BEHAVIOUR OF FINNED PILES UNDER CYCLIC LOADING

PROJECT REPORT

Submitted by

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of

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DECLARATION

I undersigned hereby declare that the project report "Behaviour OF Finned Pile Under Cyclic Loading Condition", submitted for partial fulfillment 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 Prof. Rekha Ambi, Assistant professor, 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 any data or idea or fact source in my submission. I understand that any violation of the above will be a cause 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 permission has not been degree, diploma or similar title of any other University

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CERTIFICATE

Certified that this report entitled **'BEHAVIOUR OF FINNED PILES UNDER CYCLIC LOADING'** is the report of project presented by **ATHIRA RAJ S, Roll No: TKM20CESC08** during **2021-2022** 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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I take this opportunity to express my deep sense of gratitude and sincere thanks to all who helped me to complete the project successfully.

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

ATHIRA RAJ S

ABSTRACT

The loads of the structures are transferred to the soil by foundation. Foundation 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 structuresand 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. Piles with fins on the curved surface of the pile have been found with more lateral capacity as compared to regular piles. Finned piles also found more economical than improvement methods for lateral capacity.

This thesis work is to study the behavior of finned piles under cyclic loading. The numerical analysis is done by ABAQUS software. The analysis is done on finned piles in sand. The study focuses on the lateral capacity of finned pile under the influence of different shape and geometry of fins. The study is done under cyclic loading condition of finned piles in sand

Keywords: Finned piles, cyclic loading, sand, ABAQUS.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Foundation provides support and stability for the structures and transfer the loads to the soil through direct contact. Shallow foundation and deep foundation are the two types of foundation. Shallow foundations are provided where the loads are transferred to shallow depth and deep foundations are to transfer loads to deeper depth. The material and the type of foundation selected for the desired structure depends on the loads considered in design and properties of underlying soil. The bearing capacity of soil underlying the foundation is an important design criteria in structural design. Bearing capacity is the ability of soil to withstand the loads transferred to ground. In the soil with low bearing capacity deep foundations are preferred. The load from the superstructures are directly transmitted deeper and strong soil strata. Pile foundation is one of the deep foundation commonly used. Pile is a vertical element that is drilled deep into the ground. Piles are generally drilled or driven into the soil in the site. Timber, iron, steel, concrete piles and composite piles are different materials used to make pile foundation.

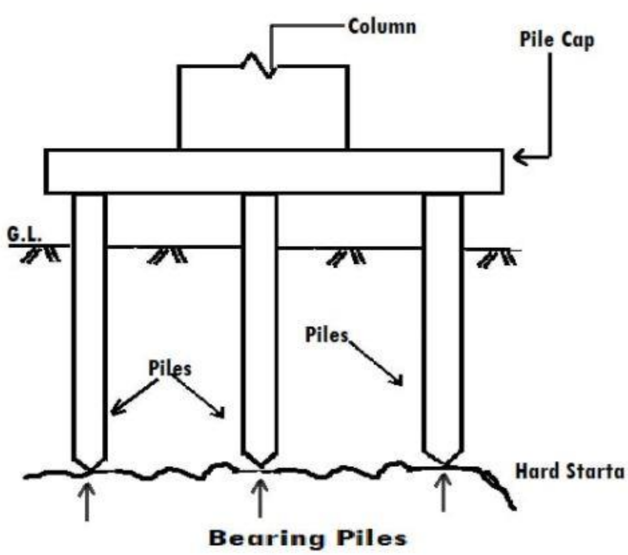


Fig 1.1: Pile foundation

(Source: civilknowledge.com)

Axial loads and lateral loads are the common types of loads acting on pile foundation. Axial load imparts compressive or tensile forces that act parallel to axis of pile. Lateral loads develop shear and moment in the foundation. The lateral deflections and resistance of foundation depends on the soil and foundation stiffness.The lateral load resistance of pile foundation is from the passive soil resistance and shear on the cap. Generally horizontal loads acting on pile foundations are much smaller than the vertical loads so, they are usually not considered. Since the lateral capacity of pile depends on the soil type, the loading direction and the pile geometry to improve the pile capacity, it is necessary to improve either the pile geometry or the soil property of near surface. However, pile foundation must be designed to resist the horizontal or lateral loads to avoid any failure hazards. The improvement methods developed by many researchers have found costly.

1.2 FINNED PILES

The lateral capacity of monopoles can be improved by providing fins at the top of piles. Finned piles are equipped with angled plates at their ends. Fins provide extra friction and boost the strength of piles. Finned piles are better choice for soft grounds.

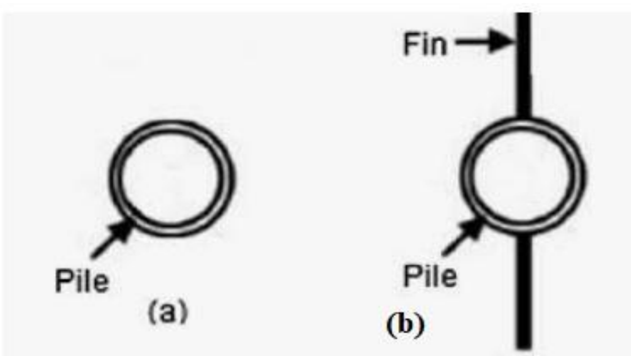


Fig 1.2: (a) Regular pile (b) Finned pile

(Source: Pankaj & Sreevalsa (2021))

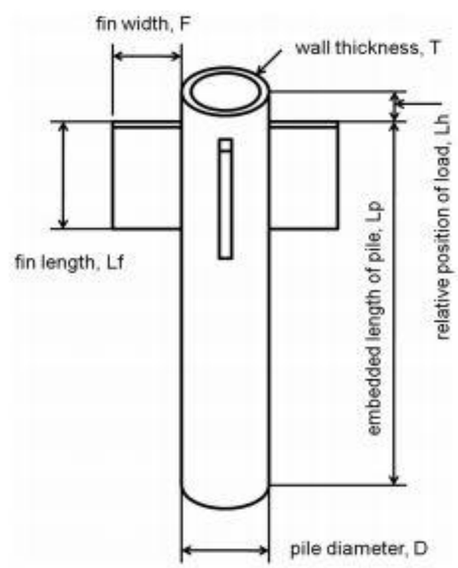


Fig 1.3: Schematic dimensions of finned pile

(Source: Peng et al. (2016))

Length of the piles can be reduced if finned piles are used. Finned piles have better lateral resistance than regular piles. Different shapes and orientation of fins on the pile are available. In deep foundation construction, lateral capacity of pile is a considerable design factor. Many studies have been done to explore the behavior of pile with fins. This thesis work analyzes the effect of finned pile in sand under cyclic loading condition.

CHAPTER 2

LITERATURE REVIEW

2.1 REGULAR PILES

Verdure et al.(2003) conducted a study on single pile placed on dry dense sand and were submitted to cyclic loads. They investigated the effect of no. of cycles on the pile from bending moment and displacement curves. The effect of cycles on the shape of reaction curve was also explored. In the study the point of application of load was on the surface of soil so, the pile head is eccentrically loaded and pile head fixity is free. From the study they obtained the p-y curve which showed large hysteresis and at smaller depths continuous degradation of soil resistance was observed. At larger depths both pile displacement and soil reaction increased with increase in no. of cycles.

Jardine and Standing(2012) done a field study on how cyclic loading might affect piles driven in sands the loading test was done on industrial steel pipe-piles driven at Dunkerque, northern France. Their study involves seven industrial-scale un-instrumented piles and the site profile was of 3 m of hydraulic marine sand fill over marine sand. Loads were controlled by an automated hydraulic system and the beam arrangements. They observed that high-level cyclic loading can impact very significantly on shaft capacity while low-level cycling showed beneficial effects on pile capacity which the piles could self-heal with time after modest losses of cyclic capacity. Cyclic loading can degrade pile capacity and stiffness markedly. The piles showed increase in tension resistance with time.

Sivapriya and Muttharam(2018) conducted an experimental study on single pile and pile group for varying L/D ratios, number of piles in a group and spacing between the piles under static and cyclic lateral load is studied. Cyclic lateral load tests were conducted for L/ D ratios of 12, 18 and 24 under cyclic load ratio of 0.6. Cyclic load tests were performed in a clay bed. From the pattern of displacement versus number of cycles, they observed that shorter piles exhibit higher magnitudes of displacement compared to longer piles upon cyclic loading. However, longer piles showed higher rate of increase in displacement with number of cycles compared to shorter piles.

Ling et al.(2021) done a model test to study the horizontal bearing behavior of pile under existing vertical loads. The test was conducted on fine sand and the pile was made of C30 gravel concrete with hoop reinforcement under static load. They observed that in sandy soil foundation, vertical loads applied in advance reduced the horizontal displacement and bending moment of horizontal loaded pile in some segments. The maximum value of horizontal soil resistance was found first increased and then decreased with increase in vertical load.

2.2 FINNED PILE

Peng et al. (2011) done a mall scale test a monopile and fin piles to determine the effect of fin length on the lateral displacement of cyclically loaded piles in sand. Ten thousand cycles were used in each test to represent 20 years of environmental loading on offshore structures. Variables involved in the study was the magnitude, frequency, and direction of the load, the type of pile tip; and the length of the fins. They observed that the pile moved significantly during the initial cycles which replicated the results of static loading. It was found the fins reduced the lateral displacement by at least 50% provided they were at least half of the length of the pile. Closing the end of a pile showed significant reduction in the vertical displacement of the pile but still had little effect on the lateral displacement.

Chandni and Ambi (2021) conducted a review study on finned pile foundation from different literatures. The parameters that can influence the lateral capacity of finned pile was focused in the study. The various parameters discussed are position, number, inclination, shape and dimensions of fin. From the literatures it was found that rectangular fins show better lateral resistance than triangular fins and also as the length and width of the fin increases the lateral capacity of pile also increases in both sandy and clayey soil under lateral loads.

Gawande and Dhatrak (2021) a numerical study was done on axially loaded circular pile and triangular shape spin fin pile group in linear-elastic soil profiles. MIDAS GTS-NX software program system was used to perform numerical analysis. The load-displacement curves for different L/D ratios are developed under vertical loading. Triangular shape spin fin piles showed ultimate vertical loads and pile resistance than conventional circular pile. It was observed that ultimate vertical load capacities of spin fin pile in dense sand is much more than that of loose sand. The vertical pile resistance increased with increase in slenderness ratio for both loose and medium dense sand. The ultimate vertical load capacities of conventional circular pile and triangular shape spin fin pile increased with increase in number of piles.

Ambi and Jayasree (2018) conducted a studyon the effect of the shape of fins on the lateral carrying capacity of a pile with fins subjected to combined loading conditions. They conducted small-scale model test on piles without fins and piles with fins inserted in a sandy medium. Experiments were conducted by changing the dimensions and the shape of the fins. The experiments were conducted on dry sand. Effect of different parameters were studied including effect of combined loading, fin length, fin width, aspect ratio of fins, fin shape and surface area of fins.They observed that under combined loading lateral resistance was higher than lateral loading and with increase in fin width the lateral capacity was increased. Rectangular shaped fin showed better performance than triangular fins.

Nemr et al. (2021) done an experimental study on the uplift capacity and displacement of pile group. The study was conducted in well graded sand with steel piles. The fins were welded at the bottom of the pile. Both experimental testing and numerical modeling were performed under tension load with different parameters. There was a significant increase in the uplift capacities of finned pile groups compared with those of conventional piles without fins. The ultimate uplift capacity of the finned pile group increases with increasing inter-pile spacing. The ultimate uplift capacity of the finned pile group increases with an increasing number of piles.

Albusodha et al. (2018)conducted an experimental study on regular and finned piles under lateral loading in sandy soil. Test was conducted in sandy soil and with aluminum alloy pipe piles. They considered the sand which was linear elastic-perfectly plastic material and a non-associated Mohr-Coulomb constitutive model was assumed to govern the soil behavior. From the study they observed increasing the spacing ratio for pile groups of the same pattern, under the same pile category showed an increase in the lateral load carrying capacity. In the case of single piles and pile groups, the lateral load carrying capacity as well as the lateral resistance showed an increasing trend as the pile type changed from regular to fin.

Sakr et al. (2021) done small scale test on finned piles in clay an alternative and novel technique to improve the lateral pile capacity in clay using fins at the top of piles. Laboratory small-scale model tests were carried out to study the behavior of laterally loaded finned piles installed in clay soil for different undrained shear strengths. The effects of fin number and inclination angle were investigated and the effects of different factors, such as pile type, stiffness, geometric dimensions, and shapes of fins, were studied. They observed an increase in the lateral pile resistance against the lateral load after placing fins at the top of the pile head. They found that the optimum length of the adopted fins should be equal 0.4 of the pile embedded length and the fin width should equal the pile diameter.

Ambi et al. (2020) conducted a study on effect of surface area on pile under combined loading. Small scale model test was conducted on monopoles and finned piles in sand. They done the study by varying the geometric factors such as length, width and area of the fins. They observed that the lateral load carrying capacity of the finned piles increased considerably in comparison with monopiles. From the study they revealed that the lateral capacity is a function of the surface area of fins. They found that under combined loading, a logarithmic relationship between the increase in lateral resistance capacity and the surface area of the fins was identified.

Peng (2006) studied on the behavior of finned piled under lateral loading in sand. He compared the lateral resistances of a monopile and of finned piles with various fin dimensions to determine the ultimate lateral loads, fin efficiency under static and repeated loadings. Small-scale lateral cyclic load tests were also performed in order to determine the effect of fin length on the lateral displacement of laterally loaded piles. From the study he observed that thelateral resistance increased with the increase in length and width of the fins. Finned pile showed the optimum fin efficiency when the fin width was as same as the radius of the monopile and the fin length same as the half of the pile length. He found that fins helped to increase lateral resistance, based on the observed variation of normalized stiffness with cycle number.

CHAPTER 3

OBJECTIVES AND SCOPE

3.1 GAPs IDENTIFIED

The research gaps identified from the literature survey are as follows:

1. Effect of fin shape under cyclic loading in finned piles studies are limited.
2. Studies on the influence of fin length in lateral capacity of pile under cyclic loading are limited.
3. Effect of no. of fins under cyclic loading in sand literatures are limited.

