The Major Project- II

On

EFFECT OF SKIN RESISTANCE AND ENLARGED BASE ON PULL OUT CAPACITY OF MODELED PILES

Submitted In Partial Fulfillment for the Award of the Degree of

MASTERS OF TECHNOLOGY

IN

CIVIL ENGNEERING

With Specialization In

GEOTECHNICAL ENGINEERING

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CERTIFICATE

This is to certify that major project-II entitled**— " Effect of skin resistance and enlarged base on pull out capacity of modeled piles"** is bona-fide record of work carried out by Ankush Chaudhary (Roll No. 2K13/GTE/21) under the guidance and supervision, during session 2015 in partial fulfillment of the degree of Master of Technology (Geotechnical Engineering) from Delhi Technological University, Delhi.

The work in this major project- II has not submitted for the award of any other degree to the best of my knowledge

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As I write this acknowledgement, I must clarify that this is not just a formal acknowledgement but also a sincere note of thanks and regard from my side. I feel a deep sense of gratitude and affection for those who were associated with the project and without whose co-operation and guidance this project could not have been conducted properly.

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DECLARATION

I hereby declare that the work in this Project Report entitled—"**Effect of skin resistance and enlarged base on pull out capacity of modeled piles"** is bona-fide record of work carried out by me as a part of major project-II in partial fulfillment for the Master of Technology in Geotechnical Engineering.

I have not submitted the matter presented in this report for the award of any other degree.

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ABSTRACT

Piles supporting high structures, such as tall chimneys, transmission towers, water towers, tents, electric poles, silos are required to resist uplift force due to wind. So piles are designed to resist this tensile uplift force. Resistance to uplift is given by the friction between the pile and the surrounding soil plus weight of pile itself. The uplift resistance of vertical pile can be computed similar to friction piles. Uplift piles are invariably provided with an enlarged area at the base in the form of a bell or a bulb. Piles develop resistance to pull-out only from the skin friction developed along the embedment length. Point bearing is not included, but weight of the pile is included in uplift capacity.

An experimental and theoretical analysis is carried out to predict the ultimate uplift capacity of piles embedded in sand. The method takes into consideration the length, diameter, surface characteristics of piles and soil properties. Charts for evaluating uplift capacity of piles are presented through figures. Experimental and theoretical results of model tests of modeled piles buried in sand are described. Comparison tests were done to determine the influence of factors on uplift capacity such as size of pile (diameter), embedment depth, roughness and enlarged base of modeled piles. Pile uplift capacity not only depends on denseness of sand it also depends on method of installation, depth of embedment, size of pile, material of pile. As pile uplift capacity is sum of frictional resistance and weight of pile, frictional resistance attains a constant value beyond critical depth.

KEYWORDS: Model piles, Pull out, Embedment depth, Pile size, Enlarge area at base, Roughness of model piles.

CONTENTS

LIST OF SYMBOLS

1. G……………………………………………Specific gravity
2. MDD…………………………………………...Maximum Dry Density
3. OMC ………………………………………...Optimum Moisture Content
4. %……………………………………………..Percentage
5. Fig.……………………………………………Figure
6. c…………………………………………….....Cohesion
7. ϕ………………………………………………Angle of shearing resistance
8. W………………………………………………Weight of pile
9. W_s …………………………………………… Weight of surrounding soil
10. D ………………………………………………Diameter of pile
11. B_1………………………………………………Base diameter of enlarged base pile
12. L……………………………………………… Embedment depth
13. γ………………………………………………..Unit weight of sand
14. K_s……………………………………………....coefficient of earth pressure
15. δ………………………………………………...wall friction angle
16. A_s ……………………………………………... Surface area of pile
17. mm ……………………………………………..millimeter

LIST OF FIGURES

LIST OF TABLES

CHAPTER1- INTRODUCTION

1.0 INTRODUCTION

In a general way, pile foundations are designed to carry the compressive loads from super structures. But, some structures like transmission towers, tall chimneys, jetty super-structures mooring systems for ocean surface or submerged platforms, etc., are constructed on pile foundations, which resist enormous uplift loads. There are several and extensive theoretical and experimental investigation been done over the decade to study the behavior of piles or pile groups subjected to axial, compressive, inclined, or lateral loads. Whereas, studies related to determine the uplift capacity of pile load are limited.

The uplift resistance of straight shafted pile in sand is assumed to dependant solely on skin friction between pile shaft and the soil. Usually, a limiting friction approach is assumed and the net uplift capacity P_u(NET) of a vertical circular pile of diameter, d, and embedded depth, L, in sand, is expressed as

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

In which p_{av} = average skin friction = $0.5 K_s \tan \delta * \gamma L$; K_s = coefficient of earth pressure; δ = angle of pile friction W=weight of pile and γ = unit weight of soil.

The available analytical approaches (Ireland 1957; Levecher and Sieffert 1984; Meyerhof 1973; Sowa 1970; Tran-Vo-Nhiem 1971) have been made to evaluate the coefficient of earth pressure, K_s , to be used in the equation 1. Extending the work of Meyerhof and Adams (1968) on uplift capacity of footing, Meyerhof (1973) introduced an uplift coefficient, K_u , in place of K_s in equation (i). For a particular angle of shearing resistance φ of the soil, the value of K_u is shown to increase with an increase in slenderness ratio, L/d, up to a maximum value and thereafter it remains constant. The depth where the value of K_u attains maximum value is designed as the critical depth. Beyond that critical depth, uplift capacity can be analyzed by using the limiting uplift coefficient, implying a linear response (increase) of average skin friction with further increase in the depth of embedment. The limiting uplift coefficient, however, increases with the increase of φ.

Several model scale laboratory test results (Awed & Ayub 1976; Chaudhari & Symons 1983; Das & Seeley 1975; Das 1983; Das, et al. 1977; Levecher & Sieffert 1984) conducted over shallow to high embedment depths of piles are reported. It has been observed that average skin friction reaches a constant value after a certain value of slenderness ratio and that is dependent on the relative density of sand (Das 1983). On the basis of test results and their comparison with Meyerhof's (1973) theoretical analysis, Chaudhari & Symons (1983) concluded that theoretical predictions possesses significant error.

Some field tests on piles embedded in sand under uplift forces were reported (Downs & Chieurizzi 1966; Ireland 1957; Ismael & Kyln 1979; Sowa 1970; Vesic 1970) suggested that limiting skin friction in pile is the same in tension and compression as well and it depends on the relative density of the surrounding soil and the mode of placement of the pile. Ismael and Klyn (1979) advocated the use of the same value of K_u in tension and compression too. However Poulos and Davis (1980) suggested evaluating the uplift capacity of the vertical circular pile by reducing to 2/3 of the calculated shaft resistance for downward loading.

Uplift Test results reported (Levecher & Seiffert 1984; McClellend 1974) on piles, which were installed by different techniques and show wide variation in uplift capacity. It was indicated that the average ratio of ultimate pulling resistance of the pile to the ultimate resistance of a statically driven pile is 0.5. The average ratio of ultimate pulling resistance of statically driven pile is 0.67(Levecher & Seiffert 1984).

The availability of the analytical methods assumes that failure takes place along the interface of the pile and surrounding soil. It has been noticed that the surface of failure, its extent and the uplift resistance of the pile are complicated phenomena involving variables like length, diameter of a pile, roughness of the pile surface, angle of the shearing resistance of the soil, and method of installation of the pile.

Increasingly use of the straight shafted piles to resist and sustain uplift loads necessitates accurate assessment of uplift resistance to achieve economy and safety. Therefore it is believed that a generalized theoretical approach to account for the different variables involved would be beneficial to the profession understand the soil-pile-uplift interaction problem.

1.1 NECESSITY OF STUDY

There is always an embedment depth related to a given diameter of a pile at which the uplift capacity of pile is maximum. So, to determine the value with different L/d ratio, the uplift capacity of pile is need to determine for exact analysis. Influence of the material is huge impact on the uplift capacity, since the material influences the skin friction and skin friction is solely responsible for the uplift capacity or uplift capacity for the stability of structure. Effect of type of soil is an important parameter which has the soil pile interaction to determine the skin friction to evaluate the uplift capacity. Differences in theoretical and experimental results show the factor of safety to be taken for calculating the safe load at which the stable structure can be constructed. Weight of pile is another important factor which adds up with the skin friction to provide the maximum Uplift load to resist the instability; hence the test helps to determine the effective weight for better uplift capacity of the pile.

1.2 OBJECTIVE OF STUDY

To fulfill the aim following objectives are made

1. To determine the basic properties of the sand to classify it.
2. To determine the shear parameters of the soil used for pile embedment.
3. To prepare different types of modeled piles in the laboratory.
4. To determine the pull out capacity of various piles based on the various L/D ratios.
5. To compare the experimental results with the theoretical results.
6. To find the influence of roughness of model piles.
7. To find the effect of enlarged base of model piles.

CHAPTER-2

LITRETAURE REVIEW

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

The test was conducted to study the shear interface and uplift resistance characteristics of cast iron pipe by full-scale field uplift tests. Here two types of backfill densities are used i.e. loose and dense. Uplift resistance of cast iron pipe buried in dense sand gives more resistance (approx more than twice) than cast iron buried in loose sand. Uplift resistance-displacement relationship were obtained for both cases and here approx 13 mm displacement were found in case of dense sand.[1]

Discussions on model tension Piles had done. In this discussion authors said that the method of installations of a pile affects significantly the uplift capacity of the pile. Here field test results of the uplift resistance of the pile on four piles of 0.51 m diameter each installed to a depth of 14.63 m by different methods of installation on sand deposits. Uplift capacity of this driven pile was 9.4 times greater than that of the pile which was installed by jetting with external return flow. They conclude that due to variation in density of soil is not feasible for direct comparison of uplift capacity of pile.[2]

The test was conducted to study the influence of enlarging the base of the pile and bearing capacity of pile and bearing capacity of pile with the principle used to evaluate the total capacity of uniform& belled piles of same length in soil. The total resistance capacity can be improved substantially by the use of piles with enlarged base. The test result shows that if we increase the base 2 times then the total resistive capacity increases up to 40 %(approx. 30 to 40%). Finally concluded that enlarged base pipes may be economically used in place of uniform diameter pile in soil (in cold region i.e., ice rich soil)[3]

Laboratory tests were performed to study the interface shearing resistance of polyethylene pipes under varying conditions. The tests were performed in a temperature controlled room where properties were investigated for thermal variations expected in the field. The test results of pill out capacity performed on polyethylene pipe at representative field temperatures show that-

The uplift capacity decreases on temperature decreases relative to the temperature at the time of installation, here installed at 21^oC, axial uplift capacity reduced to 60%, when the soil temperature dropped to 19^oC.

The piles in the moist soil environment can be locked up when soil temperature goes below freezing. However, a temperature drop from initial burial temperature and the freezing temperature should be considered because the decrease in frictional resistance will occur for that temperature drop prior to lock up.[4]

The uplift capacity of cylindrical piles embedded in sand was predicted by the theoretical method by assuming curve failure surface through the soil had been proposed. It enables a reasonable and logical analysis and quantitative estimates to be made of the effects of parameters like L/d ratio, friction angles ($\delta \fallingdotseq \varphi$) (pile friction angle), internal friction angle φ on the uplift capacity of pile as well as on the skin friction value. It has been found that the critical depth of embedment beyond which any skin friction attains a constant value depends not only on internal friction of sand but on pile friction angle δ significantly.[5]

The main purpose of this paper is to point out those contaminations of sand bed has an effect on the behavior of the pile under uplift capacity. On the basis of experimental investigation carried out on model piles embedded in clean and contaminated sand under uplift loads are on uplift capacity ratio, PCR for piles is affected by the thickness of contaminated sand layer. As the thickness of contaminated sand decreases and skin friction factor decreases by 25% for light gas oil and 33% for heavy oil. The percentage of oil contamination also affects the uplift resistance and skin friction factor. Uplift resistance decreases moreover when oil contamination is greater than 2%.[6]

The result of model test of ground anchors vertically buried in sand are studied. Also a test on half section model anchors which were tested to observe movement and behavior during uplift loading of soil surrounding the anchors.

Comparison tests were done to determine the influence of factors such as diameter, fixed length and embedded depth on uplift capacity of anchors.

Two types of failure were seen on the test when the anchors were lifted up- Shallow & Deep failure.

A deep failure is characterized by a cylindrical shear surface along the shaft and on expansive cavity on the top of the shaft. The uplift force is carried by the top resistance and skin resistance of the shaft. For the case of an anchor buried in shallow conditions the expansive sphere can't appear/ develop fracture appear, loading directly to an uplift cone. The uplift force is initially resisted by weight of the cone is frictional forces along the surface of the shaft. From this is clear that critical depth exists distinguished between shallow and deep failure. If the embedment depth is greater than critical depth then anchor will fail in deep failure else shallow failure.[7]

On the basis of experiment performed on nails in dry sand (dense clean) results shows that the differences in uplift resistance between rapid and quasi-static uplift tests are highly dependent on the roughness of the nail surface. For nails having more roughness

then critical normalized roughness, rapid uplift resistance response was significantly stiffer in pre peak load displacement characteristics and larger in uplift strength. These improvements are more uttered for larger diameter nails. Based on limited experimental results. The radiation damping effect appears to be the most likely factor that contributes to these improvements. The 'actual' damping coefficients that quantifies the radiations damping resistance mobilized in a rapid uplift test was found not to be constant but decreases with increase in uplift displacement.
These results on derived from soil nail embedded in dense dry clear sand medium. In contrast, natural soil medium and usually partially to fully saturated and a mix of clay, silt and sand. The difference between rapid uplift test and quasi static uplift response of soil nails embedded in natural soil, especially in fully saturated clayey soil on expected to be more uttered due to additional influence factor like viscosity, creep and pore pressure effect. [8]

In this paper result obtained from centrifuge model test on investigating dynamic installation and monotonic uplift of torpedo anchors in lightly over consolidates clay and calcareous silt. The tests were carried out varying the drop heights hence impact velocity.
Here the achieved input velocities were 15-22 m/sec, which increased with increased drop height. These values were found to be consistent. They were 10-15% less than theoretical prediction because of frictional loss in launcher guide. The anchor embedment depth increased with increasing drop height. The embedment, for a similar impact volume was around 1.6 times than that of silt.
During extraction, that soil provides a seal over the top of the anchor shaft and fins, which may lead reverse bearing to the mobilized at the base of the anchor shaft and fins and higher skin friction along the anchor surface. The anchor holding capacity increased with increasing post installation consolidation time, depth of embedment and soil un-drained shear strength. [9]

Analysis to predict the critical uplift load and load deformation characteristics of anchor using hyperbolic stress-strain curve of soil on the constitutes law is proposed. The analysis incorporates the effect of shape of the anchor strip, square and circular anchor and analyzed. Analytical data are compared with the available experimental results.
This theory is valid for shallow anchors only. Though a definite differentiation between shallow and deep anchors is not yet established. The change in behavior can be explained with the help of critical depth ratio. The critical depth ratio varies with size- shape of anchors and soil parameters. [10]
A method has been proposed for calculating the axial static pile capacity from dynamic measurements of force and accordingly made under the impact of large hammer.

The theoretical uniqueness case Pile wave analysis program (CAPWAP) resistance distribution has been proven within the limitation of an assumed ideal plastic soil behavior.
Limitation in the soil model used has been discussed and it has been shown that large quick soil can be identified and analyzed. This method can be easily and practically applied in the understanding of pile driving. The dynamically determined static capacity correlates well with the statically measured results since the method gives the capacity at the time of testing is recommended to be performed to include soil strength changes due to setup. [11]

The equivalent static force acting on a bridge pier due to vessel input and various pier protective systems are briefly discussed. Equation and closed form expression are developed to obtain transverse and longitudinal components of ship impact, redistributed between piers and superstructure according to their relative stiffness. Plumb and batter pile combination are compared.
Based on relative stiffness of a pier and the superstructure, the shearing of ship-impacts forces between them should be found for each pier. The plumb piles are often a more economical foundation than a system of batter piles, but the piles flexure capacity should be checked at the bottom of footing and compared to the required flexural capacity. In case of large moments, battered piles could be a better solution. [12]

This paper represents the effect of surcharge support pressure on pile load settlement response during static load testing. A 3-D non linear finite element model is developed to investigate the loading sequences of an axial compressive static load test, using surcharge loads as the reaction system results of a static load test at a construction site for which the geotechnical data are available were used for verification of numerical model. The results show that the surcharge pressure on supports has little impact on ultimate capacity of pile, as the shaft skin friction is slightly influenced by the surcharge and effect on the tip resistance is negligibly small. The initial stiffeners of the pile, however might be considerably affected by the surcharge pressure distributed around the pile. The influence of stiffness increases in pile diameter. The effect of surcharge pressure is more altered for piles embedded in frictional soil compared with cohesive soil. [13]

A field test program was carried out on bored piles and pile group in medium dense sand in south Kuwait. This program includes single pile in tension and compression and two group piles in compression consisting of five piles each. On the basis of field test and laboratory results collusion are on the single pile in tension failed at an average frictional resistance of 91kPa. The axial load distribution along the pile in compression was nearly linear and it was observed that friction in compression and tension was very similar. [14]

Experimental model test have been concluded on single pile and pile group embedded in cohesion less soil and subjected to pure tension. The tests were conducted on vertical steel piles with an outer diameter of 26mm. The tested piles have L/d ratio of 14, 20, 26 and sand bed is prepared at different values of relative densities of 75%, 85%, 95%.
The uplift capacity of single piles under tension mainly depends on the both pile embedment depth to diameter ratio (L/d) and soil properties. The net uplift capacity of pile increases with increase in both L/d and relative density of soil. [15]

The tests are conducted on model steel piles installed in loose, medium and dense sand to an embedment depth ratio, L/d vary from 7.5 to 30 and with various batter angle of 0^o(vertical pile), 10^o,20^o, 30^o. Results shows that the uplift capacity of batter pile constructed in dense and medium dense sand increases in batter angle attains maximum value and then decreases. The maximum value acquires at an angle of 20^o and it is about 20 to 21 % more than vertical pile. While the uplift capacity decreases in loose sand when increases in batter angle. Results also show that circular pile is more resistant to uplift forces than square and rectangular pile. The rough model is experienced 18-75% increases in capacity compared with the smooth model piles. In case where moment is large batter pile is preferred. The suggested relation for the uplift capacity of batter pile is preferred. The suggested relations for the uplift capacity of batter pile regarding the vertical pile capacity are well predicted.[16]

The literature available on the pullout capacity of the pile includes either single pile or group of pile. The various parameters involved are shear strength and relative density of the soil as well as characteristic of the pile. Based on these literature reviews the problem has been identified and defined in the form of objectives as given in chapter1.in the succeeding chapter the experiments are carried out to obtain the results

.

CHAPTER-3

MATERIALS AND METHODS

3.0 INTRODUCTION

In the current chapter the selection of materials and the methods of carrying out the test are explained in detailed

A series of laboratory test were performed to determine the uplift capacity of steel piles. Three steel piles are of diameters 22 mm, 28 mm, 35 mm respectively, and length 450mm each are used. The test was performed in dense sand. Uplift resistance displacement was obtained and theoretical analysis is done and then compared. The tests are also done on enlarged base piles and results are compared.

3.1 MODELED PILES

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

- **Type 1**
  Steel pile: For experimental investigation we used three different steel piles having diameter of 22mm, 28mm, and 35mm respectively, and having same length of 450mm each.
- **Type 2**
  Steel pile covered with cement slurry: For experimental investigation we used three different steel piles having diameter of 22.5mm, 28.5mm, and 35.5mm respectively, and having same length of 450mm each coated with cement slurry with water cement ratio 0.5 to enhance the roughness of pile material.
- **Type 3**
  Steel pile with enlarged based: For experimental investigation we used three different steel piles having diameter of 22mm, 28mm, and 35mm respectively, and having same length of 450mm each and enlarged base of 1.5 times their diameter.
- **Type 4**
  Steel pile covered with cement slurry and enlarged base: The type 3 piles are coated with cement slurry as mentioned in case of type 2 piles.

3.2 SAND

The soil sample selected is obtained from Yamuna bank. The foreign and vegetarian materials were removed. The sand is procured by sieving it through 4.75mm sieve and retained on 75 micron IS sieve, so that all fines are removed.

In order to categories the sand, the geotechnical properties such as specific gravity, gradation analysis are carried out.

To obtain the shear parameters of the sand it was compacted at optimum moisture content as obtained from modified Proctor test.

3.3 DETERMINATION OF SPECIFIC GRAVITY:

The specific gravity of the soil found out to be **2.68** by density bottle method.

Table 3.1 Specific gravity of sand

Weight of density bottle(gm)	W_1	20.6	20.6	20.6	20.6
Weight of density bottle+ dry soil (gm)	W_2	125.50	103.50	130.10	115.10
Weight of density bottle+ dry soil+ water (gm)	W_3	136.90	142.70	139.60	129.90
Weight of density bottle+ water (gm)	W_4	70.80	70.80	70.80	70.80
Specific gravity	**G**	2.70	2.67	2.69	2.67

SPECIFIC GRAVITY= $\frac{W2-W1}{(W2-W1)-(W3-W4)}$

AVERAGE SPECIFIC GRAVITY= (2.7+2.67+2.69+2.67)/4

= **2.6852**

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

3.4 GRAIN SIZE ANAYLSES

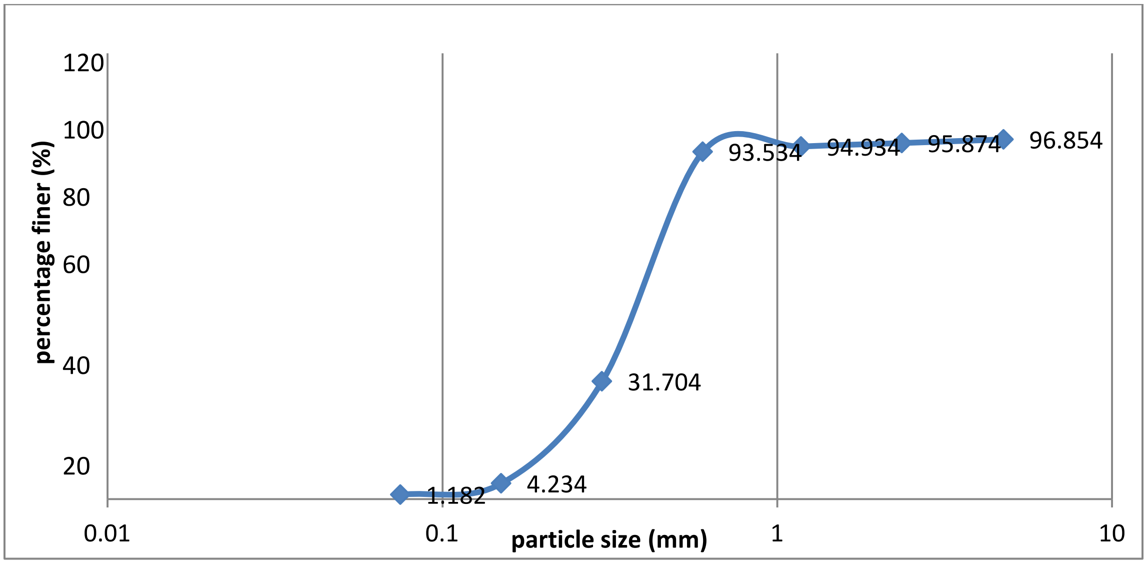

Figure 1: Graph for Sieve Analysis for sand

From the graph plotted between percentage finer and sieve size (on log scale), the value of D_{10}= 0.18, D_{30}= 2.0, D_{60}= 0.4; C_U, the coefficient of uniformity and C_C, the coefficient of curvature are given as

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

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

The result shows that the soil is poorly graded and designated as SP.

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

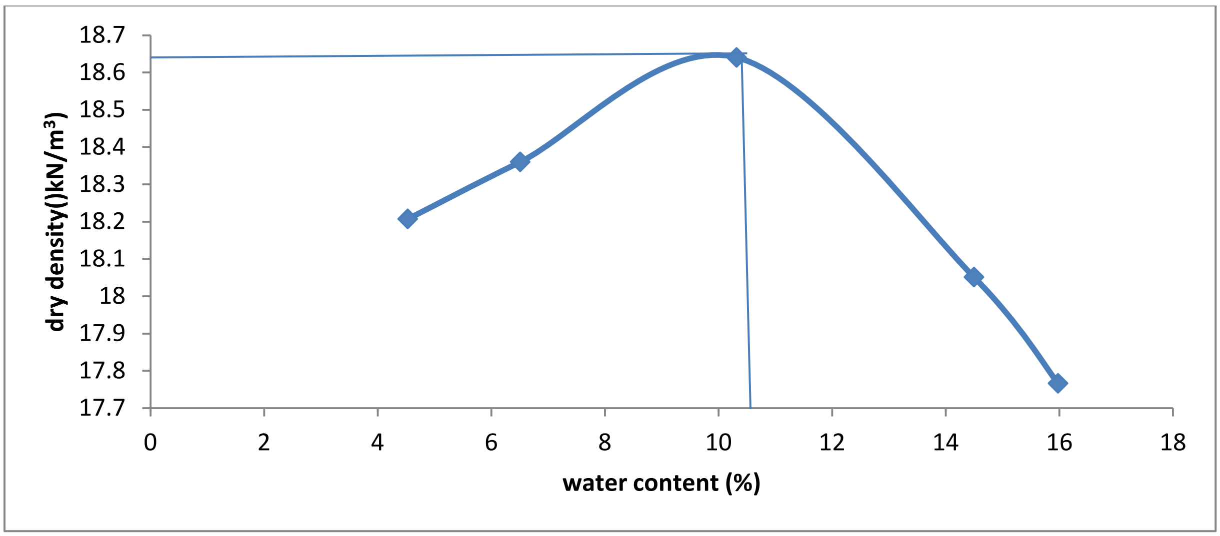

Figure 2: Graph between dry density and water content

Maximum dry density=18.64KN/m^3

Optimum moisture content=10.32%

3.5 Determination of shear parameter using Tri-axial test

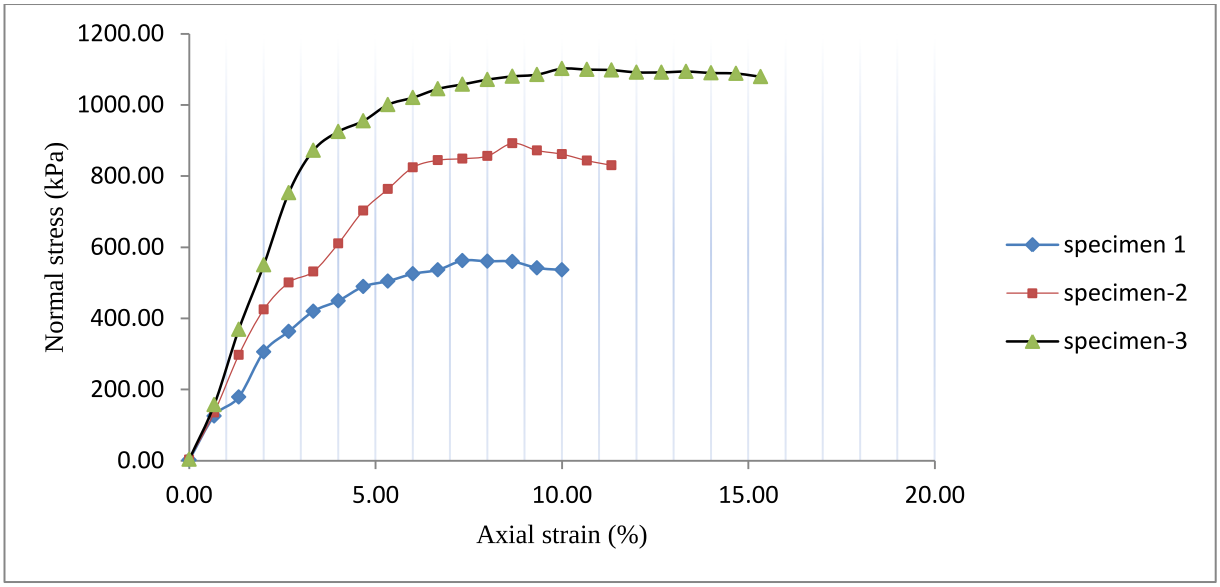

Figure 3 Graph between normal stress and axial strain

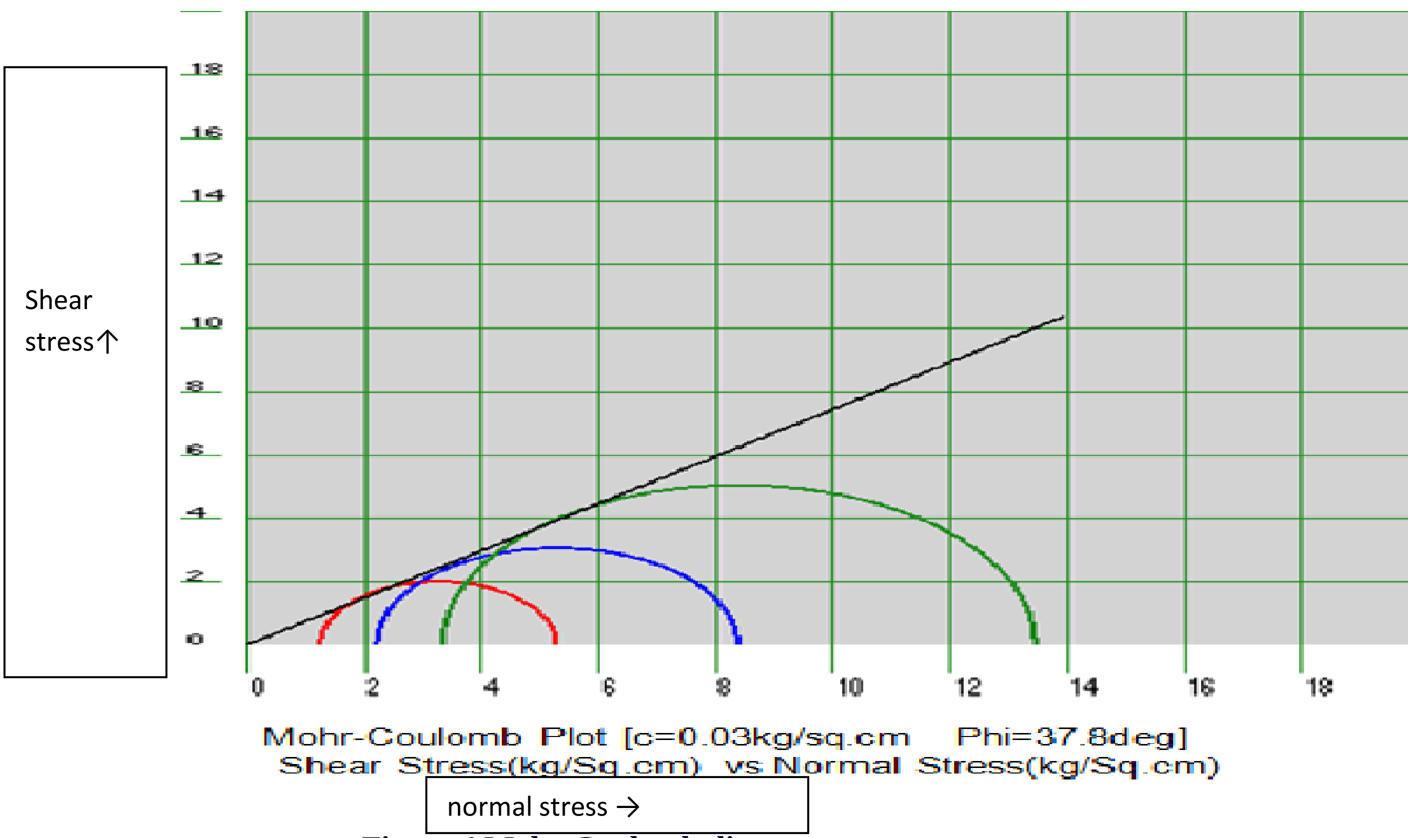

Figure 4 Mohr-Coulomb diagram

3.6 CEMENT In order to cover the steel piles with cement slurry 53 grade OPC cement is used with following properties

Table 3.4. Properties of cement

S.No.	Physical Property	Test results	Requirements as per IS:12269-1987
1.	Normal consistency	30%	-
2.	Initial setting time	120 minute	30 minute(minimum)
3.	Final setting time	320 minute	600 minute(maximum)
4.	Fineness modulus of fine aggregate	2.79	-
5.	Specific gravity	3.10	-

Water cement ratio of the slurry was **0.5.**

3.7 WATER The water used for preparing cement slurry was tap water with following properties

Table 3.5 Properties of water

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

CHAPTER- 4

EXPERIMENTATIONS

4.1 EXPERIMENTAL SET UP

4.1.1 LOADING FRAME AND TEST TANK

The experimental set up consisted of a loading frame designed to resist a vertical uplift, pulling device(pulley fitted into angle), loads, vertical displacement measuring unit(dial gauges) and test tank. Schematic diagram is shown below.

Uplift was applied with the help of pulling device, one side of wire is connected to the pile and other to the hanger and loads are putted to hanger and vertical displacement with respect to loads and are measured with the help of dial gauges accurate to 0.01mm.

Tests were conducted in rectangular steel tank with inner dimension 800 x 600 x 650 mm. the tank was made of bricks. The inside walls of the tank are smooth. The tank was designed to be large enough so that there will be no interference between the walls of the tank are smooth. The failure zone was in the range of 3 to 8 times pile diameter. In present case the piles were installed at the centre of the test tank so that the clear surrounds of the piles is 16 to 27 times the diameter of the pile. Hence the boundary effect is ignored.

Fig 5 experimental set up for pull out test.

4.1.2 SAND FILLING AND ITS PROPERTIES

The sand has round grain which minimizes the friction between sand and wall of the test tank. Controlled pouring and taming techniques were employed to achieve homogeneous sand bed. Experiments were done at the unit weight of 18.6 kN/m^3 for dense sand. Sand was filled in tank in six layers compacted with the help of rammer up to desired density. To check the density of sand surrounding the piles penetrometer was used.

4.1.3 MODELED PILES

Three model piles are used in this investigation and of three different types-

Type 1 <u>Steel pile</u>

- Pile 1- length 50 cm , diameter 22 mm and weight 715 gm
- Pile 2- length 50 cm , diameter 28 mm and weight 882 gm
- Pile 3- length 50 cm , diameter 35 mm and weight 1350 gm

Type 2 <u>Steel pile covered with cement slurry</u>

- Pile 1- length 50 cm , diameter 22.5 mm and weight 795 gm
- Pile 2- length 50 cm , diameter 28.5mm and weight 977 gm
- Pile 3- length 50 cm , diameter 35.5 mm and weight 1427 gm

Type 3 <u>Steel pile with enlarged based</u>

- Pile 1- (length 50 cm, diameter 22 mm , base diameter 33 mm and weight 845 gm)
- Pile 2- (length 50 cm, diameter 28 mm , base diameter 42 mm and weight 1028 gm)
- Pile 3- (length 50 cm, diameter 35 mm , base diameter 52.5 mm and weight 1400 gm)

Type 4 <u>Steel pile covered with cement slurry and enlarged base</u>

- Pile 1- (length 50 cm, diameter 22.5 mm , base diameter 33 mm and weight 910 gm)
- Pile 2- (length 50 cm, diameter 28.5 mm , base diameter 42 mm and weight 1103 gm)
- Pile 3-(length 50 cm, diameter 35.5 mm , base diameter 52.5 mm and weight 1485 gm)

4.1.4 INSTALLATION OF MODEL PILE IN THE TANK

In this investigation method was used to install the pile inside the tank was undisturbed method (no displacement), method represents no displacement in the soil around the pile during installation. It does not specifically correspond to any field method of pile installation. In this method, the pile was poured and compact in several layers around the pile to achieve required density along the depth with an acceptable homogeneity.

4.2 EXPERIMENTAL SETUP

This experimental procedure consisted of the placement of pile, placement of sand to the tank, pulling/uplift of pile and recording of loud and displacement.

The pile with all the arrangement procedure was vertically suspended and lowered into the empty tank to desired height with the help of pulling device. The sand placing is done in layers and compaction to achieve required density. Soil placement into the tank was not suitable and did not provide uniformly compaction. Therefore, the sand unit weight was controlled by placing the pre-calculated weight of sand to the box for each layer separately and the sand surface was leveled by using a leveler.

Finally dial gauges was placed on opposite sides across the center of angle connected to the pile top and the load applied with the help of hanger and vertical displacement is measured.

4.3 TEST PROGRAMME

The test program included a parametric study that investigates various variables. Table shows a summary of test parameter and their values. To study the effect of size, embedment depth, enlarged base, a total number of 36 uplift test was performed on vertical pile in sand.

Initially, the behavior of model pile with size was determined say (study I). In study of II, the investigation of model piles with roughness by cement slurry layer was determined, in study III, the investigation of mould pile with enlarged base was determined and in study IV behavior of model pile covered with cement slurry and enlarged base are studied.

4.4 THEORITICAL ANALYSIS OF MODEL PILES:

4.4.1Uplift capacity simple pile:

According to IS 2911 [part I / Sec 2], the uplift capacity of a pile is given by the sum of frictional resistance and the weight of pile. Uplift capacity is given as:

$$\text{Uplift capacity} = \sum_{i=1}^{n} 1\ K_i\, P_{Di} \tan\delta_i\, A_{si} + W$$

P_D = effective overburden pressure at pile tip

$\sum_{i=1}^{n}$ = summation for layers 1to n in which pile is installed.

K_I = coefficient of earth pressure

W = weight of the pile

Table 4.1 Data for theoretical analysis

Type	steel	Concrete
K	1	1.5
ϕ	37.23	37.2
δ	37.23	0.75 ϕ

4.4.2Uplift capacity of enlarged base pile:

Meyerhof and Adams (1968) suggested that uplift capacity of a pile is calculated as:

$$Q_u = \pi\, c_u\, B_1 D + S_f\, \gamma\, (\pi\, D_1/2)\, D^2 K_u \tan\phi + W$$

B_1 = diameter of enlarged base , c_u = cohesion , D = pile length , ϕ = angle of shearing resistance S_f = shape factor , K_u = coefficient of lateral earth pressure , W = weight of pile and soil in a cylinder of diameter , D_1 = nominal diameter of pile and B_1 and height equals to embedment depth.

Table 4.2 Values of shape factor

ϕ	20^0	25^0	30^0	35^0	40^0	45^0	50^0
S_f	1.12	1.30	1.60	2.25	3.45	5.50	7.60

Table 4.3 Weight of piles

Type of pile	Diameter of pile(mm)	Weight(N)
Type 1 (steel pile)	22.0	7.15
	28.0	8.82
	35.0	13.50
Type 2 (steel pile covered with cement slurry)	22.5	7.95
	28.5	9.77
	35.5	14.27
Type 3 (steel pile with enlarged base)	22.0	8.45
	22.0	10.28
	22.0	14.00
Type 4 (steel pile with enlarged base covered with cement slurry)	22.5	9.10
	28.5	11.03
	35.5	14.85

Table 4.4 Weight of surrounding soil

Diameter of pile(mm)	**Enlarged base diameter (mm)**	**Embedment depth(mm)**	**Weight(N)**
22.0	33.0	200.00	12.75
		266.67	17.00
		400.00	25.50
28.0	42.0	200.00	20.65
		266.67	27.54
		400.00	41.30
35.0	52.5	200.00	32.28
		266.67	43.04
		400.00	64.00

CHAPTER- 5

RESULTS AND DISCUSSION

5.1 INTRODUCTION

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:

5.1 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 200 mm in test I, 266.7 mm in test II and 400 mm in test III.

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

Table5.1. Experimental and theoretical uplift capacity of steel pile

			Embedment depth (mm)		
S.no.	Diameter	Uplift capacity (N)	200.00	266.67	400.00
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

Table5.2. 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.

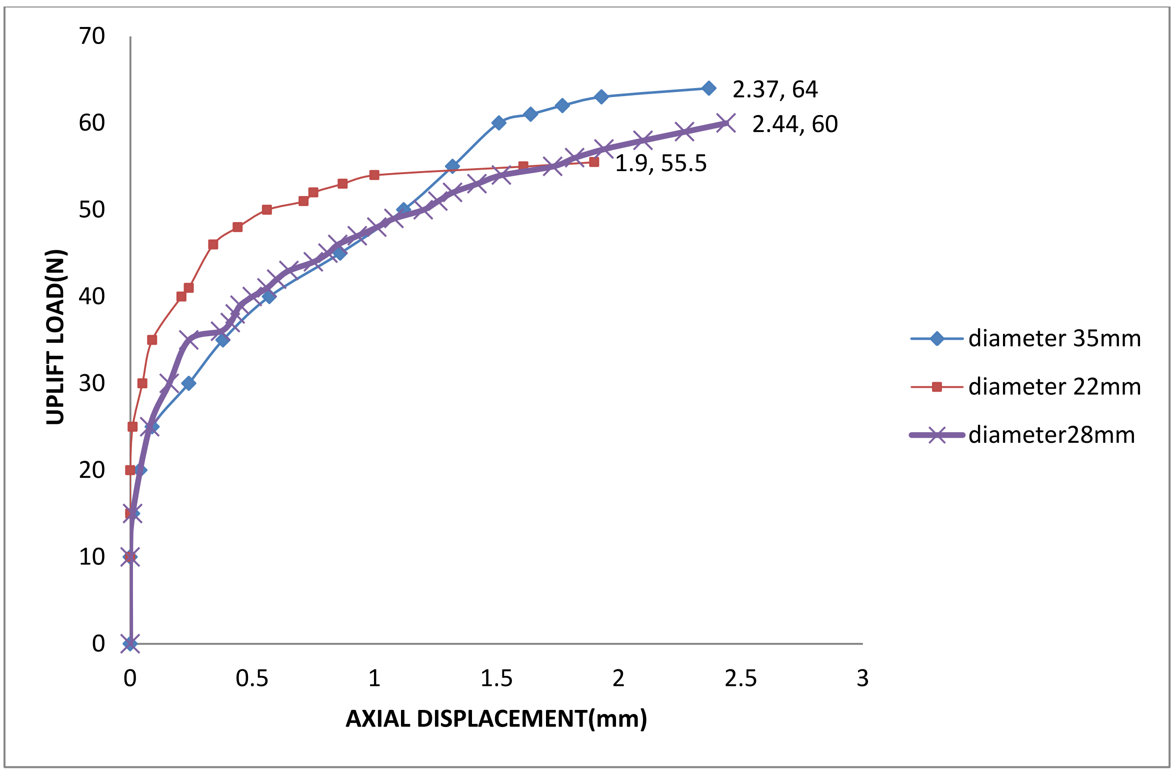

Fig6. Uplift load versus axial displacement curve of steel pile with embedment depth 200mm and varying diameter

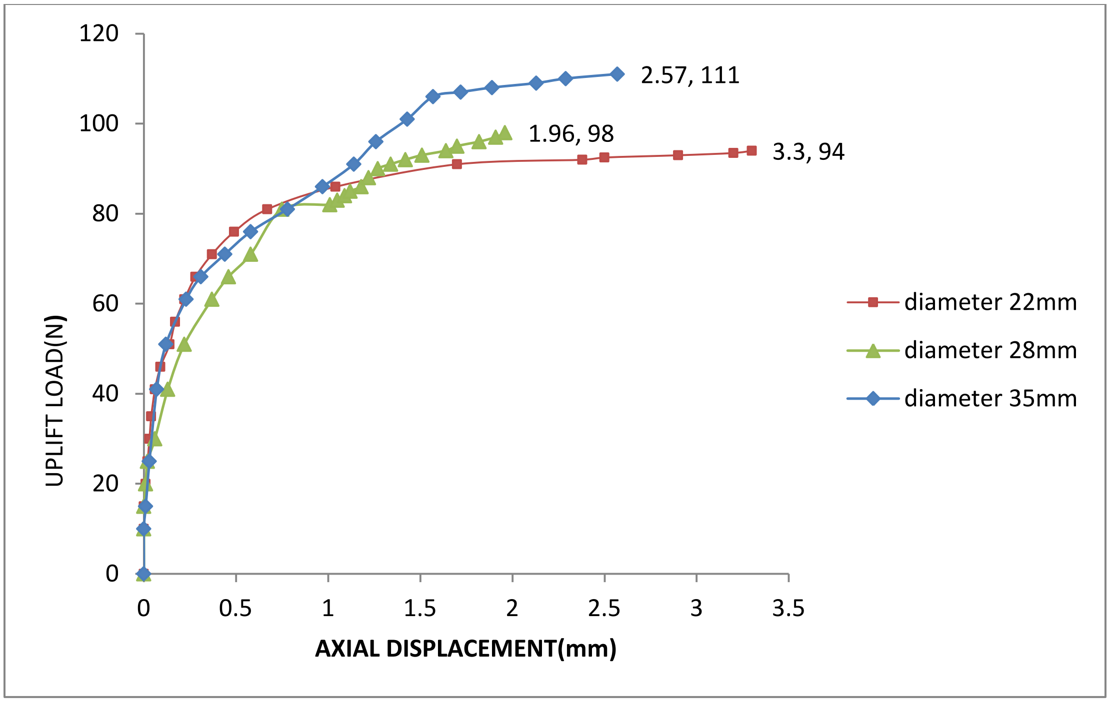

Fig7. Uplift load versus axial displacement curve of steel pile with embedment depth 266.67mm and varying diameter

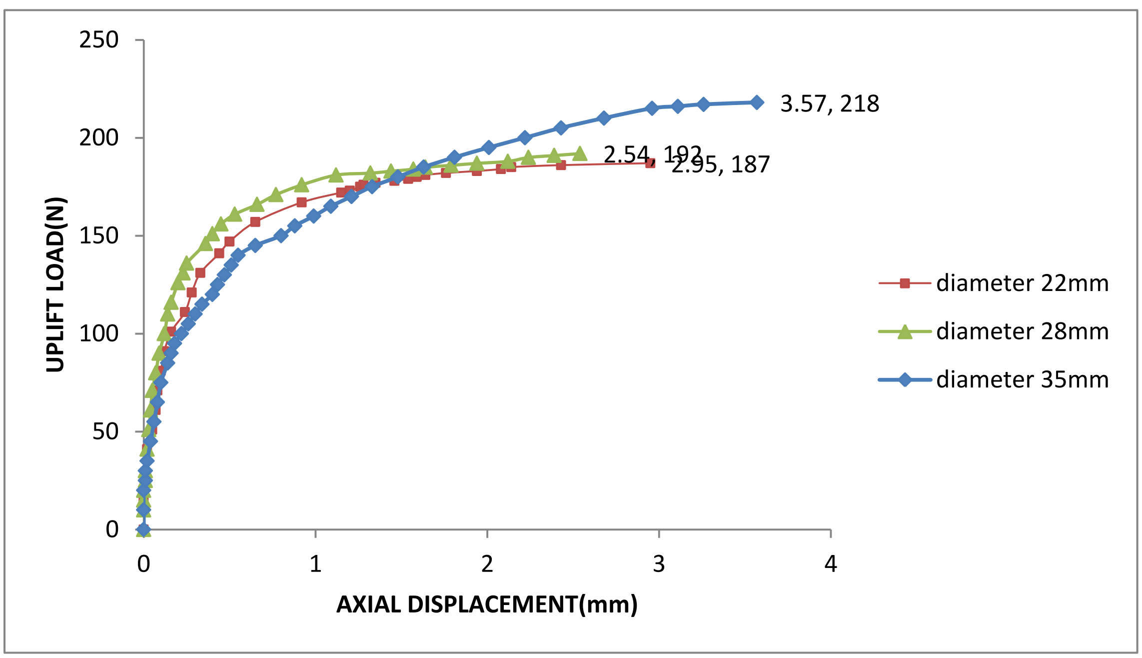

Fig8. Uplift load versus axial displacement curve of steel pile with embedment depth 400mm and varying diameter

5.1INFLUENCES OF EMBEDDMENT 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 200 mm, 266,67mm and 400 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 200mm to 266.67mm and increase in uplift capacity is 131.5N when embedment depth changes from 200mm to 400mm.

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

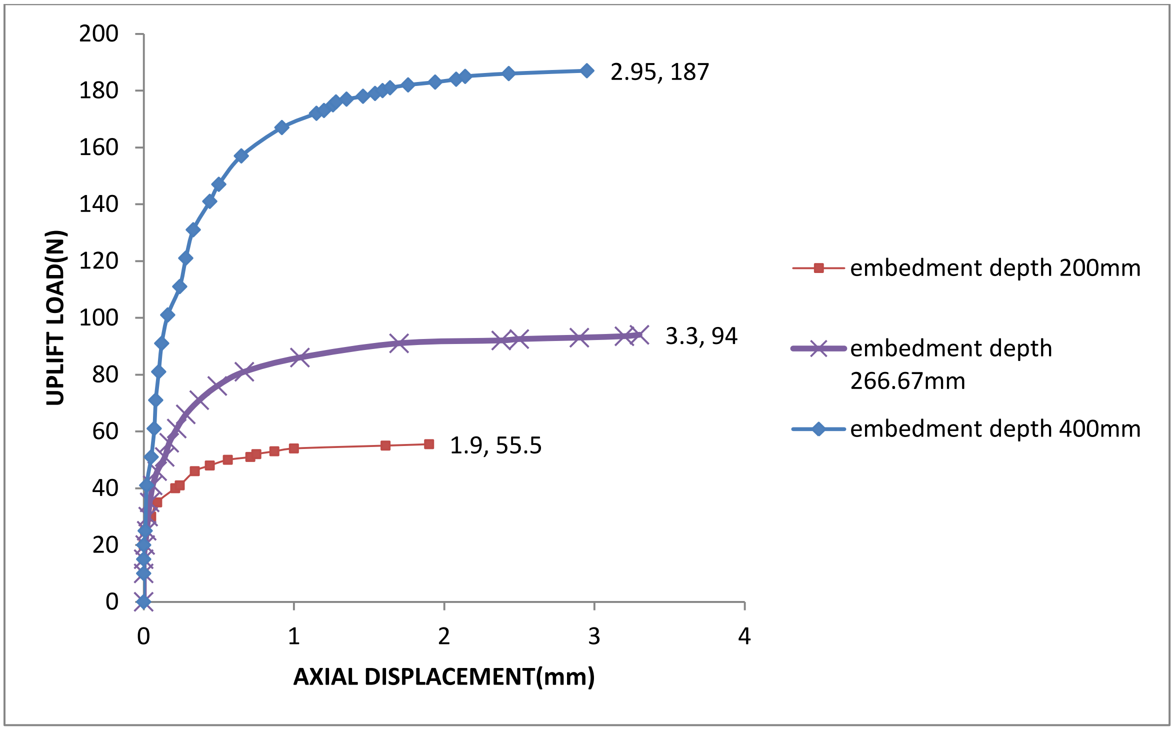

Fig9. Uplift load versus axial displacement curve of steel pile with diameter 22mm and varying embedment depth

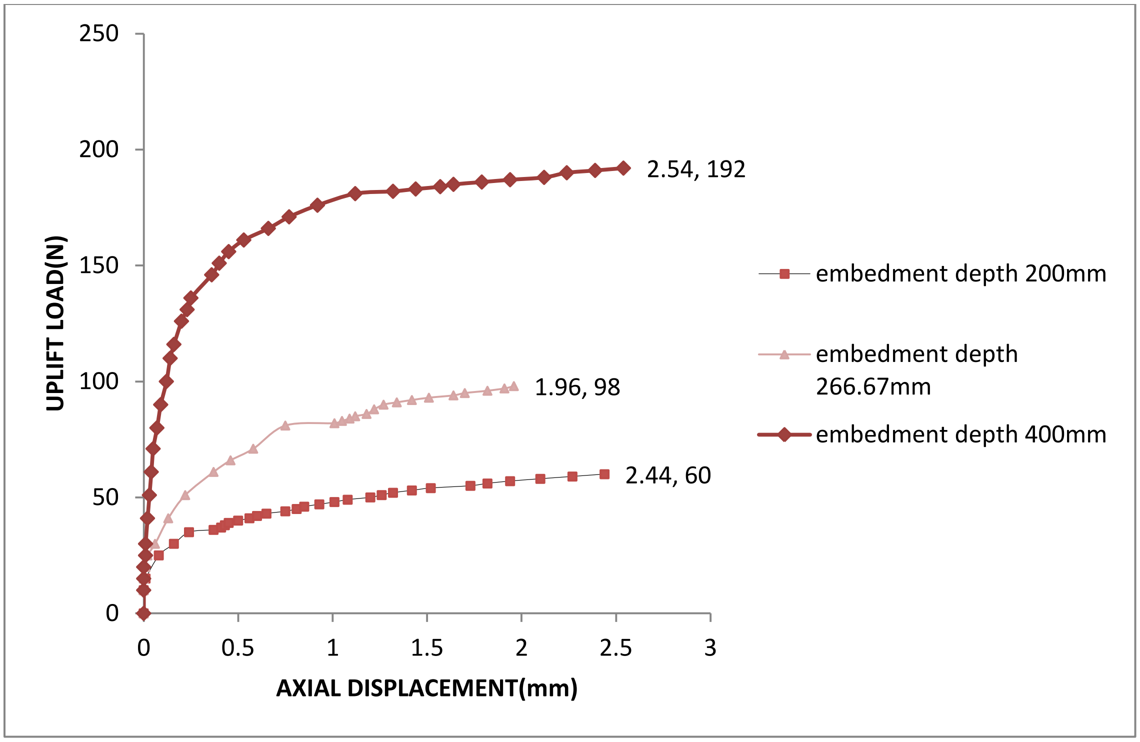

Fig10. Uplift load versus axial displacement curve of steel pile with diameter 28mm and varying embedment depth

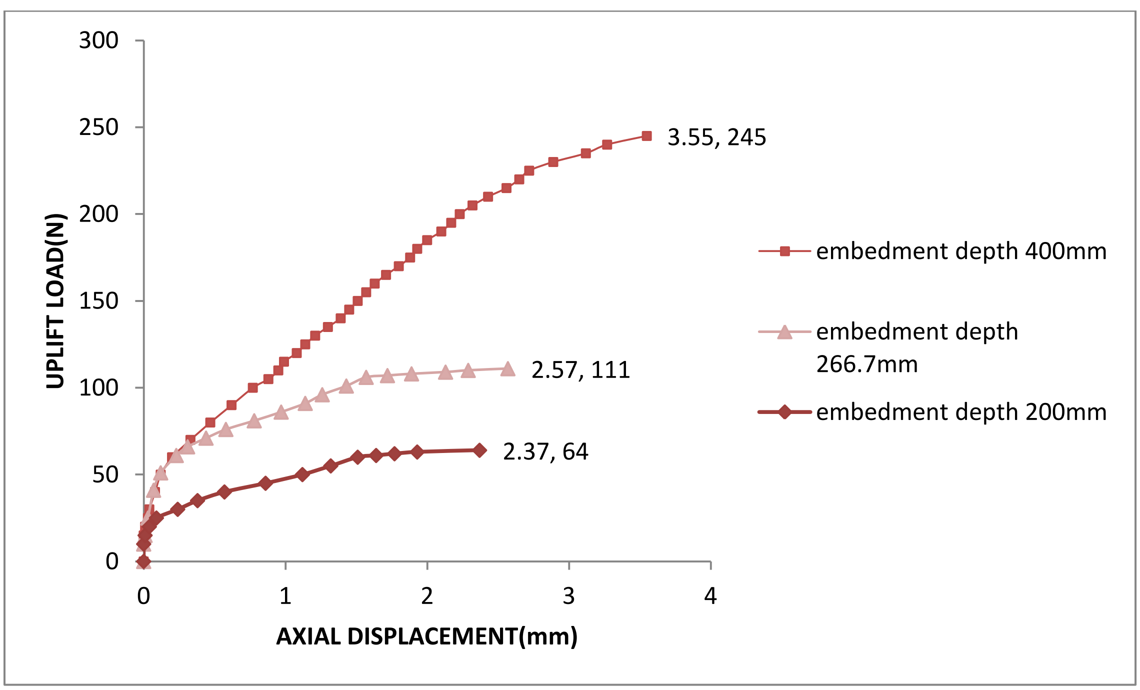

Fig11. Uplift load versus axial displacement curve of steel pile with diameter 35mm and varying embedment depth

5.2INFLUENCE OF SURFACE ROUGHNESS OF MODELED PILES

Shaft resistance in a major factor for piles subjected to uplift. Pile surface play great role in the uplift resistance of pile. So, in this study we concentrate on the effect of pile surface roughness we perform 18 uplift tests, 9 on smooth and 9 on rough pile having different diameter also varying embedment depth. From the results, the uplift capacity is more when surface roughness of pile is more.

Table5.3 Experimental and theoretical uplift capacity of steel pile and steel pile covered with cement slurry

				Embedment depth (mm)		
S.no.	Diameter (mm)		Uplift capacity (N)	200.00	266.67	400.00
1.	22.0	Steel pile	Experimental	55.50	94.00	187.00
			Theoretical	27.38	48.65	108.50
	22.5	Steel pile covered with cement slurry	Experimental	63.00	115.00	218.00
			Theoretical	39.11	69.50	183.80
2.	28.0	Steel pile	Experimental	60.00	98.00	192.00
			Theoretical	34.80	61.50	138.00
	28.5	Steel pile covered with cement slurry	Experimental	66.00	136.00	320.00
			Theoretical	49.71	87.85	197.14
3.	35.0	Steel pile	Experimental	64.00	111.00	245.00
			Theoretical	43.55	77.00	172.50
	35.5	Steel pile covered with cement slurry	Experimental	108.00	193.00	417 .00
			Theoretical	62.21	110.00	246.00

The uplift capacity of steel pile increase with the increase in roughness of the skin area. This may be due to the fact that on decrease in angles of shearing resistance the coefficient if earth pressure increases.

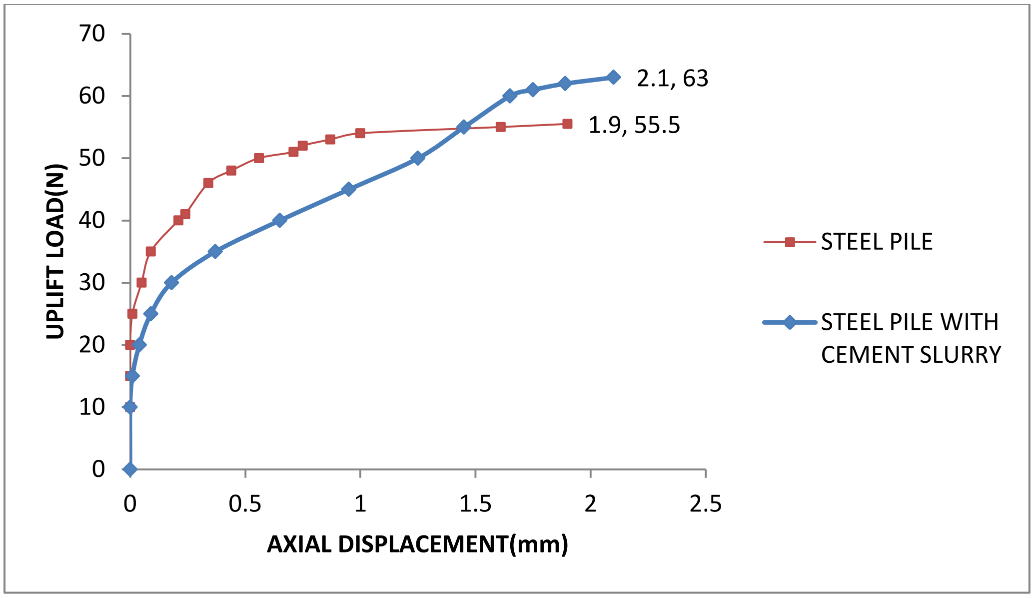

Fig12. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 22mm diameter and embedment depth 200mm

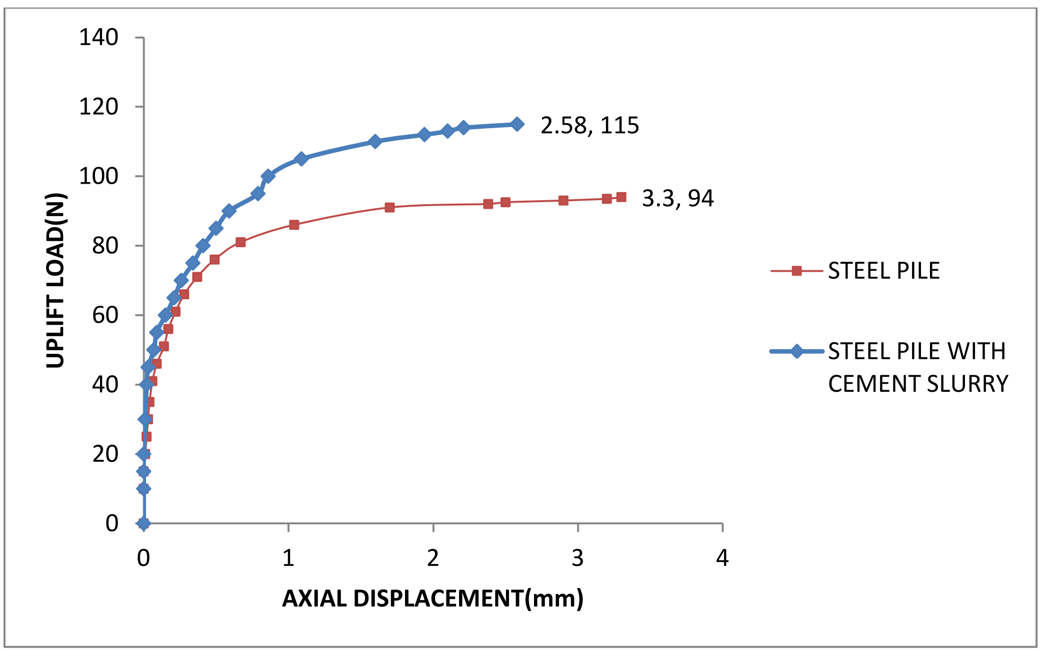

Fig13. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 22mm diameter and embedment depth 266.7mm

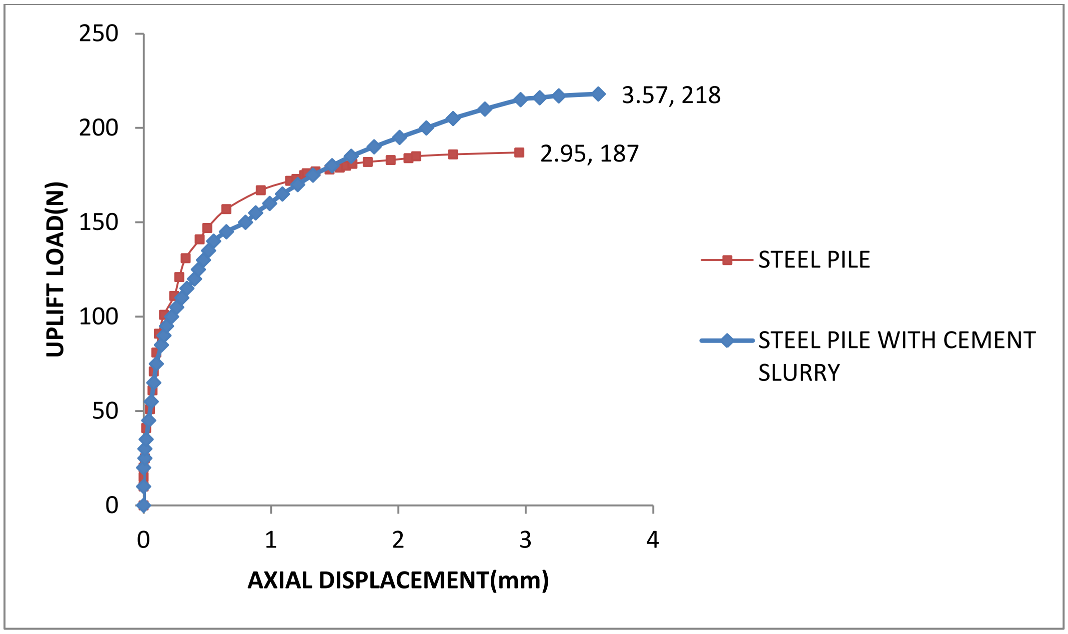

Fig14. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 22mm diameter and embedment depth 400mm

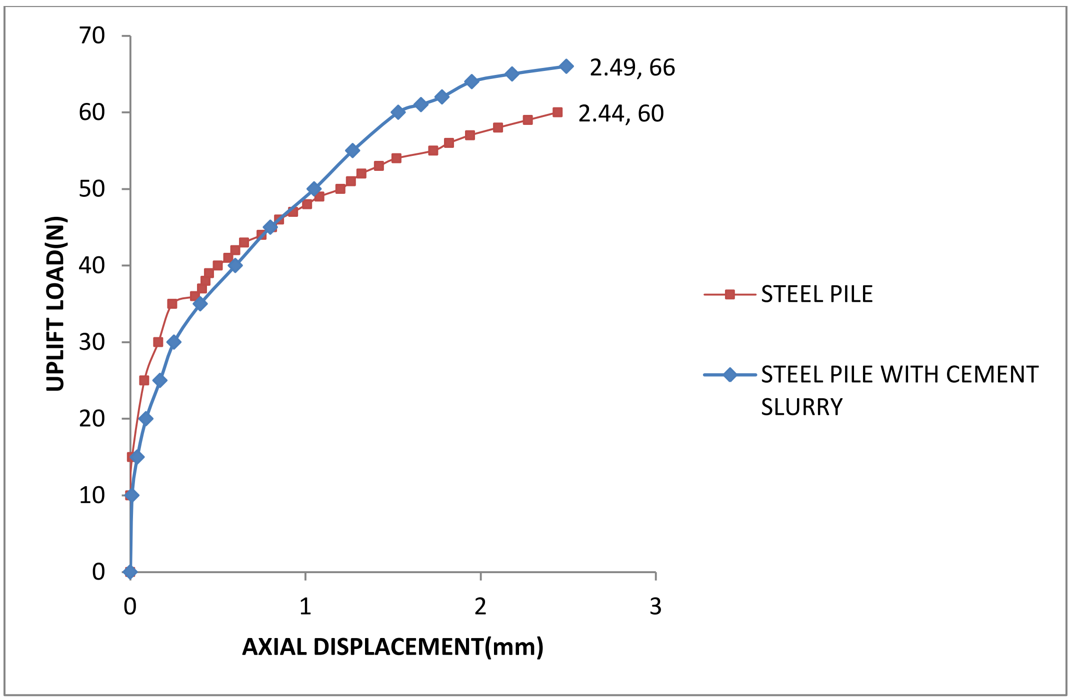

Fig15. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 28mm diameter and embedment depth 200mm

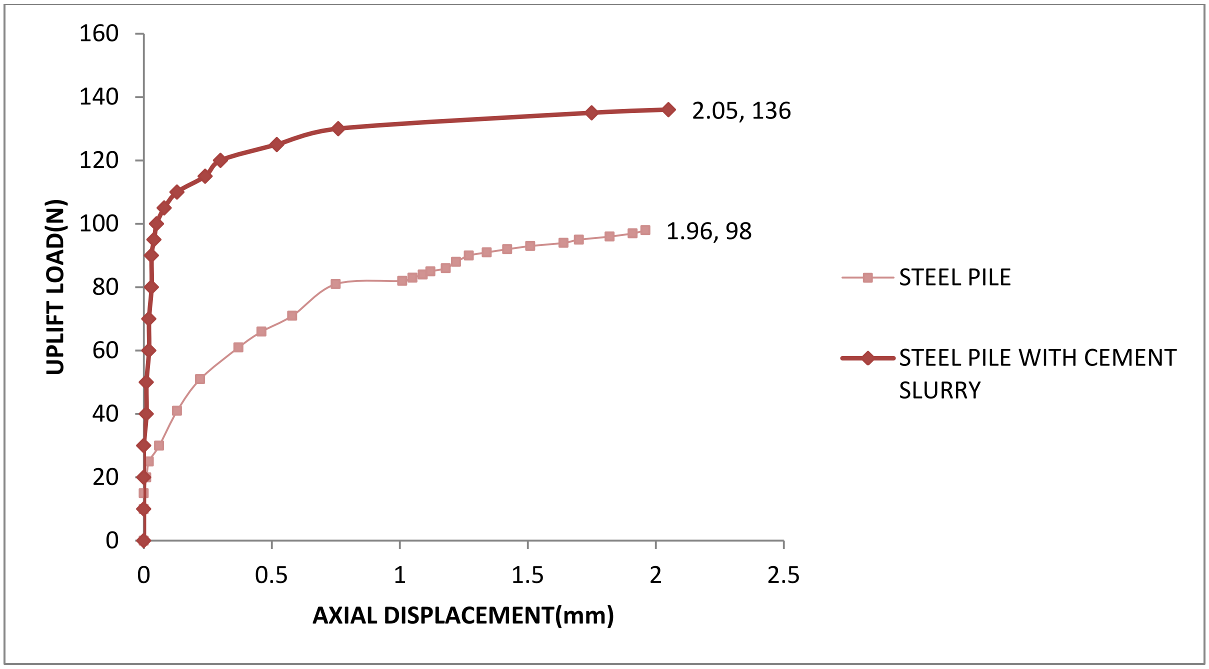

Fig16. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 28mm diameter and embedment depth 266.7mm

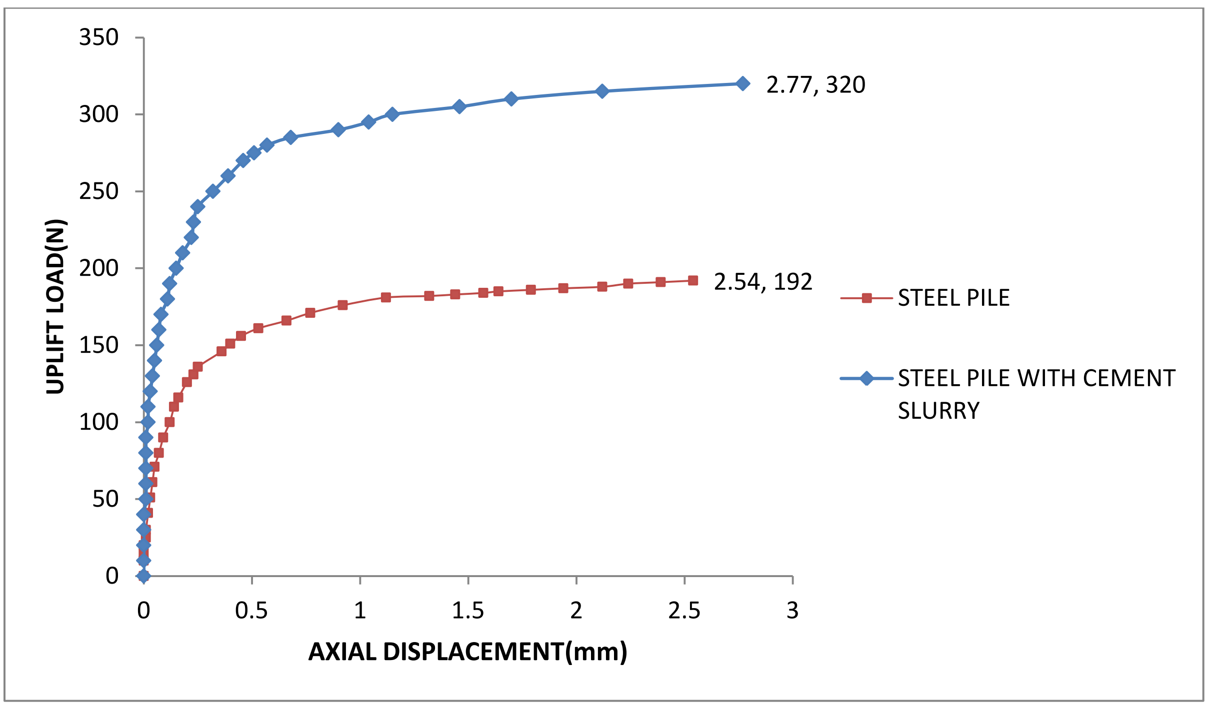

Fig17. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 28mm diameter and embedment depth 400mm

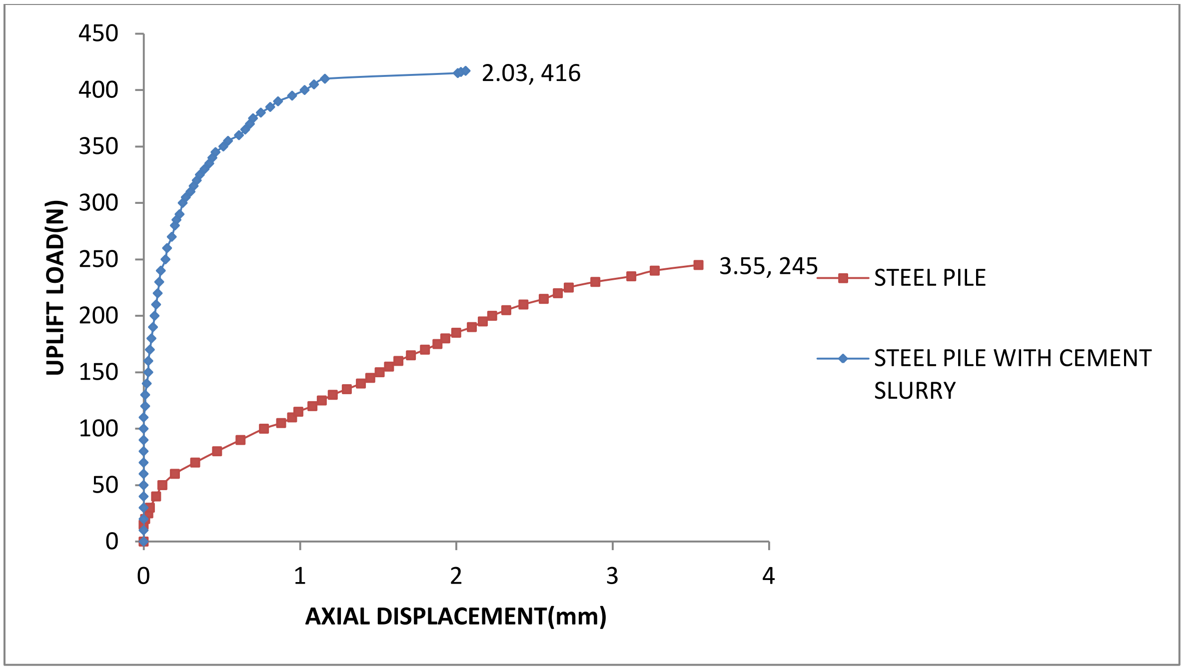

Fig18. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 35mm diameter and embedment depth 200mm

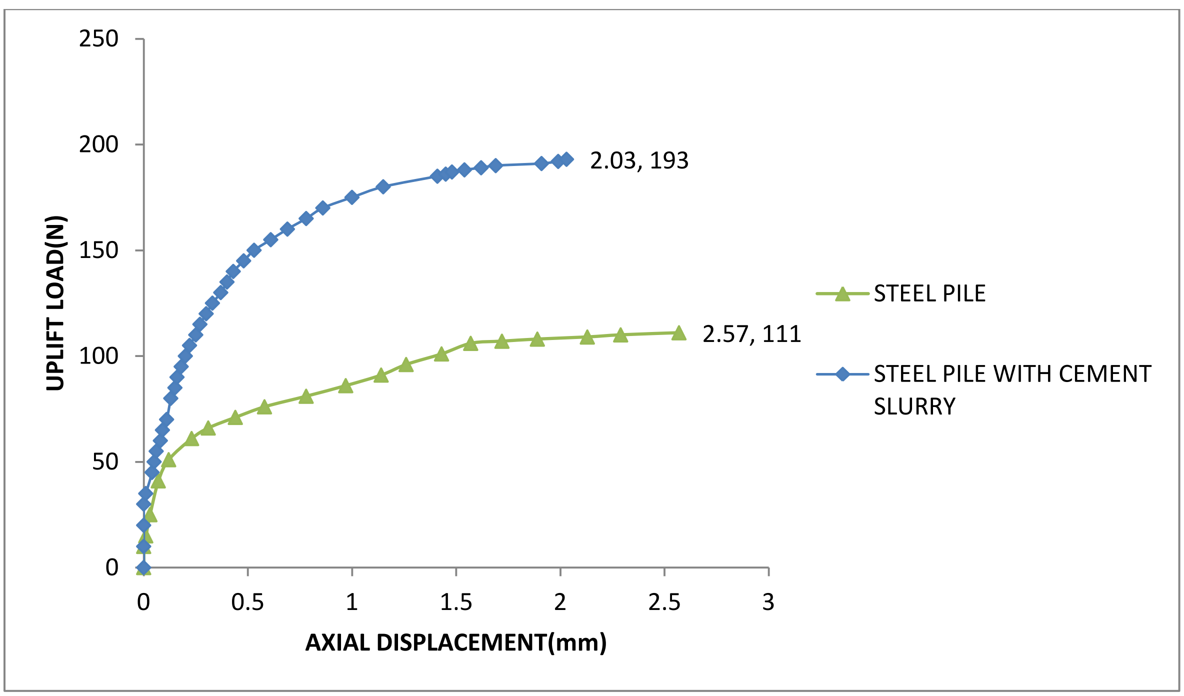

Fig19. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 35mm diameter and embedment depth 266.7mm

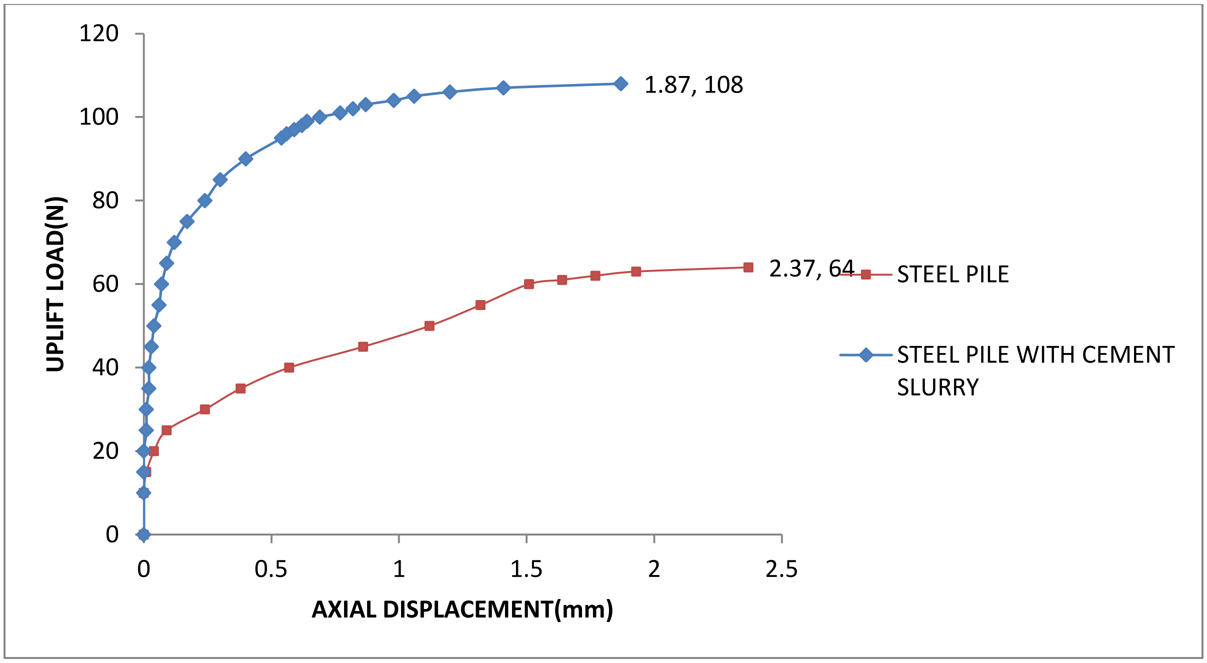

Fig20. Uplift load versus axial displacement curve of steel pile and Steel pile covered cement slurry of 35mm diameter and embedment depth 400mm

5.4 INFLUENCE OF ENLARGED BASE OF MODELED PILES.

To study the influence of enlarged base of model pile several tests on model pile embedded in sand at varying diameter and embedded depth by enlarging base to 1.5 times the shaft diameter/ piles diameter performed and test result as compared with test results of test pile without enlarging base.

In comparing the test results, we get uplift capacity increases up to 60% by the enlargement of base. The test results are shown in figure. A resistance offered by pile is very much. Generally tests pile having uniform diameter(without enlarged base) have a displacement up to 9 to 11% of diameter or 2 to 3 mm, but offer enlarging base at a great displacement of 5 mm. it shows increased resistance .

The theoretical analyses were carried out as per equation suggested by Myerhof and Adams.

The uplift capacity of pile with enlarged base is more as compared to simple pile in similar condition (i.e. same diameter and embedment depth).this may be due to the increase in the weight of surrounding sand with the area of enlarged base

<u>Table5.4 Experimental and theoretical uplift capacity of steel pile and steel pile with enlarged base</u>

				Embedment depth (mm)		
S.no.	Diameter(mm)		Uplift capacity (N)	200.00	266.67	400.00
1.	22.0	Steel pile	Experimental	55.50	94.00	187.00
			Theoretical	27.38	48.65	108.50
	22.0	Steel pile with enlarged base	Experimental	119.00	205.00	353.00
			Theoretical	93.67	155.00	180.00
2.	28.0	Steel pile	Experimental	60.00	98.00	192.00
			Theoretical	34.80	61.50	138.00
	28.0	Steel pile with enlarged base	Experimental	150.00	265.00	480.00
			Theoretical	121.73	201.85	424.65
3.	35.0	Steel pile	Experimental	64.00	111.00	245.00
			Theoretical	43.55	77.00	172.50
	35.0	Steel pile with enlarged base	Experimental	200.00	345.00	620.00
			Theoretical	163.64	276.41	589.41

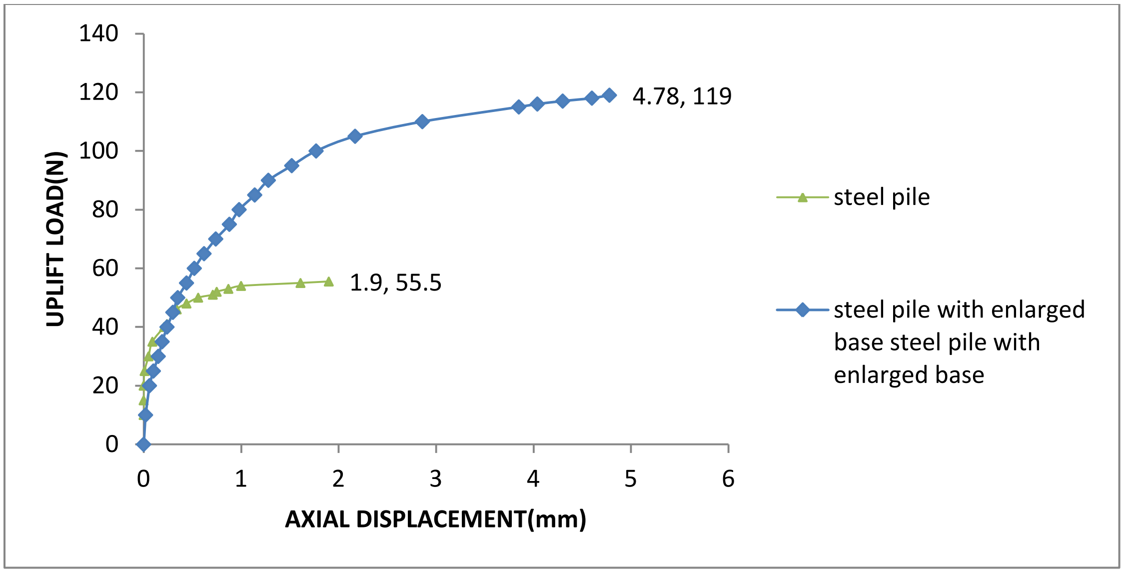

Fig21. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 22mm diameter and embedment depth 200mm

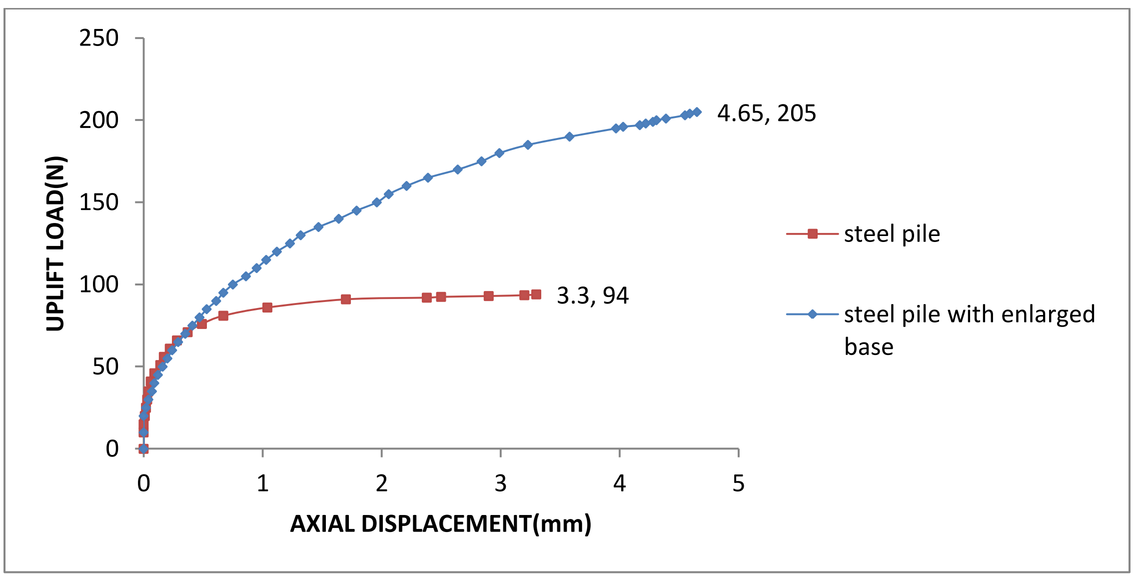

Fig22. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 22mm diameter and embedment depth 266.7mm

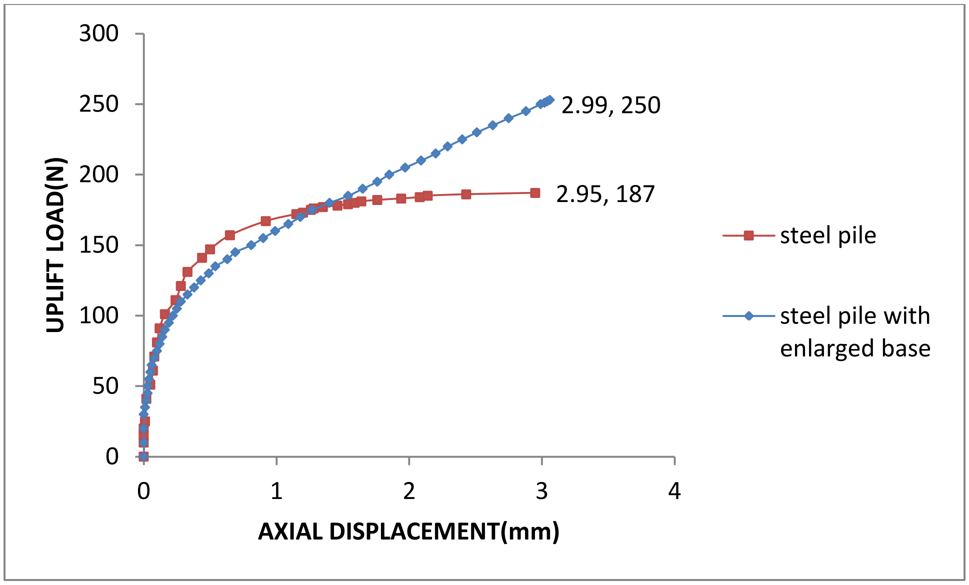

Fig23. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 22mm diameter and embedment depth 400mm

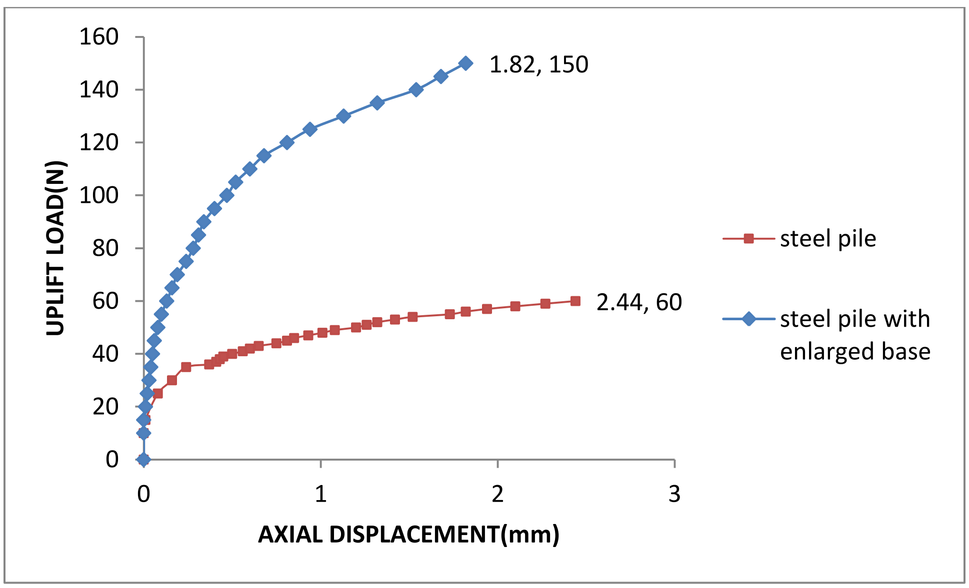

Fig24. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 28mm diameter and embedment depth 200mm

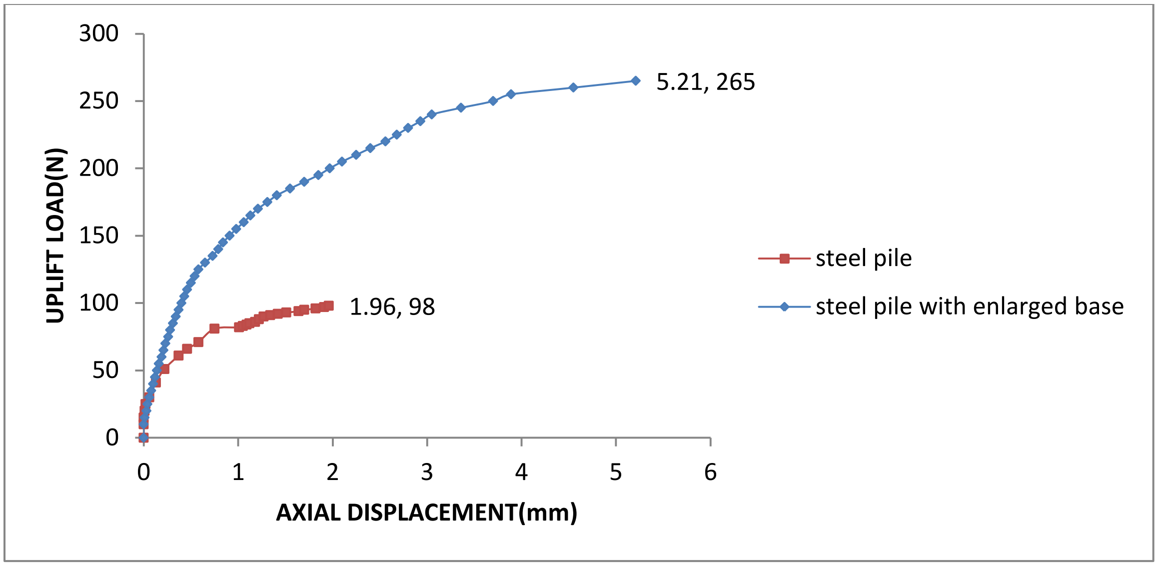

Fig25. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 28mm diameter and embedment depth 266.7mm

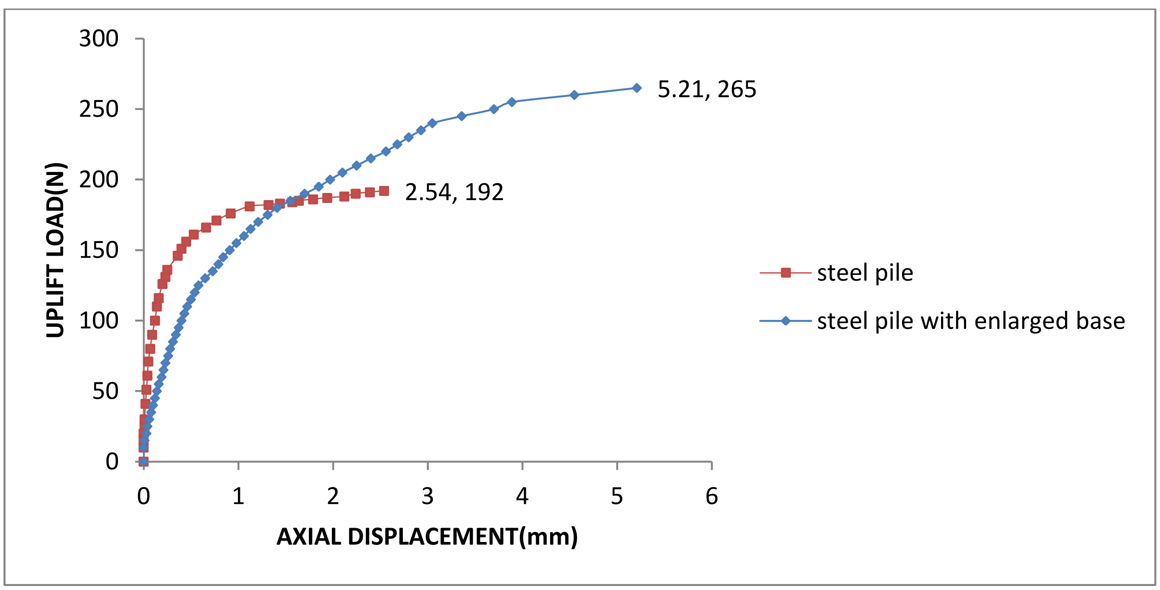

Fig26. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 28mm diameter and embedment depth 400mm

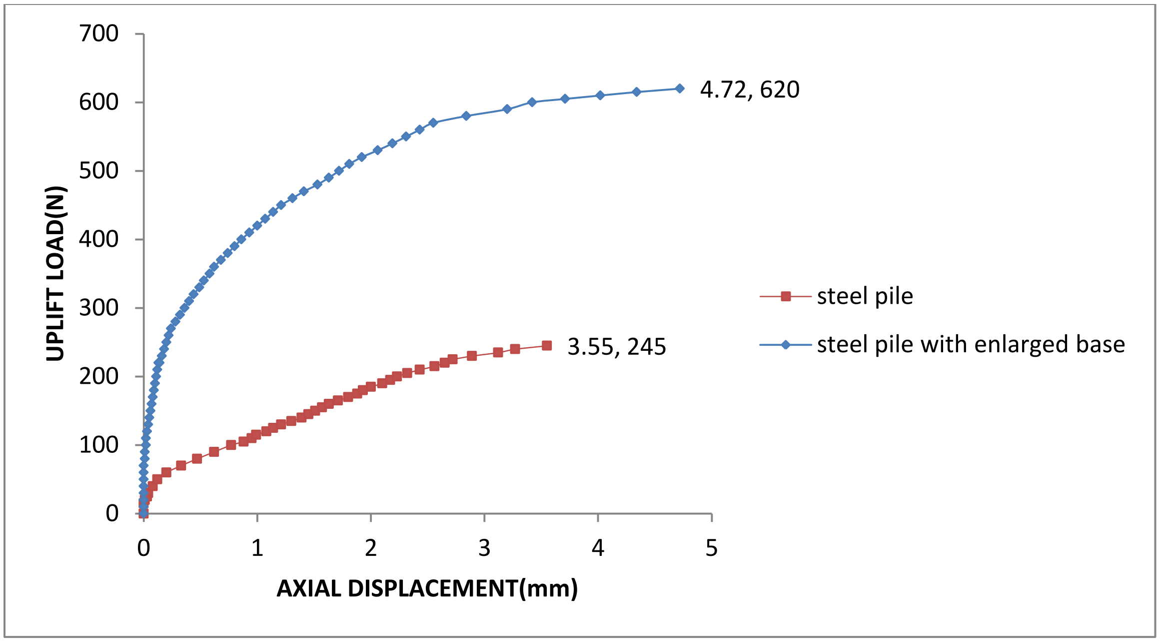

Fig27. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 35mm diameter and embedment depth 200mm

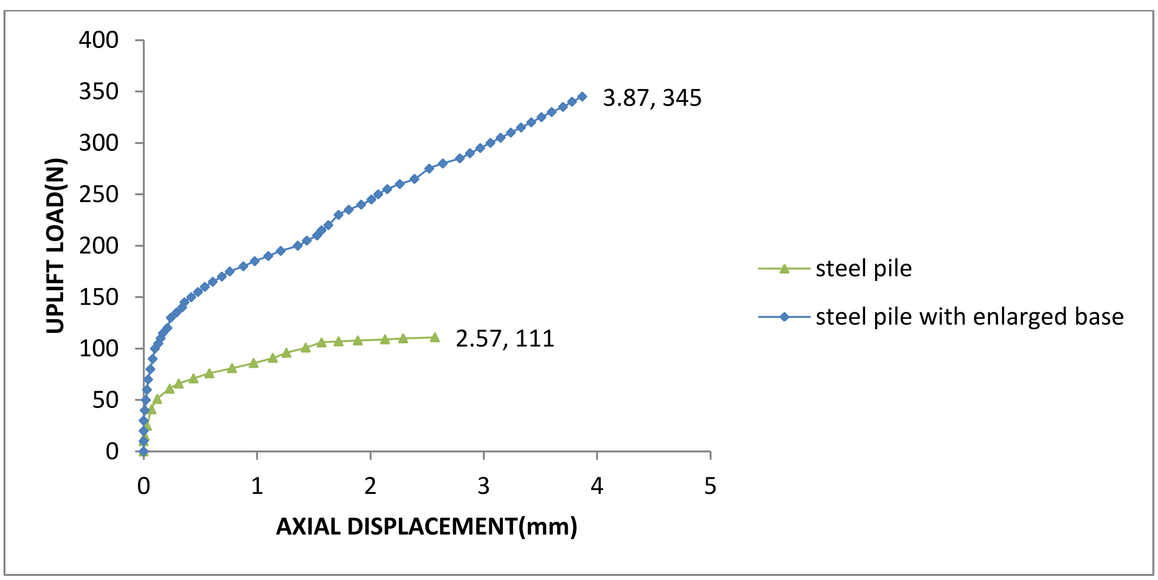

Fig28. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 35mm diameter and embedment depth 266.7mm

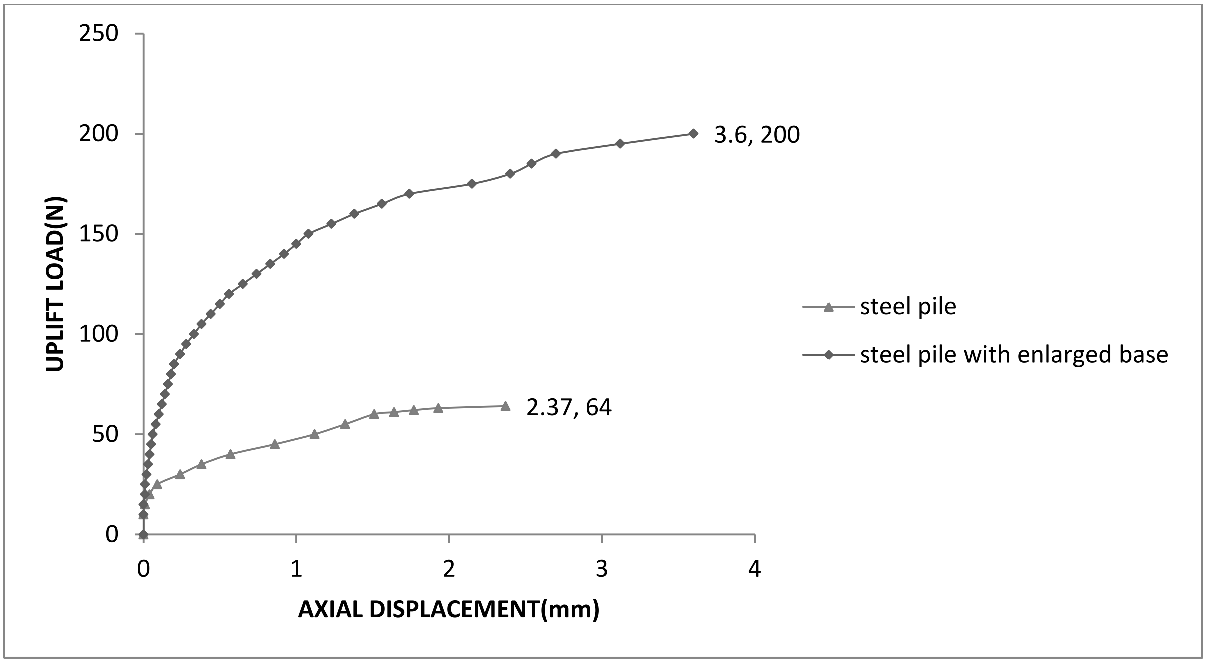

Fig29. Uplift load versus axial displacement curve of steel pile and Steel pile with enlarged base of 35mm diameter and embedment depth 400mm

5.4 INFLUENCE OF SURFACE ROUGHNESS ON MODELED PILES WITH ENLARGED BASE

To study the effect of roughness on enlarged base piles 18 tests are conducted and results are shown in fig given below, results shows that roughness plays an important role and increases uplift resistance of model piles.

On comparing test result it is found to be increase in uplift resistance up to 13%.

Table5.5 Experimental and theoretical uplift capacity of steel pile covered with cement slurry and enlarged base and steel pile with enlarged base

				Embedment depth (mm)		
S.no.	Diameter		Uplift capacity (N)	200.00	266.67	400.00
1.	22mm	Steel pile with enlarged base	Experimental	119.00	205.00	353.00
			Theoretical	93.67	155.00	320.00
	22mm	Steel pile covered with cement slurry and enlarged base	Experimental	130.00	230.00	335.00
			Theoretical	99.85	166.25	352.60
2.	28mm	Steel pile with enlarged base	Experimental	150.00	265.00	480.00
			Theoretical	121.73	201.84	424.65
	28mm	Steel pile covered with cement slurry and enlarged base	Experimental	160.00	280.00	500.00
			Theoretical	121.73	214.84	368.40
3.	35mm	Steel pile with enlarged base	Experimental	200.00	345.00	620.00
			Theoretical	163.64	276.34	589.40
	35mm	Steel pile covered with cement slurry and enlarged base	Experimental	215.00	365.00	625.00
			Theoretical	172.28	281.94	611.36

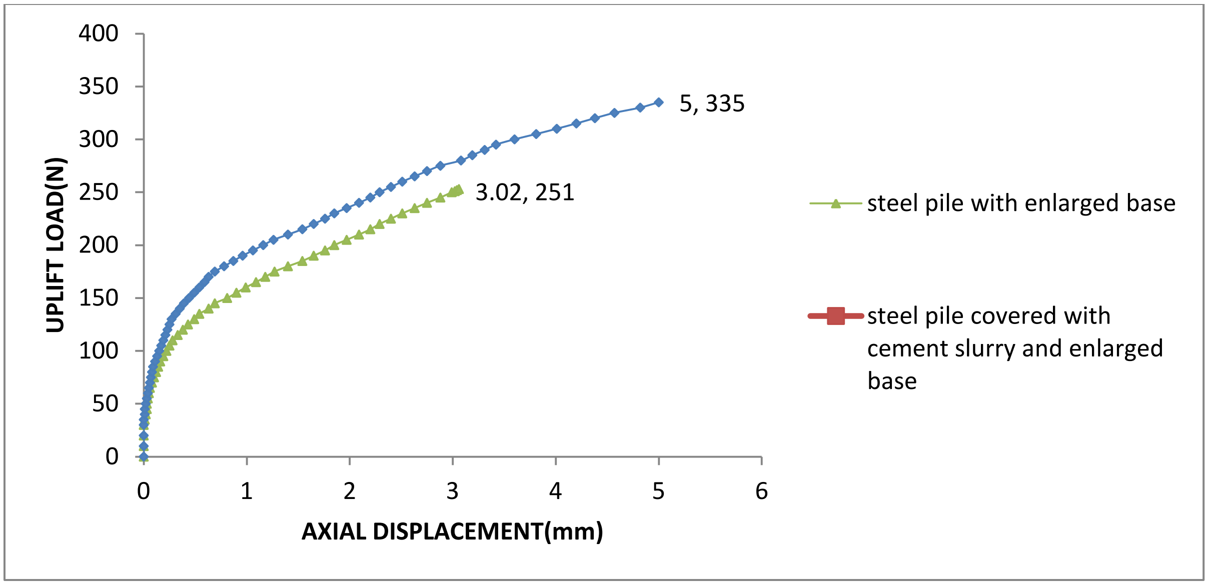

Fig30. Uplift load versus axial displacement curve of Steel pile with enlarged base and
Steel pile covered with cement slurry and enlarged base of 22mm diameter and embedment depth 200mm

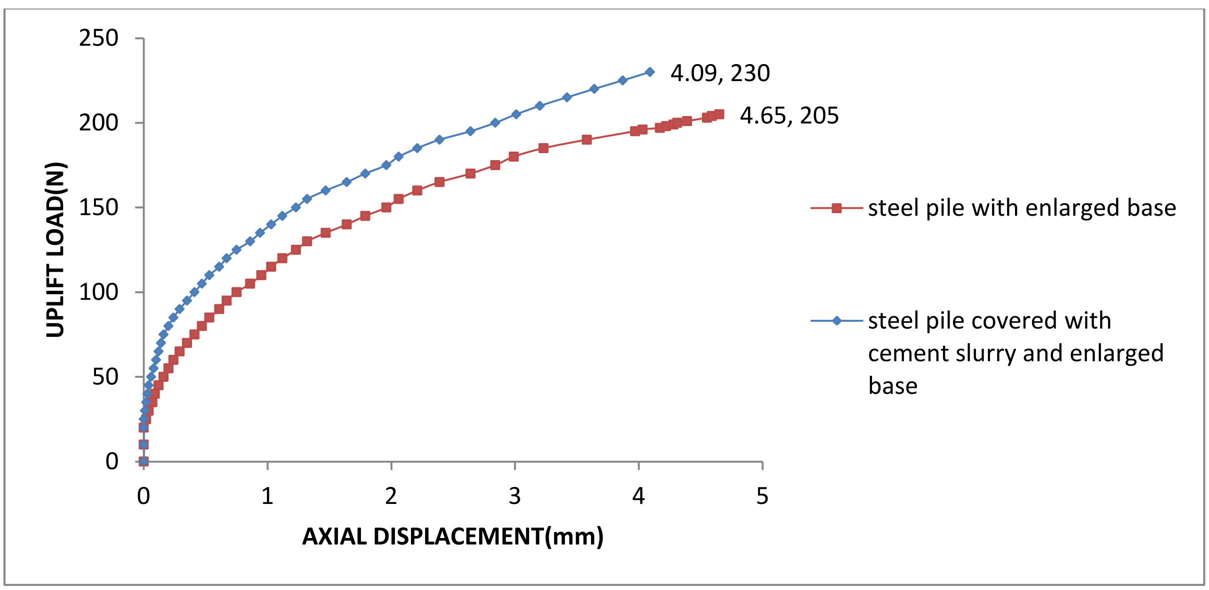

Fig31. Uplift load versus axial displacement curve of Steel pile with enlarged base and
Steel pile covered with cement slurry and enlarged base of 22mm diameter and embedment depth 266.7mm

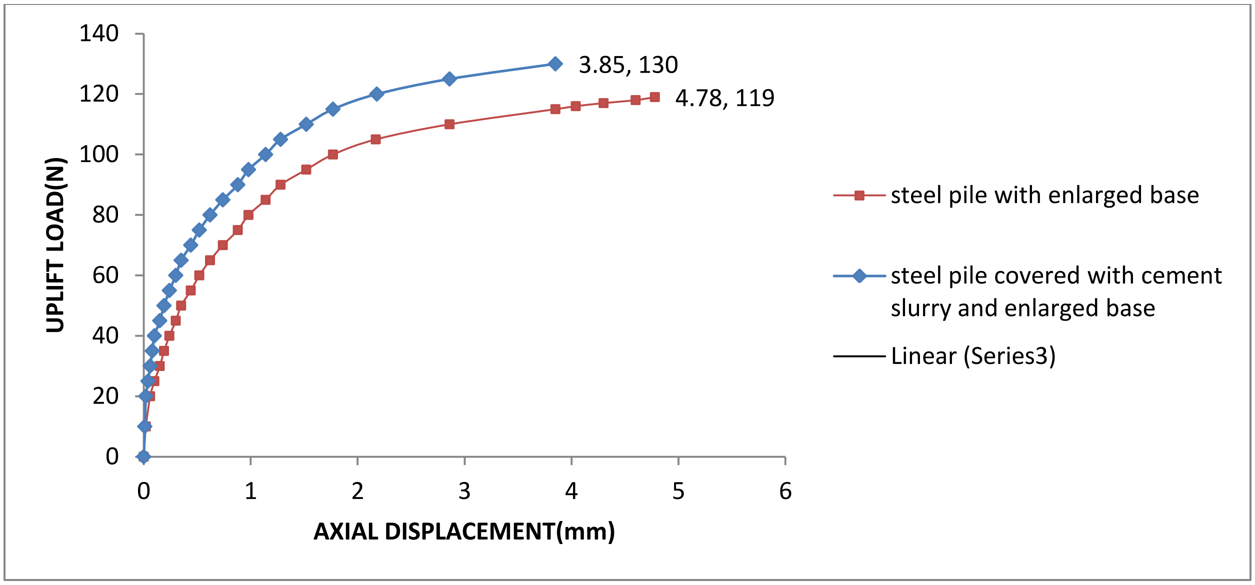

Fig32. Uplift load versus axial displacement curve of Steel pile with enlarged base and Steel pile covered with cement slurry and enlarged base of 22mm diameter and embedment depth 400mm

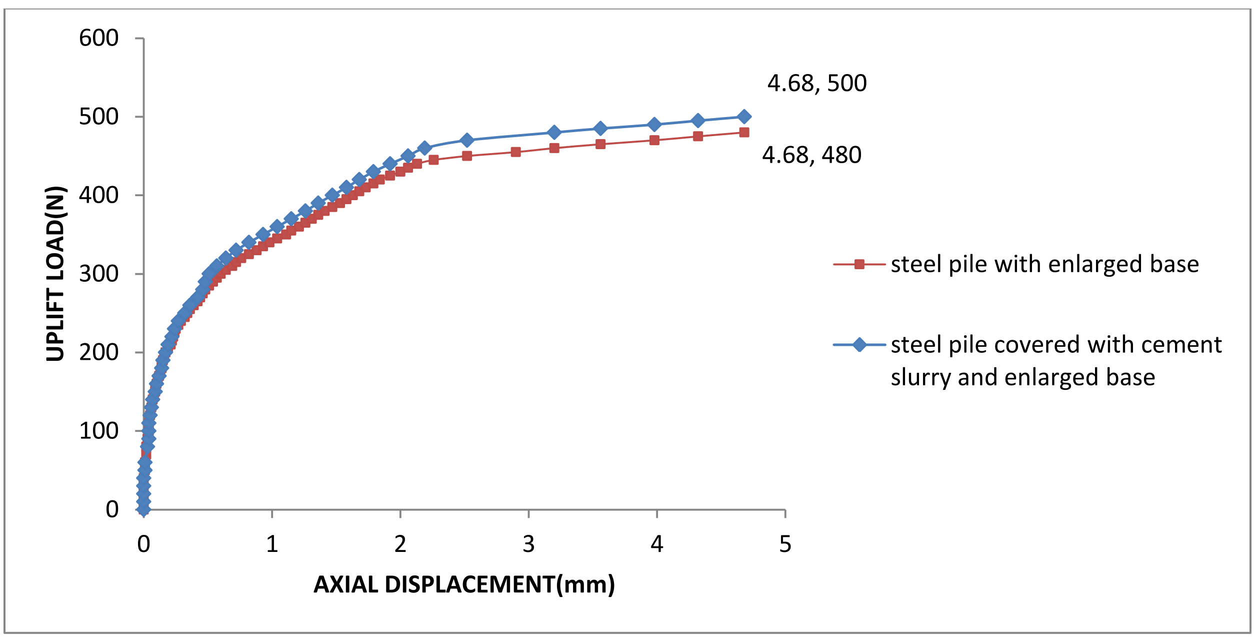

Fig33. Uplift load versus axial displacement curve of Steel pile with enlarged base and Steel pile covered with cement slurry and enlarged base of 28mm diameter and embedment depth 200mm

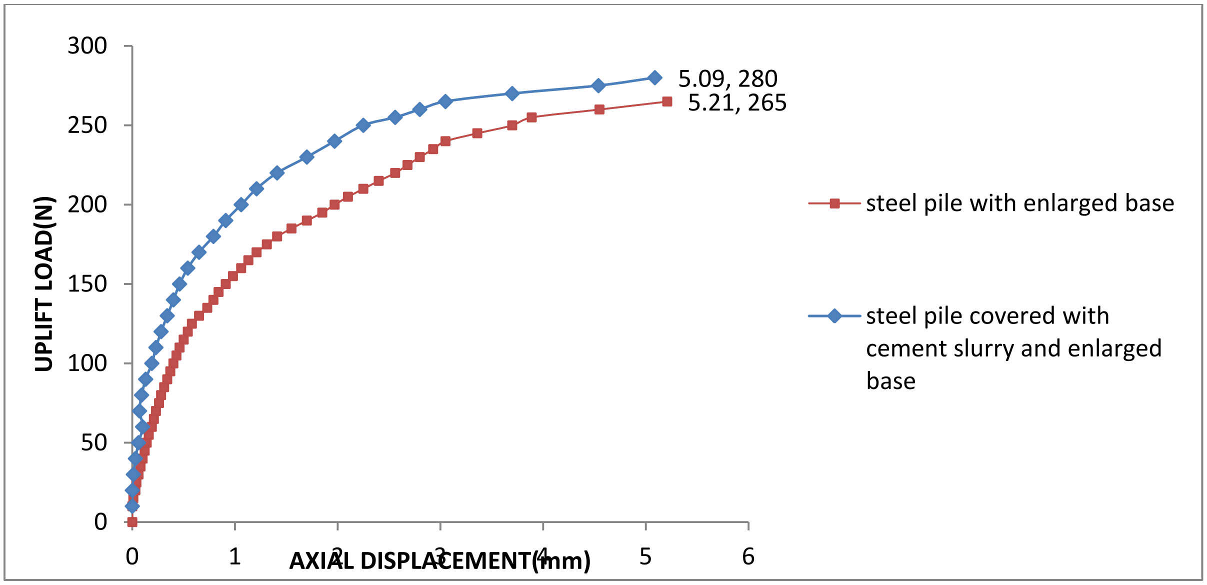

Fig34. Uplift load versus axial displacement curve of Steel pile with enlarged base and
Steel pile covered with cement slurry and enlarged base of 28mm diameter and embedment depth 266.7mm

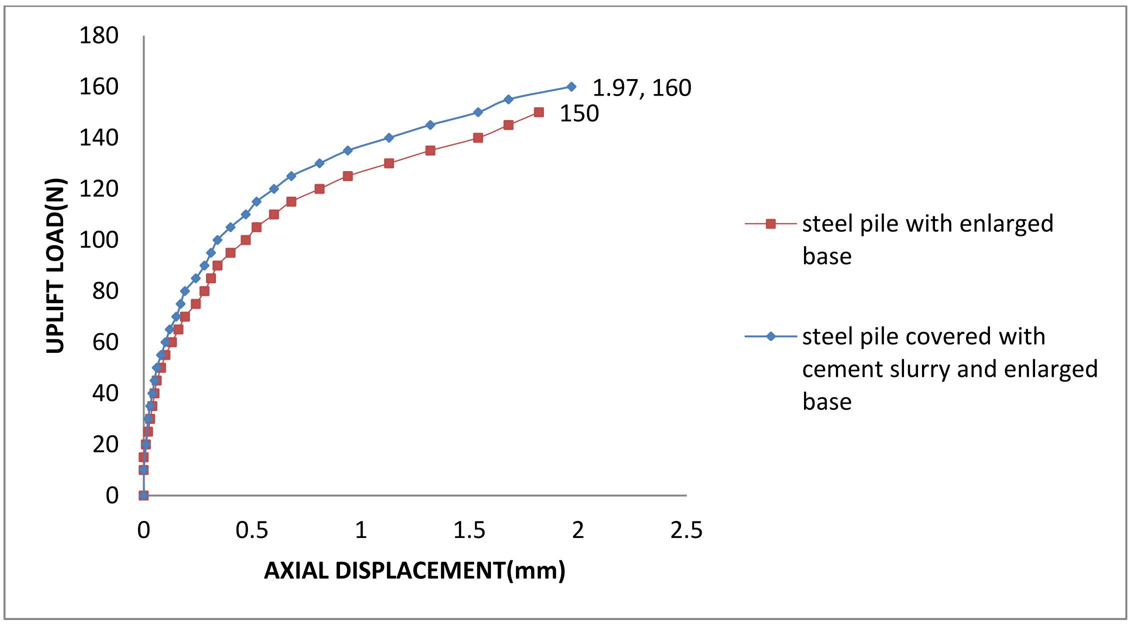

Fig35. Uplift load versus axial displacement curve of Steel pile with enlarged base and
Steel pile covered with cement slurry and enlarged base of 28mm diameter and embedment depth 400mm

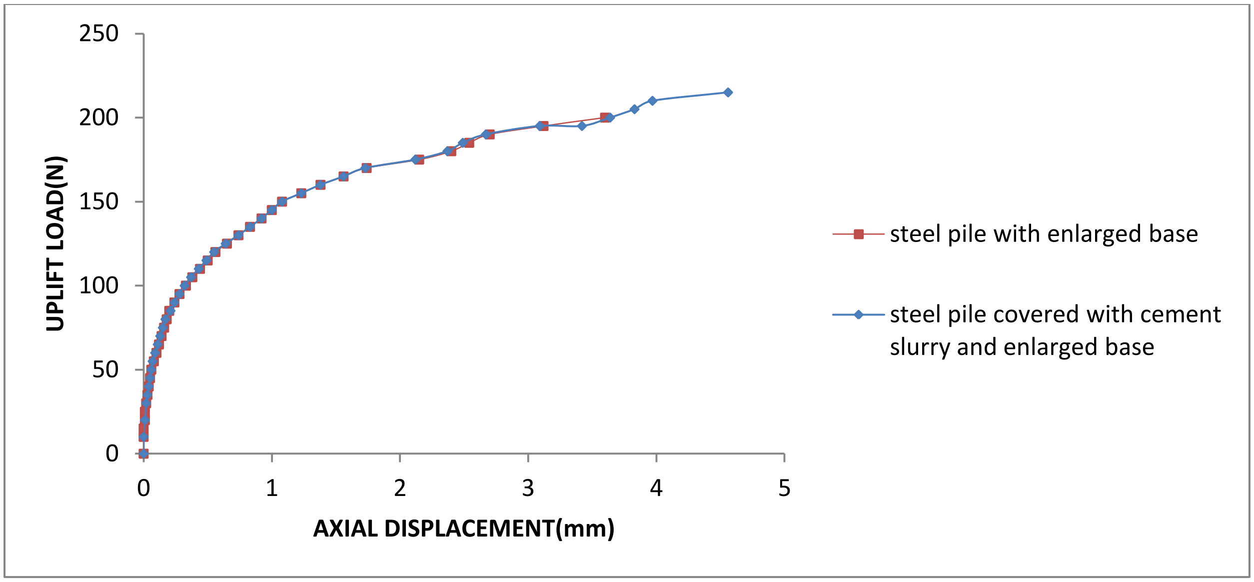

Fig36. Uplift load versus axial displacement curve of Steel pile with enlarged base and Steel pile covered with cement slurry and enlarged base of 35mm diameter and embedment depth 200mm

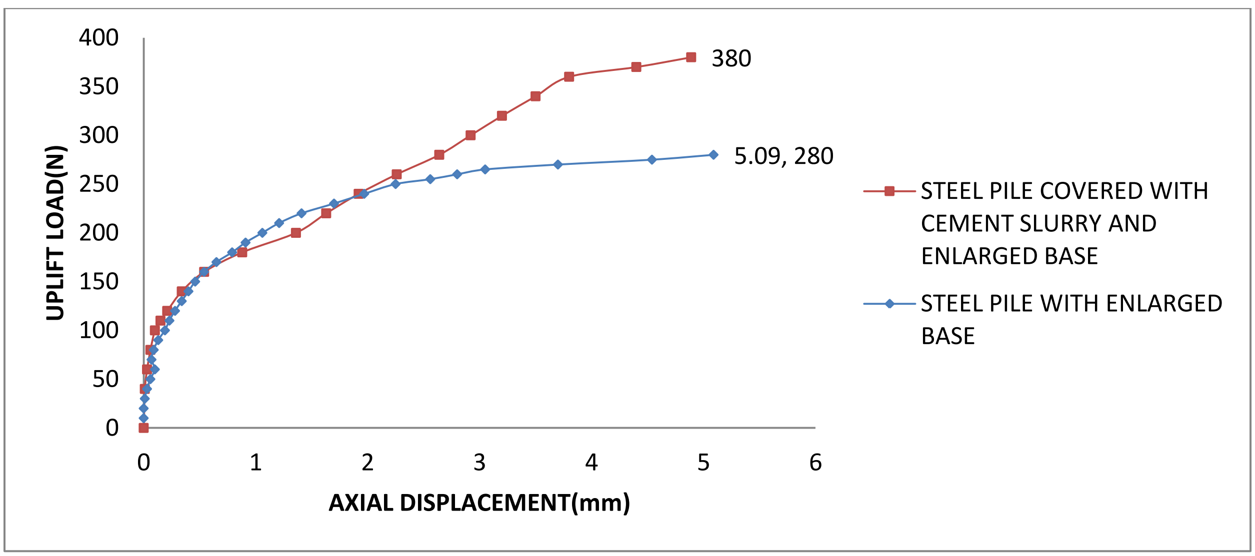

Fig37. Uplift load versus axial displacement curve of Steel pile with enlarged base and Steel pile covered with cement slurry and enlarged base of 35mm diameter and embedment depth 266.7mm

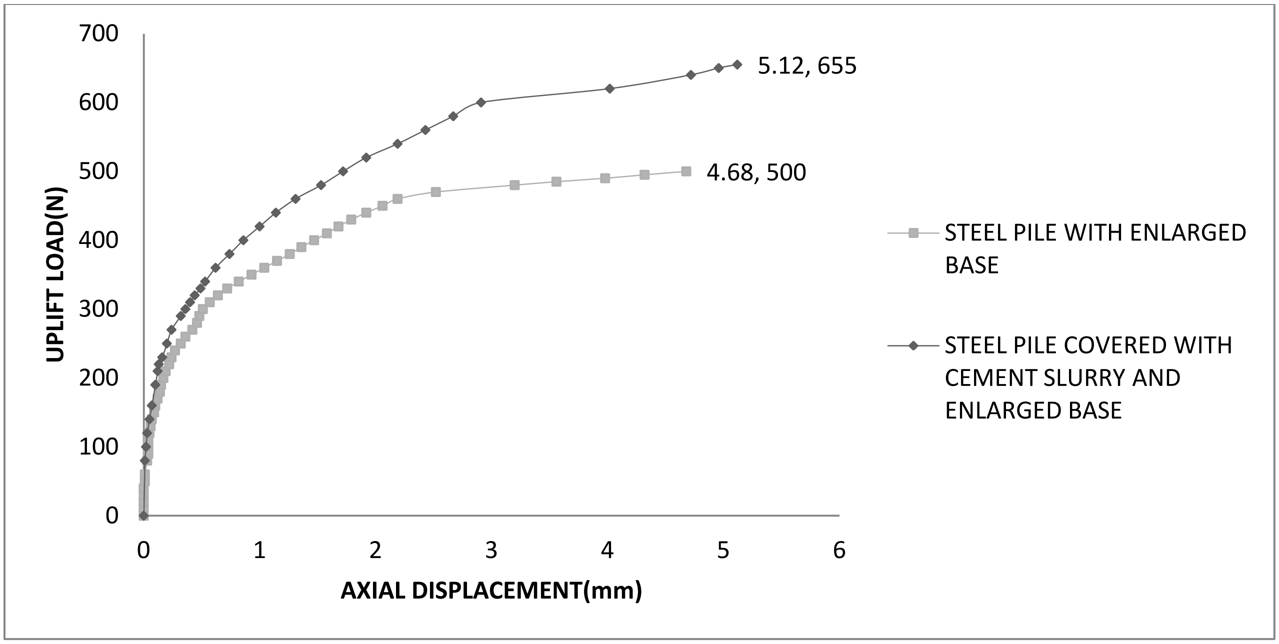

Fig38. Uplift load versus axial displacement curve of Steel pile with enlarged base and
Steel pile covered with cement slurry and enlarged base of 35mm diameter and embedment depth 400mm

CHAPTER- 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

6.1 CONCLUSIONS: On the basis of experimental study carried out on modeled pile in sand with varying diameter , depth , roughness of surface and enlarged base , following conclusion may be drawn.

1. The uplift capacity of steel pile increases with diameter and depth of embedment.
2. The uplift capacity of steel pile also increases with roughness of the surface in similar condition as mentioned in conclusion 1.
3. The uplift capacity of steel pile increases with enlarged base with and without increase the roughness of the surface.
4. The uplift capacity of steel pile with increase roughness and with enlarged base is maximum as compared to other types of pile.

6.2 RECOMMENDATIONS FOR THE FUTURE WORK: On the basis of conclusion of the project the following recommendations may be proposed for future work

1. The above study may be repeated for different types of pile material such as concrete, timber etc.
2. The study may also be repeated on other types of soil.
3. The test on proto type pile may be carried out for the validity.
4. 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)		
	200.0	266.7	400.0
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)		
	200.0	266.7	400.0
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	-	-	-

Annexure 3

35mm diameter steel pile	Embedment depth(mm)		
	200.0	266.7	400.0
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)		
	200.0	266.7	400.0
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

Annexure 5

Type 2	Embedment depth(mm)		
Diameter(28mm)	200.0	266.7	400.0
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

Annexure 6

Type 2	Embedment depth(mm)		
Diameter(35mm)	200.0	266.7	400.0
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
360	-	-	0.61
370	-	-	0.68
380	-	-	0.75
390	-	-	0.86

400	-	-	1.03
410	-	-	1.16
420	-	-	2.36

Annexure 7

Type 3	Embedment depth(mm)		
Diameter(22mm)	200.0	266.7	400.0
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.02	0.00	0.00
20	0.06	0.00	0.00
30	0.15	0.04	0.00
40	0.24	0.09	0.02
50	0.35	0.16	0.03
60	0.52	0.24	0.05
70	0.74	0.35	0.08
80	0.98	0.47	0.12
90	1.28	0.61	0.16
100	1.77	0.75	0.22
110	2.86	0.95	0.28
120	4.80	1.12	0.38
130	-	1.32	0.49
140	-	1.64	0.63
150	-	1.96	0.81
160	-	2.21	0.99
170	-	2.64	1.18
180	-	2.99	1.40
190	-	3.58	1.65
200	-	4.31	1.85
210	-	-	2.09
220	-	-	2.29
230	-	-	2.51
240	-	-	2.75
250	-	-	2.99

Annexure 8

Type 3	Embedment depth(mm)		
Diameter(28mm)	200.0	266.7	400.0
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.01	0.03	0.00
30	0.03	0.06	0.00
40	0.05	0.10	0.00
50	0.08	0.14	0.01
60	0.13	0.19	0.01
70	0.19	0.23	0.02
80	0.28	0.28	0.02
90	0.34	0.34	0.03
100	0.47	0.40	0.04
110	0.60	0.46	0.04
120	0.81	0.54	0.05
130	1.13	0.65	0.06
140	1.54	0.79	0.07
150	1.82	0.91	0.09
160	-	1.06	0.10
170	-	1.21	0.12
180	-	1.41	0.14
190	-	1.70	0.15
200	-	1.97	0.17
210	-	2.25	0.21
220	-	2.56	0.23
230	-	2.80	0.25
240	-	3.05	0.29
250	-	3.70	0.34
260	-	4.55	0.39
270	-	-	0.44
280	-	-	0.48
290	-	-	0.54
300	-	-	0.60
310	-	-	0.69
320	-	-	0.76
330	-	-	0.88
340	-	-	0.98
350	-	-	1.11
360	-	-	1.21
370	-	-	1.31
380	-	-	1.41

390	-	-	1.53
400	-	-	1.63
410	-	-	1.73
420	-	-	1.84
430	-	-	2.00
440	-	-	2.13
450	-	-	2.52
460	-	-	3.20
470	-	-	3.98
480	-	-	4.68

Annexure 9

Type 4	Embedment depth(mm)		
Diameter(28mm)	200.0	266.7	400.0
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.01	0.00	0.00
30	0.02	0.00	0.00
40	0.04	0.01	0.00
50	0.06	0.02	0.00
60	0.10	0.03	0.00
70	0.14	0.04	0.00
80	0.18	0.06	0.01
90	0.24	0.08	0.01
100	0.33	0.10	0.02
110	0.44	0.15	0.02
120	0.56	0.21	0.03
130	0.74	0.24	0.04
140	0.92	0.34	0.05
150	1.08	0.42	0.06
160	1.38	0.54	0.07
170	1.74	0.69	0.08
180	2.40	0.88	0.09
190	2.70	1.10	0.10
200	3.60	1.36	0.11
210	-	1.53	0.12
220	-	1.63	0.13
230	-	1.72	0.14
240	-	1.92	0.16
250	-	2.07	0.18
260	-	2.26	0.20
270	-	2.43	0.22
280	-	2.64	0.24
290	-	2.88	0.28
300	-	3.06	0.32
310	-	3.24	0.36
320	-	3.42	0.44
330	-	3.60	0.49
340	-	3.78	0.53
350	-	-	0.58
360	-	-	0.62
370	-	-	0.68
380	-	-	0.74
390	-	-	0.8

400	-	-	0.86
410	-	-	0.93
420	-	-	1.00
430	-	-	1.07
440	-	-	1.14
450	-	-	1.21
460	-	-	1.31
470	-	-	1.41
480	-	-	1.53
490	-	-	1.63
500	-	-	1.72
510	-	-	1.81
520	-	-	1.92
530	-	-	2.06
540	-	-	2.19
550	-	-	2.31
560	-	-	2.43
570	-	-	2.55
580	-	-	2.84
590	-	-	3.20
600	-	-	3.42
610	-	-	4.02
620	-	-	4.72

Annexure 10

Type 4	Embedment depth(mm)		
Diameter(22mm)	200.0	266.7	400.0
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.02	0.00	0.00
30	0.06	0.01	0.00
40	0.10	0.03	0.01
50	0.19	0.06	0.02
60	0.30	0.10	0.04
70	0.44	0.14	0.06
80	0.62	0.20	0.08
90	0.88	0.29	0.11
100	1.14	0.41	0.15
110	1.52	0.53	0.19
120	2.18	0.67	0.23
130	3.85	0.86	0.27
140	-	1.03	0.35
150	-	1.23	0.44
160	-	1.47	0.54
170	-	1.79	0.63
180	-	2.06	0.78
190	-	2.39	0.96
200	-	2.84	1.16
210	-	3.20	1.40
220	-	3.64	1.65
230	-	4.09	1.85
240	-	-	2.09
250	-	-	2.29
260	-	-	2.51
270	-	-	2.63
280	-	-	3.08
290	-	-	3.31
300	-	-	3.60
310	-	-	4.01
320	-	-	4.38
330	-	-	4.82
340	-	-	-

Annexure 11

Type 4	Embedment depth(mm)		
Diameter(28mm)	200.0	266.7	400.0
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.01	0.00	0.00
30	0.02	0.01	0.00
40	0.04	0.03	0.00
50	0.06	0.06	0.01
60	0.10	0.10	0.01
70	0.15	0.07	0.02
80	0.19	0.09	0.03
90	0.28	0.13	0.04
100	0.34	0.19	0.04
110	0.47	0.23	0.04
120	0.60	0.28	0.05
130	0.81	0.34	0.06
140	1.13	0.40	0.07
150	1.54	0.46	0.09
160	1.97	0.54	0.1
170	-	0.65	0.12
180	-	0.79	0.14
190	-	0.91	0.15
200	-	1.06	0.17
210	-	1.21	0.19
220	-	1.41	0.22
230	-	1.70	0.24
240	-	1.97	0.27
250	-	2.25	0.32
260	-	2.80	0.36
270	-	3.70	0.42
280	-	5.09	0.46
290	-	-	0.48
300	-	-	0.51
310	-	-	0.57
320	-	-	0.64
330	-	-	0.72
340	-	-	0.82
350	-	-	0.93
360	-	-	1.04
370	-	-	1.15
380	-	-	1.26
390	-	-	1.36

400	-	-	1.47
410	-	-	1.58
420	-	-	1.68
430	-	-	1.79
440	-	-	1.92
450	-	-	2.06
460	-	-	2.19
470	-	-	2.52
480	-	-	3.2
490	-	-	3.98
500	-	-	4.68

Annexure 12

Type 4	Embedment depth(mm)		
Diameter(35mm)	200.0	266.7	400.0
Uplift load (N)	Displacement(mm)	Displacement(mm)	Displacement(mm)
10	0.00	0.00	0.00
20	0.01	0.00	0.00
30	0.02	0.00	0.00
40	0.04	0.01	0.00
50	0.06	0.02	0.00
60	0.09	0.03	0.00
70	0.13	0.04	0.00
80	0.17	0.06	0.01
90	0.24	0.08	0.01
100	0.32	0.10	0.02
110	0.43	0.15	0.02
120	0.55	0.21	0.03
130	0.74	0.24	0.04
140	0.92	0.34	0.05
150	1.08	0.42	0.06
160	1.38	0.54	0.07
170	1.73	0.69	0.08
180	2.37	0.88	0.09
190	2.67	1.10	0.10
200	3.64	1.36	0.11
210	3.97	1.53	0.12
220	-	1.63	0.14
230	-	1.72	0.16
240	-	1.92	0.18
250	-	2.07	0.20
260	-	2.26	0.22
270	-	2.43	0.24
280	-	2.64	0.28
290	-	2.88	0.32
300	-	3.06	0.36
310	-	3.24	0.40
320	-	3.42	0.44
330	-	3.60	0.49
340	-	3.78	0.53
350	-	4.02	0.58
360	-	4.87	0.62
370	-	-	0.68
380	-	-	0.74
390	-	-	0.80

400	-	-	0.86
410	-	-	0.93
420	-	-	1.00
430	-	-	1.07
440	-	-	1.14
450	-	-	1.21
460	-	-	1.31
470	-	-	1.41
480	-	-	1.53
490	-	-	1.63
500	-	-	1.72
510	-	-	1.81
520	-	-	1.92
530	-	-	2.06
540	-	-	2.19
550	-	-	2.31
560	-	-	2.43
570	-	-	2.55
580	-	-	2.84
590	-	-	3.20
600	-	-	3.42
610	-	-	4.02
620	-	-	4.72
630	-	-	4.34
640	-	-	4.72
650	-	-	4.96