COMPARISON OF SIDE RESISTANCE OF STEEL PILE

FROM PULL OUT TEST VS TORSION TEST

A DESSERTATION

SUBMITTEED IN THE PARTIAL FULLFILLMENT OF REQUIREMENTS

FOR THE AWARD OF THE DEGREE

OF

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IN

GEOTECHNICAL ENGINEERING

Submitted by:

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CANDIDATE'S DECLARATION

I Binyam Asfaw Dingamo, 2k17/GTE/19 final year student of M.Tech in Geotechnical Engineering do hereby certify that the work presented is the report entitled "**Comparison of side resistance of a steel pile from pull out vs torsion test**" in the partial fulfilment of the requirement for the award of the degree of master of technology in Geotechnical engineering submitted in the department of civil engineering, Delhi Technological University, is an authentic record of my own work. I have not submitted the matter embodied in the report for the award of any other degree or diploma to any other institution.

Binyam Asfaw

(2k17/GTE/19)

CERTIFICATE

This is to certify that the major report entitled "comparison of skin friction of pile in axial direction from pullout and torsional direction from torsion Test work carried out in fulfilment of the requirments for the award of master of engineering(Geotechnical Engineering),Department of Civil Engineering,Delhi technological University,Delhi.

Dated: Binyam Asfaw

Roll no:2k17/GTE/19

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

DR.Naresh Kumar

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First of all I would like to thank the almighty God for giving me wisdom and health to accomplish this task.

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Date:

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Contents

Abstract

Extensive megaprojects held on worldwide with whatever land present lead the construction industry to introduce advanced deep foundation system with latest equipment and installation process.

Among this pile being one; is used to transfer the load coming from the superstructure to a deeper stratum. The mechanism of load transfer being complex, piles generally have the capacity to resist the load coming either through end bearing, skin friction or both.

Piles are normally subjected to axial compressive loads, inclined loads and uplift loads. In addition to these piles may be subjected to torsional stress due to an eccentricity of the applied loads.

In a condition where putting the pile to a hard stratum is uneconomical or a difficult task floating or friction piles are used. These piles are designed in such away that the shaft interacting with the soil (skin friction) playing the key role.

Skin friction factors resist the moment of pile against torsion and uplift forces.

These project attempt to investigate the skin friction of a mild steel pile when its subjected to uplift(pullout) force and torsional load at different depth in a sand bed.

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Chapter 1

General

Foundation is an element of a structure used to transmit the imposed load coming from above to the underlying soil/rock profile. Depending on the depth of the foundation it can be distributed into shallow and deep foundation. Shallow foundations transfer the load coming from the superstructure to the ground over a shallow depth i.e. L/D_f <1. However for heavy loads and other factors such soils prone to differential settlement and with soft and compressible underlying soils deep foundation are preferable.

There are different types of deep foundation such as pile, pier, caisson, well with different shape and installation mechanism.

Nowadays many megaprojects are being constructed worldwide. The appearance of high rise building with a complex architecture led to an extensive use of pile foundations. [12]

Pile foundations are widely applied to spread the different axial and horizontal loads coming from above to a deeper underneath soil stratum. The mechanism used to transfer the load can be either through end bearing, skin friction or both.

End bearing piles are preferable when rock or hard stratum is met within an economical depth. However if it's too deep for the hard stratum the load can be transmitted to the adjoining soil through shear on the side of the shaft. Normally we call these types of pile friction or floating piles.

Piles are normally subjected to compressive loads, inclined loads and uplift loads. The design of piles under compressive load is, in general based on the requirements that thorough breakdown of the pile group or of the supporting structure is not allowed under the most severe conditions and that the displacements at working loads should not be so extreme so as to impair the proper functioning of the foundation or damage the superstructure. The allowable displacements depend on the importance of the structure and the practice followed in the particular country or their Professional Societies or Institutions. [34]

In an environment where cohesion less soils is present the shaft resistance plays a major role in spreading the axial load to the surrounding soil.

Shaft resistance also contributes a major role for piles supporting structures subjected to pull out forces such as communication towers, port structures and offshore platform and for anchor piles.

Various researchers tried to point out that the behaviour of a pile shaft to resist external forces remained unaltered for both tension and axial compression loads. [1].

Nevertheless, recent published experimental test results clearly showed that the resistance needed for the uplift loads is significantly lower compared to that resistance for compressive loads. [12] , [17]

A research performed by O'Neill et.al tried to suggest that the resistance offered by the pile in pull out to be lower compared to downward shaft resistance(<12-25%). The reason for this is investigated to be the poison's ratio effect. Moreover Poulos et al. reported that the pull out ability of piles to be 2/3 of the side resistance offered by downward loading. [1]

Foundations of some structures like transmission towers, mooring system for ocean surface or submerged platforms, tall chimneys, jetty structures etc. are subjected to uplift load. [3], [13]

Some of the factors contributing for the uplift force to occur are wind effects, earth quake events, surge actions or ship impacts. This phenomenon triggers an overturning moments on the piles supporting the structure where the loads transmitted in the form either compression or tension. Furthermore in swelling soils with a potential heave uplift forces is inevitable. [1]

However there are different techniques and method available to restrain the pile against uplift. One being applying a pile shaft that is sufficiently long to take the whole of the uplift in the shaft friction. [27]

In an environment where the pile meets rock at shallow depth it may not be possible and uneconomical to drive the piles deeply enough to mobilize the required frictional resistance. In such cases additional dead weight are added to the pile to resist the uplift load. [27]

1.2 Pile-Soil Interaction Phenomenon

The assessment of the uplift capacity of pile shaft involves substantial uncertainty. [abduliasis et.al]. Extensive attempt have been made to investigate the different factors which affect the pile shaft behaviour. Generally researchers tried to distinguish the factors which arise from the characteristics of the pile itself such as types, surface roughness, length, diameter, soil-pile friction angle, geometry of group etc…

The properties of the adjoining soil such as strength ,deformation, consistency and density and also the method of installation also contribute an immense factor to its function.

Widespread theoretical and experimental investigations are available on the behaviour of piles and pile groups subjected to different loading pattern. They relate to load carrying capability of the piles/pile groups, load-displacement response, buckling etc. Consequently the design and analysis of piles under these loading conditions can be done with greater assurance and economy under normal operating conditions. [34]

Every pile foundation structure like bridges has some stress due to torsion. Torsion on pile come due to eccentric horizontal loads from wind, high speed vehicles and ship impacts. There is no such provision in IS 2911 for torsion on pile. Lacking in design of foundation against thee load lead to terrible consequences.

1.3 Objective

The aim of these research project is:

1. To check the different available literature survey done on the subject of side resistance or friction of pile shaft for both pull out and torsion loading conditions.

2. To investigate the side resistance of a model steel pile from pull out test

3. To investigate the side resistance of a model steel pile from torsional test

4. Check the different factors which affect the skin friction of the model steel pile

1.4 Structure of the project

Chapter I introduction of the research project

Chapter II describes literature reviews related to the shaft resistance of a single model pile related to uplift load and torsional load

Chapter III methodology and experimental setup followed in the present study

Chapter IV illustrates and discuss results

Chapter V gives the general conclusions of the present project from the experiment investigated

Chapter 2

2 Literature review

2.1 General

A shallow foundation is usually when the underlying soil has the capacity to support the load coming from the super structure. However in situations where the topsoil is loose or soft or has a tendency of swelling the depth of the foundation has to be increase till a sound layer is met in order to easily transfer the load without excessive settlement. [14]

When designing pile foundations in buildings located around seashore which is sandy soil, it is essential to take into account the uplift forces in addition to the axial compressive and lateral forces loads. [6]

These uplift forces tend to pull out the piles leaving the structure unstable. This phenomenon tends to remove the pile tip from transferring the load to the stratum and imposing the entire load on the pile shaft. Hence the pile shaft resistance plays a major role in these conditions.

Piles are also subjected to dynamic loads such as earth quake, vibration as in the case of machine foundation and wind load etc…these loads has a massive effect in creating moment and torsion on the pile shaft.

These conditions have been investigated in foundation structure like tall chimney tower, offshore tower, mooring structure. [11]

Although huge amount of surveying and investigation (theoretical and experimental) concerning the ultimate load carrying capacity of piles under compressive loads, small amount of effort and studies were made on pile response under uplift forces. The complexity associated with makes it difficult to predict accurately. (Vesic 1970; Meyerhof 1973;das et al.1973;das 1983;chattopadhyay and Pise 1986,shanker et al.). [11]

An attempt has been made to review some of the literatures and researches conducted on piles subjected to uplift force and the effect of skin friction during pull out test. Additionally the torsional response of the pile and the way it behaves is also part of the study here.

2.2 Review of Previous work

Alawneh et al. conducted a test to determine the different significant parameters influencing the behaviour of the pile along the entire shaft buried inside a dry sand. He concluded that method of pile installation, sand condition, the pile surface roughness and pile end type are all substantial factors with the relative density of sand being the most influencing parameter.

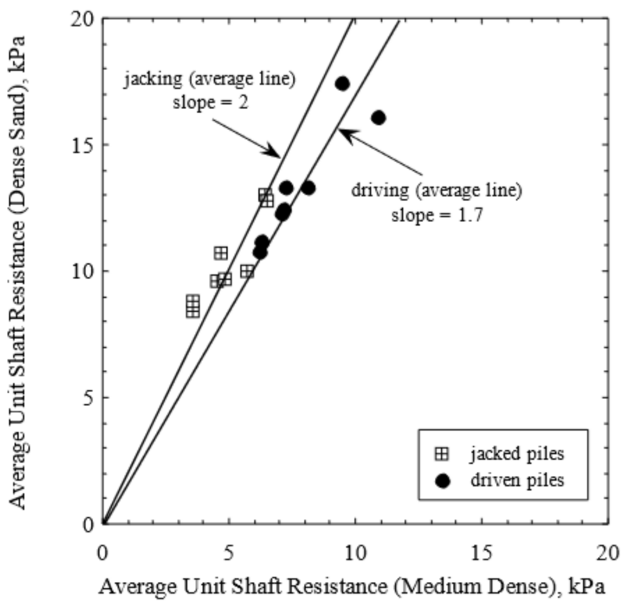


Fig. 2.1 Influence of the relative sand density on the shaft resistance of pile(Alawneh et al. 1999)

Generally the behaviour of the pile is affected by different factors. These factors can be grouped in to two. One rising from the pile properties like pile length, pile diameter, shape, pile tip properties, surface characteristics [4]

Soil properties such as deformation, strength, relative density being another factor.

The mechanism of pile installation has a great influence on the behaviour of the pile and the natural state of soil on which it tends to densify hence increasing the interaction between the soil and pile.

Skin friction between the pile shaft and the soil emerges into play when we talk about the pull out resistance of straight steel pile in sand. [2]

2.2 General methods of approach under uplift loads

Depending on the existing soil type, different theories and methods have been developed during the last five decades. These methods can be broadly categorized as total stress analysis and effective stress analysis. They further can be categorized in to the alpha(α),beta(β),and the lambda(λ) methods.[1]

B.C.Chattopadhyay et al. (1986) proposed an analytical method in order to evaluate the ultimate uplift capacity of piles under the sand layer using a vertical circular model pile of diameter d and embedment depth L. [2]

$P_U(Net)=P_{av*}\pi*d*L = {}^{1}/_{2}\, Ks *\ tan\delta\ * \gamma * l$ …………………………………….. (2.1*)

Where ,

P_{av}=average skin friction=$^1/_2\, Ks * \ tan\delta \ * \gamma$

Ks=coeffiecent of earth pressure

δ=soil pile friction angle

γ=effective unit weight

L= embedment length

According to the proposed analytical method the failure is expected to occur along the height of pile shaft and neighbouring soil. Nevertheless the complex phenomena occurring between the pile shaft and the neighbouring soil lead to the formulation of a general theoretical approach**.**

- **Theoretical Analysis**

A generalized theory is proposed to check the uplift resistance of a circular vertical pile buried in sand. A curved failure surface was assumed passing through the neighbouring soil. The extent of the failure surface being affected by the angle of shearing resistance ø of the existing soil adhering the pile, soil-pile friction angleδ, and slenderness ratio λ = L/d.

During pull out of a pile, a solid block mass of soil with pile is assumed to move up along the resulting surface. This upward motion is resisted by the induced shear strength of the soil along the failure surface and the downward mass of the soil and the pile.

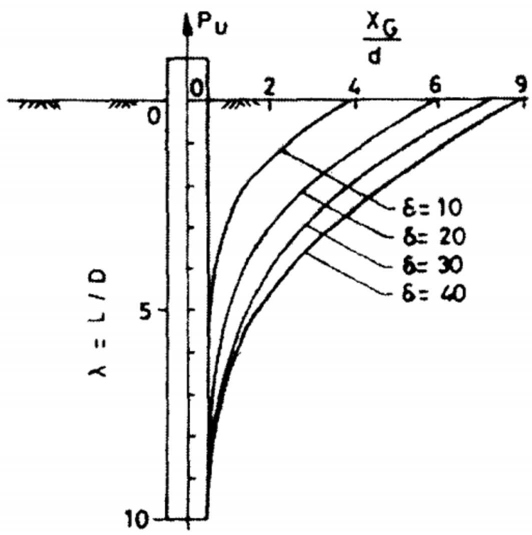


Fig. 2.4 Failure Surfaces for various Values of δ at L/D = 10(Chattopadhyay and Pise, 1986)

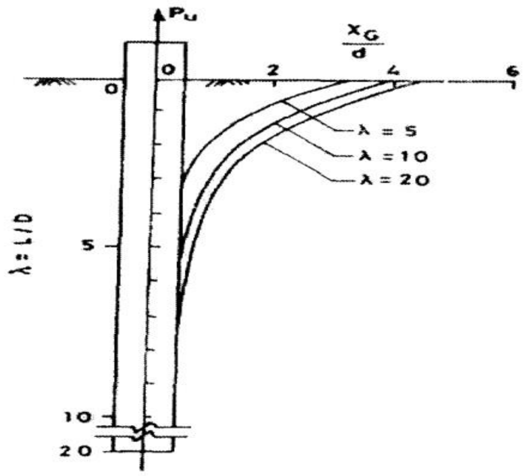


Fig. 2.5 Failure Surface for Different Slenderness Ratios (ø = 40°, δ = 10°) (Chattopadhyay and Pise, 1986)

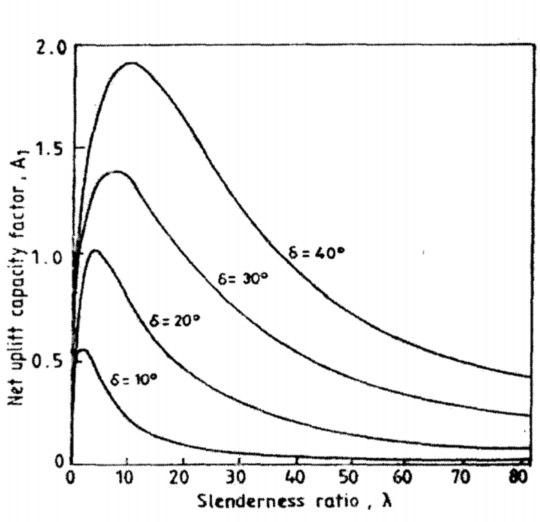


Fig. 2.6 Uplift Capacity Factor, A1 for different Slenderness Ratio λ (ø = 40°) (Chattopadhyay and Pise, 1986)

Intense investigation has been performed by different researcher (Awad & Ayoub 1976; Chaudhuri & Symons 1983; Das & Seeley 1975; Das 1983; Das, et al. 1977; Levacher & Sieffert 1984) concerning the effect of slenderness ration on the pile shaft resistance. Following their survey they concluded that the average shaft resistance increase with embedment depth to a certain level and become constant afterwards.

Specifically **Das (1983)** after studying on a model pile conveyed that the unit skin friction adjoining the pile shaft increase with an embedment depth to some extent and reach a constant value afterwards. It is expressed as a critical embedment ratio and the critical embedment ratio is reliant on the relative density (Dr) and can be evaluated as,

$(L/d)_{cr}$=0.156Dr + 3.58(for Dr≤70%)…………………………(2.1 a)

$(L/d)_{cr}$=14.5 (for Dr≥70%)………………………………..(2.1 b)

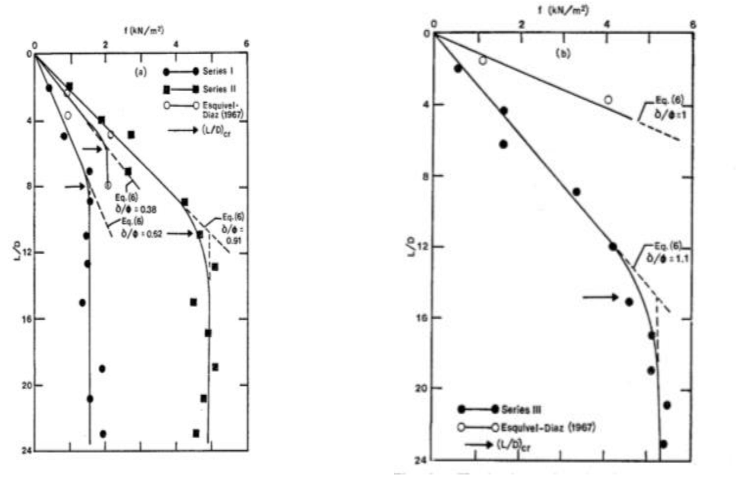


Fig. 2.7 Change of unit skin friction with L/Dr (B.M.Das 1983)

The net pull out capacity of pile in sand can be calculated as

$P_{nu}=\frac{1}{2} P\gamma L^2 Kutan\delta$ [if L/D≤(L/d)cr]…………(2.2)

$P_{nu}=1/2\ P\gamma L_{cr}^2\ K_u tan\delta + P\gamma Lcrk_u tan\delta (L-L_{cr})$ [if L/d >(L/d)cr]…………(2.3)

Meyerhof (1973) brought a new variable which is an uplift coefficient, K_u in place of Ks keeping the angle of shearing resistance fixed. It was shown that Ku to increase linearly with the slenderness ratio, L/D up to an extreme value.

The depth where the Ku value reaches maximum is defined as critical depth. [12]

Hanna and Nguyen(1986) presented an experimental investigation on the ultimate shaft resistance of batter piles. The test piles were inserted into a medium dense sand deposits at different angle (up to 30^0) with respect to the vertical and tested under axial compression loads. From the experiment it was found that the total shaft resistance decreases with increasing pile inclination. The author related the cause of this drop to the reduction of the average mobilized angle of friction between the pile shaft and sand taking into account the vertical lateral pressure distribution. [30]

The author tried to use two basic assumptions in order to check the shaft resistance ability. These are

1- Keeping the mobilized angle of friction between the pile and sand constant around the pile shaft for a given distance 'z'.

2- The local coefficient of earth pressure $K_{Z\theta}$ is a function of the angle θ and the depth Z. [30]

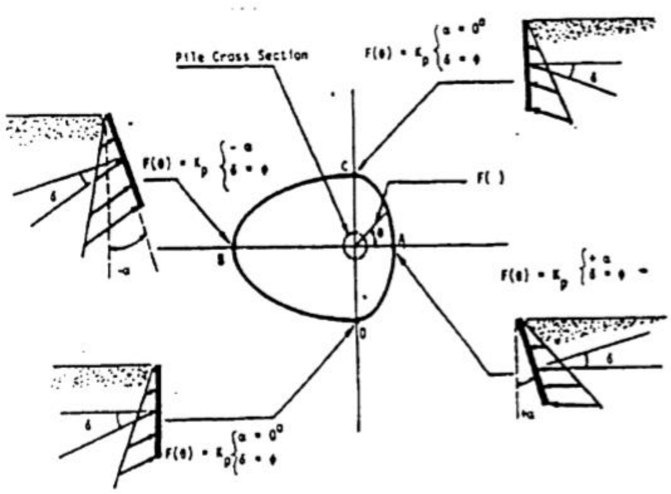


Fig 2.7.2 Assumed spreading of the unit shaft resistance around the pile, (after

Hanna and Nguyen ,1986)

A.S Alawneh et al. (1999) conducted a test on open and closed ended rough and smooth pile. From the results obtained he suggested that method used to install the piles, in situ sand state, pile exterior roughness and base of pile tip are all significant variables influencing the ultimate uplift shaft resistance of a single pile in dry sand. [10]

Load transfer mechanism

The load transfer process involves the pile ability to spread the load coming from the structure to the adjoining soil along the full height of the pile shaft, by friction. In other words, the entire surface of the pile plays a major role in transmitting the forces to the nearby existing soil.

Recent investigation on pile behaviour has established that 0.25-0.40 in (6-10mm) relative displacement is sufficient for the full mobilization of skin resistance between the pile shaft and the neighbouring soil regardless of size and length of the pile. [12]

2.2 Skin Resistance

In order to understand the behaviour of the pile shaft it's essential to study the interaction occurring at the interface of pile surface and the adjoining soil. Skin friction is defined as a resistance mobilized as a pile shaft is introduced to the soil. Skin friction is different for different soil and rock types.

Load test performed on the pile data shows that skin friction depends on depth of embedment i.e it reaches its ultimate peak at certain displacement and then gradually reduces and remain constant. As a result, the shear band zone is moved downward with the increment of the load. (akira wada)

Theoretical approach for evaluation of unit skin resistance (f_s) is generally similar to that used to analyse the resistance to sliding of a rigid body in contact with soil. It is assumed that f_s consists of two parts:

- Adhesion(a)

  This should be independent of the normal stress acting on the foundation shaft

- Friction

$fs=C_a +q_s \tan\delta$ **……………………………………………………………………(**2.4)

$\tan\delta$- coefficient of friction between the pile and soil

for cohsionless soil

The pile soil adhesion (C_a) is normally small and for design purpose it can be neglected

fs=Kstanøqv………………………………………………………………………(2.5)

for cohesive soil

$\delta=0$

q_s=Ca

The coefficient Ks depends mainly on the initial ground stress condition and method of placement of the pile.

Extensive studies has been conducted to investigate the skin friction by using different variables or factors which have the tendency to affect its magnitude. [9]

Some of these factors are

1. Material used such as steel, timber, concrete

2. Surface roughness of the material used: rough or smooth

3. the existing soil type and its natural state

4. Controlled moisture content

5. Different incremental loading

In structures like foundations which come direct in touch with the soil one should ask the relation that exists between the stress and strain? It is clear that the load coming above the pile foundation creates a stress on the vicinity around the pile shaft soil interface. Hence deforming and displacing the soil grain in every direction. However during this process there is a mutual interaction between the soil and the structure consequently the load being transferred from the pile to the adjoining soil grains through the bond formed between them. The resistance induced by the pile shaft and spreading the load to the surrounding soil is called skin friction.

From the test it was observed that in order to determine the skin friction for cohesive soils its necessary to use both cohesion and angle of internal friction. The results include ratios of adhesion/cohesion and angle of skin friction/angle of internal friction for a definite type of soil, water content, and several construction materials.

2.2.1 Material used

The material used as a pile foundation greatly affects the magnitude of the skin friction. Studies shows that the different materials used significantly alter the skin friction angle.

Nowadays, design engineers use equations that accept δ values equal for all pile materials ($\delta = {}^{2}/_{3}\ \emptyset$). This approach prevents make more realistic designs. True skin friction angles (δ) can be determined by means of the proposed chart. Thus, more economic designs can be made by selecting reasonable pile diameter, length and number.

