finite element approach to carry out their parametric research, and as a result, the soil was handled as an elastic continuum with a linearly variable soil modulus by Randolph(1981). With these formulae, one may quickly estimate the active length of the pile, ground-level deformations, and the pile's maximum bending moment. This is akin to using a Winkler idealisation of the soil. There are also new formulas for calculating interactions between piles, which can be used to forecast pile behaviour under lateral loading.

Shaia and Abbas(2015) utilised ABAQUS to run numerical simulations of pile behaviour submerged in cohesionless soil and subjected to oblique stresses. The linear elastic model was employed to represent the pile, while the Mohr-Coloumb constitutive law was used to recreate the surrounding soil in the cohesionless soil. An approach based on slave-master contact elements is utilised to describe how the pile interacts with the earth around it. A load/displacement curve for the vertical and lateral loading components is shown for various inclination degrees. After all is said and done, conclusions about pile design under oblique stresses can be drawn.

CHAPTER 3 - MATERIALS AND METHOD

3.1 ANALYSIS OF LATERALLY LOADED PILES (BROM'S 1964)

Brom's theory addresses the following issues:

1. At operating load, lateral deflection of piles at ground level.
2. The soil's ultimate resilience.

As indicated below, Brom considered both long and short piles embedded in both cohesive and cohesionless soil:

1. In saturated cohesive soils, lateral deflection at working loads.
2. In cohesive soils, pile's ultimate lateral resistance.
3. In cohesionless soil, lateral deflection at operating loads.
4. In cohesionless soil, pile's ultimate lateral resistance.

3.1.1 Lateral Deflection at Working Loads in Saturated Cohesive Soil:

It is assumed that deflection increase approximately linearly with applied loads when the applied loads are less than ½ to 1/3 to the ultimate lateral resistance of the pile. Lateral deflections are calculated using the concept of subgrade reaction. The deflections, bending moments and soil reaction depend primarily on dimensionless factor β where,

$$\beta = \sqrt[4]{\frac{kd}{4EI}} \tag{6}$$

Where,

EI = stiffness of pile section

k = modulus of subgrade reaction

d = width or diameter of the pile

L = length of the pile.

A pile is considered long or short on the following condition

Free head pile**:** For long pile : $\beta L > 2.5$ For short pile : $\beta L < 2.5$

Fixed head pile**:** For long pile : $\beta L > 1.5$ For short pile : $\beta L < 1.5$

3.1.2 Calculation of Deflection

Brom provided an equation for lateral deflection y_0 at ground level in two cases: fully free or filly locked at ground level.

1. For free headed short pile :

$$y_0 = \frac{4P\left(1 + \frac{1.5e}{L}\right)}{k.d.l} \tag{7}$$

Where, e = height above the ground level where P is applied

2. For fixed headed short pile :

$$y_0 = \frac{P}{k.d.l} \tag{8}$$

3. For free headed long pile :

$$y_0 = \frac{2P\beta(e\beta + 1)}{k_\infty.d} \tag{9}$$

4. For fixed headed long pile :

$$y_0 = \frac{P\beta}{k_\infty.d} \tag{10}$$

Where k_∞= modulus of subgrade reaction of long piles.

3.1.3 Lateral Deflection and Soil Resistance in Cohesionless Soil

Length factor for the pile is given by $\eta = \left(\frac{\eta_h}{EI}\right)^{\frac{1}{5}}$ Where η_h = coefficient of soil modulus reaction EI = flexural stiffness of pile material. Now, if ηL < 2, it is a short pile which behave as an infinitely stiff member, and when ηL > 4, it is a long pile.

Brom gave the following equation to calculate deflection at ground level.

1. Long free head pile with lateral load at ground level

$$y_0 = \frac{2.4P}{\eta_h^{\frac{3}{5}}(EI)^{\frac{2}{5}}} \tag{11}$$

2. Long fixed-head pile

$$y_0 = \frac{0.93P}{\eta_h^{\frac{3}{5}}(EI)^{\frac{2}{5}}} \tag{12}$$

3. Short free headed pile

$$y_0 = \frac{18P\left(1 + 1.33\frac{e}{L}\right)}{L^2\eta_h} \quad (13)$$

4. Short fixed-head pile

$$y_0 = \frac{2P}{L^2\eta_h} \quad (14)$$

3.2 MATERIAL PROPERTIES

The soil used in this study is a single-layered homogeneous cohesionless soil with changing density and modulus of elasticity. The surrounding soil is represented by the Mohr-Coulomb model. This elasto-plastic model is based on well-known soil properties. The model's two main parameters are the cohesion intercept, c', and the friction angle, v'. Three parameters are necessary to calculate the entire stress-strain behaviour: Young's modulus, E'; Poisson's ratio, φ'; and the dilation angle, ψ '. Only the primary stresses affect the failure envelope; the intermediate principle stress has no effect.

Table 1: Physical properties of the soil profile

S.No.	Density (Kg/m^3)	Poisson's Ratio	Permeability (M/Sec)	Void Ratio	Friction Angle	Dilation Angle
1	1500	0.25	0.0001	0.6	35	30
2	1600	0.25	0.0001	0.6	35	30
3	1700	0.25	0.0001	0.6	35	30
4	1800	0.25	0.0001	0.6	35	30

Table 2: Modulus of elasticity of soil profile

Modulus of elasticity (Mpa)	10	15	20	25	30	35

Table 3: Properties of the pile material

PILE MATERIAL	Steel
TYPE	Hollow
MASS DENSITY (kg/m^3)	8000
POISSON'S RATIO	0.3
MODULUS OF ELASTICITY (Gpa)	200

3.2.1 Soil Profile Dimension

The soil profile is 4m*4m*10m in size and has uniform and homogeneous characteristics. The 4m*4m surface features a 0.3m space in the centre for pile insertion.

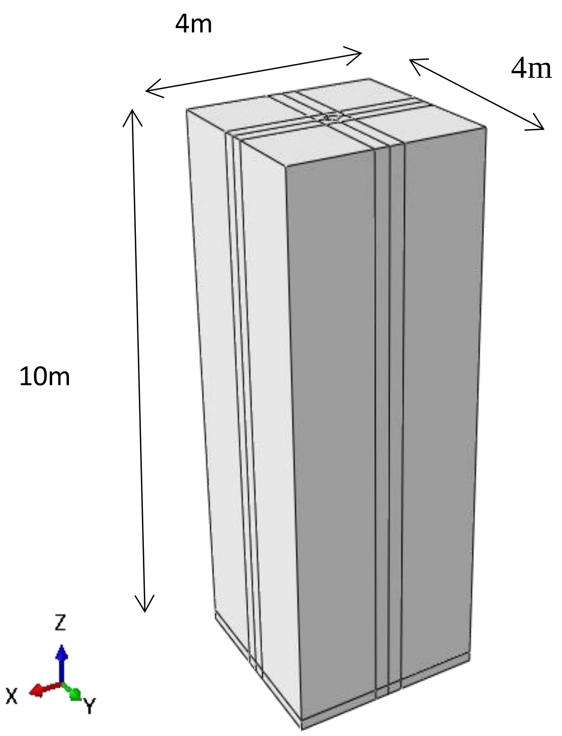

Figure 3- Dimensions of the soil profile

3.2.2 Pile Dimensions

Steel with a hollow cross-section is used for the piles. The length of the pile is 10m and the diameter of the pile is 0.3m. The pile thickness is varying 0.01m, 0.02m, 0.03m, 0.04m, 0.05m for the analysis.

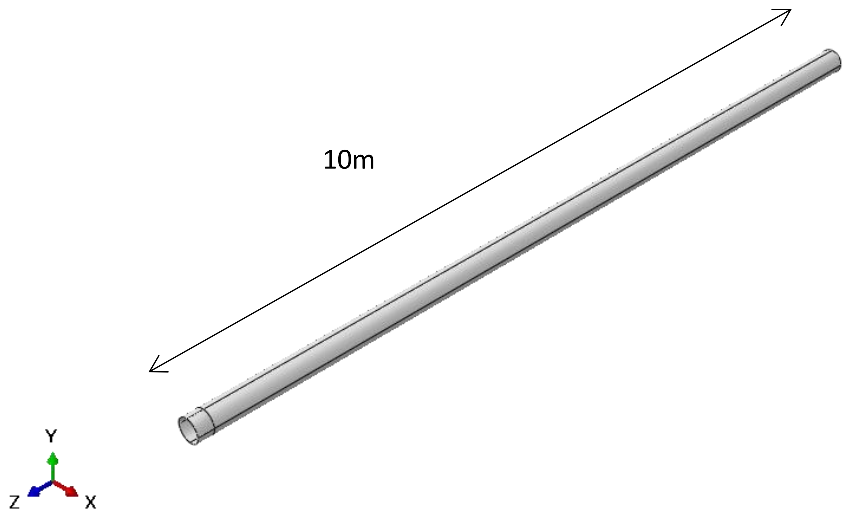

Figure 4- Length of the pile

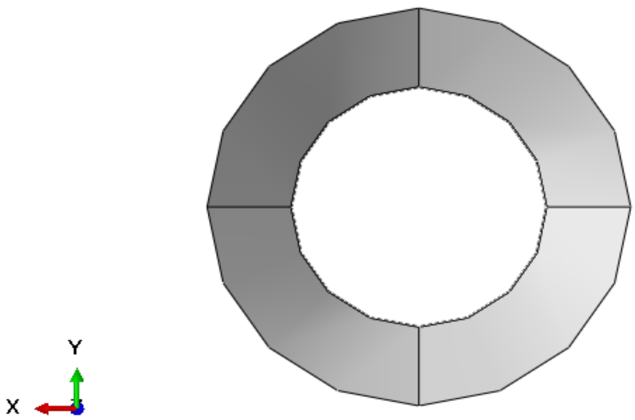

Figure 5- Radial view of the pile

3.3 FINITE ELEMENT METHOD

Partial differential equations in two or three dimensions can be solved using the Finite Element Method. The bigger system is divided into finite elements by the Finite Element Method. Structural analysis, fluid dynamics, heat transport, and other disciplines use the finite element method. The system's breakdown into smaller components offers several advantages, including –

- Representation of complex geometry accurately
- Different/dissimilar material properties included together
- Representation of the solution easily
- Local effects captured

The finite element approach is based on the concept of energy minimization. If a boundary condition is given to an object, a variety of configurations are possible, but only one of them is really possible. To convert partial differential equations to algebraic equations, the finite element approach uses an estimate for the unknown variables. The finite element approach is based on the following fundamental principles: –

- Engineering sciences are utilised to describe partial differential equations.
- Numerical approaches are employed in the formulation and solution of algebraic equations.
- Computing technologies such as finite element method software are utilised to efficiently carry out the necessary computations using a system.

The flexible pavement was modelled and analysed using the finite element method software ABAQUS in this work. Dassault systems' ABAQUS 16.4 was used for the research.

3.4 ASSUMPTIONS

Researchers want to know how lateral loads affect a single hollow steel pile buried in loose soil. That's why they're doing this study. As a result, Dassault system's ABAQUS software is used for numerical analysis. The software uses user-specified values and operates under the premise that those values are correct. The numerical analysis is based on the assumptions listed below: –

1. The soil has a supple and consistent texture.
2. The subgrade response theory can be used in this situation.

3. There is no axial force present.
4. The pile is straight and the cross-section is uniform.
5. The pile material is uniform.
6. The pile material's modulus of elasticity is the same in tension and compression.
7. There is no dynamic loading on the pile.
8. A nonlinear technique is used in the analysis.
9. A friction coefficient of 0.3 is assumed between surfaces.
10. The creep and fatigue of the materials are not taken into account.

3.5 MODELLING METHOD

The commercial ABAQUS software tool is used for the computational analysis, which employs the Abaqus standard analysis method. The diagram in the illustration depicts the analyses' flow chart. Geometry is used to model the physical circumstances of the system or structure, and meshing is carried out as necessary. The interaction property and boundary conditions are used to establish the model's limitations. The model behaviour is the response of the model to a load. The boundary conditions are required in order to clearly describe the issue.

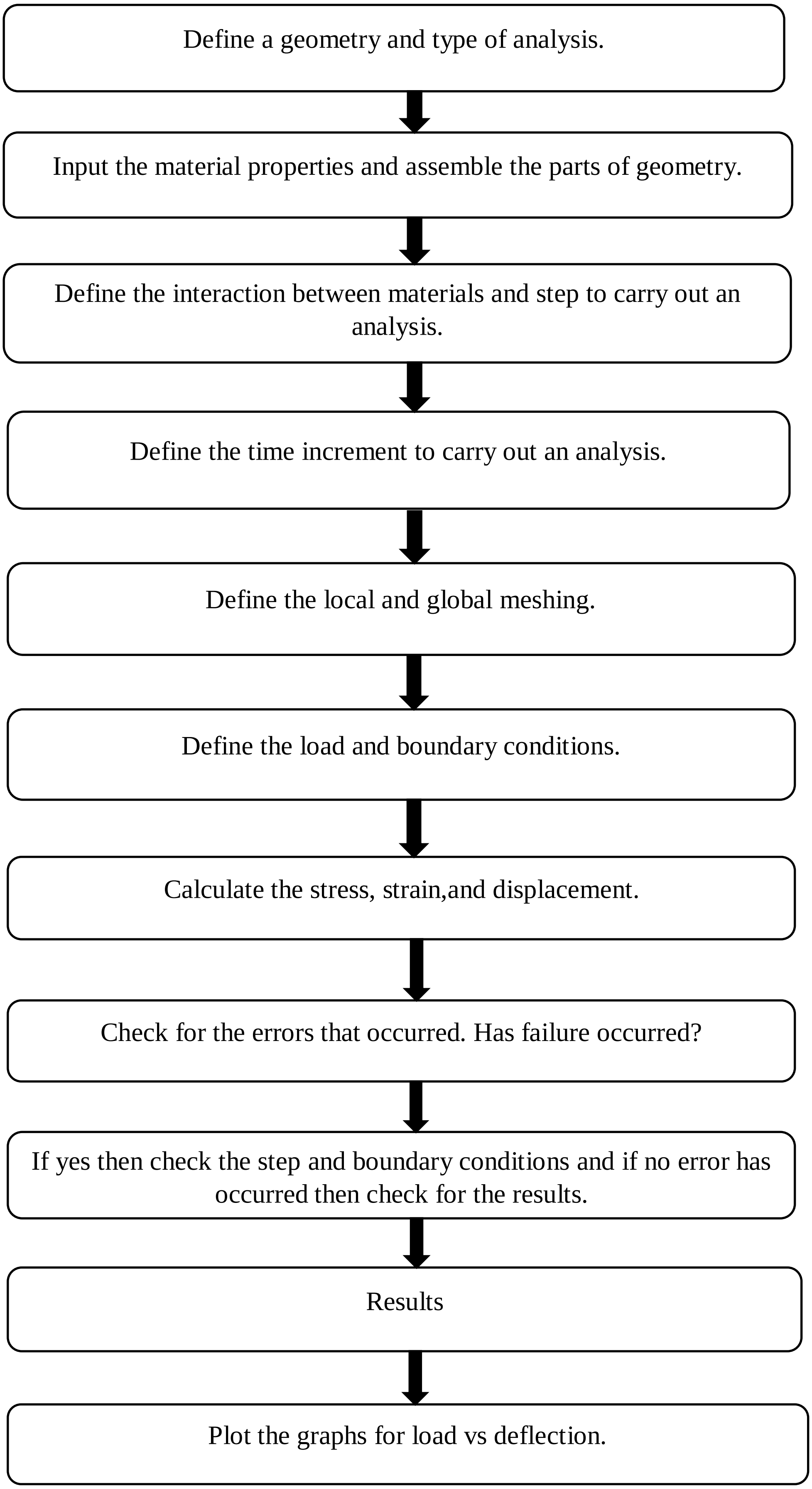

Figure 6- Flow chart for numerical analysis

3.6 MESHING

Larger portions can be divided into smaller nodes and subparts via meshing. Using a sufficiently refined and suitable mesh is critical to getting good results from the simulation/analysis. Coarse meshing gives erroneous findings in analyses involving either implicit or explicit methods. The more precise the outcome is, the finer the mesh must be. The numerical solution to the model tends to be unique as the mesh density increases. Figure 1 shows the meshing results for an 8-node brick element.

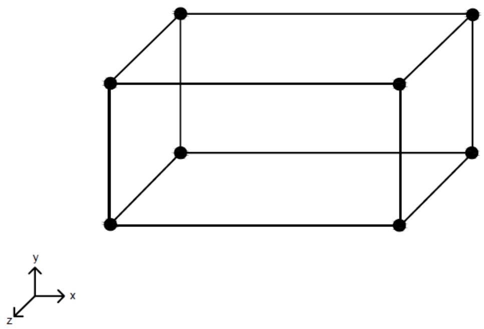

Figure 7- 8 Node Brick element mesh

The figure depicts the model's meshing. To obtain precise results, the meshing process was meticulously executed. Local seeding on the soil profile's various surfaces is followed by global seeding to complete the meshing process. There is a single bias approach used for local seeding, and each side is divided into 14 parts, with the depth of the profile being divided into 20 parts. This is done via number division. One of the reasons for using a single bias approach is the difference in mesh size. Mesh control, in which an element is a hex and the technique is sweeping, resulted in the soil profile's core meshing. Other than that, it's normal meshing using hex elements and linear geometric order. The pile's meshing is similarly separated into 20 sections using a single bias mechanism, with a global size of around 0.49. For quad type analysis, the meshing of the pile is a typical shell element with an ordered linear geometric structure.

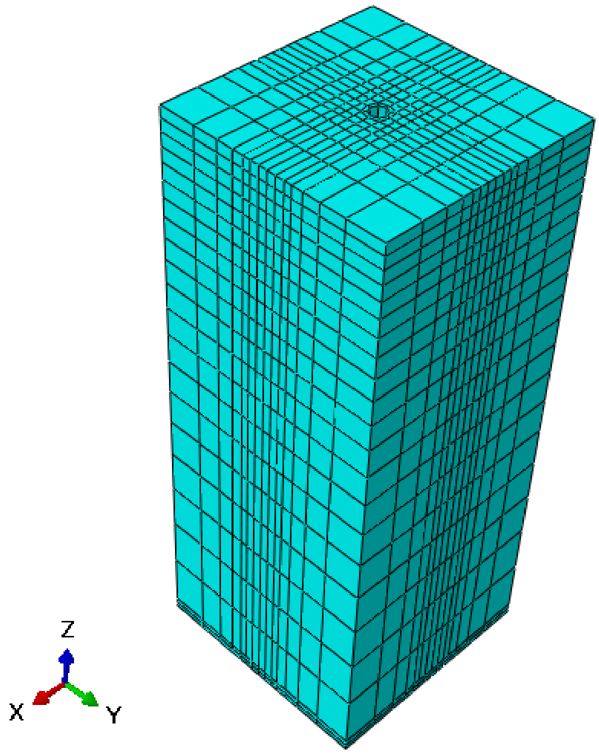

Figure 8- Soil profile mesh

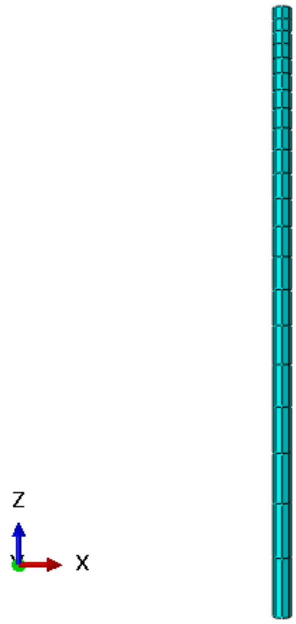

Figure 9- Pile meshing

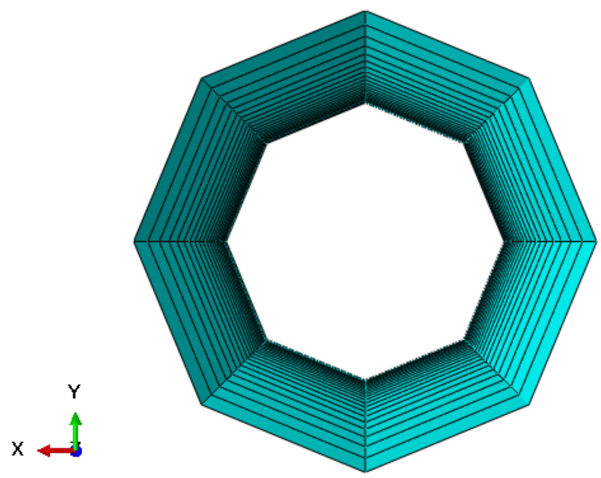

Figure 10- Radial view of pile mesh

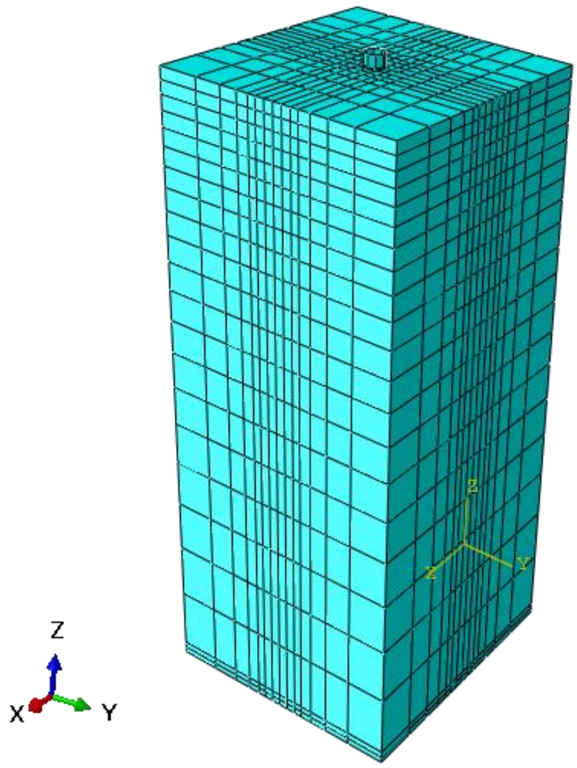

Figure 11- Whole model mesh

3.7 LOAD AND BOUNDARY CONDITION

Soil-pile interaction is viewed as an universal point of contact, with the soil serving as the master and the pile as the slave. It signifies that the model's soil and pile are in direct contact with one another through a single interaction. Finite sliding is the sliding formulation employed in the interaction. The smoothness of the master surface has been calculated to be 0.2. The contact interaction attribute, on the other hand, determines the model's tangential behaviour, which includes friction and elastic slide. Rigid contact or surface-to-surface contact are terms used to describe the property of contact interaction. We'll use a frictional coefficient of 0.3.

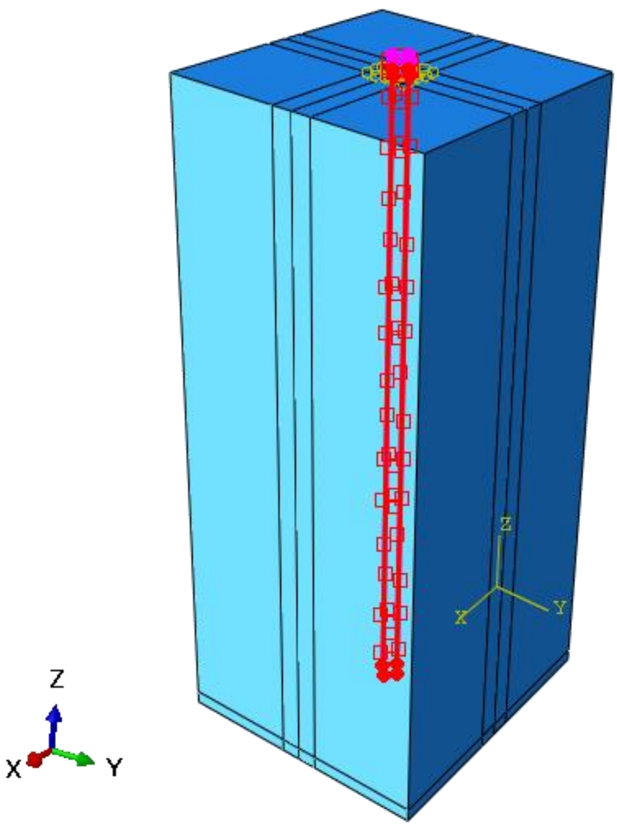

Figure 12- Interaction between soil and pile surface

3.7.1 Boundary Conditions

There are two types of boundary conditions in the model: displacement/rotation and encastre. By using a boundary condition, you can restrict how far certain degrees of freedom in the model can travel.

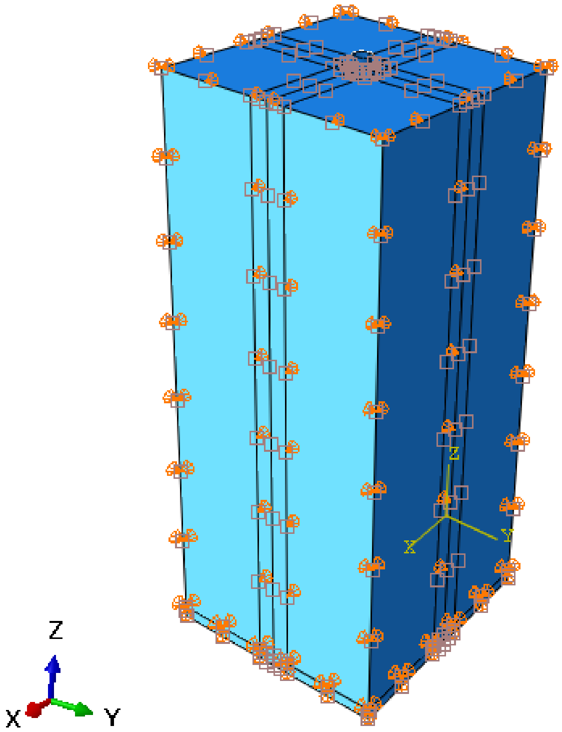

Figure 13- Boundary conditions

3.7.2 Loads

The initial phase in the analysis is the application of body forces to the soil mass, which is 17685 N/m^3, and to the pile mass, which is 78480 N/m^3. These forces are applied in the downward z-direction. The next stage is to add weight to the top of the pile of materials.

In the first step, where body forces are delivered, the load is applied using different sections that are geostatic. Unsymmetric matrix storage was used with the full newton solution approach provided by Abaqus to construct a step with 100 increments. The applied body force is depicted in the figure, which takes into consideration the void ratio.

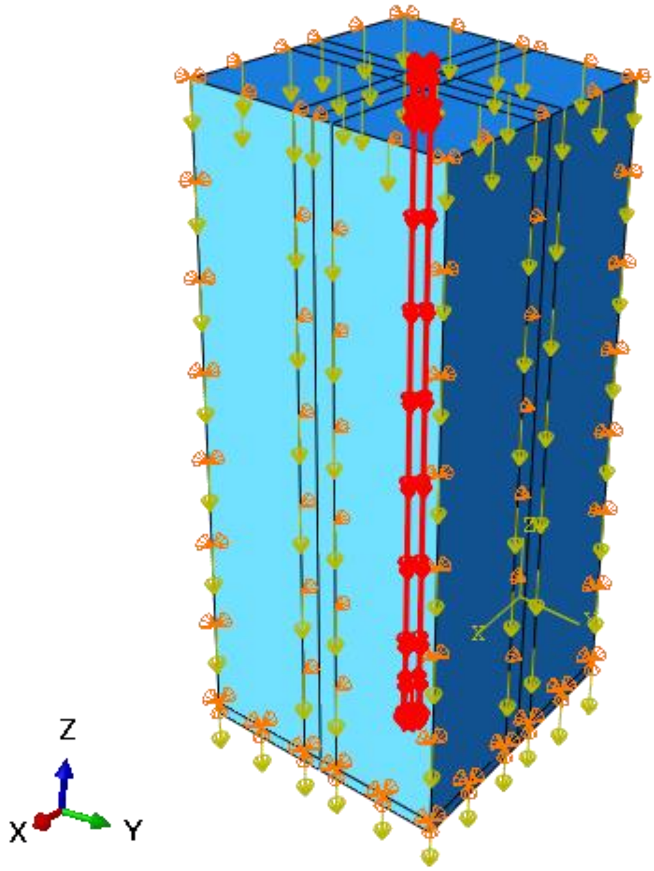

Figure 14- Body forces on the model

The next step was to apply the load on Reference point 1, which is located at the very top of the pile. Transient consolidation analysis is employed, and the time period is set at 533 seconds for the analysis. The direct technique with asymmetric matrix storing was employed. Full newton was employed as the solution technique, with the load varying linearly over time. The loading area was in RF1 and had a uniform distribution and amplitude of 0.25.

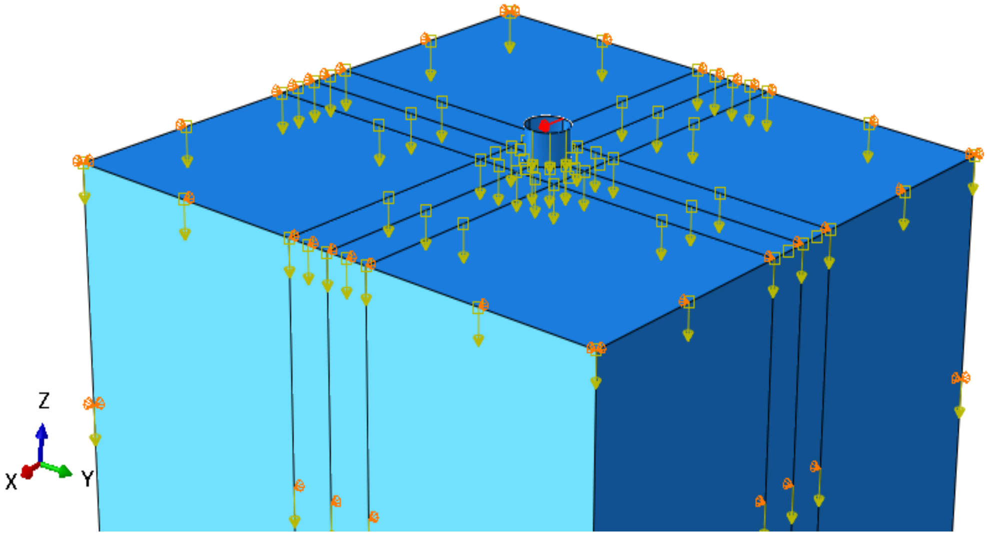

Figure 15- Lateral loading on the pile

CHAPTER 4 - RESULTS AND DISCUSSION

4.1 LOAD VS DISPLACEMENT RESULTS FOR PILE THICKNESS 10mm

For this investigation, the soil properties used were density 1800 kg/m^3, poisson's ratio 0.25, frictional angle 35, and dilation angle 30. The modulus of elasticity of soil ranges between 10 and 35 MPa.