3.2 OBJECTIVES OF THE STUDY

The objective of the study are as follows:

1. To study the influence of fin shape in lateral capacity of finned pile under cyclic loading
2. To study the lateral capacity of finned piles with different fin thickness and length under cyclic loading
3. To investigate the behavior of finned piles with different no. of fins

3.3 SCOPE OF THE STUDY

The study is restricted to following domains:

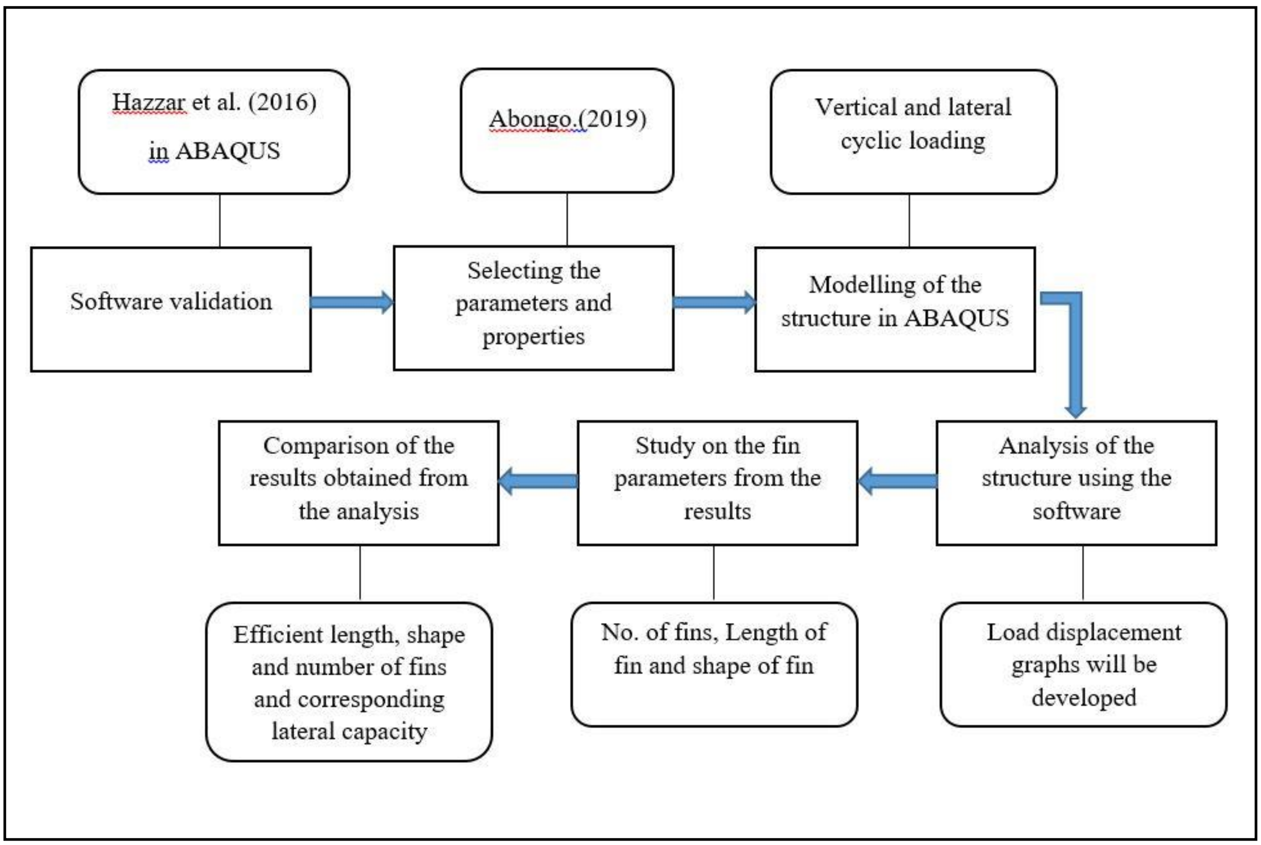
1. Shapes of fins to be analyzed are triangular and rectangular.
2. The no. of fins considered are 2, 4 and 8.
3. The orientation of fin considered is straight.
4. Analysis using ABAQUS.
5. Lateralloading.

CHAPTER 4

METHODOLOGY

4.1 GENERAL

Finned piles under cyclic loading condition is taken in the analysis. The software used for the numerical analysis is ABAQUS. ABAQUS is a finite element software used for modelling and analysis of mechanical components. It is a non-linear three dimensional software. ABAQUS has been widely used for the analysis of engineering problems due to its accuracy level in analysis results. Analysis in ABAQUS 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.



4.2 MODELLING

The modelling parts of soil and pile are created as three dimensional solid extrusion part. Each part is created separately and their properties are assigned. Software can define different material properties which enables wide range of material modelling. The properties of soil and pile considered in the study are taken from literature. Considered values of material properties are given in the following table.

Table 4.1: Properties of pile

Property	Mild steel
Density	7850 kg/m^3
Young’s Modulus	200000 N/mm^2
Poisson’s ratio	0.2

Table 4.2: Properties of soil

Property	Sand
Friction angle	35^0
Dilation angle	0^0
Young’s Modulus	40 kN/m^2
Poisson’s ratio	0.3
Cohesion	0
Unit weight	18 kN/m^3

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.

Table 4.3: Dimensions of pile

Pile outer diameter	44.5 mm
Pile inner diameter	40.3 mm
Pile wall thickness	2.1 mm
Length of pile	430 mm
Width of fin	20 mm
Thickness of fin	2.1 mm, 3.1 mm, 4.1 mm
Length of fin	$0.2L_p$, $0.5L_p$, $0.8L_p$
Number of fin	2, 4, 6
Shape of fin	Rectangular, Triangular

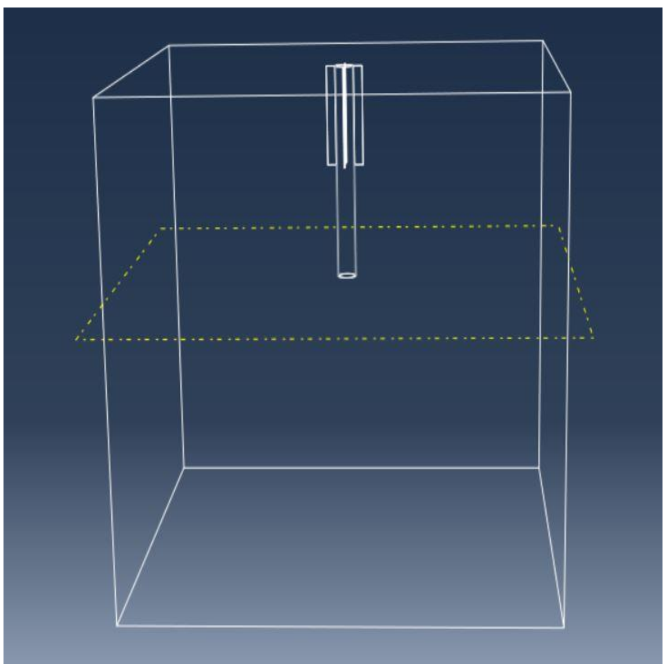


Fig 4.1: Soil pile model

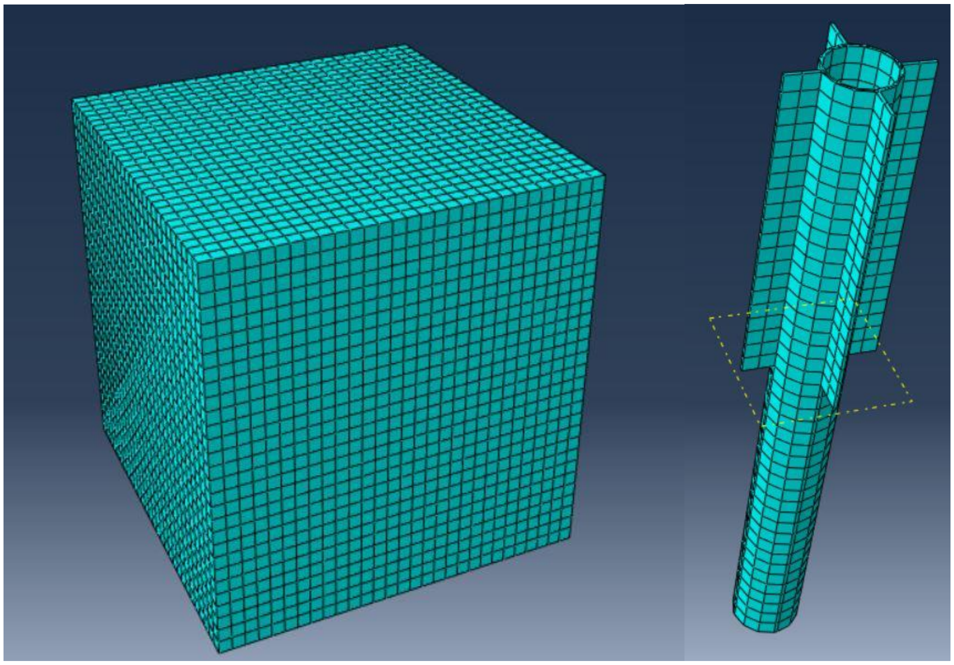


Fig 4.2: Meshed model of soil and pile

4.3 ANALYSIS

In the initial step the boundary conditions and interaction were defined. The step following the initial step is the analysis step. In this study two analysis steps were created, one for dead load analysis and other with lateral load. Nonlinear analysis was adopted to account for the deflection of pile. Full-Newton method was used to solve the analysis. The lateral displacement of the pile in the direction of loading was the field output request. The no. of cycles of load will vary linearly with time over each step.

4.4 COMPARISON OF RESULTS

The analysis results are obtained in the last module. The requested output in the step module is displayed in this module. The displacement of pile verses the no. of cyclic loads applied can be obtained as a graph by combining the load plot and displacement plot.The load displacement graphs for soil-pile models are plotted. From the analysis result of load displacement graphs, influence of no. of fins, shape of fins and length of fins in lateral capacity of finned pile under cyclic loading can be determined.

CHAPTER 5

VALIDATION

TheABAQUS is the software to be used for the analysis andis validated using the data and results from Hazzar et al. (2016). He done the analytical study in FLAC^{3D} to investigate the influence of lateral loads on regular pile and finned pile. He done the study on three soil profiles including sandy soil, clayey soil and a combination model. The pile was modelled as linearly elastic and the soil profiles were modelled using Mohr- Coulomb constitutive model. The study in clayey profile was done in undrained shear strength of 64 kPa. The pile was modelled as linearly-elastic. The loading was based on the ultimate vertical load that caused maximum curvature in displacement graph.

The model from the study is validated using ABAQUS software. The soil model was created with size of 1mx1mx1m with clayey soil. The soil behavior was described using the Mohr-Coulomb model in which the Young's modulus, Poisson's ratio, mass density and cohesion are defined. The pile model was 400mm long steel pile with inner radius 20.5mm and outer radius 22.5mm. The density and Young's modulus of pile was defined in the property. Additional properties required for the analysis in ABAQUS software was taken from other literature. The properties used for the validation study are given below.

Table 5.1: Properties of material

PARAMETERS	SOIL	PILE
Material	Clay	Mild steel
Young's Modulus (MPa)	55.68	200000
Poisson's Ratio	0.45	0.2
Density (kg/m^3)	1600	7850
Friction Angle (^{0})	0	-
Dilation Angle (^{0})	0	-
Cohesion (Cu) (kPa)	64	-

The interaction between the pile and the soil surface was defined using embedded region constraints. The soil-pile assembly was modelled as an 8 noded element which was created automatically by the software. The soil boundaries were restricted against displacements.

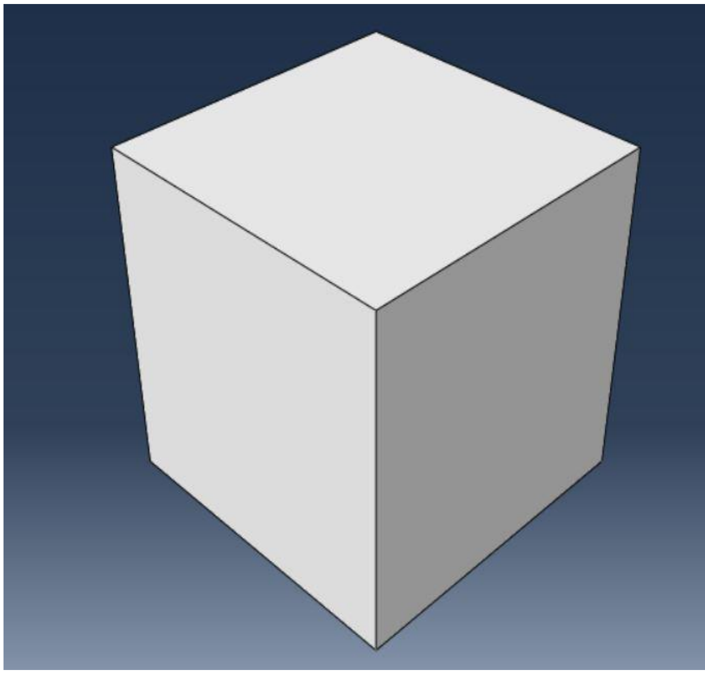
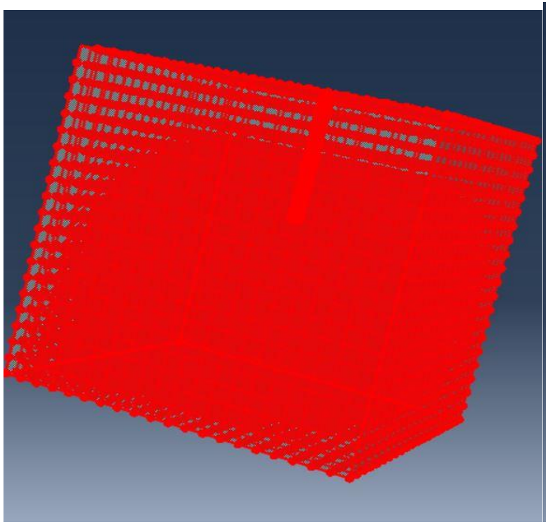


Fig5.1: Modelling of soil part   Fig5.2: Modelling of pile part



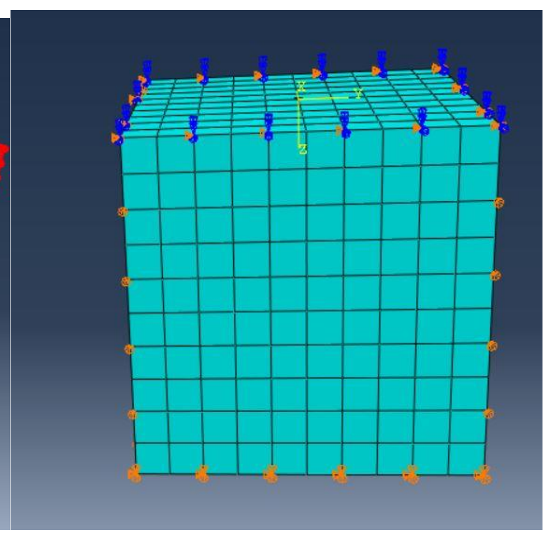


Fig 5.3: Meshed soil-pile model   Fig 5.4: Meshed model with boundary conditions

The results obtained fromHazzar et al. (2016) is represented as graph plotted between lateral load and the deflections developed due to the load in the soil-pile model. Same graph with load v/s displacement can be plotted in the software used. The load in kN(Kilo Newton) and displacement is in mm(milli meter). The comparison of the results obtained in the literature and in the software analysis is shown in the fig 5.5.

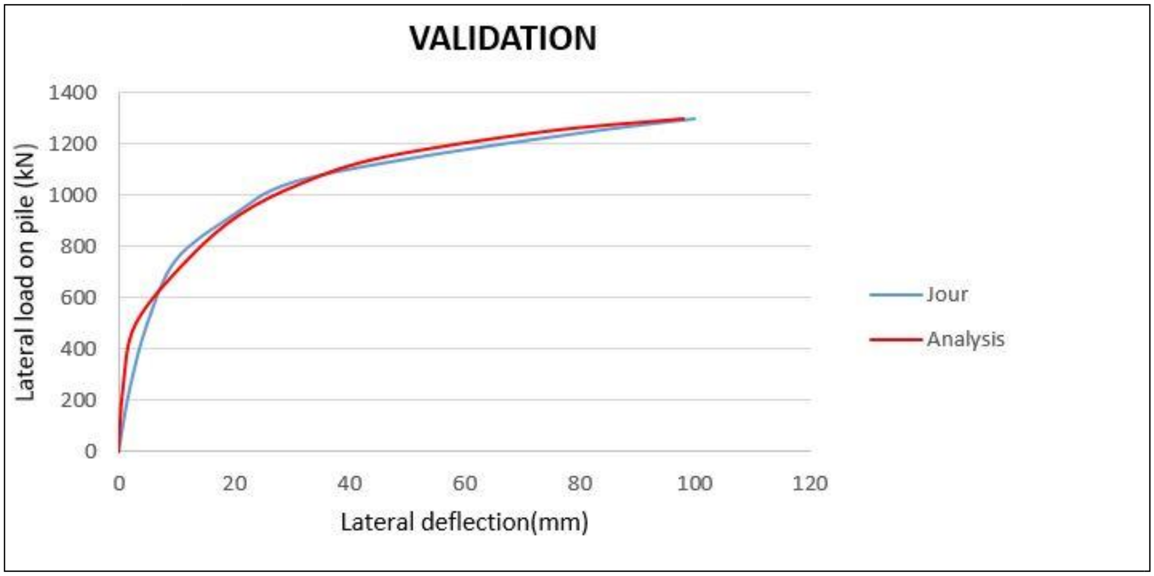


Fig 5.5: Validation of software with results from Hazzar et al. (2016)

From the comparison graph it is understood that the results from both analysis obtained close values. There is difference in the obtained results of 8% - 9%. The difference is due to the properties of materials assumed in the study which were not available in the literature. So the software can be used for the analysis.

CHAPTER 6

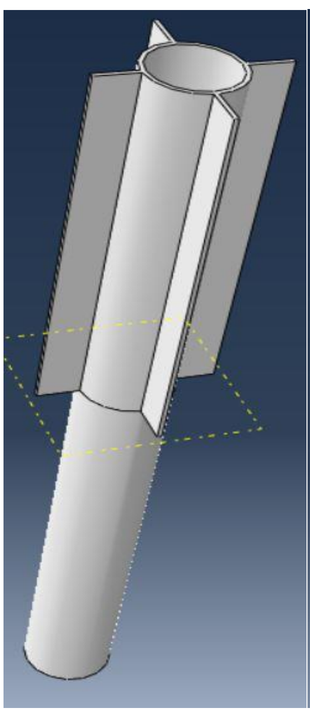
RESULTS AND DISCUSSION

6.1 General

The lateral capacity of finned pile can be improved by changing the fin parameters. To study the influence of fin parameters numerical analysis has been done on finned pile models. Fin parameters considered in the study are fin shape, fin length, fin thickness and no. of fin. Width of the fin considered for the study was taken from Peng et al. (2011) and orientation of fin considered was straight. The influence of fin parameters are studied and the analysis results are discussed below

6.2 Influence of fin shape

Analysis for fin shape was done on triangular and rectangular model pile. The influence of fin shape was studied and the results were compared with graph.



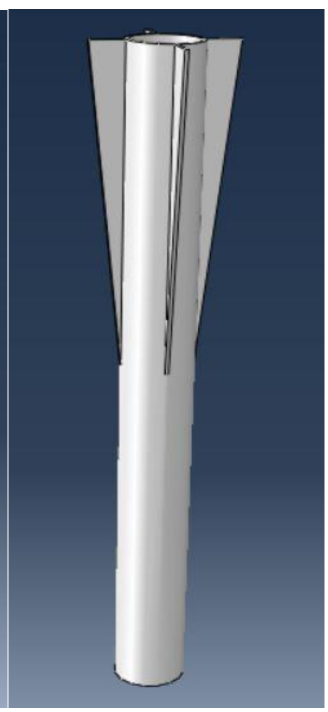
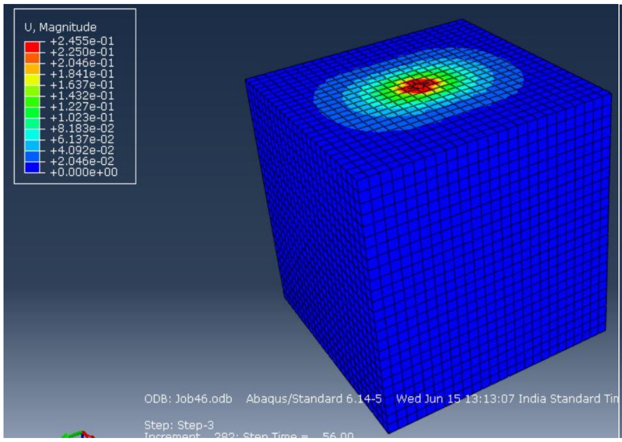
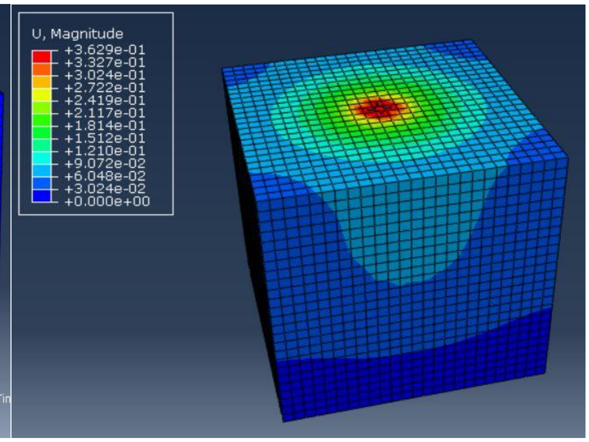


Fig 6.1: Rectangular pile

Fig 6.2: Triangular pile



(a)



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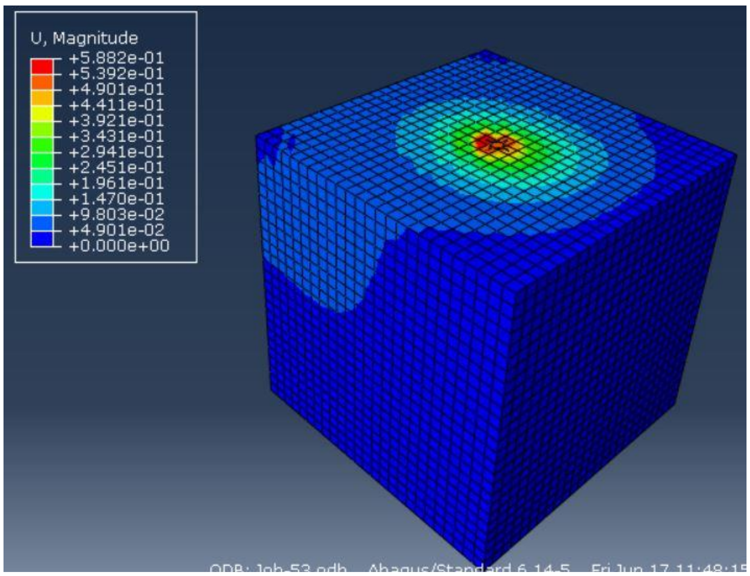


(c)

Fig 6.3: Displacement in rectangular shaped fin model with fin thickness (a) 2.1mm (b) 3.1mm (c) 4.1mm

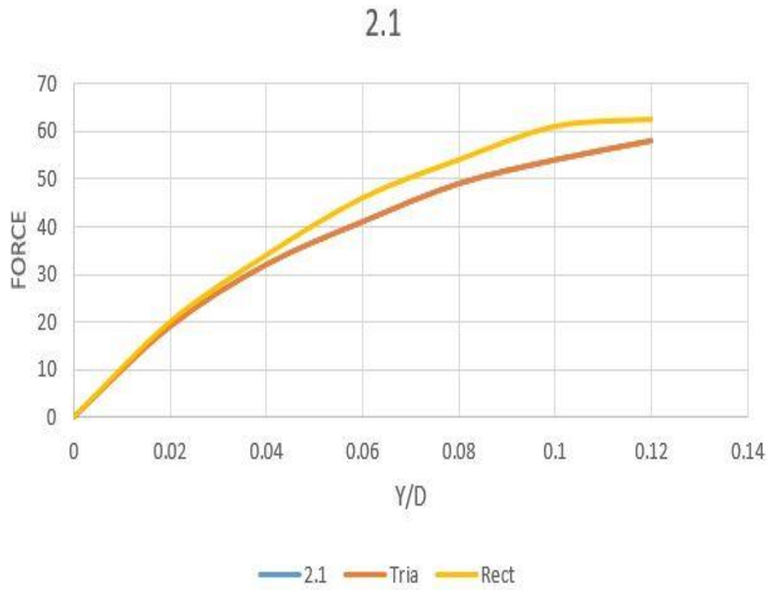


Fig 6.4: Force – y/D diagram of finned pile with 2.1mm fin thickness

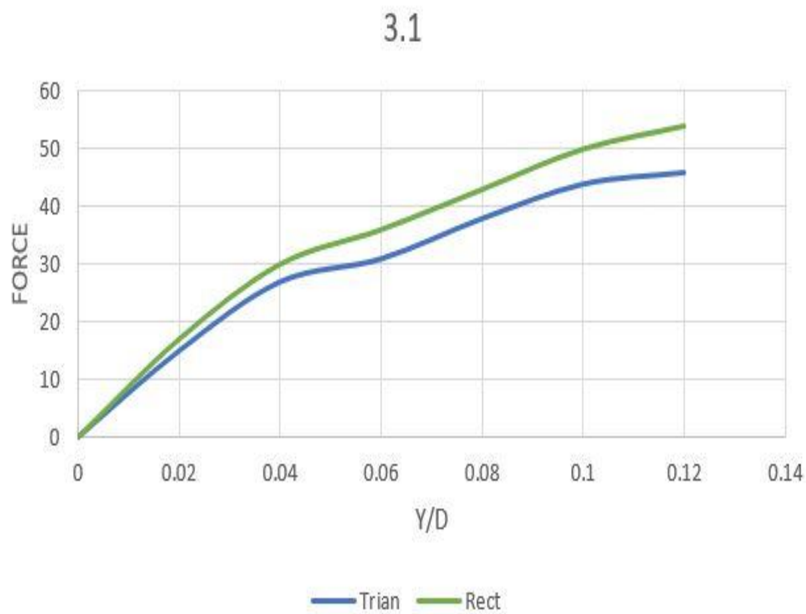


Fig 6.5: Force – y/D diagram of finned pile with 3.1mm fin thickness

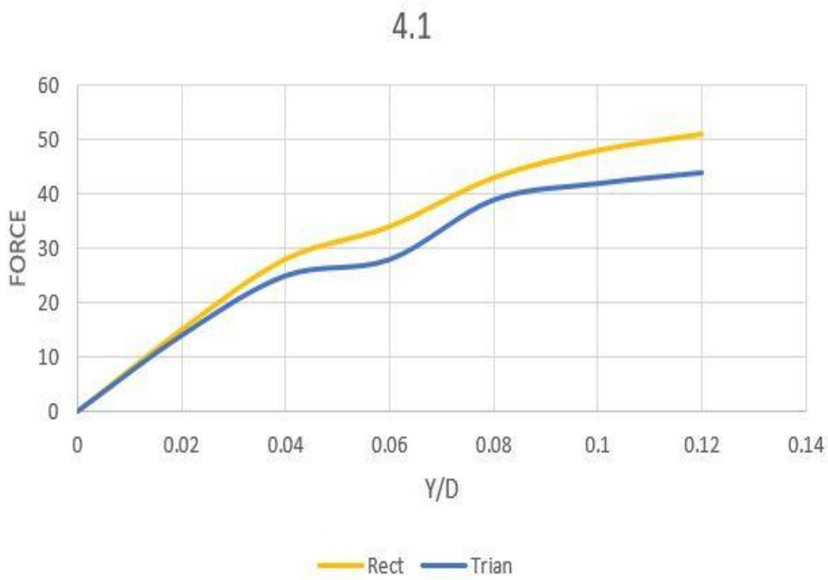


Fig 6.6: Force – y/D diagram of finned pile with 4.1mm fin thickness

Figure 6.4, figure 6.5 and figure 6.6 represents the force- y/D diagram for triangular and rectangular shaped fin. The analysis was done for different fin thickness such as 2.1mm, 3.1mm and 4.1mm. The results are compared and represented in graph. For all the considered cases of different thickness, rectangular shaped fin shows better load resisting capacity.

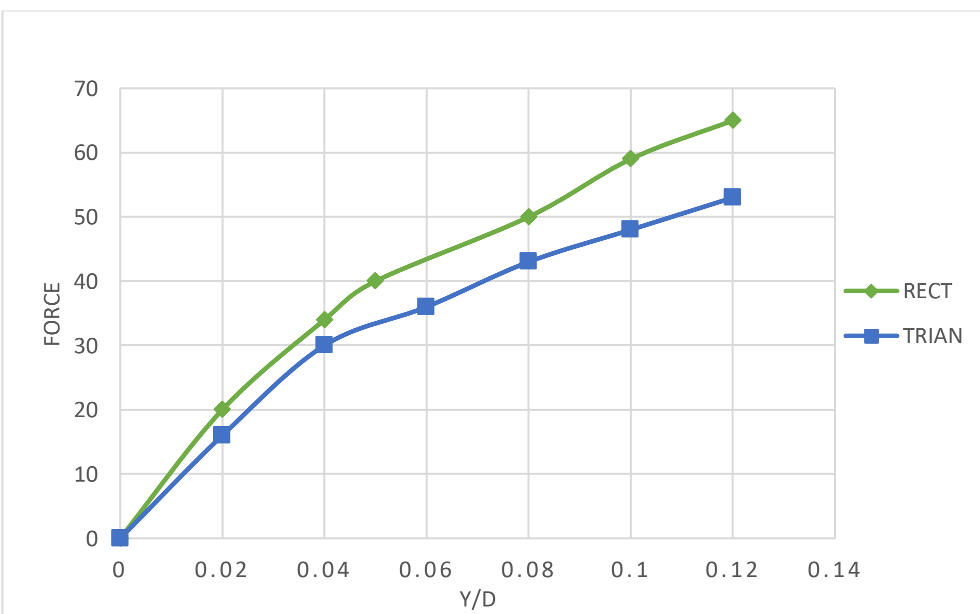


Fig 6.7: Force – y/D compared diagram of rectangular and triangular finned pile

Figure 6.7 shows the comparison graph of rectangular and triangular shaped fin. The lateral load carrying capacity of rectangular finned pile has around 18% more than that of triangular shaped fin. Rectangular shaped fin showed better lateral load resistance due to more passive soil area. Triangular shaped fin can attain better lateral load capacity by improving the area of fin. Passive area of soil plays an important role in load resistance for pile.

6.3 Influence of fin thickness

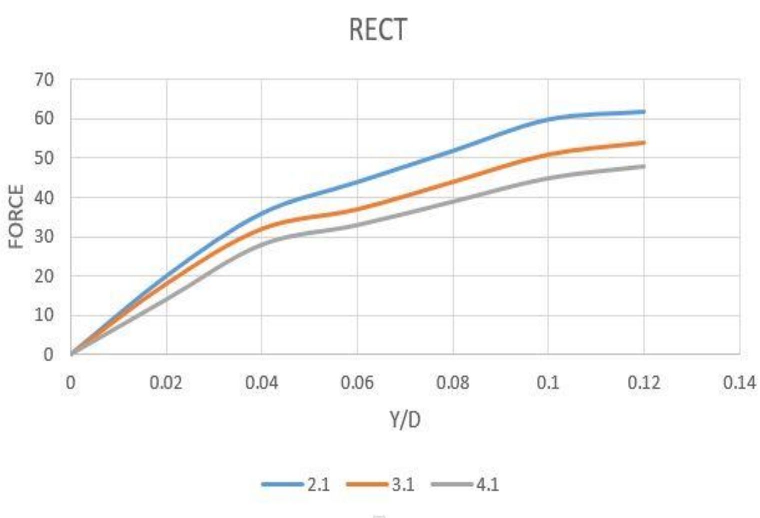


Fig 6.8: Force – y/D diagram of rectangular shaped finned pile

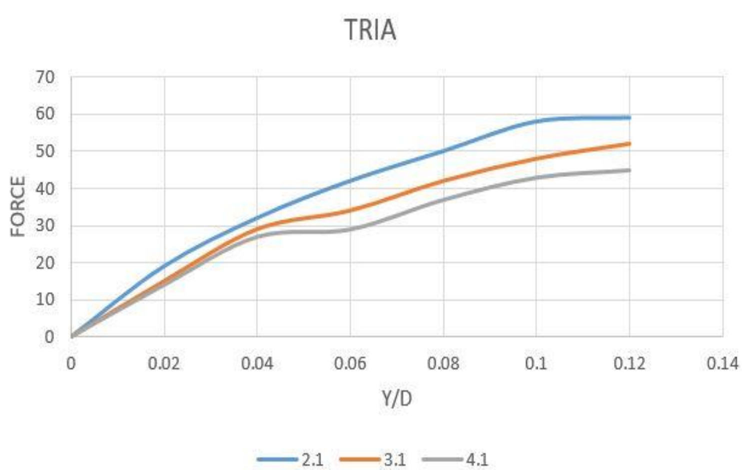


Fig 6.9: Force – y/D diagram of triangular shaped finned pile

In figure 6.8 and figure 6.9 the results of study done for different thickness are shown. The study was done with 2.1mm, 3.1mm and 4.1mm thickness of fin for rectangular and triangular shaped fin. The analysis result shows that fin thickness 2.1mm rectangular shaped pile which is same as that of pile thickness has better lateral load capacity than other 2 cases of thickness. 2.1mm thickness fin showed 10% more resistance than 3.1mm and 14% more resistance than 4.1mm.

6.4 Influence of fin length

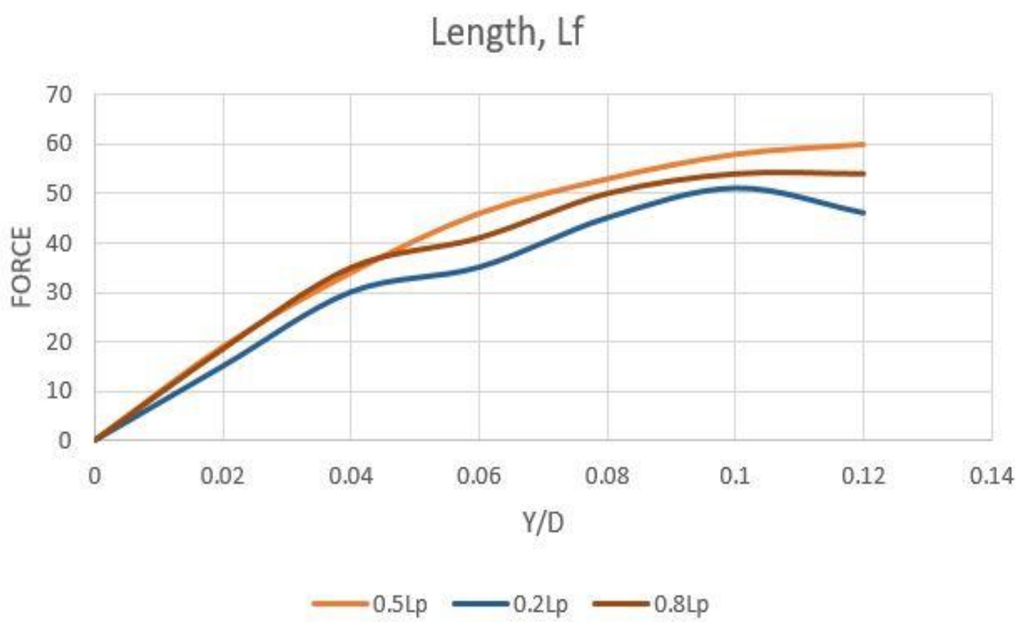
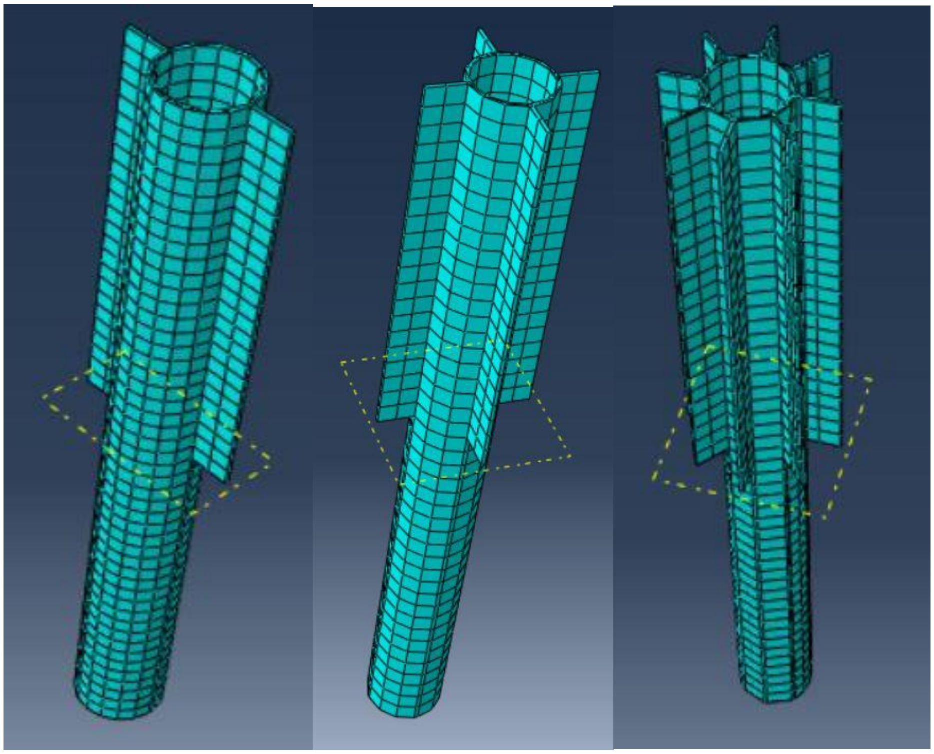


Fig 6.10: Force – y/D diagram of different length of fin

The influence of fin length was studied for rectangular shaped fin and fin thickness 2.1mm. The analysis was done for $0.2L_p$, $0.5L_p$ and $0.8L_p$. Lateral capacity of pile model increased as the length of fin increased from $0.2L_p$ to $0.5L_p$ and then showed decreasing graph for $0.8L_p$due to the change in stiffness of pile near ground surface. From the result graph showed in figure 6.10 an increase of 11% in lateral capacity is found. Optimum length of fin was obtained as 0.5 times the length of the pile.

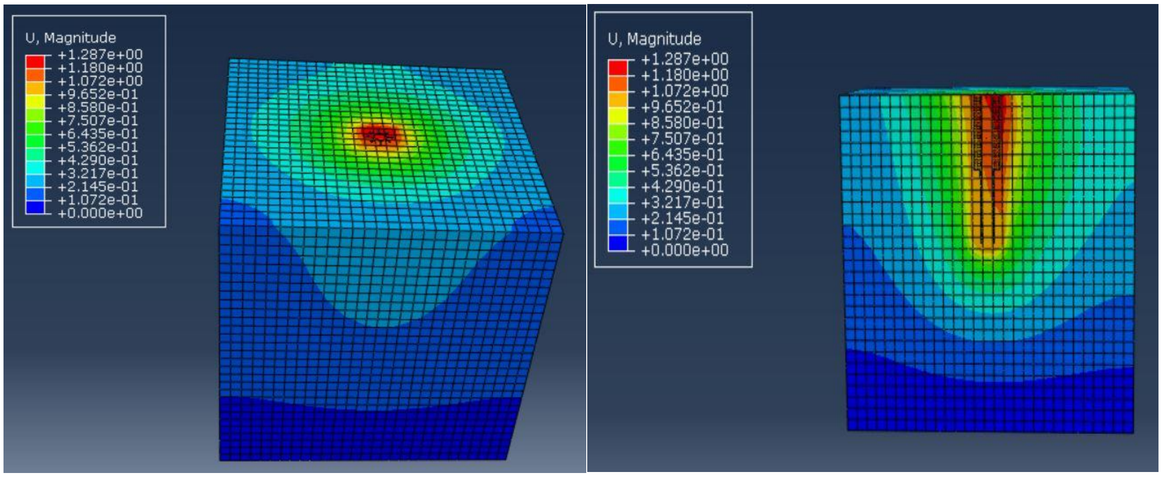
6.5 Influence of number of fins



(a) (b) (c)

Figure 6.11: Meshed pile with fin number (a) 2 (b) 4 (c) 6

The study to determine the influence of number of fins on the lateral capacity was done on 2, 4 and 6 number of fins. Parameters of fins considered for the study was length of $0.5L_p$, width of 20mm, thickness of 2.1mm and rectangular shaped fin. Figure 6.11 shows the model pile with 2, 4 and 6 number of fins.



(a) (b)

Figure 6.12: Displacement diagram of 8 number of fins (a) whole section (b) cross section

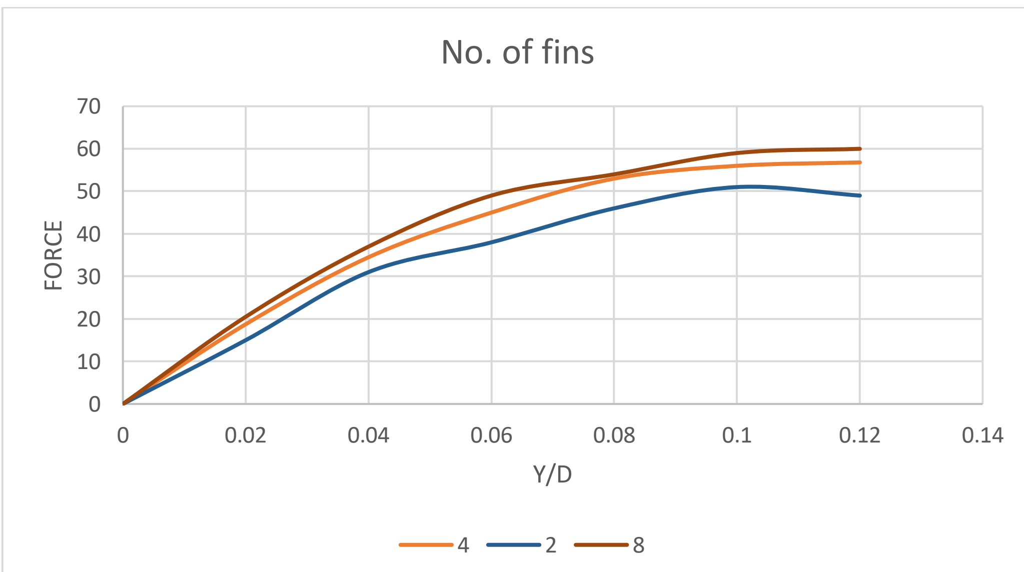


Figure 6.13: Force – y/D diagram for different no. of fins

Numerical analysis for different number of fins was done to study the influence on lateral load resisting capacity of finned pile. The model parameters are taken as per the results obtained from previous objectives. Length of fin $0.5L_p$, thickness of fin 2.1mm, width of fin 20mm and rectangular shaped fin. Figure 6.13 is the representation of results obtained from the analysis of different no. of fins in finned pile on the lateral capacity. The graph shows that as no. of fins increased from 2 to 4 lateral capacity also increased. Number of fins from 4 to 8 shows a slight change in load resistance. Lateral capacity of 4 no. of fins was improved by 25% than 2 no. of fins. As the no. of fins was increased to 8 lateral load resistance showed only 9% increase. As the no. of fins are increased the flexural rigidity of pile and frictional stress on fins are improved which enhance the lateral capacity of finned pile.

CHAPTER 7

CONCLUSION

Foundation is one of the important parts in a building. Foundation has the function to transfer the loads from the structure to the soil strata. For weak soil strata the best foundation to be provided is pile foundation. Pile foundation is one of the deep foundations. The main loads acting on pile foundation are axial and lateral loads. In order to resist the lateral forces either soil treatment or pile lateral capacity should be improved. The lateral capacity of piles can be improved by providing fins on the curved surface of pile. In this study the work is focused on the influence of fin parameters on lateral capacity of pile under cyclic loading. The soil condition adopted for the study is sand. The conclusions obtained from the study are mentioned below:

- Results obtained from the study showed that rectangular shaped fins showed 18% more lateral resistance than triangular fins. Passive area of soil in the case of rectangular fins are more than that of triangular fins.
- Thickness of fin 2.1mm, which is same as that of pile thickness showed better lateral resistance. Lateral resistance of 2.1mm thick fin was 10% more than 3.1mm and 14% more than 4.1mm.
- The effective length of fin obtained from the analysis is 0.5 times the length of the pile. 0.5Lp length fin model showed lateral resistance,11% increase than 0.2Lp length fin and 6% increase than 0.8Lp length fin.
- Lateral capacity of 4 no. of fins was improved by 25% than 2 no. of fins. As the no. of fins was increased to 8 lateral load resistance showed only 9% increase. As the no. of fins are increased the flexural rigidity of pile and frictional stress on fins are improved which enhance the lateral capacity of finned pile.

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