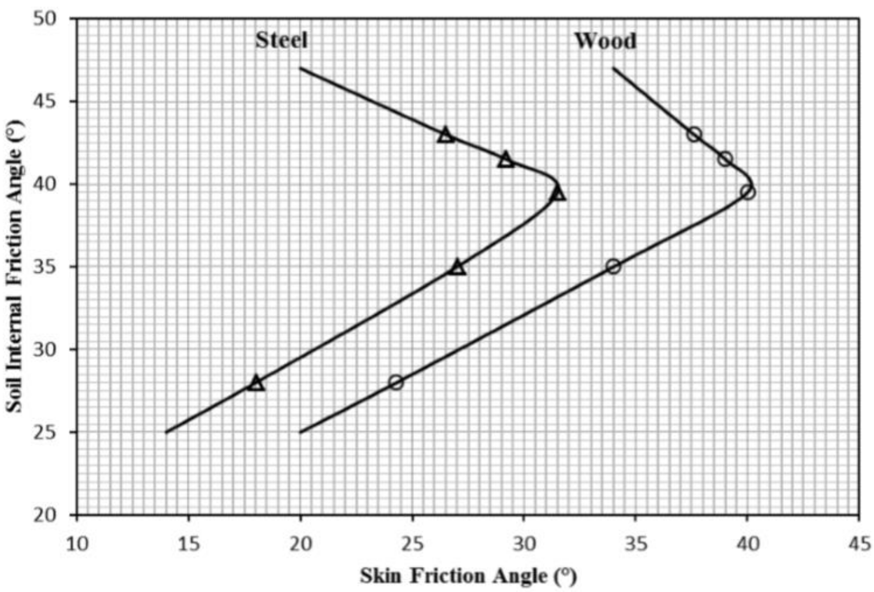


Fig. 2.2.1 comparison of skin friction for wood and steel (H. S. Aksoy etal.,2016)

Several researchers (Potyondy 1961 ; Sakr et al. 2005; Tiwari et al. 2010; Tiwari and Al-Adhadh 2014)) studied this issue and their results are compared .the values more or less show 90% similiarity.[16]

Soil (ϕ) (°)	Potyondy (1961), δ (°)		Sakr *et al.*(2005), δ (°)	Tiwari *et al.* (2010), δ (°)		Tiwari and Al-Adhadh (2014), δ (°)		Skin Friction Chart δ (°)		Similarities (Literature – Chart) (%)	
	Steel	Wood	Steel	Steel	Wood	Steel	Wood	Steel	Wood	Steel	Wood
31.0	-	-	-	24.4	27.1	-	-	21.7	28.3	89	96
31.4	-	-	-	-	-	26.1	27.2	22.4	29.0	86	94
33.1	-	-	-	27.6	28.6	-	-	24.6	31.3	89	91
33.3	-	-	-	28.5	32.3	-	-	24.9	31.8	87	99
33.4	-	-	-	-	-	27.4	30.2	25.1	32.0	92	94
34.7	-	-	-	-	-	-	-	26.6	33.7	-	-
37.0	-	-	26.6	-	-	-	-	29.1	36.9	91	-
40.0	31.5	37.0	-	-	-	-	-	31.2	40.0	99	93
43.4	-	-	-	-	-	-	-	25.8	37.2	-	-
44.5	24.2	35.0	-	-	-	-	-	24.3	36.2	100	97

Table 2.1 Comparison between chart and other studies.

2.2.2. Pile surface roughness

The pile surface roughness affects the measured pile capacity though their effect on the measure shaft resistance is less compared to the pile placement method and relative density.

A.S.Alawneh et al.1999 observed in his studies tension test on smooth and rough model piles in dry sand that 12-55% increase in resistance due to the roughness of the pile with an average value of 30%.[10]

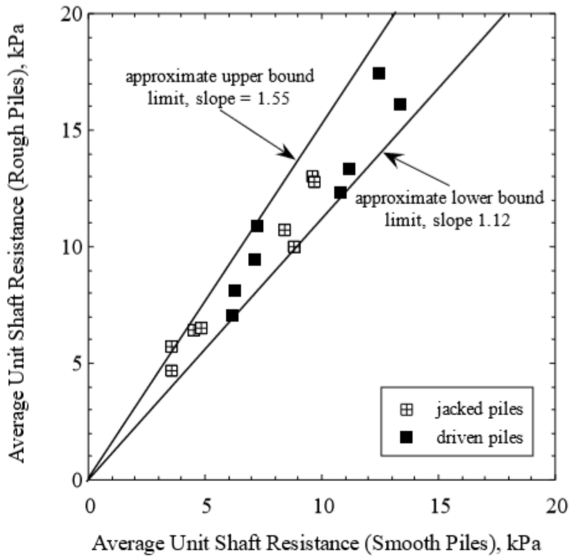


Fig. 2.9 the roughness of the pile surface on the average shaft resistance (Alawneh et al.,1999)

K.K Bose et al. after conducting a test on pull out capacity of model piles in sand ,concluded that when the roughness of the pile increases it creates a tendency to interact with the surrounding soil in a great extent and hence increasing the resistance of the shaft .[8]

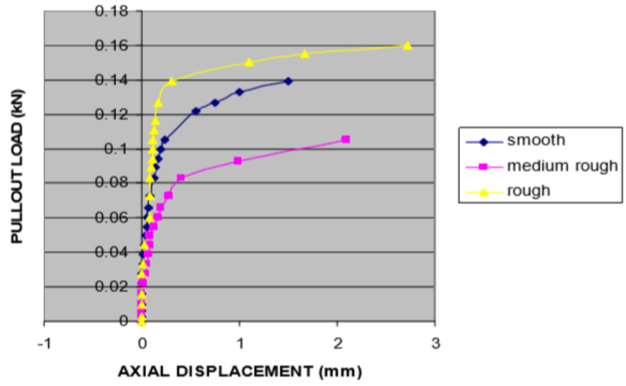


Fig. 2.10 Influence of Surface Finish on Pull out Load - Displacement Response

(after K.K.Bose et al.)

F.S.Tehranis* et al (2016) studied the effect of surface roughness on the shaft resistance of non-displacement piles embedded in sand and they observed that the region along the height of the pile surface gets altered and develop ability to oppose and hold an extensively large loads as the pile surface roughness and soil compactness(density) increases.

They also studied the advancement of shear bands around the pile shaft with an average shear band being $3.2D_{50}$-$4.2D_{50}$for rough surface piles and no shear band was developed for smooth surface piles**.** [18]

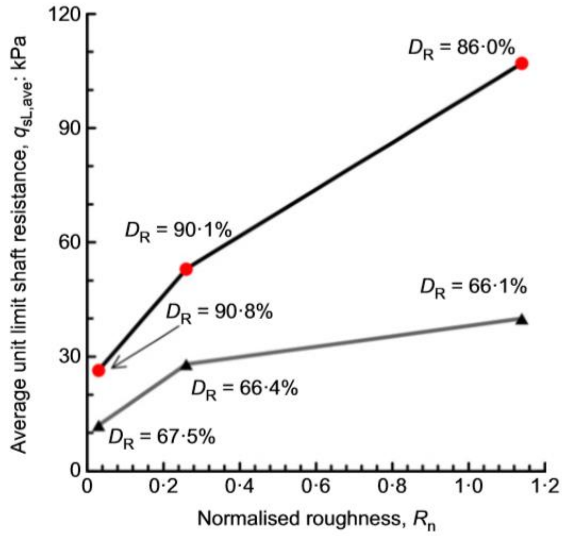


Fig 2.10 influence of surface roughness and soil density on average limit unit shaft resistance of pre-installed model piles (F.S.Tehranis* et al 2016)

2.2.3 Relative density

It is one of the properties of the soil which affect the behaviour piles. Relative density tells the state of compactness of the soil in cohesion less soils.as the relative density increased the pile shaft resistance increased.

Khaled E.Gaaver 2013 conducted an experiment to check the behaviour of the pile in cohesion less soil under different relative density of 75%, 85%, 95%. He concluded that the net pull out capacity of the pile showed improvement with the increment of the relative density.[1]

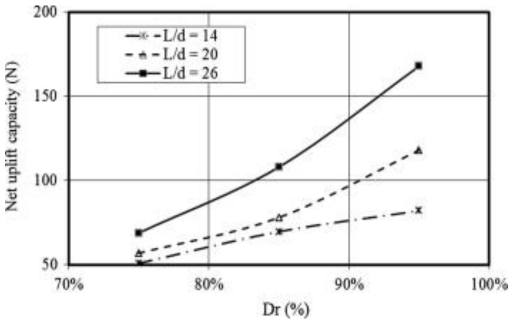


Fig. 2.11 Relation between the net uplift ability with the relative density for an individual pile (Khaled E.Gaaver 2013)

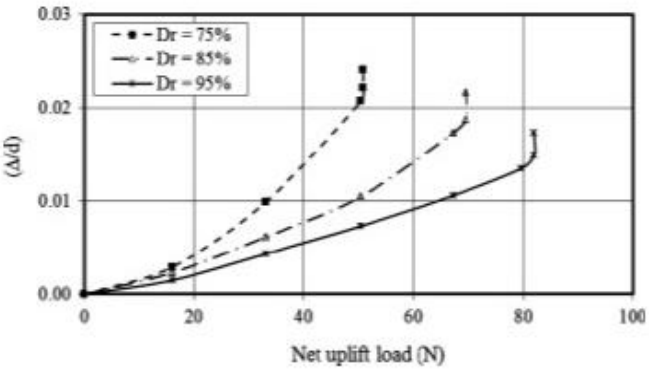


Fig 2.12 net pull out capacity for single steel pile versus controlled displacement L/d=14(Khaled E.Gaaver 2013)

Parthipan N. et al. (2015) after conducting an experimental study on pull out Load Carrying Capacity of Steel Pile in Sand, he reported that the behaviour of a single pile under pull out loadings gets altered by different variables like the compactness of the soil, the properties of the soil and on the pile embedment ratio. [3]

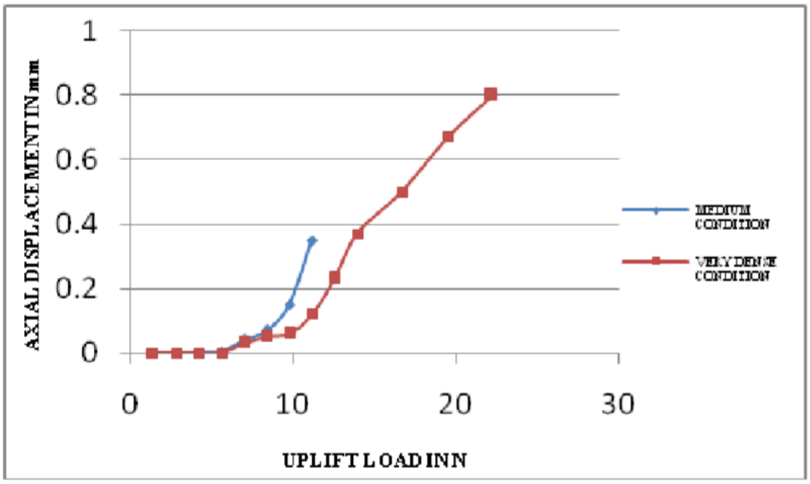


Fig.2.12 Uplift load-Axial displacement

2.2.4 Pile placement method

Pile installations are among the factors that affect the shaft resistance of the piles. The several methods employed for pile installation are difficult to determine or estimate quantitatively due to the complication involved between soil pile interactions. Usually load test are used to investigate the load carrying capacity of the pile as well as the effects of pile installation related to it. [4]

Due to the occurrence of disturbance around the surrounding soil and followed by altering of the stresses in the soil mass; pile placement methods plays important role. [4]

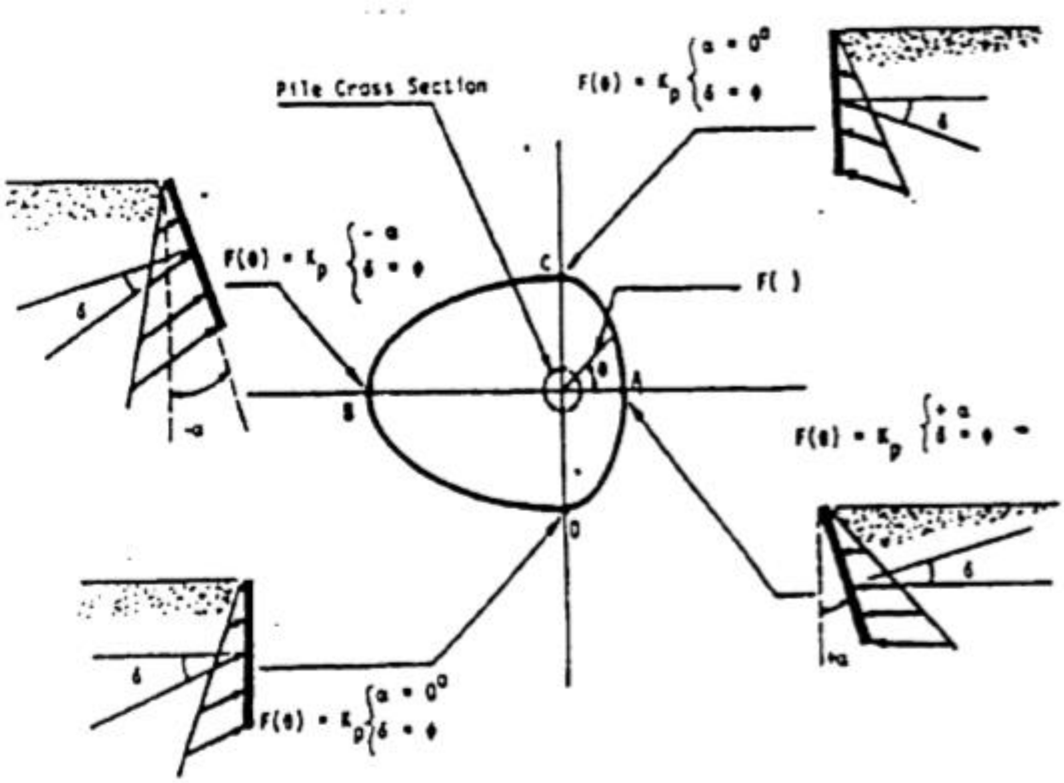
When the pile enters in to the soil, the soil is subjected to compression, deformation and pushed laterally aside. And depending on the degree of vibration it might affect existing neighbour construction.

There are different pile installation methods. Some of these are undisturbed method (no displacement installation), jacking method (quasi static displacement installation) and driving method (dynamic displacement installation)

Although there are limited quantitative studies, it was observed from these data that the method of installation and the equipment used show a significant impact on the property of the pile.

McClelland conducted an experiment for studying the effects of installation methods on uplift capacity of piles in sand. He used method of driving installation, jetting and combination of jetting and driving. He examined that the use of jetting together with driving being highly decreasing the ultimate resistance compared to that of driving alone or jetting alone. [4]

A.I.AL-MHAIDIB* et al.(1995) after conducting a test on effects of pile installation method on uplift capacity of piles in sand reported that the average unit skin friction resistance of the model pile used shows different pull out capacity for different method installation. He used three methods of installation (undisturbed, jacking, driving) with driven piles showing a large



tried to put it quantitatively like methods used by driven pile being 52% of the piles placed by the undisturbed method and then followed by jacked piles is being 70% of the methods used by undisturbed installation in both loose and dense sand. And finally he generalized that installation methods which causes less disruption or change in the initial state of the soil give higher uplift capacity

2.2.5 **Different incremental loading**

The side resistance of a single pile in sand is usually affected by the method of loading and the loading direction. Mostly piles are subjected to carry axial compressive loads. However these are not the only cases. Several recent studies have suggested that Piles are also subjected to tension loads and twisting or torsional loads .It has been investigated that the uplift resistance in a single pile in sand to be highly dependent on the local peak skin friction which is related to radial effective stress at failure, $\sigma_{rf.}$

$$Q = \pi D \int_0^L \sigma rf tan\delta f dz \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

where,

Q is the net ultimate uplift side resistance, D is the pile diameter, L is the pile embedded length and δf is the pile sand friction angle at failure

2.3 Pull out test on pile

{IS:2911-part 4-1985}

1.By using a suitable pull out setup uplift force may prefer by means of hydraulic jack with dial gauge. Hydraulic jack rest on rolled steel joists resting on two supports on ground surface is one of the method for pile pull out test. Top of test pile attach to the frame and hydraulic jack react against it. Pile is pulling out when jack operated. Reaction transfer to the ground through support which is at least 2.5D away from the test pile. Reinforcement bars of pile threaded bolt or mat be welded to the frame work. A central rod design to bear pile load and embedded central in pile to a length equal to bond length load required use as an alternative sometimes. More number of rods should be used for heavier load and rods in symmetrical manner.

2. To withstand pulling adequate steel should be in test pile. Additional reinforcement may be necessary in order to allow for neck tension in pull out test.

3. The safe uplift least of the following

a) For piles up to and including 600mm diameter

Load Displacement curve show a clear break at half of load

b) For piles more than 600 mm diameter

1) Load displacement curve show at half of load

4. initially test should be carried out until load displacement curve shows a clear break or up to 2.5 times estimated safe load

5. 12mm total displacement or one and half times the estimated safe load which ever is earlier carried out in routine test

2.1.6 Mainly pull out test shall be carried on initial test piles. For the following considerations pull out test necessary to conduct:

a) To check the pile shaft is designed to cater for such uplift load each

b) To limit the displacement with in elastic deformation of pile beyond which test should be discontinued.

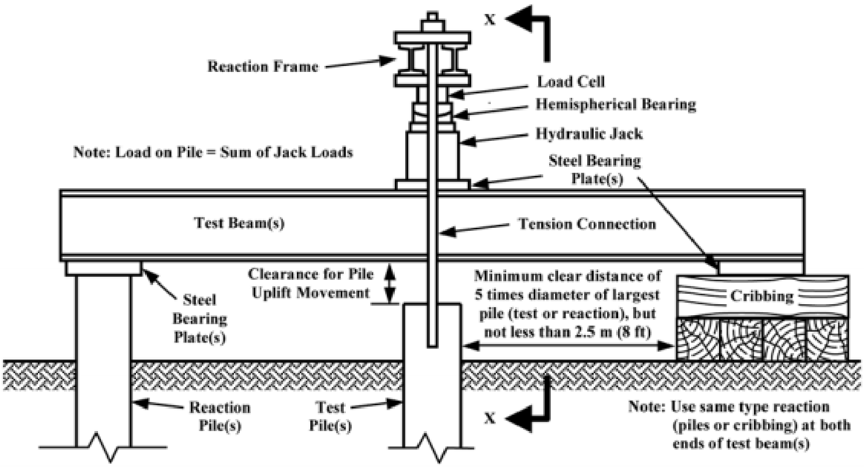


Fig 2.3 Typical Setup for Tensile Load Test Using Hydraulic Jack(s) Supported on Test Beams(ASTM : D3689 – 07)

2.4 Torsion of a pile

Most piles are deigned to carry static axial compressive loads coming from superstructures. They are rarely designed to carry torsional loads or stresses. However there are conditions where piles being subjected to torsional stress. To give an example, when pile in a pile group is exposed to an eccentric horizontal loading [16]

Pile foundation may also be subjected to dynamic loads in addition to the static loads. These dynamic loads can be induced due to excitation Caused by earthquake, machine foundation or traction braking heavy vehicles etc. Consequently the load induced might create torsional vibration in the pile foundation. It’s known that the primary purpose of pile foundation is resisting the axial vertical load .However when piles are exposed to torsional loads they have a tendency to reduce the axial carrying capacity by twisting it and hence leading to gradual increase in axially displacement. [26]

Several theoretical and experimental surveys show that torsional response of a single pile being affected by parameters like the dimension of the pile cross section, the properties of the pile material, the soil and the pile length.

Studies show that the shearing at the circumferential interface of pile soil plays a significant role in resisting the twisting moment (torque) developed.

When unbalanced loads act on massive constructions and structural elements like bridge piers, tall buildings, offshore platforms and communication towers, it tends to create an immense amount of torsional forces. The loads arising from ship impacts, braking of high-speed vehicles, storm and surge actions, and other sources of loading. If proper design measure is not undertaken the piles might face a serious damage and destruction under the serviceable load state. Leading to catastrophic damage to the structure built as whole. [26]

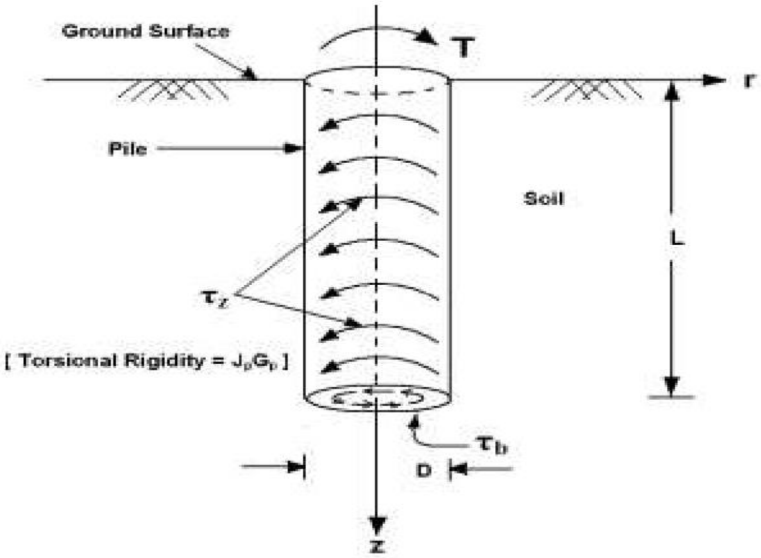


Fig.2.4 Idealized pile diagram

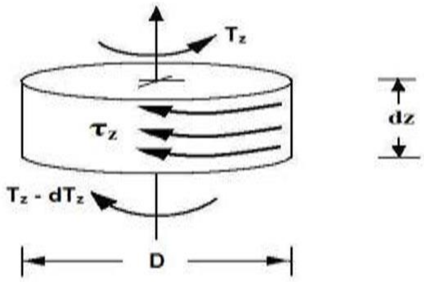


Fig.2.5 The pile element

A limited amount research is done in piles subjected to torsional loads. This is due to the complicated phenomena of shear stress in the soil pile interaction and lack of field test for analysis of the problem.[16]

2.4.1 Torsion on a circular shaft

Twisting of a body (rod) by applying a force tending to rotate one end or part about its longitudinal axis while the other side is held fast. For example wrench is using for tighten a nut on a bolt. The force applied can be changed in to torque as : T=F*L, N-m is SI unit of torque[15]

Simple torque : T=F X L…………………………….………………….(2.7)

2.5 Generation of shear stresses

From the figures below we can see how the shear stress is generated.

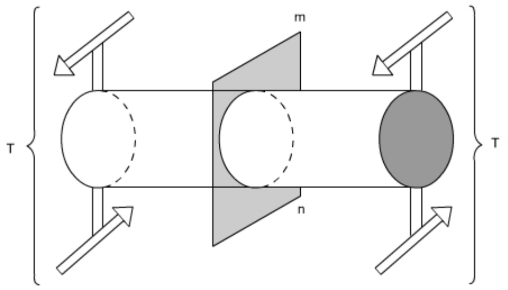
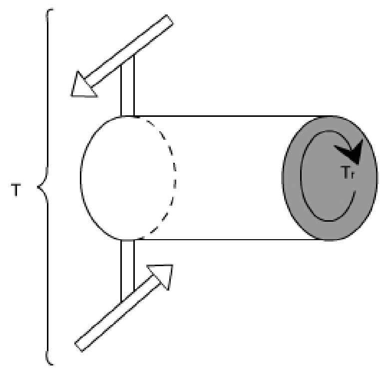


Fig 2.51 Cylindrical member where external torque T is acting on the cylindrical shaft and an imaginary plane mn to be cut to the member be imagined [15]



+

Fig 2.52 internal torque after portion of the shaft is cut by the plane"mn".

Before the section was cut the total shaft element was in equilibrium so each slice must be in equilibrium after cut of the section. So, the cylindrical member is in equilibrium resisting torque Tr developed due to under the action of resultant external torque. {nptel.ac.in}

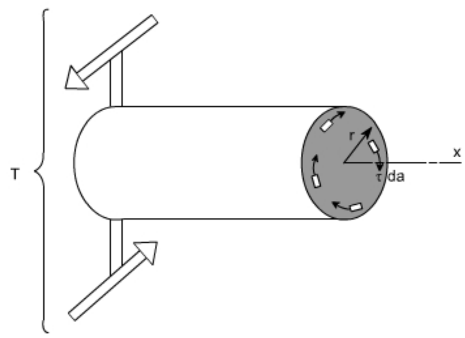


Fig 2.53 How counteracting torque T_r is developed shows in figure.

When an enormous amount of shear loads acts on the plane vertical to the axis of cylindrical member the resisting torque T_r is generated. Certainly the shear force developed induces shear stresses so; we can say that when we apply torque to a particular member there will be shear forces acting on any element. Although on other side the reciprocal shear force come into role. An element of these force subjected to a pure shear due to applying of torque. [15]

2.6 Twisting moment

It is total amount of moments of the applied couples that is found under one part of the section under consideration.

We can determine the magnitude of the ultimate torque from equation proposed as ,

$$T_u = T_{us} + T_{ub} \quad \text{……………………………………………(2.8)}$$

Where T_u= ultimate torque

T_{us}=ultimate value of the torsional shaft

T_{ub}=ultimate value of base resistance

T_{us} can be expressed by the equation given below after integration the whole height of the pile shaft as follow:

$$T_{us} = \frac{\pi}{2} D^2 \int_0^L Tu\, dz \quad \text{…………………………………………………….(2.9)}$$

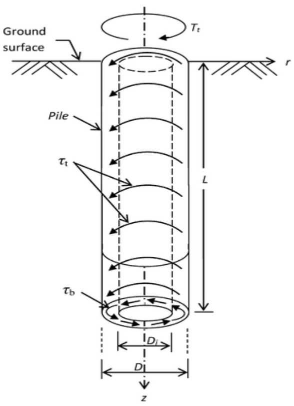


Fig 2.54 idealized diagram the twisting moment

2.7 Shearing strain

When a circular shaft gets twisted by a rotating or twisting moment, there will be a shift or displacement of the shaft diameter. The measure this displacement is called shear strain.

In order to illustrate these we can see in the figure 2.7 below, where marked line ab on the surface of the bar shifts to line 'ab' when a twisting moment 'T' is involved.with the torsions follows displacement of each elements of the bar. We call this displacement shearing strain, γ it is the displacement measured between final and initial position.from the figure below we can see the position of line 'ab' changing to ab' by γ. [15]

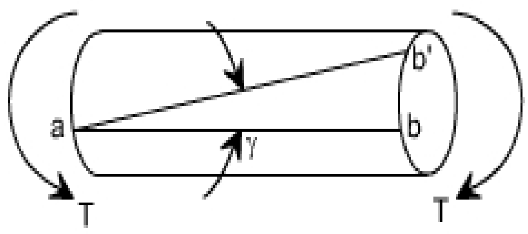


Fig.2.7 shaft subjected to shearing strain {nptel.ac.in}

2.8 Modulus of rigidity

Shear modulus or modulus of rigidity in shear is ratio of shear stress to shear strain. It indicates the materials response to a deformation caused by a shear stress. Modulus of shear is represented by the symbol of G. The derived SI unit is Pascal (Pa), usually it is expressed in giga pascal (GPa). [15]

2.9 Angle of Twist

When a constant turning torque is induced in a shaft or bar of length it tends to twist the bar shifting the position of each element in the shaft. The angle at which these rotations occur is called angle of twist. Its denoted by angle, θ. θ is in radian.[15]

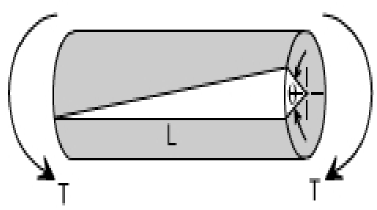


Fig.2.8 shaft under torsional force {nptel.ac.in}

2.10 Relationship in torsion

$\frac{\bar{C}}{R} = \frac{T}{J} = \frac{G\theta}{L}$……………………………………….(2.10)

- Where,
- Ƈ=Shear stress (Mpa)
- R=radius of cross-section of circular shaft (m)
- T=torsion force(N-m)
- J=polar moment of inertia (m^4)
- J== $\pi/32(D^4 - d^4)$
- D=external diameter
- D=internal diameter
- G=shear modulus (GPa)
- θ= angle of twist(radian) (1 radian=$\frac{180}{\pi}\, degree$)
- L= length of the embedded shaft (m)

CHAPTER 3

3. Experimental setup and Model tests

3.1 pit construction

Tests under axial pull out and torsion have been carried out on tubular mild steel model piles. The test was conducted in soil mechanics laboratory in a pit constructed previously. Fig below shows the real image, cross sectional, planar and side view of the pit. Pit was constructed by my senior Ombir tomar.

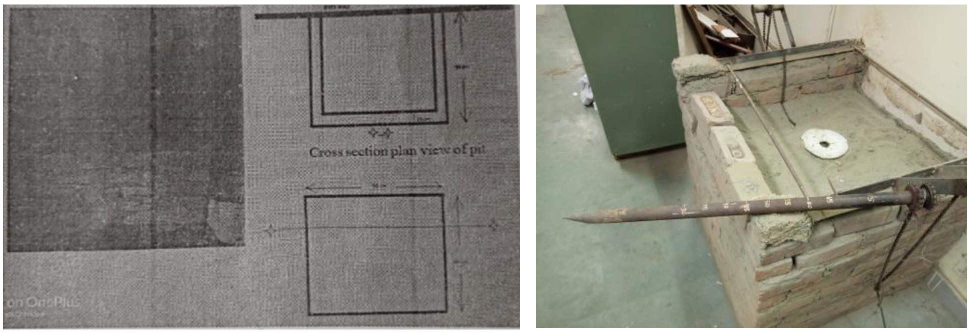


Fig 3.1 pit used from different view(side ,top and left side view)

The size of the pit was 98cm x 98cm x 85cm. material used for construction of the pit was cement, fine aggregates, coarse aggregates and bricks. Only three sides of the pit were constructed, fourth side was wall of laboratory.

3.2 soil property

The test was conducted on dry Yamuna sand. The Yamuna sand was brought from the building material shop near DTU. The sand was deposited in the pit in three layer. Each layer of dry sand being allowed to fall to the pit from height of 1.5m.this process was done for three consecutive layers.

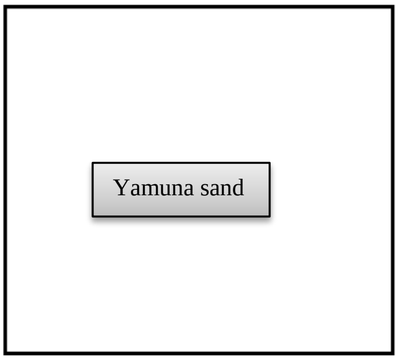


Fig 3.2 pit with Yamuna sand

3.3 Model pile

The pull out Tests was carried out on piles. The shaft was made of Mild steel closed pipe with the tip of pile being pointed (cone shape tip).The diameter of the steel pile used was 30mm with length 900mm.

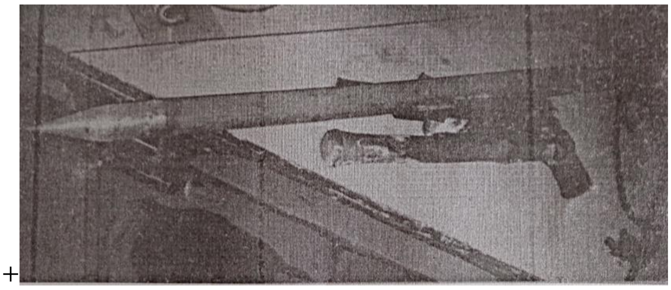
+

Fig 3.3 mild steel model pile

Fig 3.4 pile with a diameter 30mm

3.4 fixing the girders or inclined pulleys in position

After filling the Yamuna sand was completed, it’s time to placing the girders on the wall of the pit. They had used two T-shaped steel channel sections. Length of steel channel section was 1.10m.each girder was placed on the pit wall and hold fasted about 10cm inside the laboratory wall. Pulleys were welded with the T-Shaped channel section at an angle of $45^0$with vertical.

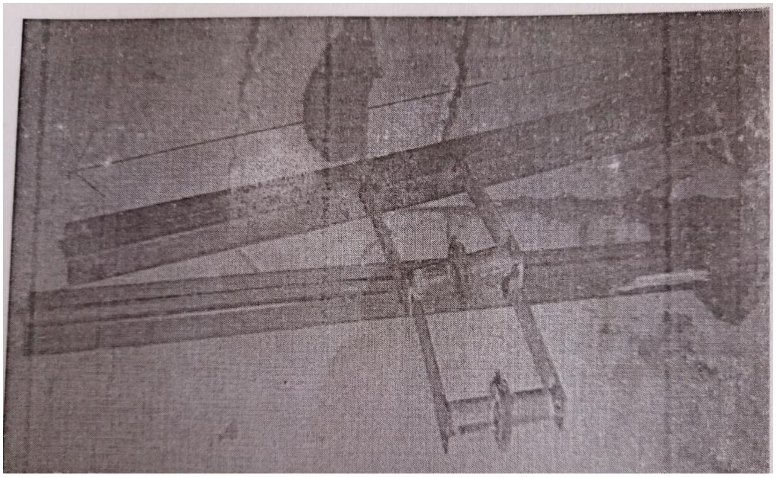


Fig 3.5 girder of length 1.10m

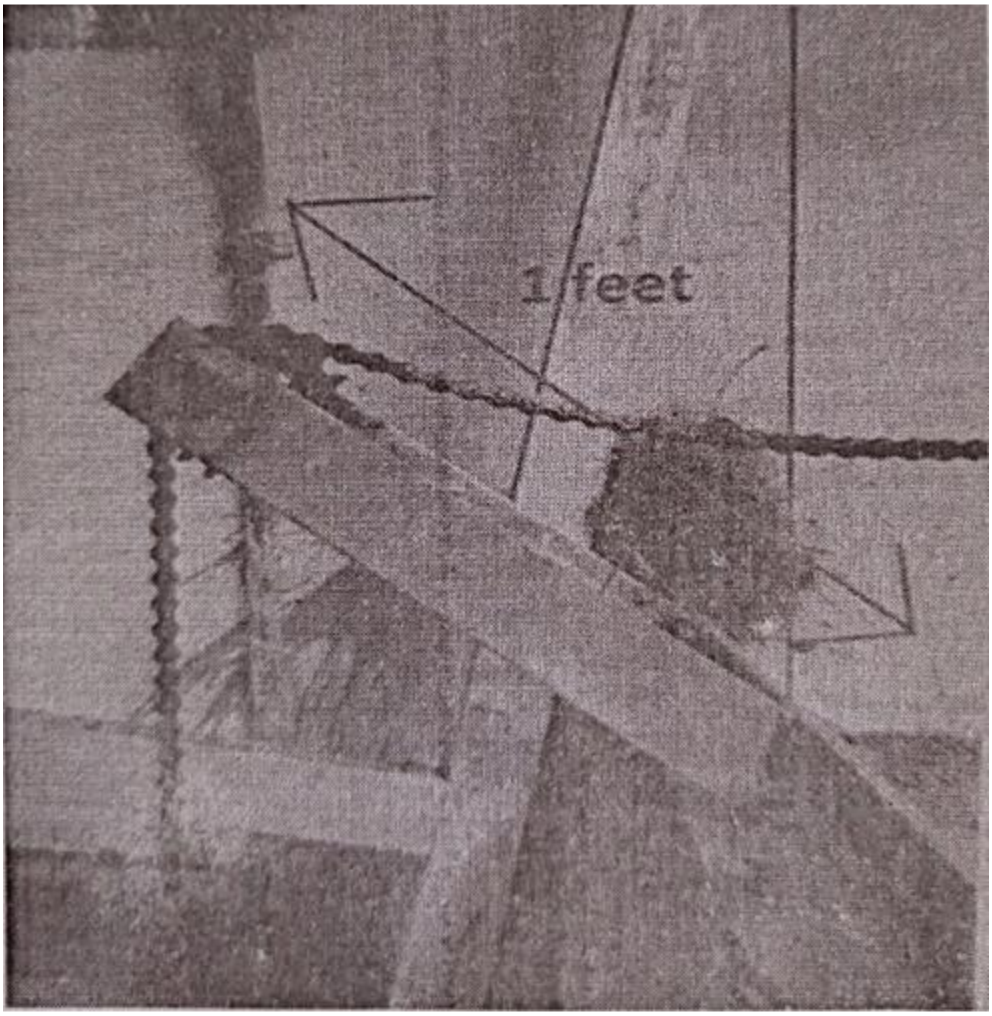


Fig 3.6 pulley inclined at 45^{O} with vertical and girder fixed on the top of the wall of pit

3.5 Procedure of the pull out test

Pulleys, High tension bearing wires and weight are used for the pull out of pile. The mechanism was made in such a manner that when we hang equal weight both side of the high tension wire, additive pull out force acting on the pile in axial direction.

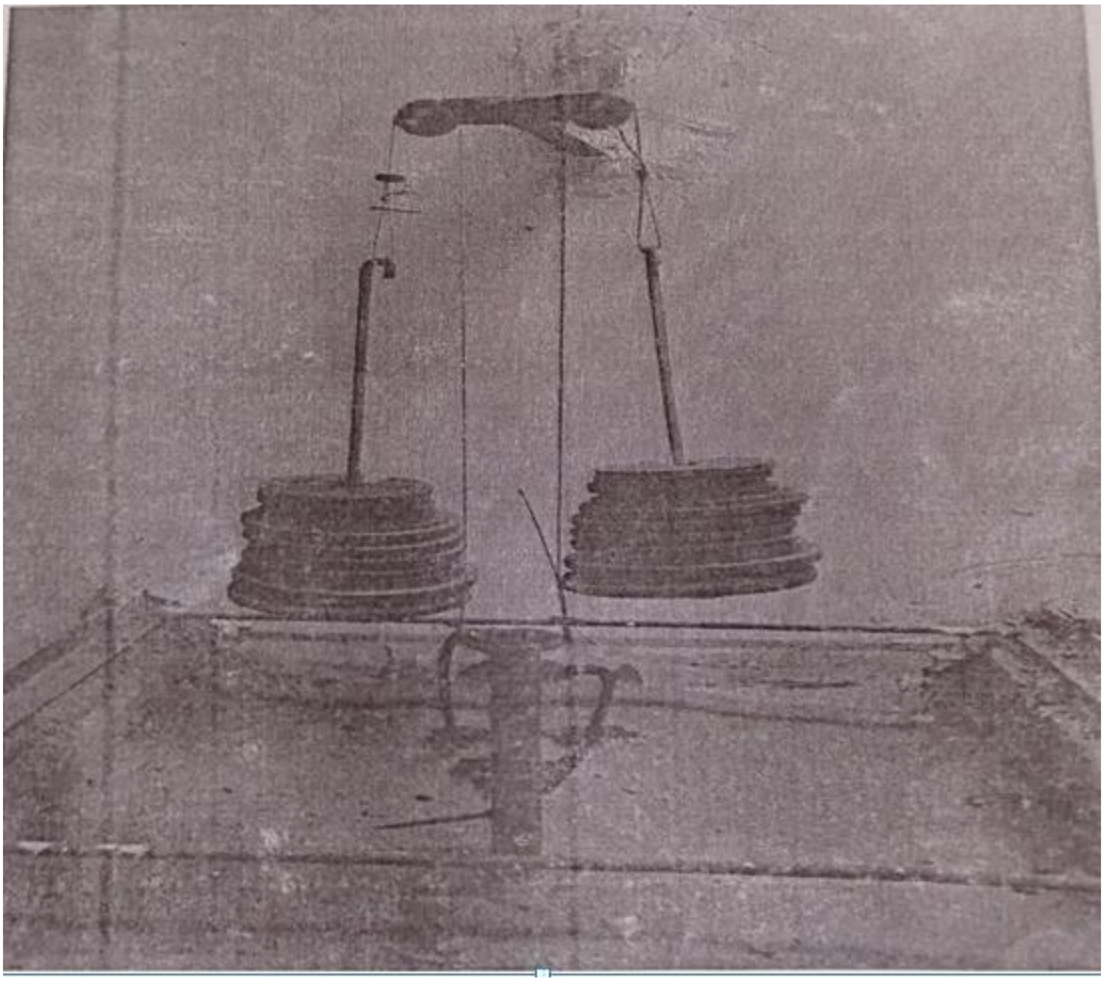


Fig 3.7 full set up of pull out test

When load on high tension wire hang was increased, pull out force acting on pile was also increased simultaneously. When load increased up to a limit pile suddenly came out from Yamuna sand.

3.6 Procedure for torsional test

Top end of steel was welded with two sprockets. Sprockets were welded from top and bottom with pile and chain was also wrapped around it. The system followed is that additive torsional force was produced when same forces apply on both the chain. Steel pile was rotated when additive torsional force acting on pile.

Fig. 3.9 complete vied of the test setup

Chain was in tension when we hanged the load on both sides of the chain. As we increased the load, Torque acting on pile also increases at the same time. When torque was produced by hanging load, pile rotates on its longitudinal axis and angle of twist also come out on scale as shown in figure 3.10

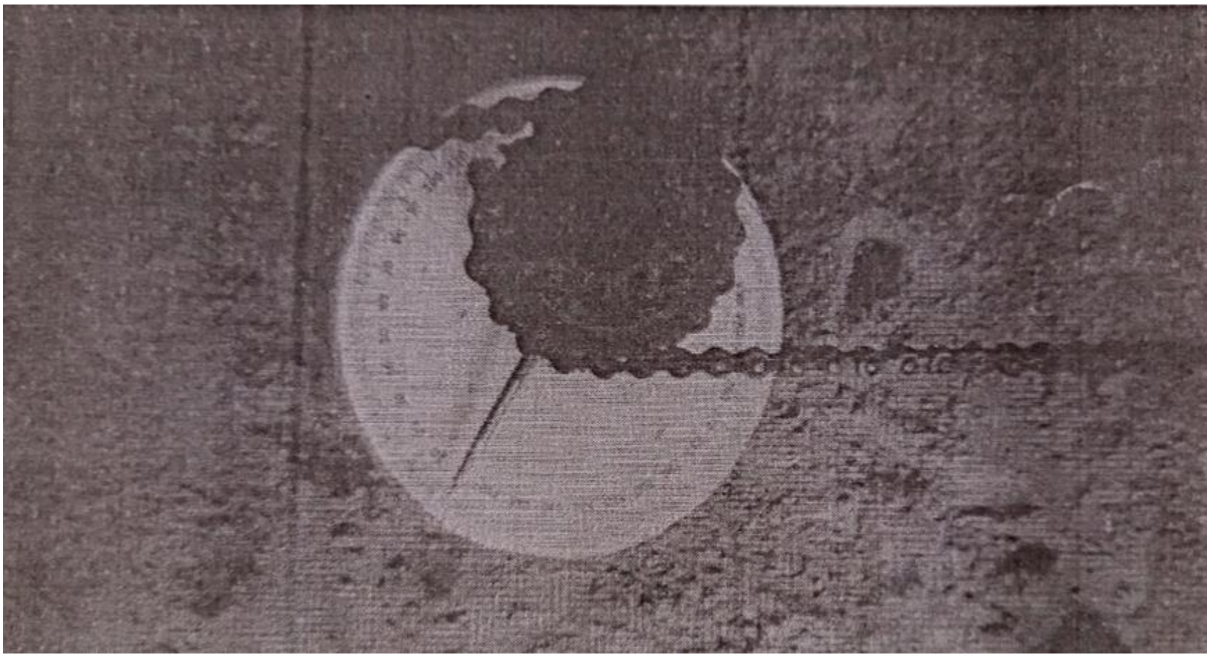


Fig. 3.10 angle of twist (in degrees)

3.7 Experimental procedure

3.7.1 For pull out test

Mechanism was made in such a manner that standard weight loaded with the help of high tension wire and pulley. Photo show the mechanism of pull out of pile. Pull out test was performed on different depth of the pile. Skin friction of pile was calculated at different depth of pile.

Pull out of pile from Yamuna sand at which weight was noted in field book.

Mathematically,

Static formula method

Qu=Qb+Qs

Qu=qb.As + f.As

Qb.Ab=0

f = $\frac{Qu}{As}$

f = $\frac{Qu}{\pi DL}$

Where,

A= pile surface area(m^2)

A_b = Area of pile base (m^2)

f = skin friction resistance by pull out test (N/m^2)

Q_u= ultimate load bearing capacity of pile

Q_b= unit bearing pile

D = diameter of pile

L= length of pile

3.7.2 for torsion test on the pile

Standard weights was loaded and hung on the tension wires and this tension wires were connected to the pulley system. The mechanism was shown in photos. Experiment was done on loose Yamuna sand. After setting the wire and the pulley in position load was placed and increased gradually. When we apply torsion on piles, piles start rotating at incremental load and it was observed that the angle of twist also increased. Skin friction of pile was also finding out by torsion method. By torsional test on pile we find the skin friction on pile at different depth and different angle of twist.

Mathematically,

F= m1.g + m2.g

F= f $\times \pi \times D \times L$

$$f = \frac{F}{\pi \times D \times L}$$

where,

F= Applied force

m_1= load on first hanger

m_2= load on second hanger

f=skin friction resistance (N/m^2)

D=external diameter

L= length of pile

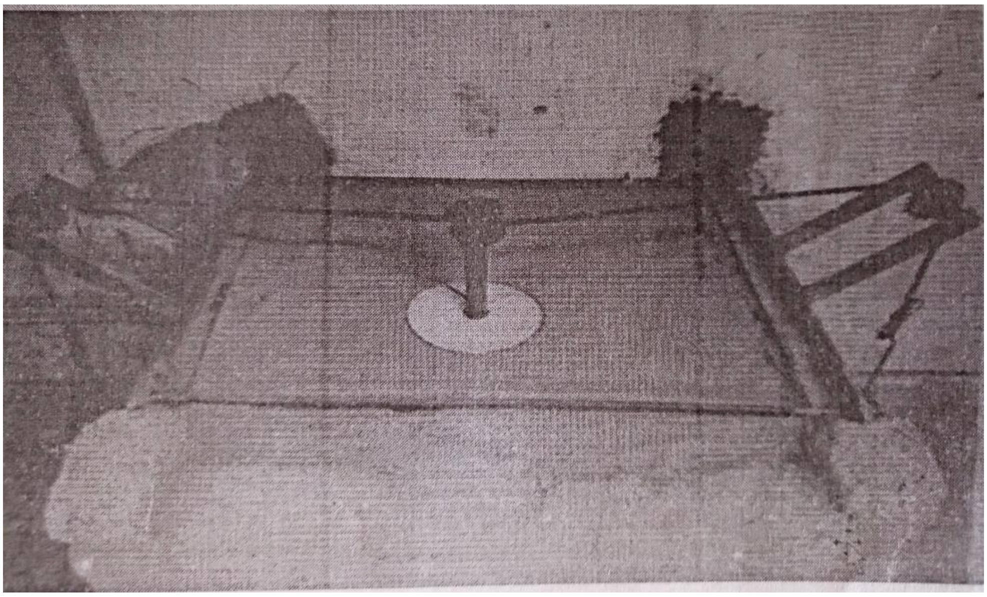


Fig. 3.11 top view of the load setup of for torsion test pile

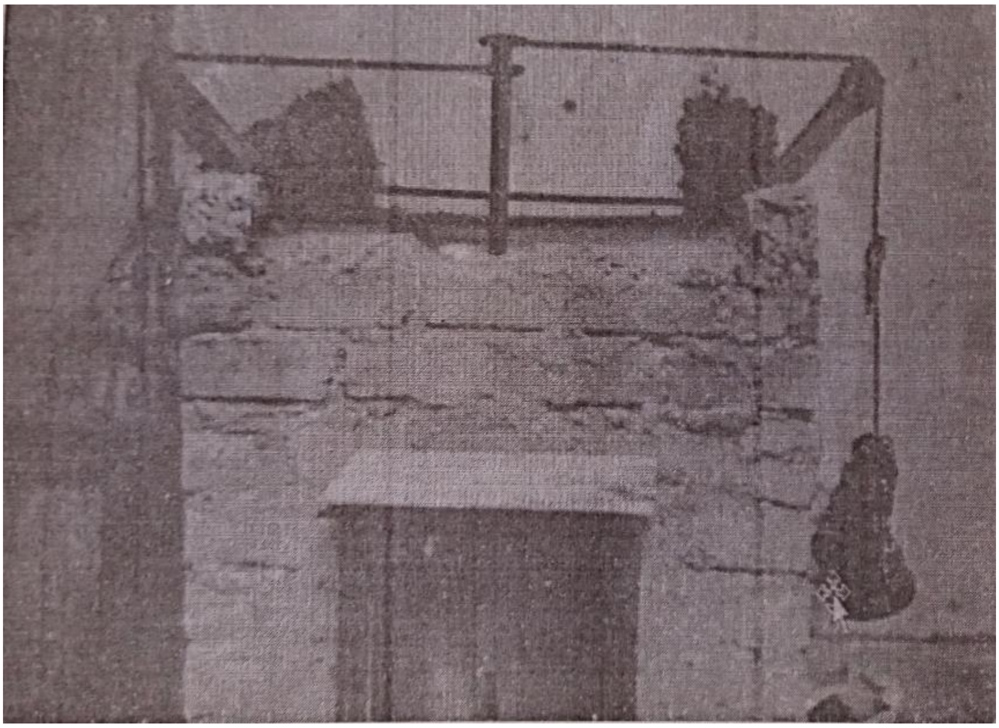


Fig 3.12 Elevation view of load setup of for torsion test pile

Chapter 4

4.Result and Discussion

4.1 sieve analysis

Sieve analysis of Yamuna sand was done in laboratory and observation sheet was prepared as follows:

S.No	IS sieve	Mass retained(g)	% retained	Cumulative % retained	Cumulative % finer(N)
1	4.75	0	0	0.00	100
2	2.36	2.6	0.26	0.26	99.74
3	1.18	4.70	0.47	0.76	99.24
4	600	8.75	0.88	1.67	98.33
5	300	154.25	15.43	17.64	82.36
6	150	740.80	74.08	94.34	5.66
7	75	54.60	5.46	100	0.00

Table 4.1 sieve analysis

4.1.1 Grain size distribution curve

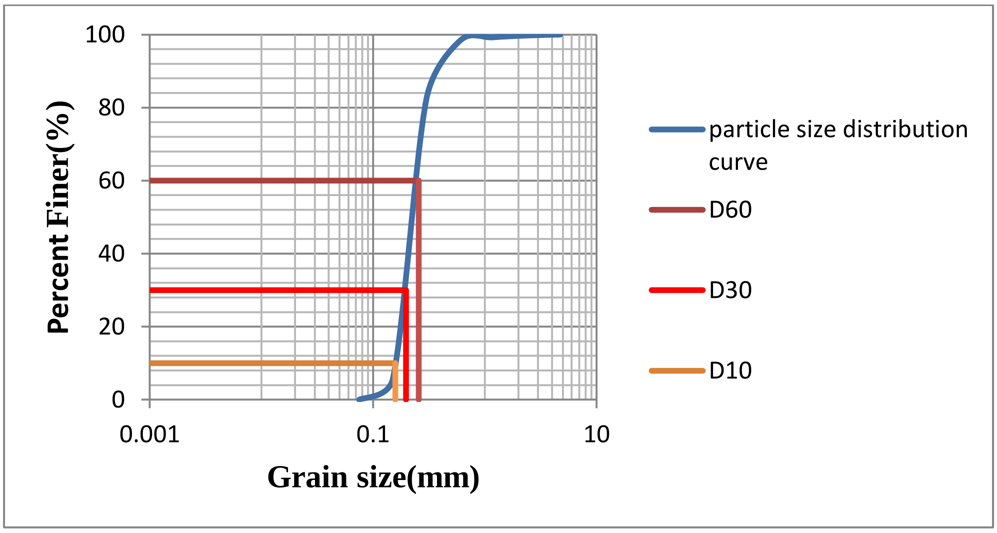


Fig 4.1 grain size distribution curve for Yamuna sand

From observed grading curve,

D_{60}=0.256mm

$D_{30=}$0.197mm

D_{10}=0.158mm

Effective size=D_{10}= 0.158 mm

Uniformity coefficient, Cu = $\frac{D60}{D10} = \frac{0.256mm}{0.158mm} = 1.62$

Curvature coefficient, Cc= $\frac{(D30)^2}{(D10D60)} = \frac{0,197}{0.158*0.256}^{2} = 0.959$

From Cu and Cc result we can conclude that the sand is poorly graded

Coefficient of uniformity, Cu	1.62
Coefficient of curvature, Cc	0.959
Gradation of soil	Poorly graded
Relative Density, Dr (%)	32
Unit Weight, (KN/m3)	15.38

Table 4.1 b, detail of Yamuna sand

4.2 Model steel pile for pull out test

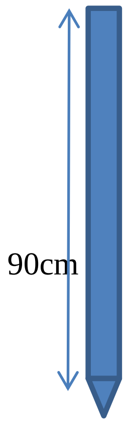


Fig 4.2: Dimensions of steel pile

1. pile length = 90cm

2. outside pile diameter = 3.5 cm

3. pile thickness = 3 mm

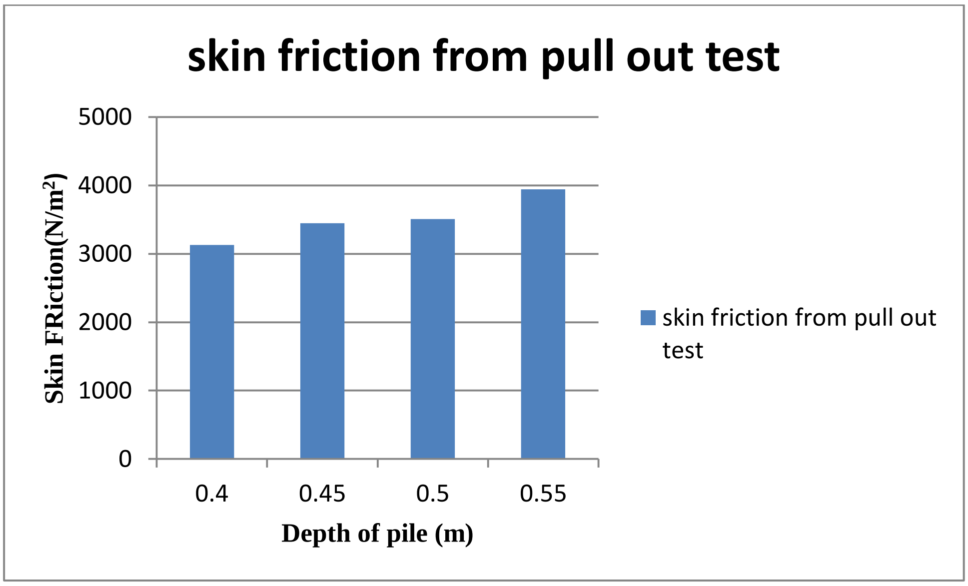
4. Mass of pile = 6.79 Kg

5. f = skin friction resistance by pull out test (N/m^2)

f = $\frac{Qu}{As} = \frac{Qu}{\pi DL}$

S.No	Pile depth inside sand(m)	Pile diameter(m)	Pull out mass (Kg)	Pile mass(kg)	Net pile pull out mass (kg)	Force= mg	Skin friction=f(N/m^2)
1	0.40	0.035	20.81	6.79	14.02	137.54	3128.75
2	0.45	0.035	24.17	6.79	17.38	170.50	3447.93
3	0.50	0.035	26.43	6.79	19.64	192.67	3506.28
4	0.55	0.035	31.08	6.79	24.29	238.28	3942.42

Table 4.2 skin friction of pile for different depth of pile inside yamunna sand



Graph 4.1: Variation in skin friction of pile at different depth inside sand

4.3 Experimental study of single pile for torsional test

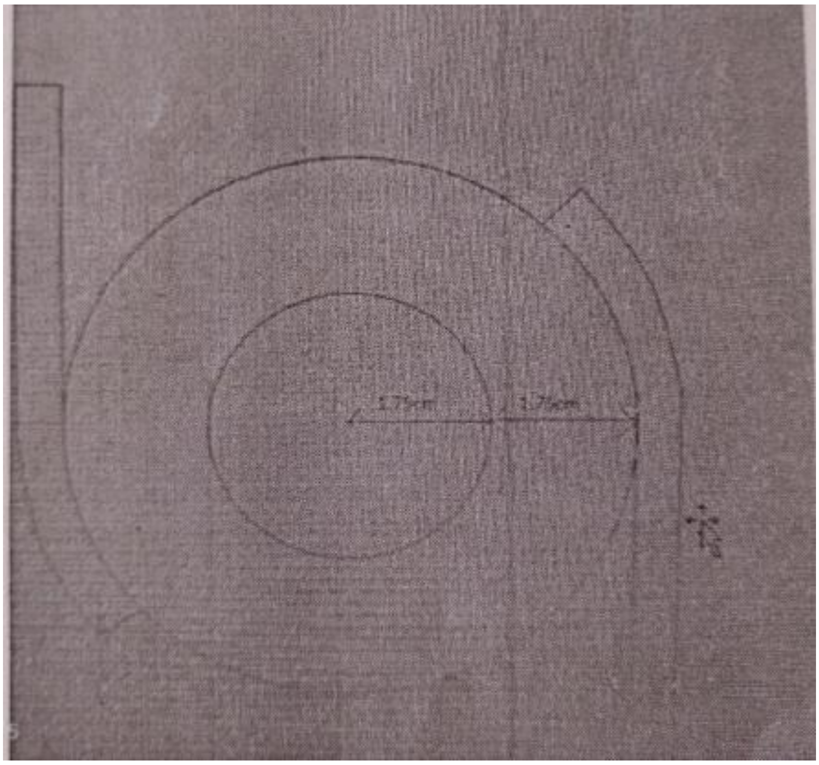


Fig 4.2 dimension of pile with sprocket

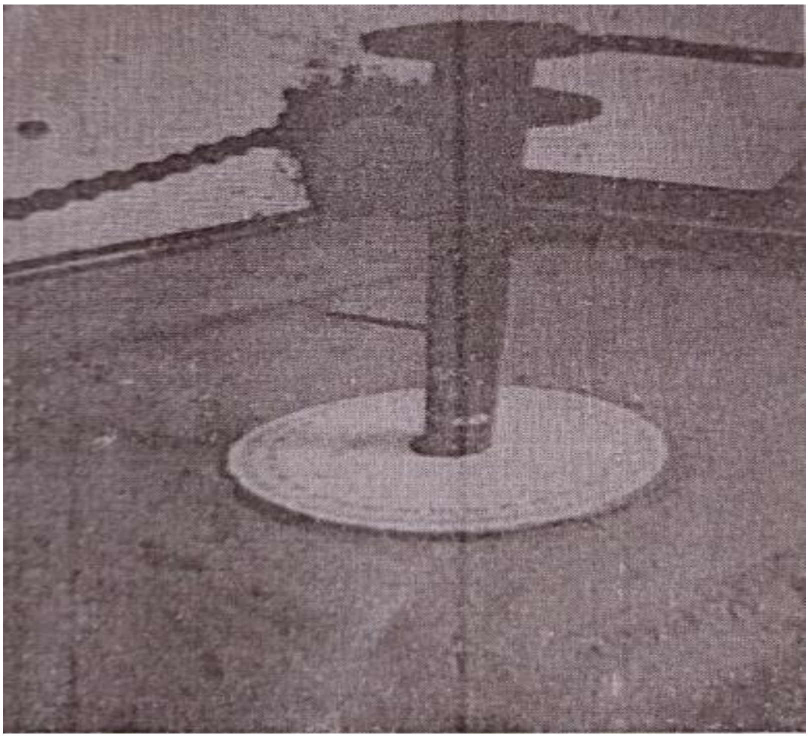


Fig 4.3 pile inside Yamuna sand up to depth 55 cm

1.pile length=90cm

2.external pile diameter =3.5cm

3.angle of twist=2^0

4.Pile thickness =3mm

5.length from center of pile r = 3.5cm

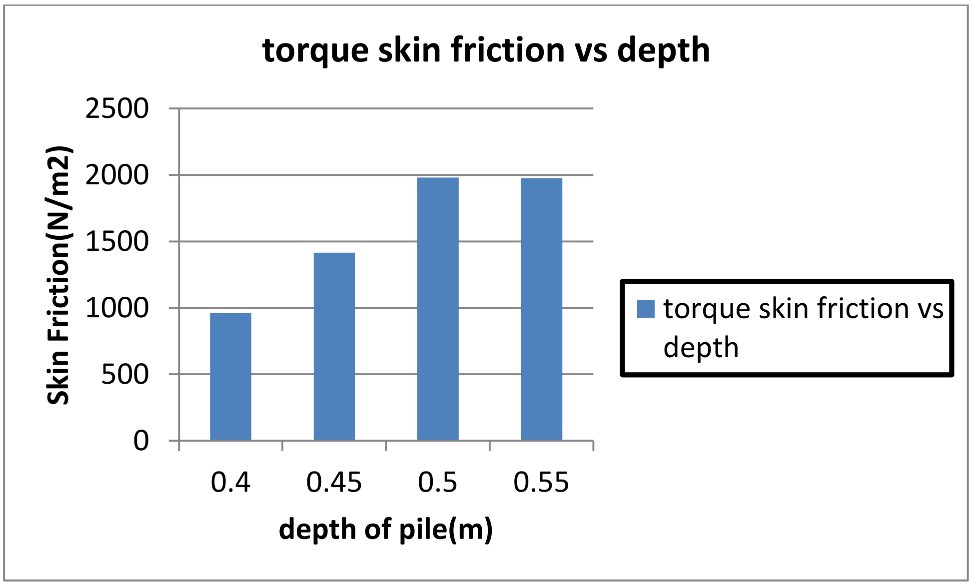
6.skin friction by torsional test(N/m^2)

$F=f_o \times \pi \times D \times L$ [$r_{pile} \times f_o \times \pi \times L = 2 \times F \times 3.5$ where r_{pile}=1.75cm]

$$f_o = \frac{F}{\pi X D X L} \times \frac{3.5}{1.75} = \frac{F}{\pi X D X L} x2$$

S.NO	Pile depth inside sand (m)	Angle of twist(θ)	Total mass on both hanger	Total force(F)=mg, (N)	Skin friction=fo	Final skin friction=2xfo
1	0.4	2^0	4.3	42.18	959.51	1919.02
2	0.45	2^0	7.13	69.95	1414.42	2828.84
3	0.5	2^0	11.1	108.89	1981.62	3963.24
4	0.55	2^0	12.17	119.39	1975.18	3950.36

Table 4.3: skin friction of pile at an angle of twist $2^0$for different depth of pile



Graph 4.2: Variation in skin friction of pile at angle of twist 2^0 for different depth of pile inside sand

1. pile length = 90 cm

2. External pile diameter = 3.5 cm

3. Angle of twist = 7^0

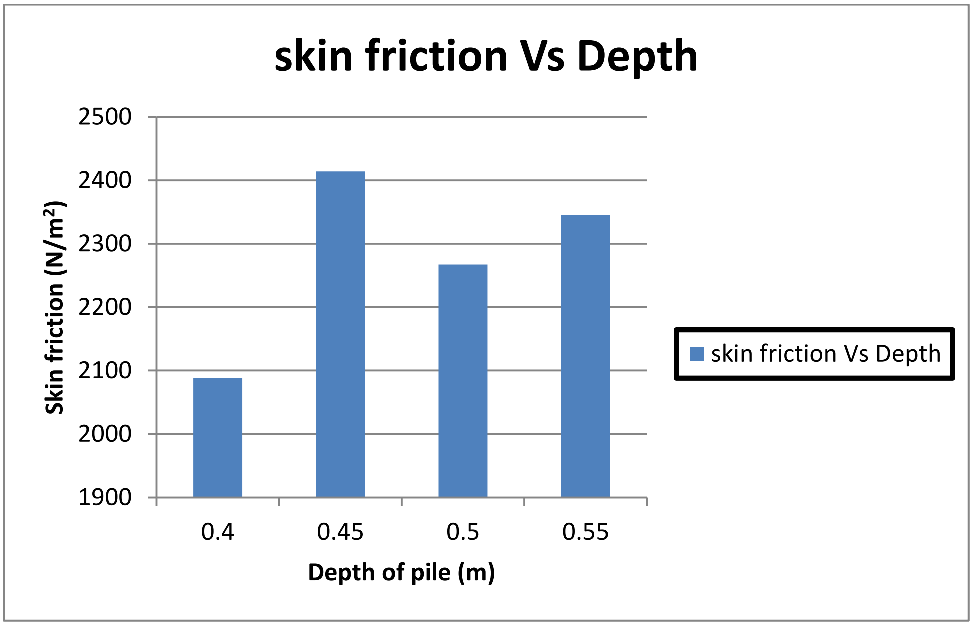
4. Pile thikness = 3mm

5. r = length from center to center of pile = 3.5 cm

6. f_o= skin friction by torsional test(N/m^2)

S.NO	Pile depth inside sand (m)	Angle of twist,θ(degree)	Total mass on both hanger	Total force(F)=mg, N	Skin friction=fo	Final skin friction=2xfo
1	0.4	7	9.36	91.82	2088.72	4177.44
2	0.45	7	12.17	119.39	2414.11	4828.22
3	0.5	7	12.7	124.59	2267.33	4534.66
4	0.55	7	14.45	141.75	2345.11	4690.22

Table 4.4: Skin friction of pile at angle of twist 7^0 for different depth of pile



Graph 4.3: Variation in skin friction of pile at angle of twist $7^0$for different depth of pile inside sand

1. pile length = 90 cm

2. External pile diameter = 3.5 cm

3. Angle of twist = 10^0

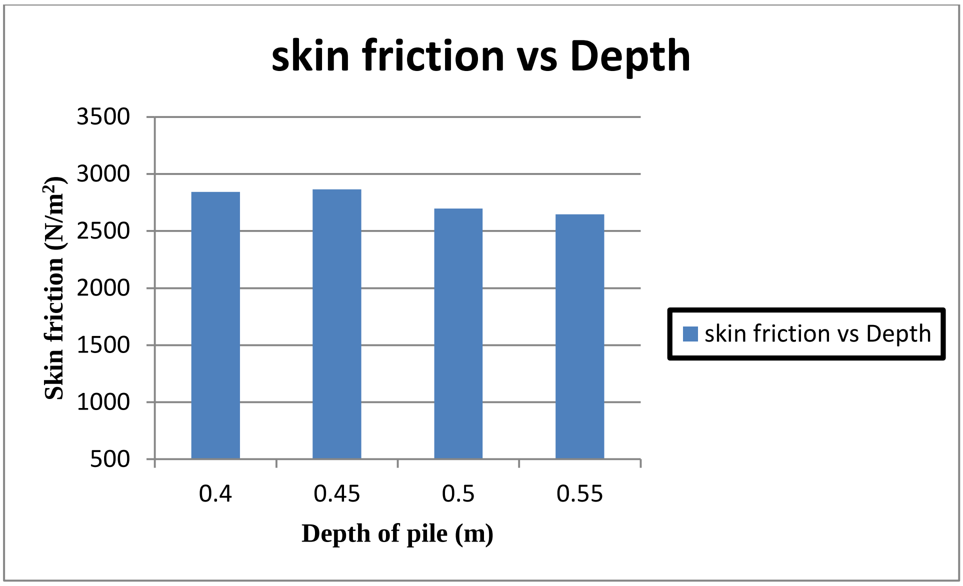
4. Pile thikness = 3mm

5. r = length from center to center of pile = 3.5 cm

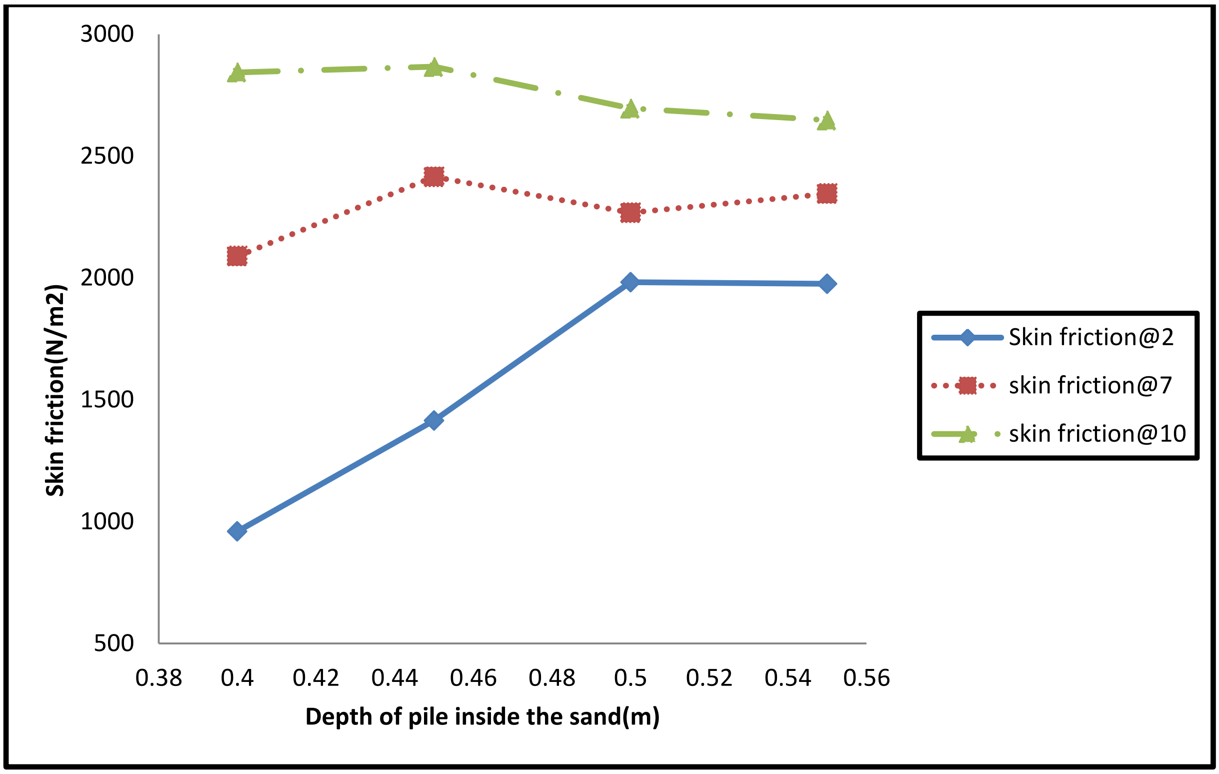
6. f_o= skin friction by torsional test(N/m^2)

S.NO	Pile depth inside sand depth (m)	Angle of twist(θ)	Total mass on both hanger	Total force(F)=mg, N	Skin friction=fo	Final skin friction=2xfo
1	0.4	10	12.74	124.98	2843.04	5686.08
2	0.45	10	14.45	141.75	2866.24	5732.48
3	0.5	10	15.1	148.13	2695.72	5391.48
4	0.55	10	16.31	160	2647.03	5284.06

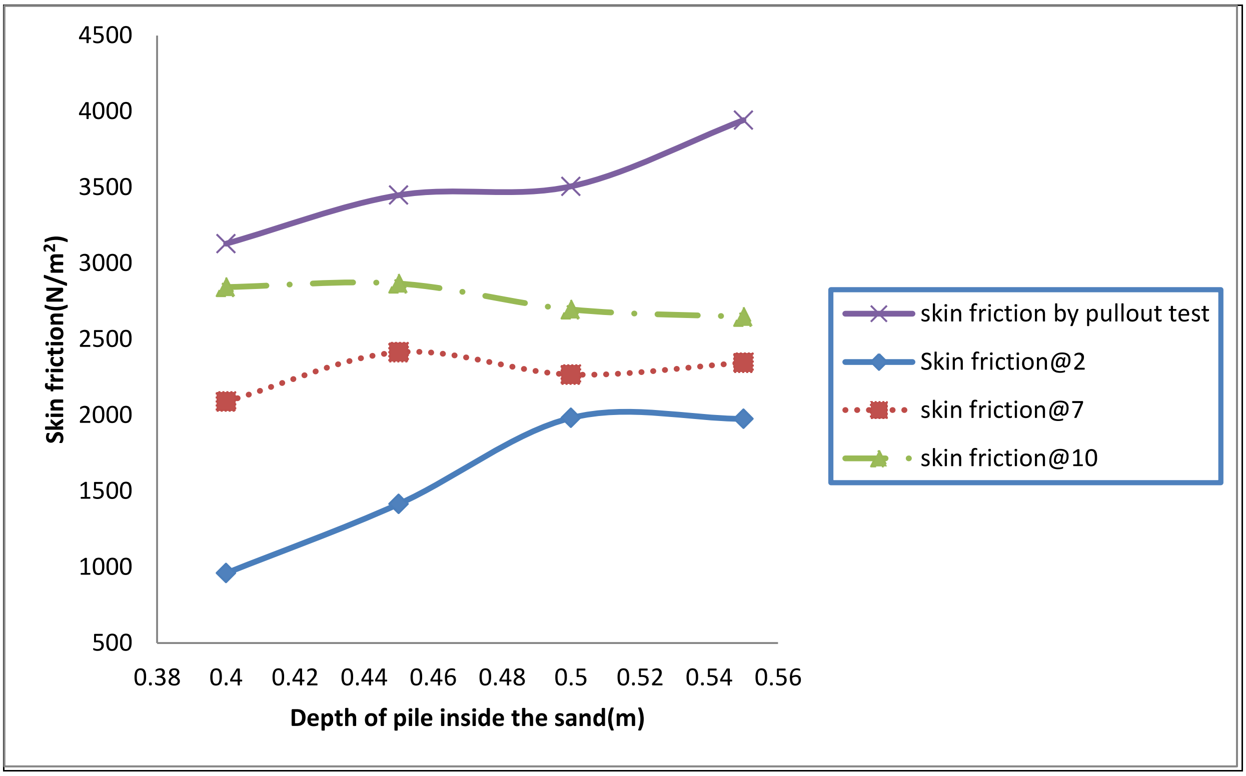
Table 4.5: Skin friction of pile at angle of twist 10^0 for different depth of pile



Graph 4.4: Variation in skin friction of pile at angle of twist 10^0 for different depth of pile inside sand



Graph 4.5: Variation in skin friction of pile at different angle of twist and depth inside the sand



Graph 4.6: Variation in skin friction of pile by pull out and torsional test

Chapter 5

Conclusion

In this project an attempt was made to study the side resistance a single model steel pile from pull out and torsional test under different embedment depth and loading condition. Depending on the examined test results the following conclusions are drawn:

1. Skin friction plays important role in resisting loads arising from uplift load and torsional load.it is expressed in N/m^2

2. It is observed from the test that skin friction of pile in pull out test, increase with increase in depth of pile inside the Yamuna sand.

3. It is also observed that skin friction of pile in torsional test increases with increase in angle of twist.

4. Torsional force also increase with increase in depth of the pile inside the sand.

5. in torsional test, as we go further down the embedment depth the angle of twist gets decreasing.

6. Several factors such as relative density of sand, method of installation, shape of the pile, surface of the pile, the embedment depth have significant effect on the average unit skin friction of the pile

7. Main conclusion of my thesis is skin friction by pull out test and by torsional test at 2^0 is almost same.

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