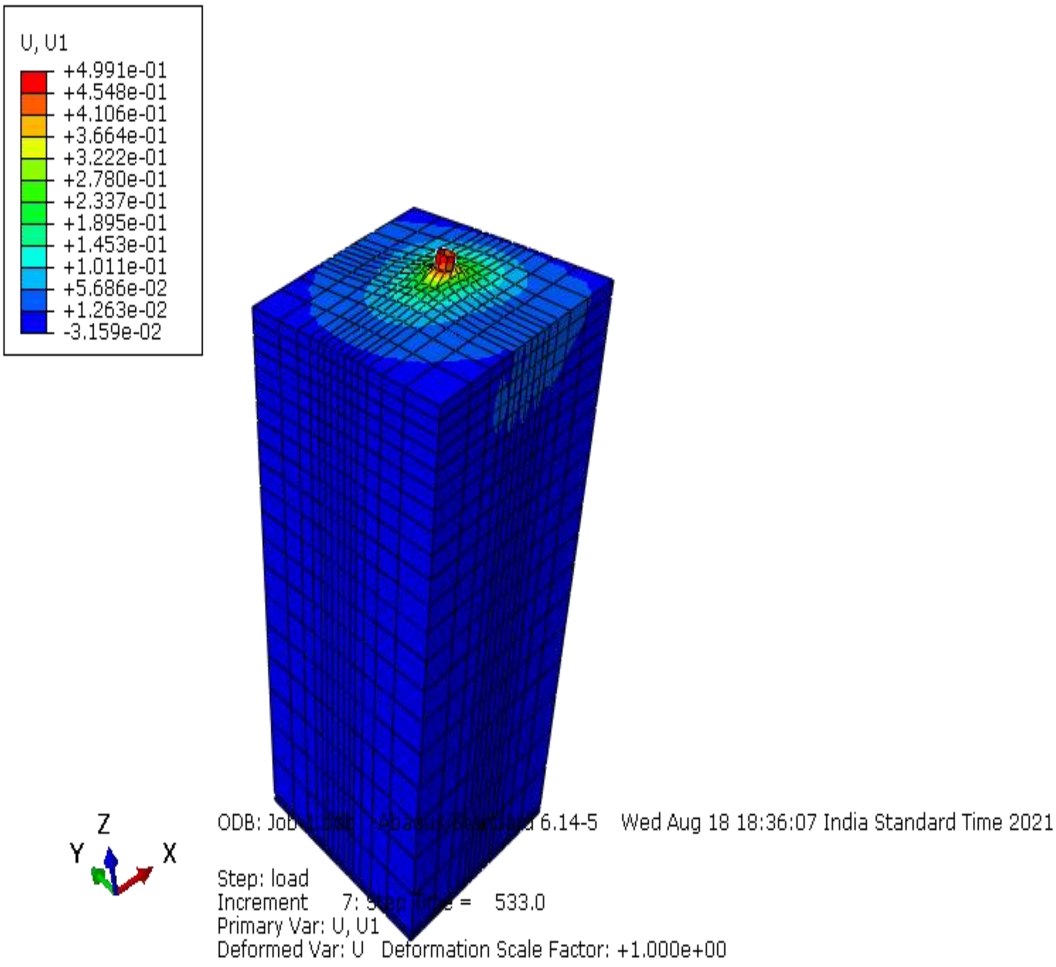

Figure 16- Displacement of the pile of thickness 10mm

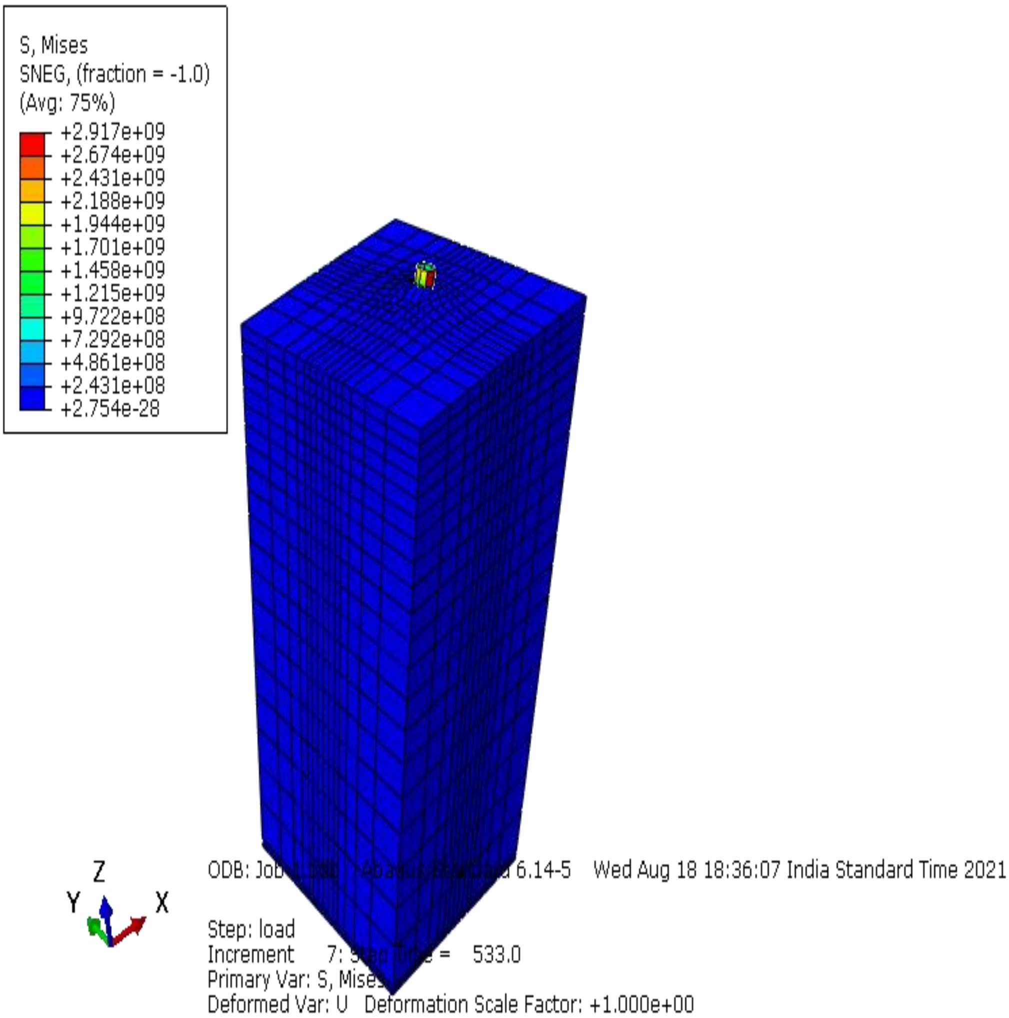

Figure 17- Stress variation in the pile of thickness 10mm

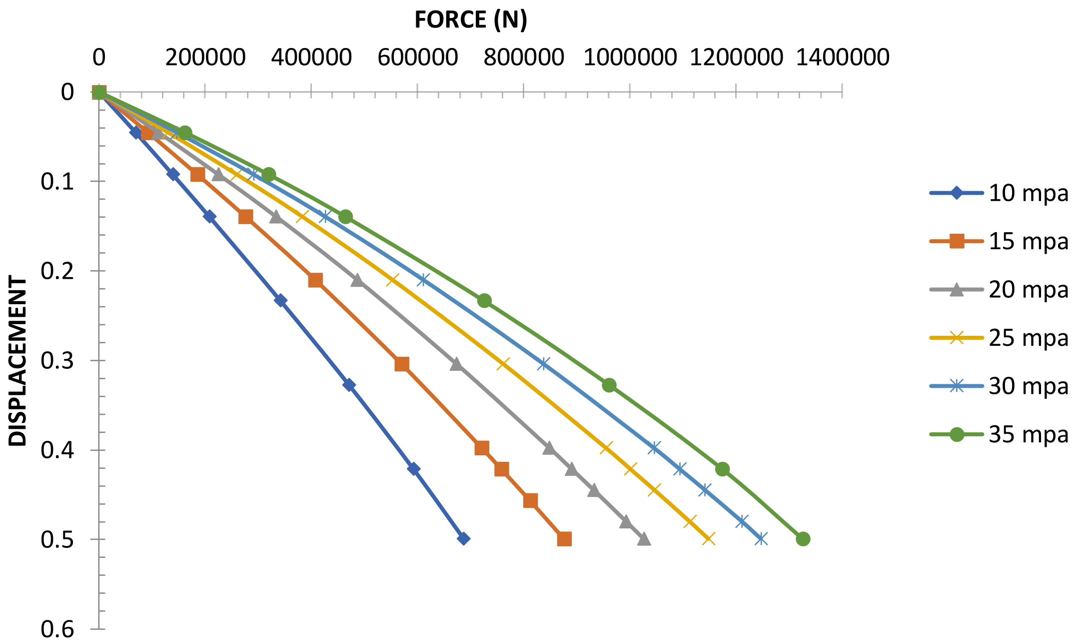

Figure 18- P-Y curve of pile 10mm thick for varying E

4.2 LOAD VS DISPLACEMENT RESULTS FOR PILE THICKNESS 20mm

We used soil density of 1800 kg/m^3, poisson's ratio of 25, frictional and dilation angles of 35 and 30 for this investigation. In terms of elasticity, soil has a modulus ranging from 10 MPa to 35 MPa.

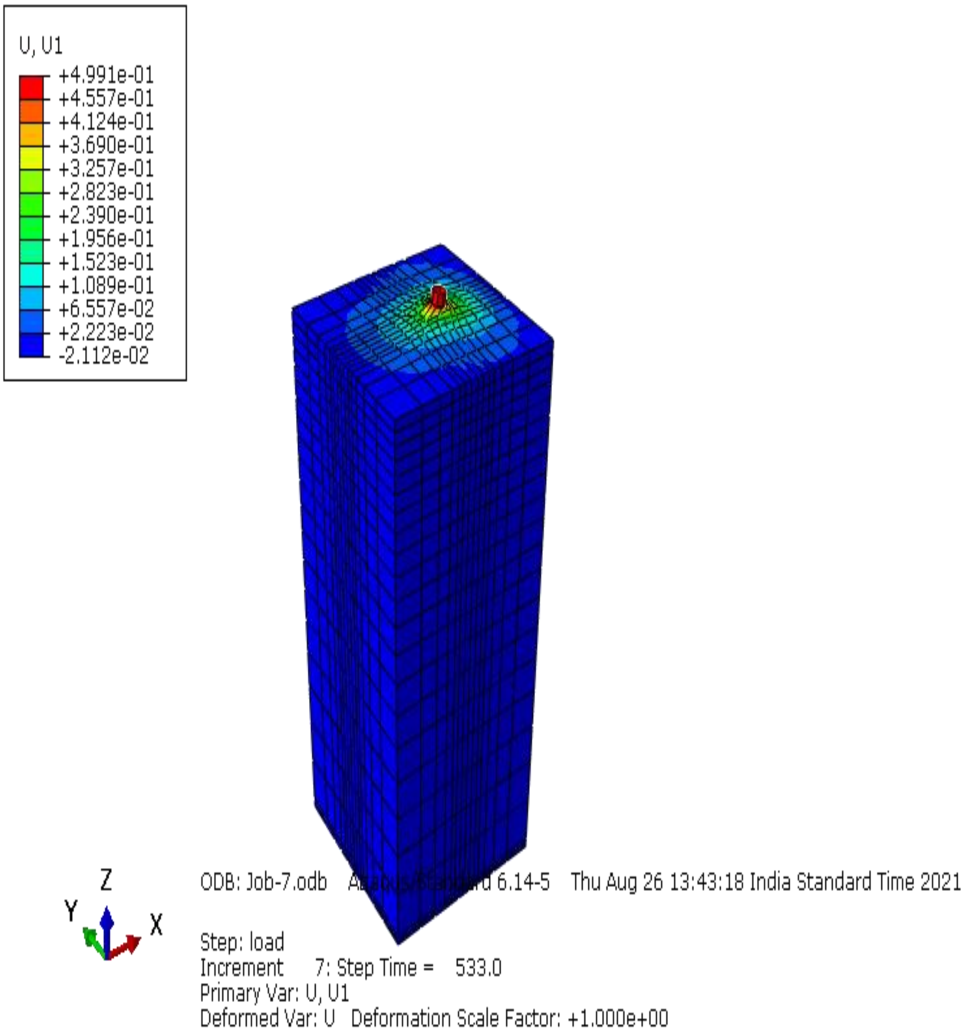

Figure 19- Displacement of pile of thickness 20mm

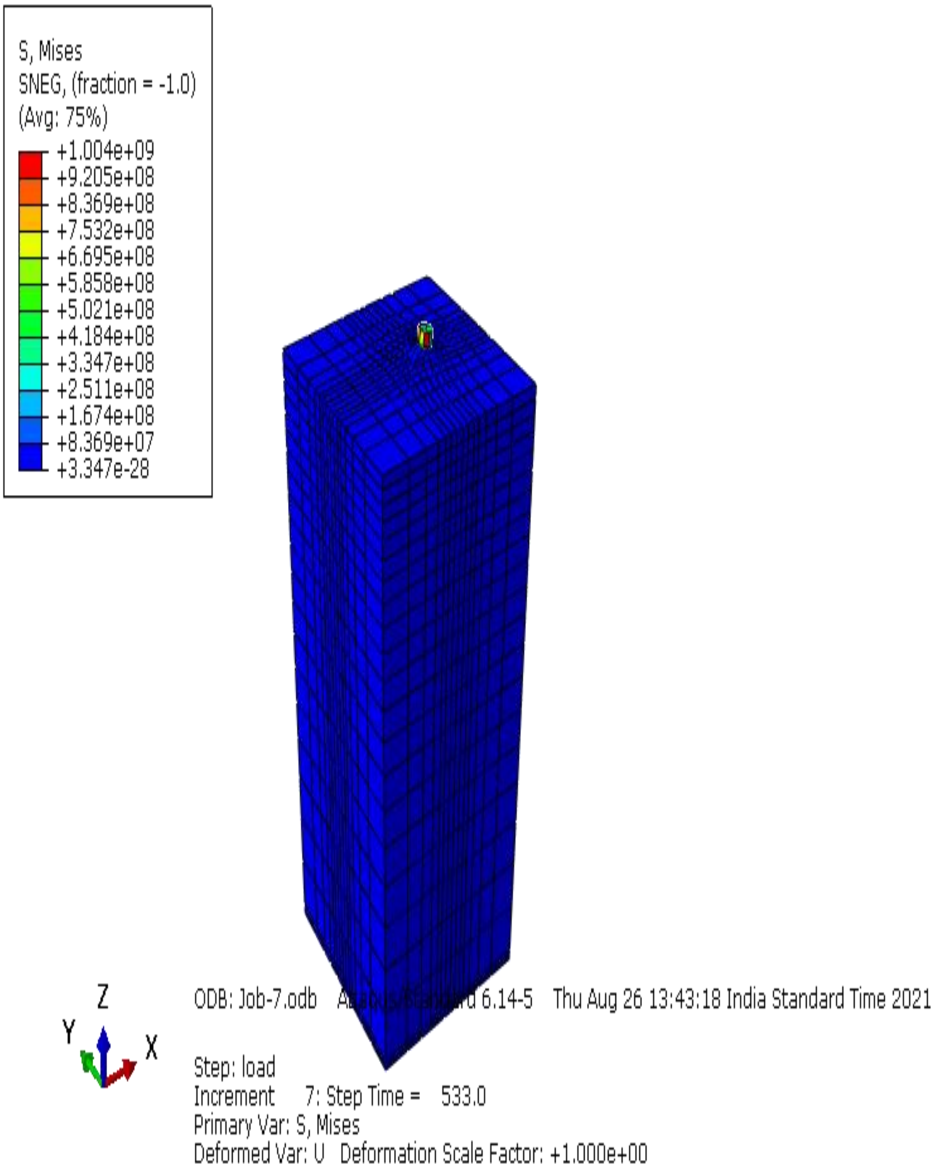

Figure 20- Stress variation in pile of thickness 20mm

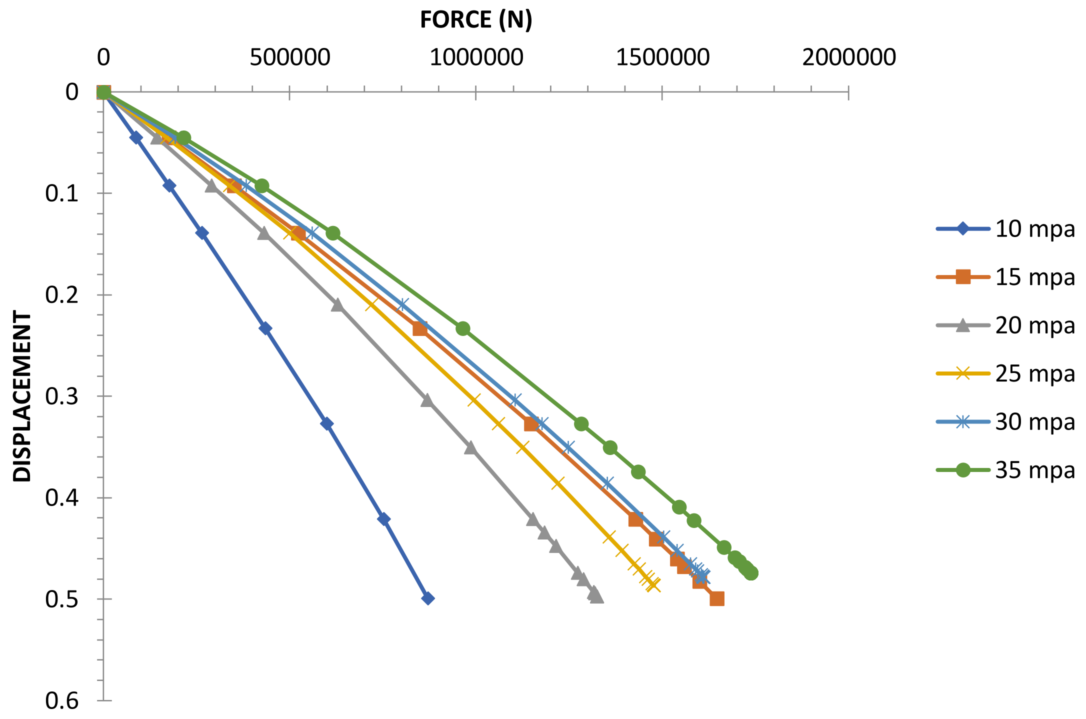

Figure 21- P-Y curve of pile 20mm thick for varying E

4.3 LOAD VS DISPLACEMENT RESULTS FOR PILE THICKNESS 30mm

We used soil density of 1800 kg/m^3, poisson's ratio of 25, frictional and dilation angles of 35 and 30 for this investigation. In terms of elasticity, soil has a modulus ranging from 10 MPa to 35 MPa.

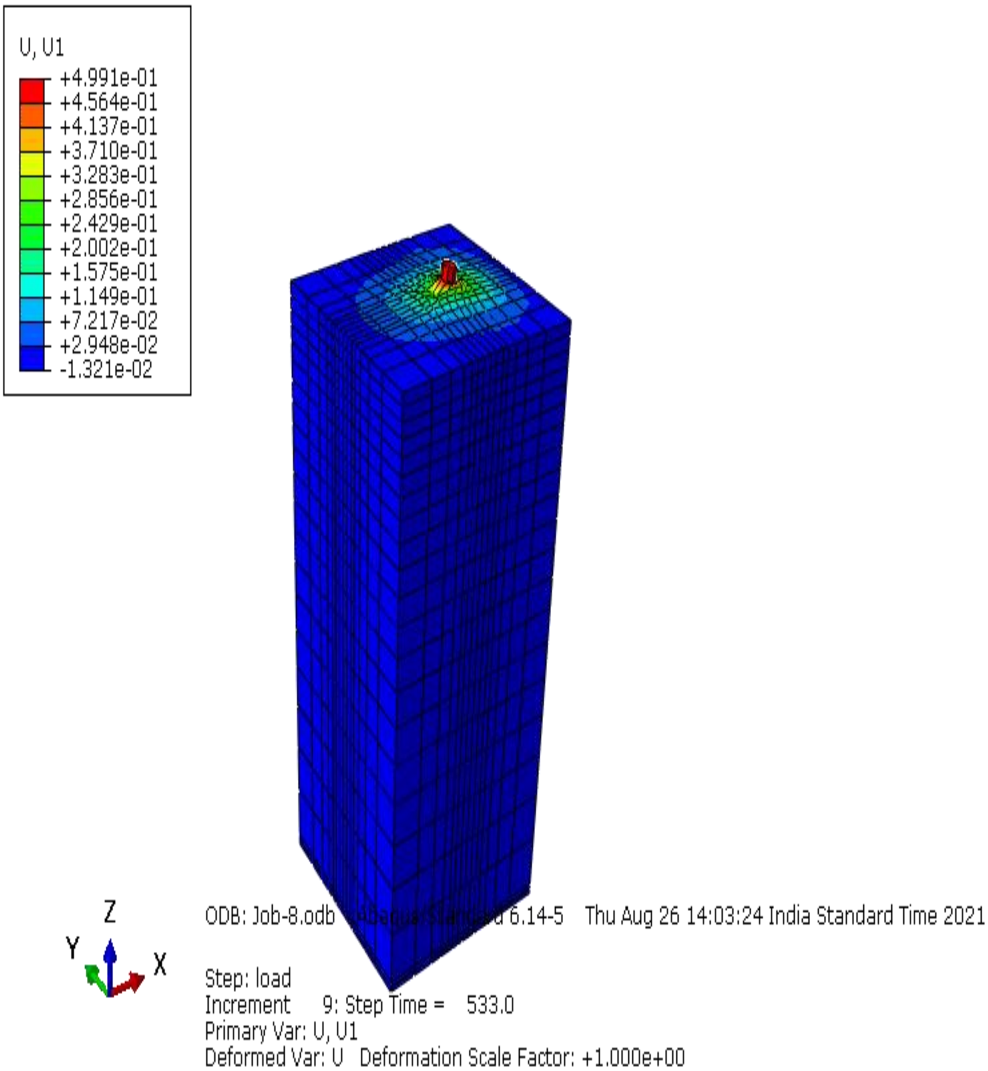

Figure 22- Displacement in the pile of thickness 30mm

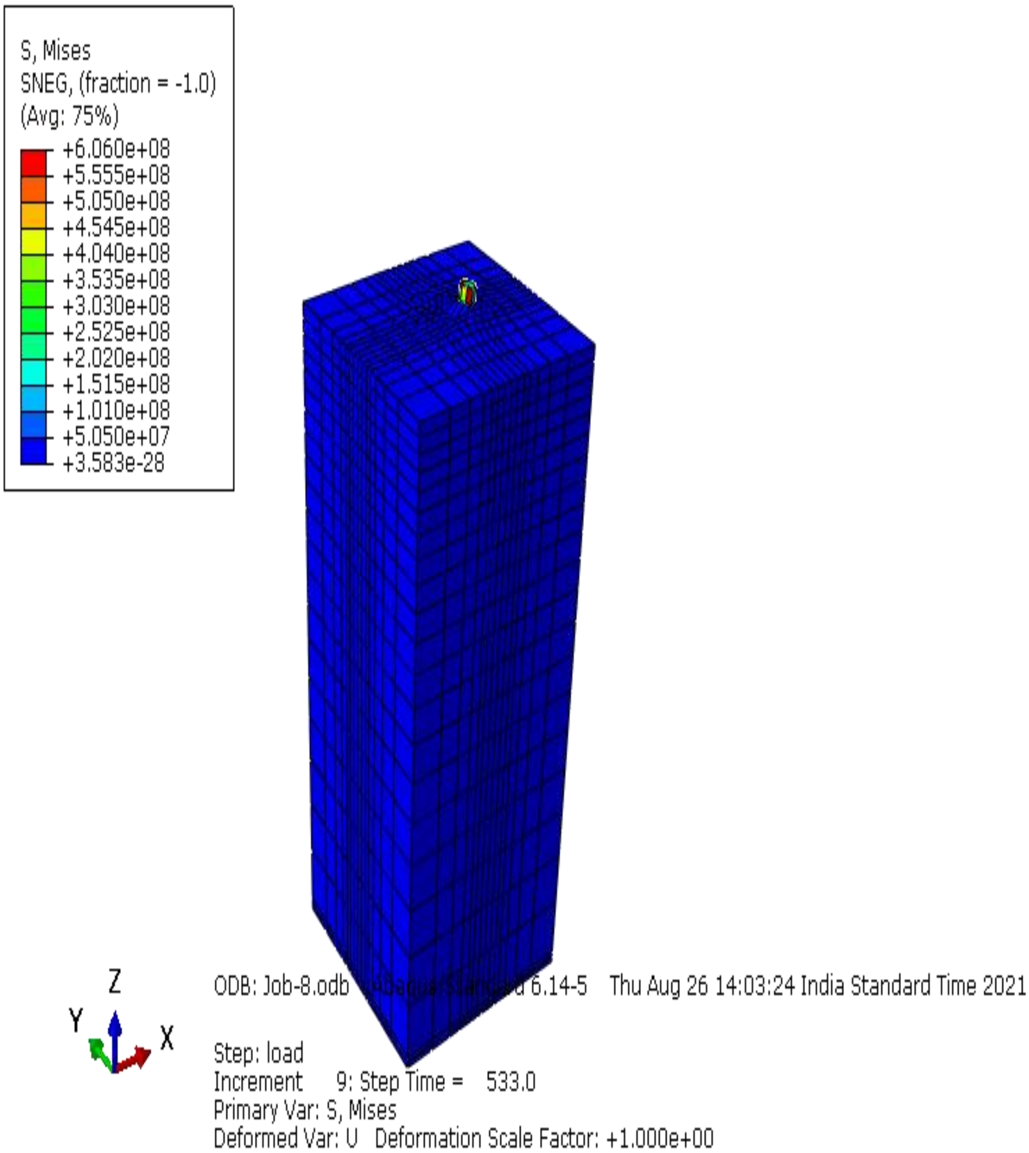

Figure 23- Stress variation in the pile of thickness 30mm

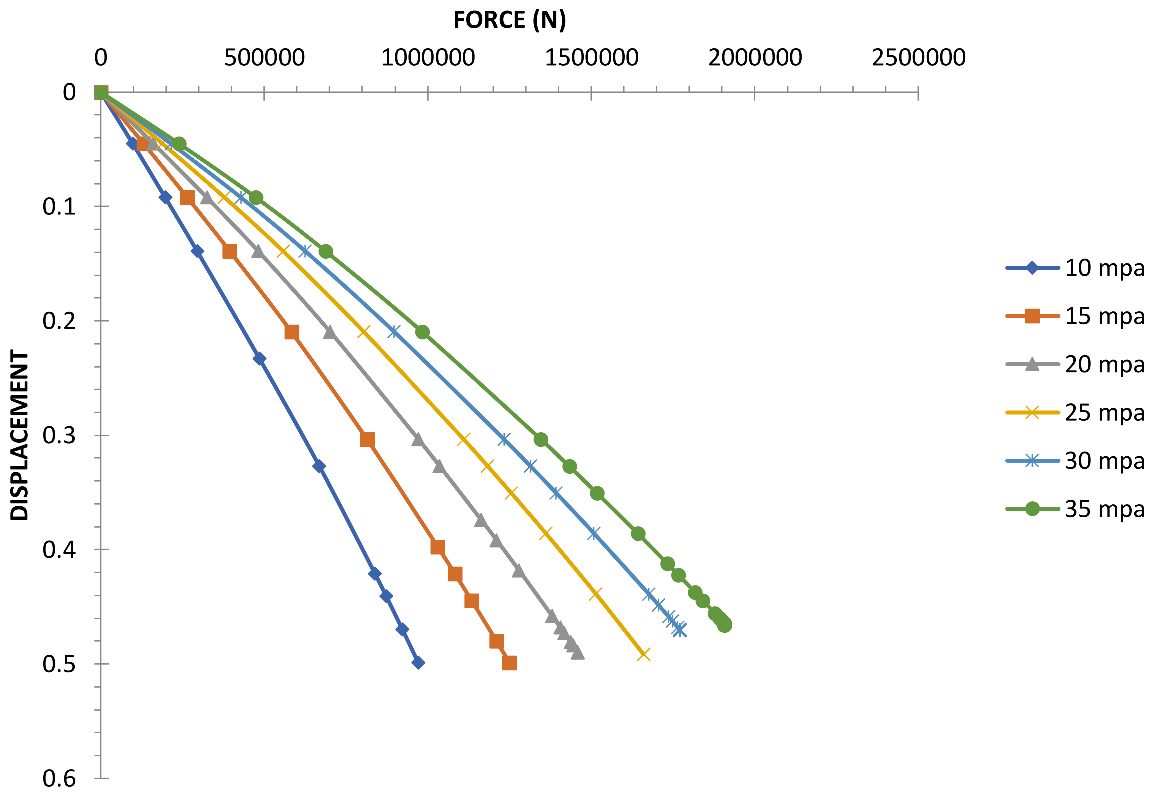

Figure 24-P-Y curve of pile 30mm thick for varying E

4.4 LOAD VS DISPLACEMENT RESULTS FOR PILE THICKNESS 40mm

We used soil density of 1800 kg/m^3, poisson's ratio of 25, frictional and dilation angles of 35 and 30 for this investigation. In terms of elasticity, soil has a modulus ranging from 10 MPa to 35 MPa.

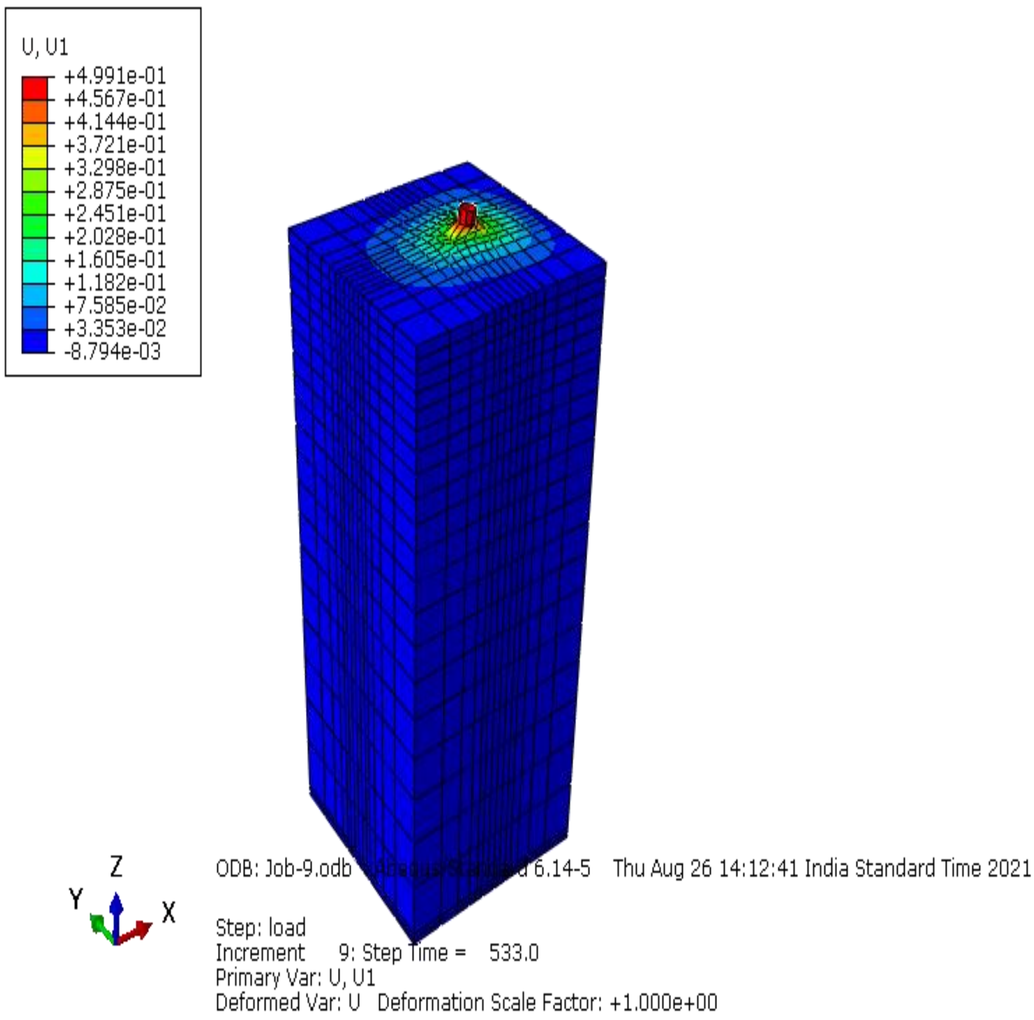

Figure 25- Displacement of the pile of thickness 40mm

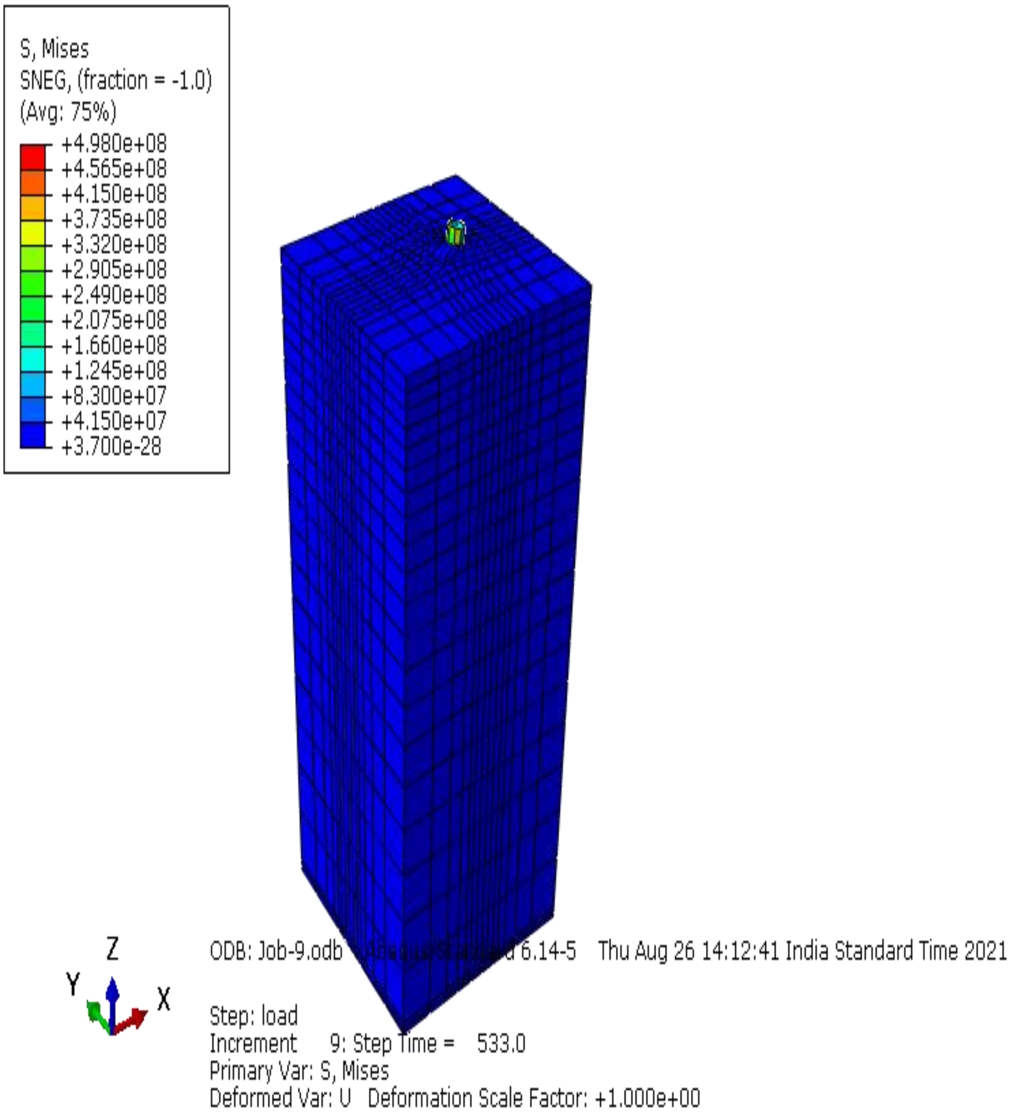

Figure 26- Stress variation in the pile of thickness 40mm

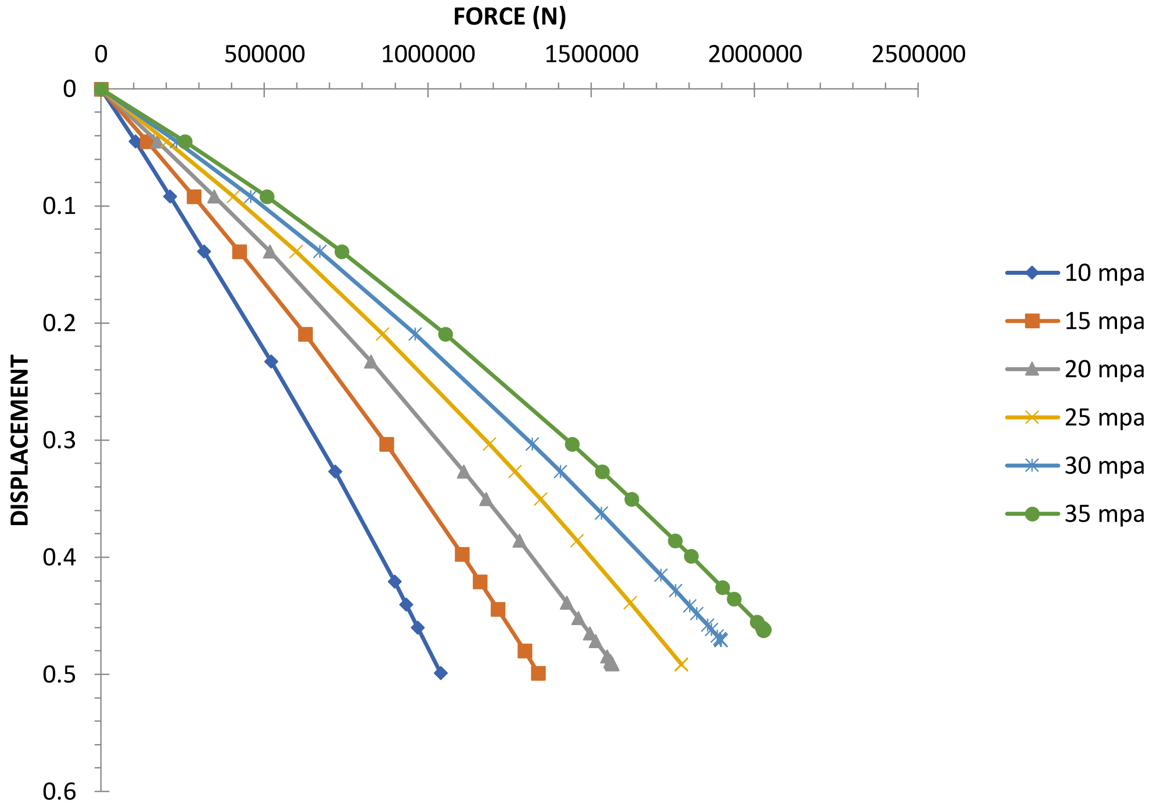

Figure 27- P-Y curve of pile 40mm thick for varying E

CHAPTER 5 - CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

- There are similarities in the load-deflection curves for the various pile thicknesses. When the system achieves its maximum deflection, soil and pile surfaces lose contact, as seen in the graphs, since loading increases over time and the deflection increases.
- According to the findings, displacement is essentially constant as modulus of elasticity changes, however displacement occurs under different loading conditions. In comparison to E=35Mpa, the modulus of elasticity of 10Mpa provides less resistance to loading and the maximum deflection point occurs sooner at lower loads.
- As seen in the figure and as reported by Brom, there is more deflection at the top of the pile than along its entire length.
- Statistics show that the stress in the pile varies, with the stress on the loading side being greater than the stress on any other side.
- Design parameters for pile systems to resist lateral loading are not the ultimate loads, but the displacement of the piles.
- Every time the soil's density varies, the load vs deflection plots cross over. When it comes to density adjustments, it doesn't make much of a difference.

5.2 FUTURE SCOPE

With this research, we hope to better understand pile lateral loading and the effects it has on offshore structures like oil rigs and pylons. This research looked at soil qualities and how they change over time, and how that impacts pile behaviour. This research will aid in figuring out how stresses and displacements fluctuate throughout a pile's length, which can then be used to better comprehend laterally loaded sand heaps.

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