A Project Report on

# SOIL STABILIZATION BY USING MICROPILE

Submitted in partial fulfillment of the requirements
for the degree of

**BACHELOR OF ENGINEERING**

in

**CIVIL ENGINEERING**

by


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# CERTIFICATE

This is to certify that the project entitled **"Soil Stabilization using micropile"** is a bonafide work of **Mr. Aniket Tuse (14CE61)**, **Mr. Zaid Abdullah (14CE63)** and **Mr Mohd. Mahboob (15DCE65)** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of Bachelor of Engineering" in "Civil Engineering"

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# APPROVAL SHEET

This project report entitled “Soil Stabilization using micropile” by Aniket Tuse, Zaid Abdullah and Mohd. Mahboob is approved for the Bachelor’s degree of “Civil Engineering

Examiners

1. …………………………
2. …………………………

Supervisors:

1. …………………………
2. …………………………

Date:

Place: Panvel

# DECLARATION

I declare that this written submission represents my ideas in our own words and where others ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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# ABSTRACT

Micropiles have been primarily used as foundation support elements to resist static and dynamic loadings, and to a lesser extent, to provide reinforcements to the stabilization of slopes and excavations. Micropiles have been used effectively in many applications of ground improvement to increase the bearing capacity and stabilization of slopes.

The purpose of this study is to determine fundamental design guidance for using micropiles for the stabilization of slope by performing slope stability analyses referring manual or codal provisions, Construction and installation of Micropile is also discussed. The study gives a brief idea about the optimum angle of inclination of micropile to resists the horizontal force for different soil samples having different cohesive properties and angle of friction.

Keywords: Micropile, Soil Stabilization, Slope Stability, