`

COMBINED EFFECT OF EMBEDMENT DEPTH AND DIAMETER ON PULL OUT STRENGTH OF MODELED PILE

A DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

Submitted by

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DECLARATION

I hereby certify that the work which is presented in the Major Project- II entitled "Combined Effect of Embedment depth and Diameter on Pull out strength of Modeled Pile" in fulfilment of the requirement for the award of the Degree of Master of Technology in Geotechnical Engineering and submitted to the Department of Civil Engineering, Delhi Technological University, Delhi is an authentic record of my own, carried out during a period from January to June 2020, under the supervision of Prof. Naresh Kumar.

The matter presented in this report has not been submitted by me for the award of any other degree of this or any other University.

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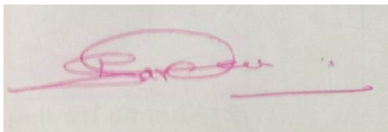
CERTIFICATE

I hereby certify that the Project Dissertation titled "Combined Effect of Embedment depth and Diameter on Pull out strength of Modeled Pile", which is submitted by Shivank Sharma, Roll no. 2K18/GTE/14 Civil Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.



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SHIVANK SHARMA

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ABSTRACT

Piles are used in civil construction work from the prehistoric times. They are used for supporting structures having large height, for example chimneys, transmission towers, high potential electrical poles and many more. All the above stated structures faces very high tensile uplift force and other forces which may cause extraction of the structure from the soil, hence pile or group of piles are designed to counter these force and to stabilize the structure, moreover pile/group of piles become indispensable support member when the soil is unstable and exceptionally large loads are involved. Resistance to high tensile uplift is given by the friction between the surrounding soil and the pile along with pile weight. Such piles (which counter uplift) are termed as uplift piles, anchor piles or tension piles, their computed uplift resistance is equivalent to that of friction piles. Uplift resistance is been developed by the uplift piles, from the skin friction generated along with the length of embedment. Uplift piles are driven in such a way that an inflated area is there at the base which expands to bulb like structure. Pile weight is included in this procedure of uplift capacity excluding the point bearing.

In this study, theoretical as well as practical evaluation has been done in order to determine the pile's ultimate uplift capacity when the same were embedded in sand. Different parameters were taken into consideration the soil properties and pile parameters like diameter, length, surface characteristics. In order to work out the uplifting capacity or pull out strength of piles embedded in sand, various charts has been generated. Description of analysis results of modeled pile laid into soil is presented in the study. In order to know the influence of various parameters like size of pile (diameter), embedment depth, comparison tests were done.

Pile uplift capacity or pull out strength is not only the function of (depends on) denseness but

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it varies with method of laying of pile into the soil i.e. method of installation, depth up to which pile is embedded into the soil, material and size of pile, roughness etc. It is already known that uplift capacity/pull out strength of pile is only summation of frictional resistance and pile weight, on the other hand frictional resistance reaches a constant value after attaining critical depth.

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LIST OF SYMBOLS

G	Specific gravity
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
%	Percentage
Fig	Figure
C	Cohesion
ϕ	Angle of shearing resistance
W	Weight of pile
W_s	Weight of surrounding soil
D	Diameter of pile
B_1	Base diameter of enlarged base pile
L	Embedment depth
γ	Unit weight of sand
K_s	coefficient of earth pressure
δ	wall friction angle
A_s	Surface area of pile
mm	millimeter

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CHAPTER-1 INTRODUCTION

1.1 General

Generally the basic work of the any foundation is to transmit compressive loads from the superstructures to the soil beneath them or around them, for the same job pile is provided. But, in some special cases like structures for tall chimney, transmission tower etc. are provided with the pile foundation to resist enormous uplift loads due to wind and their long height. Various extensive experimental and theoretical investigations have been done in the last decade in order to reveal the behavior of the pile or group of pile caused to undergo compression, axial load or lateral loads but still the topic "determination of uplift capacity" is unrevealed one.

Straight shafted pile's uplift resistance in sand is the function of skin friction in between the surface of soil and pile. Limiting friction technique, for the calculation of the net uplift capacity P_u(NET) of a vertical circular pile having diameter d, and having embedded depth L in sand is used and it is expressed as stated below

$P_u(NET) = p_{av}*L*\pi d = (0.5\ K_s \tan\delta *\gamma L)L*\pi d + W$ (i)

In the above formula,

γ = unit weight of soil

p_{av} = average friction

δ = angle of pile friction

K_s = coefficient of earth pressure

W= weight of pile

The available analytical approaches for calculation of earth pressure coefficient, K_s, as stated in equation (i) are given by (Meyerhof 1973; Ireland 1957; Sowa 1970; Levecher and Sieffert 1984; Tran-Vo

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Nhiem1971) have used. Later on the work of Adams and Meyerhof in 1968 to calculate uplift capacity of footing have been extended, and a new uplift coefficient, K_u, in place of K_s as in equation (i) is introduced by Meyerhof (1973).

It was found out that the value of K_u is directly proportional to slenderness ratio i.e. the earlier (K_u) is increasing with the later (slenderness ratio), L/d, but after a attaining a certain higher value it becomes constant, provided angle of shearing resistance of the soil i.e. φ is constant. The depth at which value of K_u cease to further increase after attaining a maximum value is called and used as critical depth for designing. Beneath this point i.e. after critical depth, average skin friction versus depth of embedment attains a linear response (increase) i.e. with additional upsurge in the penetration of pile, skin friction increases hence in order to calculate the uplift capacity of pile limiting uplift coefficient can be used. However it (limiting uplift coefficient), rises with the escalation of φ.

Numerous experimental test by modeling in laboratory (Ayub & Awed 1976; Chaudhari & Symons1983; Das, et al. 1977; Seeley and Das (1975); Levecher & Sieffert 1984) were also performed on shallow to deep embedment depths of piles. Which results into observation that the value of slenderness ratio does not affect the average skin friction after reaching a certain maximum value but average skin friction keeps on changing with the sand's relative density (Das 1983). On the basic of investigational results and hence their assessment with Meyerhof's (1973) theoretical analysis, Symons & Chaudhari (1983) get to know that theoretical forecasts by Meyerhof's (1973) entail of substantial error.

Some in-situ tests on piles placed in sand were carried out by (Chieurizzi & Downs 1966; Vesic 1970; Ismael & Kyln 1979; Ireland 1957; Sowa 1970) in order to find out the uplift pile capacity and they in turn concluded that the limiting skin friction in pile is same in case of both tension and compression and as is mostly reliant on on the relative density of the soil nearby pile and the process of embedment of pile into the soil. Klyn and Ismael(1979) did some theoretical studies and in turn suggested to use the similar value for K_u in both tension and compression.

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Even though Davis and Poulos (1980) suggested that in order to evaluate the uplift capacity of the vertical circular pile, reduce the shaft opposition i.e. resistance for downward (plunging) loading by 2/3.

Uplift Test results testified by McClellend 1974; Seiffert & Levecher 1984 on piles, which were embedded in changed ways shows a very wide disparity in uplift capacity. It was mentioned on the basic of their studies that the average ratio of the ultimate pulling resistance of a statically driven pile to the ultimate resistance of statically driven pile is 0.5.

According to (Seiffert & Levecher 1984), the average proportion of the ultimate pulling resistance of a statically driven pile to the ultimate resistance of statically driven pile is 0.67.

The existing investigative methods presumes that failure takes place along the boundary of the pile and surrounding soil. It has been observed that surface of failure, its extent and the uplift pull out resistance of the pile are daunting phenomena as it depend on various variables like pile's diameter, length, pile surface roughness, angle of the shearing resistance, and method of laying of the pile.

Therefore it is believed that in order to predict out variable involved, a generalized approach must be used, increasing use of straight shafted piles necessities the correct assessment of pullout strength in order to procure safety and as well as economy.

1.2 Need of the Study

Various extensive experimental and theoretical investigations have been done in the last decade in order to reveal the behavior of the pile or group of pile caused to undergo compression, axial load or lateral loads but still the topic "determination of uplift capacity" is unrevealed one.

Uplift capacity depends on various factors like length of pile, diameter, (for certain l/d ratio uplift capacity attains a maximum value).

Material of the pile and surface roughness also have great influence on the uplift capacity since the material and roughness accounts for skin friction which in turns accounts for uplift capacity as skin friction is solely

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responsible for uplift capacity.

Type of soil and its various parameters like grain size, specific gravity/relative density etc. also have impact on uplift capacity which need to be analyzed.

As per various researchers there is differences in theoretical and experimental value of factor of safety to be taken for calculating the safe load at which the stable structure can be constructed. This is to be check.

Impact of diameter of pile and depth of embedment of pile (and also comparison between theoretical and experimental values is to be done) is to be analyzed.

Weight of pile is important factor which adds up with the skin friction and thus directs the maximum Uplift load to resist the instability; hence the testing helps us to determine the effective weight on uplift capacity of the pile.

1.3 Objective of the study

To fulfill the aim following objectives are made

- To determine the basic properties of the sand to classify it.
- To prepare different types of modeled piles in the laboratory.
- To construct a prototype in order to perform testing for uplift capacity at a better scale.
- To determine the pull out capacity of various piles based on the various L/D ratios.
- To compare the experimental results with the theoretical results.
- To find the influence of diameter of model piles on its pullout strength.
- To find the effect of depth of embedment of pile on pullout strength of model piles.

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CHAPTER-2 LITERATURE REVIEW

2.1 General:

The literature has been represented in the following paragraphs to identify the problem related to uplift capacity of the piles under various conditions.

2.2 Review of Literature

In order to obtain the effect of relative density and shear resistance on pull out strength or uplift resistance of the piles various tests were performed by making a prototype of the pile and field by some scale, for doing this piles of cast iron having different diameters have been fabricated and a prototype of the field i.e. a tank in which soil (sand) is poured and having known dimensions is also constructed on the ground by doing brick work. Sand has been filled into the tank by pouring it from different height, which in turn results into varying relative density (from low to high). It was observed that uplift resistance was maximum in case of the densest sand i.e. maximum relative density than in case of loosest sand i.e. minimum relative density. Displacement for both the case is also were also obtained, in case of the densest sand displacement of about 13mm is obtained. [1]

Discussion on effect of the method of installation of the pile has been done. It has been observed that the method of installation significantly affects the uplift capacity of the pile. In this four piles of 0.51m diameter each was laid down to a depth of 14.63m by different ways of installation into sand deposit. It was found out that the uplift capacity of the driven pile was 9.4 times to that of the pile laid down by jetting with external return flow. They also concludes that it is not feasible to compare the uplift capacity of the piles installed by different methods as density of sand gets varied by method of installation of pile. [2]

In order to find out the effect of enlarging the base of the piles on the bearing capacity of pile tests were performed, total capacity of the uniform and belled piles of same length is also compared.

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It was observed that the pullout resistance is improved by the use of pile with enlarged base. The test result obtained shows that by enlarging the base with a factor of 2, the total resistivity increases by about 40%. Moreover it is economical to install enlarge base pile in cold regions. [3]

Test were performed to check the temperature dependency of the uplift resistance of piles. Various test were performed in the temperature controlled chamber. It was observed that uplift capacity is directly proportional to the temperature. At the time of installation the temperature was at 21^{o}C, with the decrease in temperature to 19^{o}C the uplift capacity get reduced by about 60%. [4]

Theoretical method had been used by assuming the curve failure surface, it leads to the quantitative estimates of the effect of parameters like friction angle, internal friction angle, L/d ratio on skin friction as well as uplift capacity of pile. It was observed after a certain depth (critical depth) skin friction attains a constant value does not depends only on internal friction of sand but it varies significantly with pile friction angle. [5]

Effect of contamination of soil on uplift capacity was checked by performing various tests, for this one pile is embedded in clean sand and another in the sand having impurities like oil etc. it was observed that the skin friction get decreases by 33% for heavy oils and 25% for light oils with the decrease in the thickness of the contaminated sand. Uplift resistance varies inversely with the contamination. [6]

Test piles with anchors were buried in the sand, and one half section modeled anchor is also laid into the sand hence type of failure was observed, two types of failure happened i.e. shallow and deep failure.

When the embedded depth is more than critical depth, anchors shows deep failure rather than shallow one, which was characterized by cylindrical shear failure along the shaft. [7]

K. Kimi Bose1, The vertical model piles and batter piles were used in the experiment which were embedded in the sand along with the subjection of pull out pressure in a (1m x 1m x 1m)specimen tank. Model piles steel piles and having different shapes, length and diameters. Sand from the river was taken with the values of the max and min void ratio of 0.81 and 0.54, it was the medium for foundation with 2.67

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value of specific gravity and coefficient of uniformity as 3.53.The Investigation include the pile characteristics such as diameter, length, inclination of pile, shape and characteristics of surface. It was observed that increased length diameter proportion leads to increase in pull out capacity. As diameter size increases the increase in pullout capacity was also observed. It also follows the direct relationship with angle of batter, simultaneous increase and decrease can be seen. Smooth piles seems insignificant in resisting the pull out pressure than the piles with sand coated. Piles with constant volume and different shape, more resistant is observed by circular pipe than the rectangular or square ones. Comparison was made with the different values observed for pullout capacity and also comparison was done for theories available related to them. [8]*

Jaswant Singh This research paper presented the granular anchor pile behavior of the force deformation along with the investigation of force displacement behavior of pile group subjected to pull out load in non-cohesive soil. This paper aimed at determination of pull out capacity, with varying effect of diameter, length of embedment, spacing and diameter of system of Granular anchor pile also with iterations in S/D ratio and L/D ratio with the different soil types. This system of pile resist the uplift pressure more effectively and is quite innovative and latest. The pull out capacity of the granular anchor pile varies linearly with the increment change in L/D ratio, as compared to 2 gap 4 granular anchor pile arrangement in the two soil type considered.

It was also observed that single granular pile system with 100mm and 50 mm diameter shows the pullout capacity increase up to 40% L/D ratio increment. Therefore single granular anchor pile arrangement shows much greater advantages with length to diameter ratios of 7 and 10.50. The loose soil having relative density lower shows less increase in pull out capacity as compared to that of dense soil which have relative density quite high. The characteristics of soil and granular anchor pile diameter follows a linear relationship with pull out capacity. The observance in case of four and two gap systems was that there was an increment in the pull out capacity in both type of soil. [9]

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The results obtained on the basis of experiment on nails shows that difference between quasi-static and rapid uplift test depends on roughness of surface of nail, nail having roughness more than critical roughness shows more uplift resistance response. Uplift resistance is more for larger diameter nails. The difference between quasi static and rapid uplift test of nail led in natural soil (fully saturated clay soil) is expected to be more due to factors like creep, pore pressure, and viscosity. [8]

This paper investigated monotonic and dynamic installation of anchors in over consolidated clay and high calcium silt. In order to conduct test, drop height is varied which in turn varied the impact velocity (15-22m/s) which increases with drop height.

Anchor holding capacity increases with increase in consolidation time after installation, soil undrained shear strength and depth of embedment. [9]

Anchor's critical uplift load and load deformation characteristics was predicted using hyperbolic stress strain curve of soil. This analysis did not took account of shape effect of anchors strip. The theory was valid for shallow anchors only, differentiation between shallow and deep anchors was not considered. [10]

For calculation of axial static pile capacity, a method was proposed, in which dynamic measurement of force was taken into consideration and impact was provided by hammer accordingly.

By considering plastic behavior of soil, a new program to work out wave analysis of pile called CAPWAP was developed. This program eases the understanding of pile driving. Both statically measured pile capacity and dynamically measure results correlates with each other. [11]

Equivalent static force on bridge pier due to various factors like protective equipment and input from vessel was discussed theoretically. An equation was developed from which longitudinal and transverse ship impact can be calculated. Batter and plumb pile are compared, plumb pile are more economic than batter piles. [12]

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In situ tests were done on board pile and group of piles in dense and medium sand in south Kuwait. Results shows that single pile in tension failed at resistance of 91 kpa and the axial load distribution in compression was nearly linear also the friction is almost same for both the case i.e. compression and tension. [14]

Several test has been conducted on modeled piles and group of pile in cohesion-less soil and piles or group of pile are subjected to tension only. The outer diameter of pile is 26mm having l/d ratio of 14, 20, and 26. The sand is compacted to relative density of 75%, 85% and 95%.It was observed that uplift capacity depends upon depth up-to which pile was embedded to diameter ratio (l/d) and also on soil properties. Uplift capacity varied proportionally with l/d ratio and relative density. [15]

Modeled steel pile were laid in loose, medium and dense sand with varying l/d ratio (from 7.5-30), also piles were embedded at different batter angles, i.e. 0^o(vertical pile), 10^o,20^o, 30^o .for piles installed in dense and medium sand, uplift capacity increase proportionally with batter angle and after attaining a maximum value decreases i.e. maximum value is attained at 20 degree, which is about 20-21% more than vertical pile. Uplift capacity in loose sand varied inversely with batter angle. Circular pile have more uplift resistance than rectangular and square pile. Uplift capacity increased by 18-75%,

Rough surface pile instead of smooth pile are used. In the structures having high movement large batter piles are preferred. [16]

All these literatures put stress on analysis on pull out strength of single pile or group of pile by taking into account the shear strength, material of pile as well as properties of soil. Based on the literature review, gap in the study has been found out and mentioned under the title “objectives” in chapter 1.

In succeeding chapters, various test were conducted in order to get the result as per the objective.

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CHAPTER-3 MATERIALS AND METHODS

3.1 General

In this chapter brief discussion about the methodology and the selection of the material is discussed in brief, process of performing the test is also discussed in detail.

In order to determine the uplift capacity of the pile and effect of various parameters on it, various field as well laboratorial tests were performed by constructing a prototype. Piles of diameter 22mm, 28mm, 35mm and 45mm respectively of steel are used for testing. A brick masonry box like structure is constructed in the field and it is filled with the sand in order to get the uplift resistance of the pile. After obtaining the results from the field test, analysis is done and comparison with the theoretical results is done.

3.2 Modeled Apparatus

The following types of modeled piles are used for the experimental study

Steel pile: For field test piles made up of steel of diameter 22mm, 28mm, and 35mm with 1000mm length each is used.

Sand tank: The sand tank was made from brick masonry with dimensions 0.7m X 0.7m X 3m, the inner walls of the tank were plastered properly. These dimensions were chosen so that a sufficient amount of sand can be poured into the tank, moreover we have to test the pull out capacity of pile, effect of lateral pressure on piles, etc. Hence piles of varying length, diameter can be tested for a wide range of tension, torsion etc. If a tank of smaller dimensions is to be used in determination of relative density, it will put a constraints on the range of testing for the later. That's why a sand tank was made from brick masonry with dimensions 0.7m X 0.7m X 3m.

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3.3 Sand

The soil sample is collected/dig out from Yamuna bank near signature bridge, Delhi. All kind of vegetation waste and other unrequired particles were removed. Finally the sand obtained by manually removing the waste from it is sieved, sand passing through 4.75mm sieve but retained on .75mm/75 micron sieve is taken for further testing process.

In order to know the properties and hence to comment the type of sand or to find out various geotechnical properties such as specific gravity, gradation laboratorial analysis is done.

Various laboratory test such and sieve analysis, modified proctor test etc. are performed.

3.4 Determination of Specific gravity:

Density bottle method is performed in the laboratory and the relative density/specific gravity of the sand is found out to be **2.6925** by density bottle method.

Table 3.1 Specific gravity of sand

Weight of density bottle(gm)	**W_1**	20.5	20.5	20.5	20.5
Weight of density bottle+ dry soil (gm)	**W_2**	124.50	130.50	130.20	116.25
Weight of density bottle+ dry soil+ water (gm)	**W_3**	136.90	140.70	139.60	129.90
Weight of density bottle+ water (gm)	**W_4**	70.80	70.80	70.80	70.80
Specific gravity	**G**	2.74	2.74	2.68	2.61

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Specific gravity ____________________

Average specific gravity= (2.74+2.74+2.68+2.61)/4

= **2.6**

3.5 Sieve analysis

In order to classify the sand sieve analysis is performed by passing the soils through a series of sieves of progressively smaller mesh size, arranged as per IS specifications. Readings are given below, hence a curve shown figure 1 is drawn.

Table 3.2 Sieve analysis for sand

Sieve size (mm)	Mass retained (gm)	%mass retained (gm)	Cumulative % retained	% finer
4.75	31.460	3.146	3.146	96.854
2.36	9.800	0.980	4.126	95.874
1.18	9.400	0.940	5.066	94.934
0.6	13.800	1.380	6.446	93.534
0.300	928.400	62.840	68.296	31.704
0.150	26.480	26.480	95.766	4.234
0.075	3.052	3.052	98.818	1.182
Pan	2.110	0.211	99.029	0.971

3.6 Grain size analysis curve

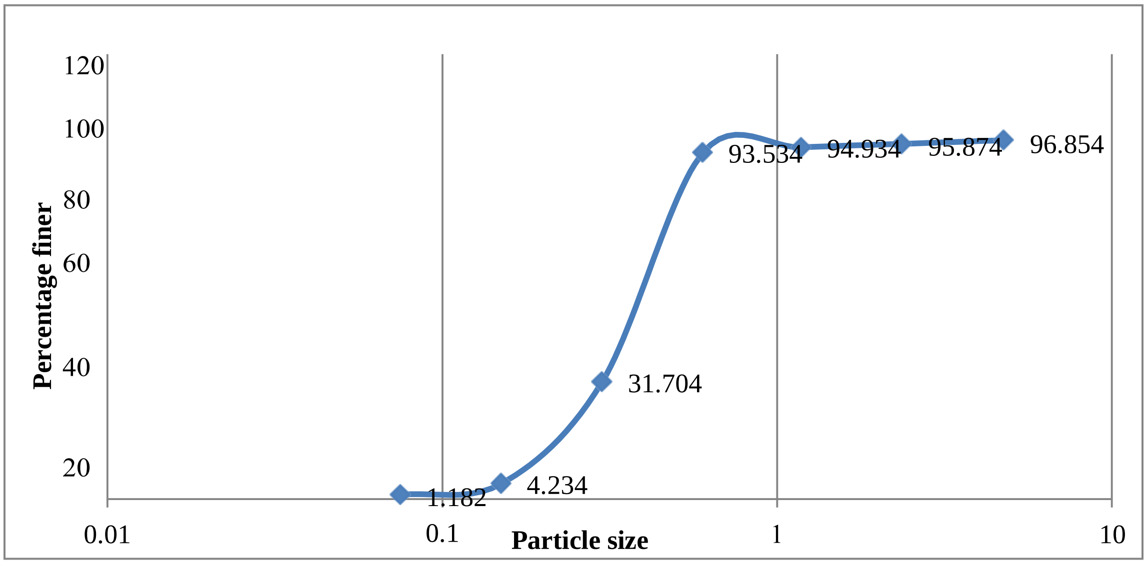

Figure 3.1 Graph for Sieve Analysis for sand

From the graph as drawn above between sieve size versus percentage finer on log scale, from the graph the value of D_{10}= 0.18, D_{30}= 2.0, D_{60}= 0.4 respectively; therefore we can work out C_U, the coefficient of uniformity and C_C, as follow:-

$$C_U = \frac{D_{60}}{D_{10}} = \frac{0.41}{0.18} = 2.27$$

$$C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}} = \frac{0.29^2}{0.41*0.18} = 1.13$$

As per results the soil is designated as SP and poorly graded.

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3.7 Modified proctor test

In order to obtain the maximum dry density and optimum moisture content and to obtain the relationship between water content and dry density of the soil sample, modified proctor test is carried out in laboratory as per IS standards. The result obtained is given below.

Table 3.3 Data for modified Proctor test

WATER CONTENT (W)(%)	MASS OF MOULD +SOIL (gm)	MASS OF SOIL (gm)	DENSITY OF SOIL (Kg / m^3)	DRY DENSITY (Kg / m^3)	DRY UNIT WEIGHT (KN/ m^3)
4.53	12300	6000	1.940	1.856	18.207
6.51	12990	6590	2.130	1.999	18.360
10.32	13426	6998	2.262	2.054	18.640
14.50	13095	6685	2.161	1.887	18.051
15.98	12903	6500	2.101	1.811	17.766

From the data obtained after performing modified proctor test a smooth curve/graph between water content and dry density is drawn as shown below. Initially the dry density increases with the corresponding increase in the water content of the soil, then after reaching a certain maximum point, it (dry density) start decreasing with further increase in the water content. The value of dry density and the water content corresponding to the point of maxima in the curve is termed as maximum dry density and optimum moisture content respectively.

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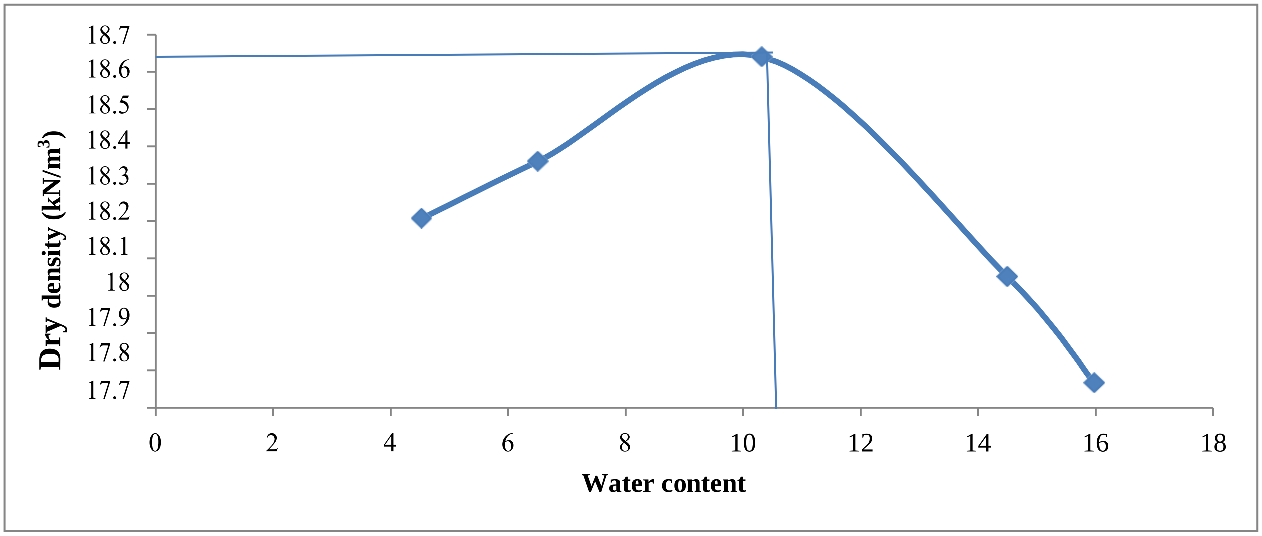

Figure 3.2: Graph between dry density and water content

The value of the two as obtained from the graph are as follow.

Maximum dry density=18.64KN/m^3

Optimum moisture content=10.32%

3.8 Water

The water used was tap water with following properties as given below

Table 3.5 Properties of water

S.No.	Property	Value
1.	pH	6.8
2.	Hardness	182 mg/l

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CHAPTER- 4 EXPERIMENTAL WORK

4.1 Experimental Set up

4.1.1 Loading frame and test tank

In order to perform the experiments, a setup is made in the field. A brick masonry box like structure is constructed. Pulley system and a cycle bearing is also placed on the top of the pile so as to apply torsional load on the pile. All the said arrangement is clearly shown in the figure below.

In order to lower the pile and to apply uplift load, a pulley system is placed on the top it, pile is attached to the pulley by a string, string's one and is attached to pile and other to hanger having weight, in this way uplift load is applied on the pile. A dial gauge is also attached to get the displacement, hence both uplift load and displacement of pile at respective weight could be noted. Dial gauge is accurate to 0.01mm.

Test is conducted in rectangular box made up of bricks of size 700 x 700 x 3000 mm.

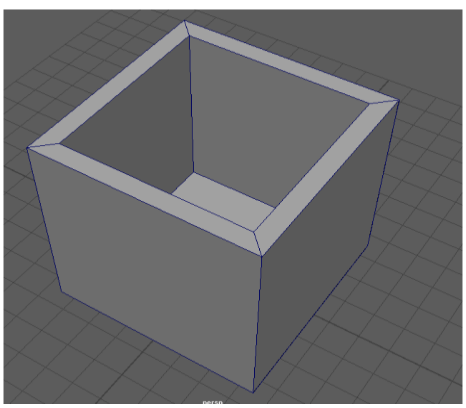

Fig 4.1 Experimental set up for pull out test

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The inside walls of the tank are smooth by plastering it. Failure occurs in pile within the range of three to eight times the diameter of tank, which is why a tank of dimensions 700 x 700 x 3000 mm is chosen to conduct the test. In order to perform test piles were inserted at the center of the pit so that the walls of the tank is at distance of about 16 to 27 times the diameter of pile, hence no interference occurs to failure zone due to wall.

4.1.3 Sand filling and its properties

The sand used for testing is having round grains because of which friction between the sand and the wall has been minimized. In order to pour the sand in the controlled way, a wooden box is made having dimensions slightly less than that of box, box is lowered with the help of pulley system in order to pour the sand from required height. Hence a homogenous soil bed is achieved. Experiments were conducted at the unit weight of 18.6 kN/m^3 for dense sand. Sand was filled in tank in six layers compacted up to desired density. To cross check the density of sand surrounding the piles penetrometer was used.

4.1.4 Modeled piles

Three model steel piles are used for this investigation and are of three different diameter-

<u>Steel pile</u>

- Pile 1- diameter 22 mm , length 1000 mm and weight 3058 gm
- Pile 2- diameter 28 mm, length 1000 mm and weight 4954 gm
- Pile 3- diameter 35 mm, length 1000 mm and weight 6550 gm

4.1.5 Installation of model pile in the tank

In this investigation, pile is installed in the tank by hammering it with the hammer used in proctor test, the number of blows for each 30cm insertion were also noted except for first 30cm insertion into the soil, It does not specifically correspond to any field method of pile installation. In order to pour the sand in

The controlled way, a wooden box is made having dimensions slightly less than that of box, box is lowered with the help of pulley system in order to pour the sand from required height. Hence a homogenous soil bed is achieved. Experiments were conducted at the unit weight of 18.6 kN/m^3 for dense sand. Sand was filled in tank in six layers compacted up to desired density.

4.2 Experimental setup

In this experiment, firstly sand was poured with the help of wooden box lowered into the box from different height with the help of pulley, then pile is lowered and finally weight has been putted and displacement and the load is noted.

In order to pour the sand a box having dimensions slightly less than that of tank having uniform small openings of size 6mm at its base as shown in figure below. The box is lowered into the tank with the help of pulley system above the tank, hence sand can be poured from the desired height and in uniform layers. After sand was filled, relative density for each case is calculated, and then pile is inserted with the help of hammer upto desired depth. Load is applied and readings of displacement and respective load are noted. For each layer separately and the sand surface was leveled by using a leveler.

Finally dial gauges placed on opposite sides and at the center connected to the pile top gives the value of displacement and the load applied at the hanger can be manually noted down.

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4.3 Test program

The test program comprised of a parametric study that examines various variables. Table shows a summary of test parameter and their values. To study the effect of embedment depth, size of pile, numerous uplift test was executed on vertical pile in sand.

Initially, the in-situ relative density was calculated, height of fall leading to densest sand is also noted, and then the effect of various parameters like diameter, relative density, roughness on uplift capacity is analyzed through testing.

Finally a comparison between theoretical and experimental value is made.

4.4 Theoretical analysis of model piles:

4.4.1 Uplift capacity simple pile:

As mentioned in IS 2911 [part I / Sec 2], the uplift capacity of a pile can be calculated by the summation of weight of pile and frictional resistance of pile. The formula given for Uplift capacity in IS 2911 is as follow:

Uplift capacity $=K_i\, P_{Di} \tan\delta_i\, A_{si} + W$

Where,

$_I$ = coefficient of earth pressure

P_D = effective overburden pressure at pile tip = summation for layers 1ton in which pile is installed.

W = weight of the pile

<u>Table 4.1 Data for theoretical analysis</u>

Type	Steel
K	1
Δ	37.23
ϕ	37.23

4.4.2 Uplift capacity of enlarged base pile:

As per Adams and Meyerhof (1968) the formula for determination/calculation of uplift capacity of a pile is as follow:

$Q_u = {}_u B_1D + S_f D_1/2) D^2K_u\tan\phi + W$

Where,

C_u = cohesion,

B_1 = diameter of enlarged base,

ϕ = angle of shearing resistance

D = pile length,

S_f = shape factor,

W = weight of pile and soil in a cylinder of diameter,

K_u = coefficient of lateral earth pressure,

D_1 = nominal diameter of pile and B_1 and height equals to embedment depth.

Table 4.2 Shape factor's value as per IS CODE:

S_f	1.120	1.300	1.600	2.250	3.450	5.500	7.600
ϕ	20^0	25^0	30^0	35^0	40^0	45^0	50^0

`

Table 4.3 Weight of piles

Type of pile	Diameter of pile(mm)	Weight(KG)
Type 1 (steel pile)	22.0	3.058
	28.0	4.954
	35.0	6.550

Table 4.4 Weight of surrounding soil

Diameter of pile(mm)	**Embedment depth(mm)**	**Weight(KN)**
22.0	300.00	14.73
	450.00	15.40
	600.00	15.70
28.0	300.00	14.75
	450.00	15.45
	600.00	15.69
35.0	300.00	14.71
	450.00	15.41
	600.00	15.72

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CHAPTER- 5 RESULTS AND DISCUSSION

5.1 General

The results of each test were plotted in terms of uplift load v/s axial displacement/ settlement. The various tests were performed with various changes and their effects on uplift capacity are given below:

5.2 Influence of size of model piles

For this three test performed on three different pile each having diameter 22 mm, 28 mm, and 40 mm having same embedment depth 300 mm in test I, 450 mm in test II and 600 mm in test III.

From the test result, as we increase the diameter the uplift capacity increases.

Table 5.1**.** Experimental and theoretical uplift capacity of steel pile

			Embedment depth (mm)		
S.no.	Diameter	Uplift capacity (N)	300.00	450.00	600.00
1.	22mm	Experimental	55.50	94.00	187.00
		Theoretical	27.38	48.65	108.50
2.	28mm	Experimental	60.00	98.00	192.00
		Theoretical	34.80	61.50	138.00
3.	35mm	Experimental	64.00	111.00	245.00
		Theoretical	43.55	77.00	172.50

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Table 5.2. Improvement in uplift capacity with diameter

Diameter (mm)	%increase in diameter	Uplift capacity(N)	% increase in uplift resistance
22	-	55.5	-
28	27%	60.0	9%
35	59%	64.0	16%

The results obtained from the table 5.1 shows that the uplift capacity of the pile in each increases with the increase in diameter of the pile both theoretical and experimentally. The uplift capacity of pile increase to 9% and 16% due to increase in diameter of pile 27% and 59% respectively (as shown in table 5.2) Since uplift capacity is the sum of skin resistance and weight of the pile. This increase in uplift capacity of the pile may be due to increase in skin resistance and weight of the pile.

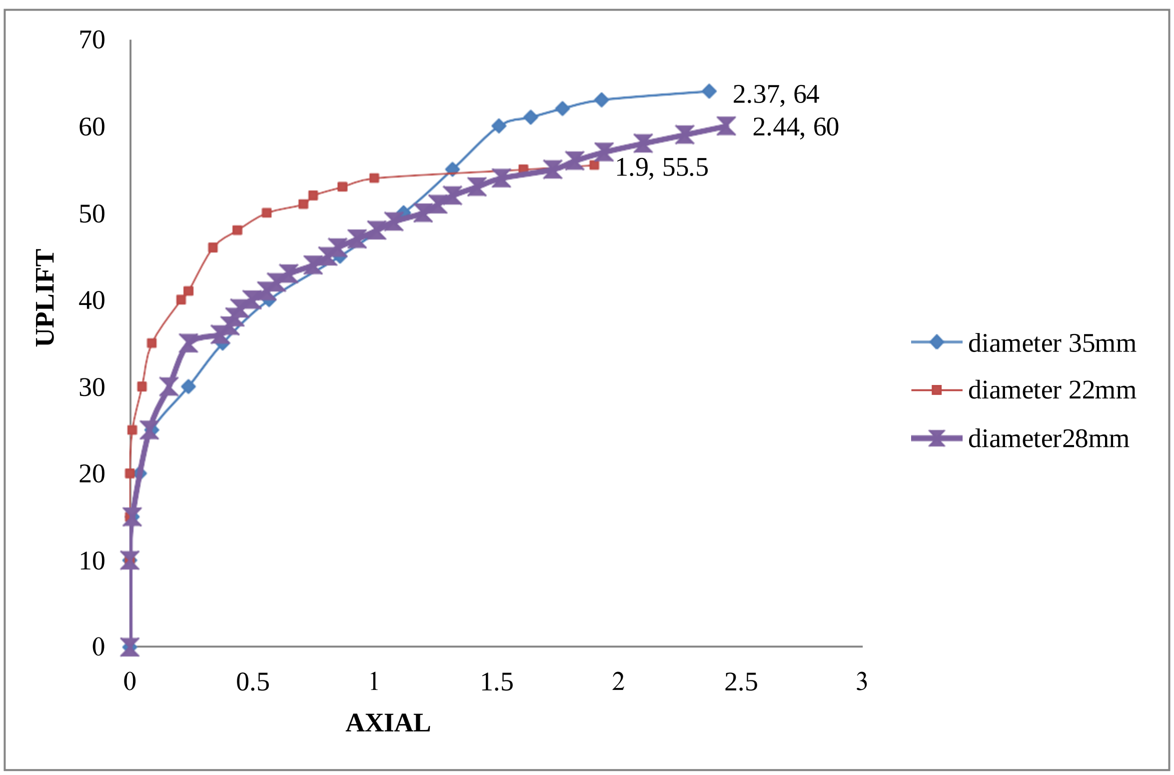

Fig 5.1. Uplift load versus axial displacement curve of steel pile with embedment depth 300mm and varying diameter

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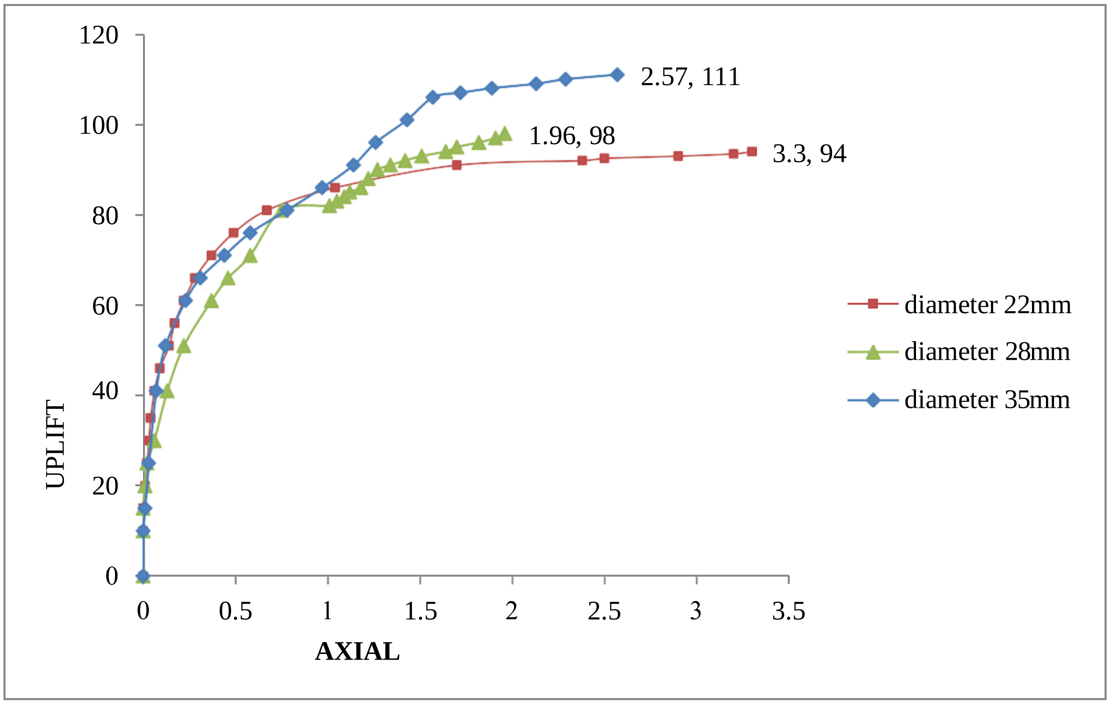

Fig 5.2 Uplift load versus axial displacement curve of steel pile with embedment depth 450mm and varying diameter

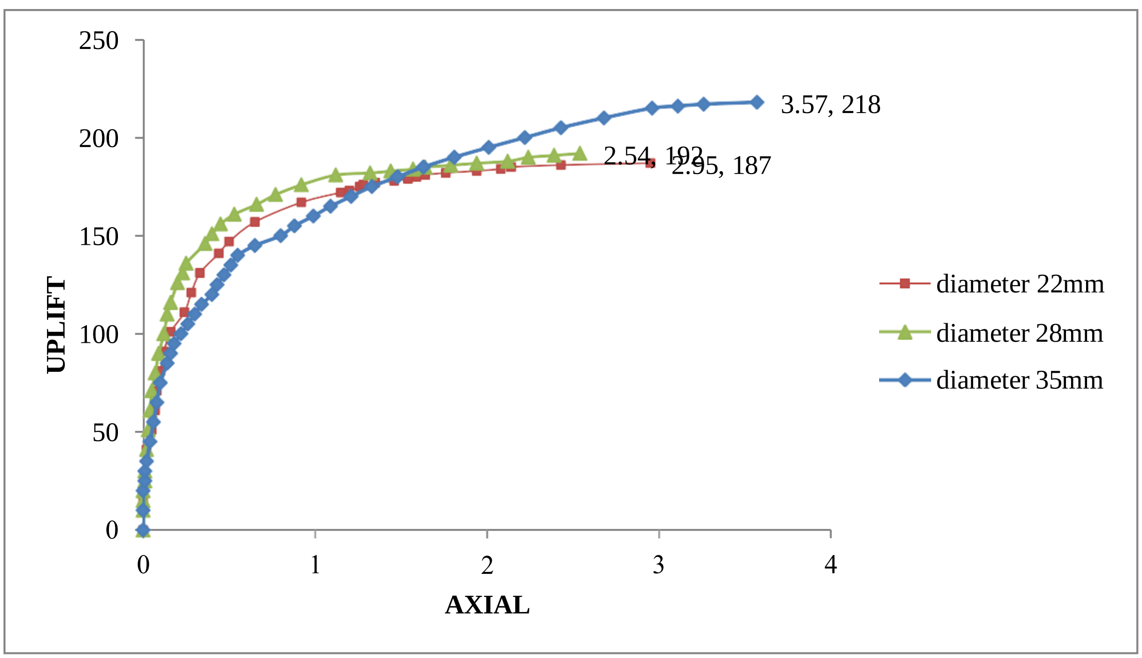

Fig 5.3. Uplift load versus axial displacement curve of steel pile with embedment depth 600mm and varying diameter

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5.3 Influences of embedment depth of model piles

For evaluating the depth factors, here we perform total 9 pull-outs on three different piles having different diameter at varying embedment depth as 300mm, 450mm and 600 mm.

Embedment depth is a major factor which affecting the uplift resistance/capacity of model pile. From the result as shown in figure, it is clear that as increase the embedment depth the uplift capacity increases. The results are shown in table 2.

The uplift capacity of piles increase with the embedment for 22mm diameter of pile the increase in uplift capacity is 38.5N, when embedment depth 300mm to 450mm and increase in uplift capacity is 131.5N when embedment depth changes from 300mm to 600mm.

Due to increase in embedment depth the overburden pressure increases thereby skin resistance increases hence uplift capacity increases.

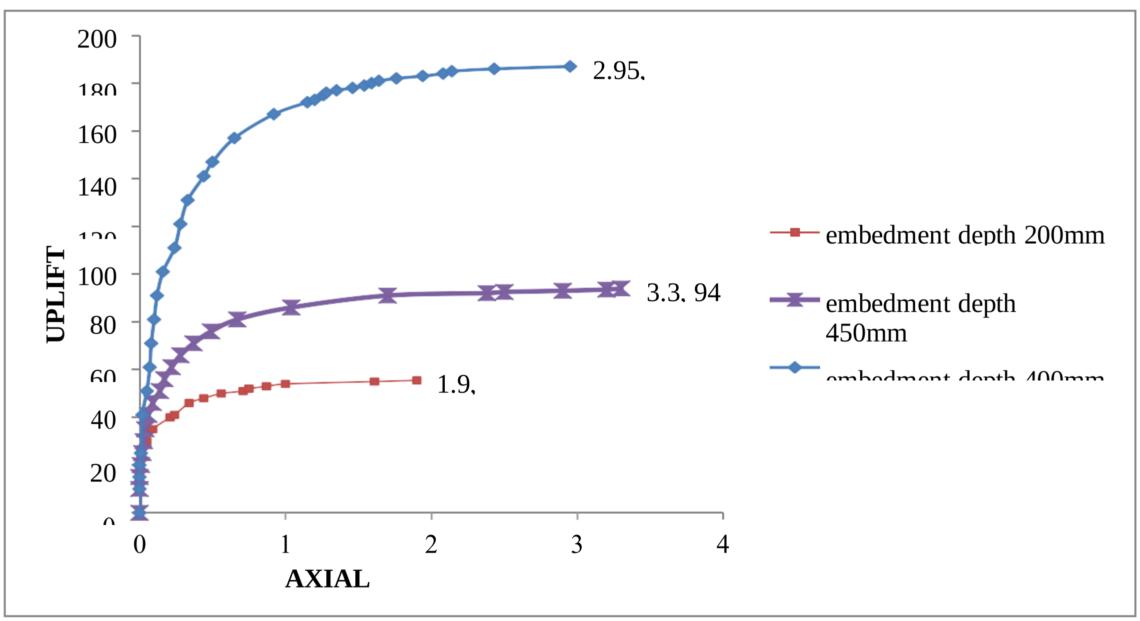

Fig5.4. Uplift load versus axial displacement curve of steel pile with diameter 22mm and varying embedment depth 450mm

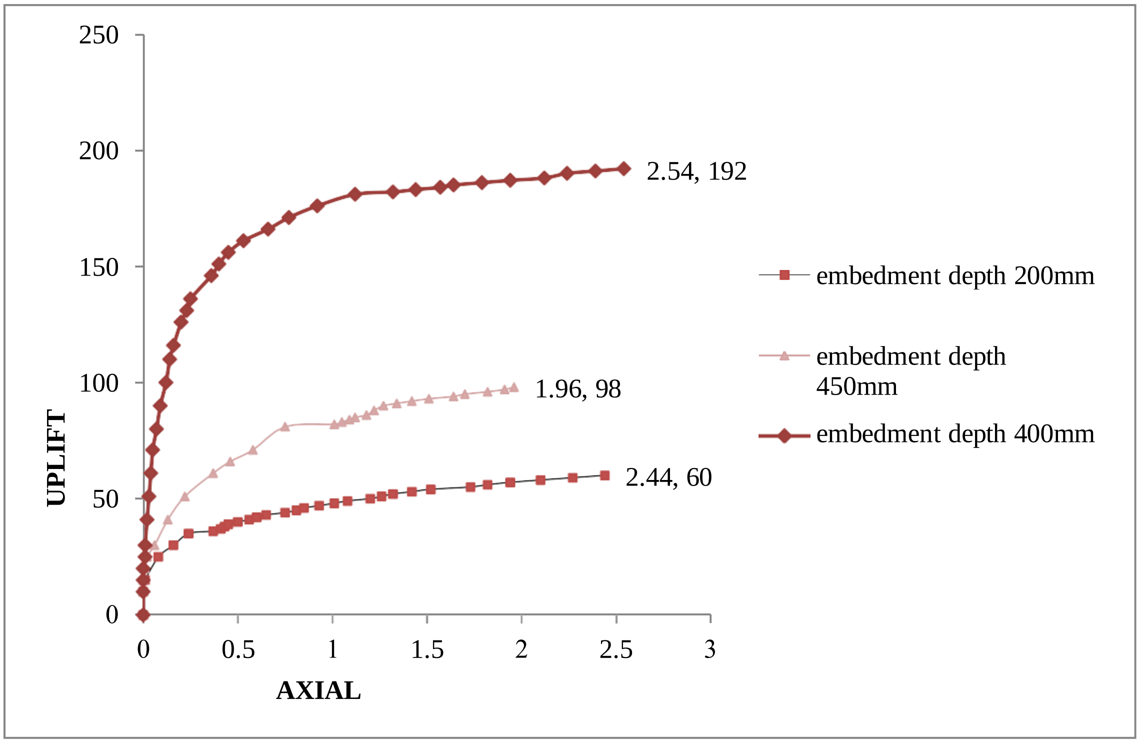

Fig 5.5. Uplift load versus axial displacement curve of steel pile with diameter 28mm and varying embedment depth

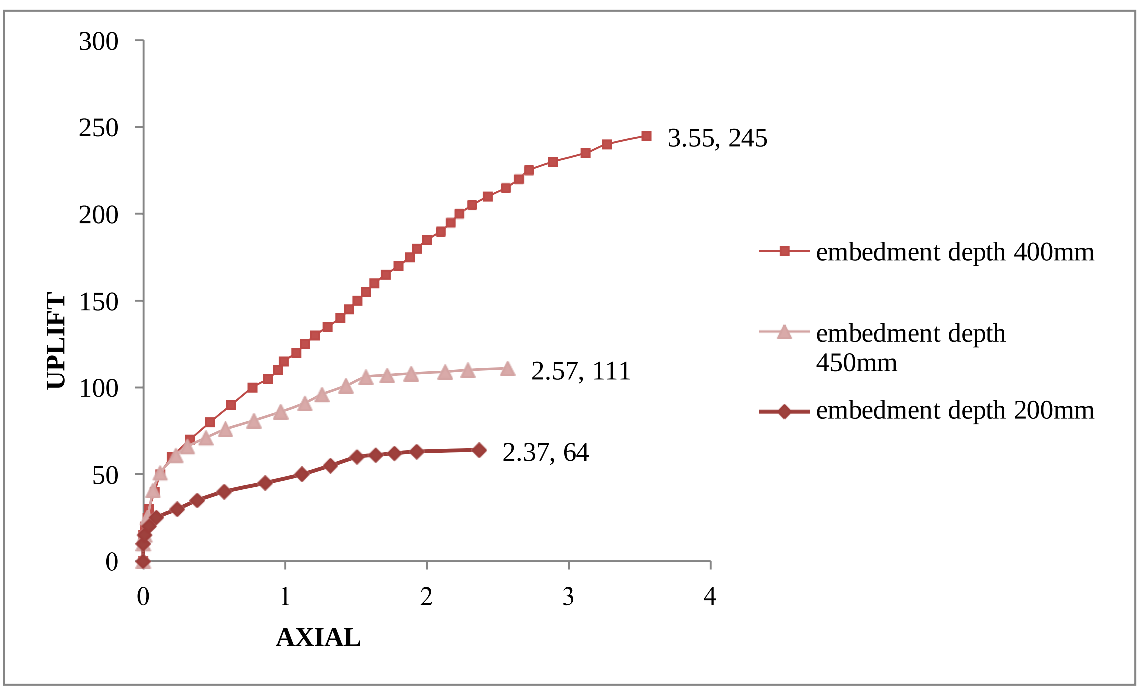

Fig 5.6 Uplift load versus axial displacement curve of steel pile with diameter 35mm and varying embedment depth

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CHAPTER- 6 CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusion of the work:

The Experimental work done with varying different parameters leads to the following conclusions summarizes in the points below:

- The uplift capacity of steel pile is found to be a direct function of its diameter.
- The pile's uplift capacity increases with as the embedment depth increases.
- Uplift capacity is also found to be a direct function of the relative density of soil.

6.2 Future scope:

On the basis of conclusion of the project the following recommendations may be proposed for future work

- The above study may be repeated for different types of pile material such as concrete, timber etc.
- The study may also be repeated on other types of soil.
- The test on proto type pile may be carried out for the validity.
- The effect may also be seen by change in environment such as temperature, contamination of soil etc.

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Annexure – 1

22mm diameter steel pile	Embedment depth(mm)		
	300.0	450.00	600.00
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.01	0.01	0.00
30	0.09	0.03	0.01
40	0.24	0.06	0.02
50	0.71	0.14	0.05
60	-	0.22	0.07
70	-	0.37	0.08
80	-	0.67	0.10
90	-	1.70	0.12
100	-	-	0.16
110	-	-	0.24
120	-	-	0.28
130	-	-	0.33
140	-	-	0.44
150	-	-	0.61
160	-	-	1.15
170	-	-	1.59
180	-	-	-
190	-	-	-
200	-	-	-

Annexure 2

28mm diameter steel pile	Embedment depth(mm)		
	300.00	450.00	600.00
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.04	0.01	0.00
30	0.16	0.06	0.01
40	0.50	0.13	0.02
50	1.20	0.22	0.03
60	2.44	0.37	0.04
70	-	0.58	0.05
80	-	0.75	0.07
90	-	1.27	0.09
100	-	1.96	0.12
110	-	-	0.14
120	-	-	0.20
130	-	-	0.23
140	-	-	0.30
150	-	-	0.40
160	-	-	0.53
170	-	-	0.77
180	-	-	1.12
190	-	-	-
200	-	-	-

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Annexure 3

35mm diameter steel pile	Embedment depth(mm)		
	300.00	450.00	600.00
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.04	0.02	0.00
30	0.24	0.04	0.01
40	0.57	0.07	0.02
50	1.12	0.12	0.03
60	1.51	0.23	0.04
70	-	0.44	0.05
80	-	0.78	0.07
90	-	1.14	0.09
100	-	1.43	0.12
110	-	2.29	0.14
120	-	-	0.18
130	-	-	0.23
140	-	-	0.32
150	-	-	0.40
160	-	-	0.53
170	-	-	0.77
180	-	-	1.12
190	-	-	2.24
200	-	-	-

Annexure 4

22mm diameter	Embedment depth(mm)		
	300.00	450.00	600.00
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.04	0.00	0.00
30	0.18	0.01	0.01
40	0.65	0.02	0.03
50	1.25	0.07	0.05
60	1.65	0.15	0.07
70	-	0.26	0.09
80	-	0.41	0.12
90	-	0.59	0.16
100	-	0.86	0.22
110	-	1.60	0.30
120	-	-	0.40
130	-	-	0.47
140	-	-	0.55
150	-	-	0.80
160	-	-	0.99
170	-	-	1.21
180	-	-	1.48
190	-	-	1.81
200	-	-	2.22
210	-	-	3.59

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Annexure 5

	Embedment depth(mm)		
Diameter(28mm)	300.00	450.00	600.00
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.01	0.00	0.00
20	0.09	0.00	0.00
30	0.25	0.00	0.00
40	0.60	0.01	0.00
50	1.05	0.01	0.00
60	1.53	0.02	0.01
70	-	0.02	0.01
80	-	0.03	0.01
90	-	0.03	0.01
100	-	0.05	0.02
110	-	0.13	0.02
120	-	0.30	0.03
130	-	0.76	0.04
140	-	-	0.05
150	-	-	0.06
160	-	-	0.07
170	-	-	0.08
180	-	-	0.11
190	-	-	0.12
200	-	-	0.15
210	-	-	0.18
220	-	-	0.22
230	-	-	0.23
240	-	-	0.25
250	-	-	0.32
260	-	-	0.39
270	-	-	0.46
280	-	-	0.57
290	-	-	0.90
300	-	-	1.15
310	-	-	1.70
320	-	-	2.77

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Annexure 6

	Embedment depth(mm)		
Diameter(35mm)	300.00	450.00	600.00
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.00	0.00	0.00
30	0.01	0.00	0.00
40	0.02	0.03	0.00
50	0.04	0.05	0.00
60	0.07	0.08	0.00
70	0.12	0.11	0.00
80	0.24	0.13	0.00
90	0.40	0.16	0.00
100	0.69	0.20	0.00
110	1.87	0.25	0.00
120	-	0.30	0.01
130	-	0.37	0.01
140	-	0.43	0.02
150	-	0.53	0.03
160	-	0.69	0.03
170	-	0.86	0.04
180	-	1.15	0.05
190	-	1.69	0.06
200	-	-	0.07
210	-	-	0.08
220	-	-	0.09
230	-	-	0.10
240	-	-	0.11
250	-	-	0.14
260	-	-	0.15
270	-	-	0.18
280	-	-	0.20
290	-	-	0.23
300	-	-	0.25
310	-	-	0.30
320	-	-	0.34
330	-	-	0.39
340	-	-	0.44
350	-	-	0.51

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360	-	-	0.61
370	-	-	0.68
380	-	-	0.75
390	-	-	0.86
400	-	-	1.03
410	-	-	1.16
420	-	-	2.36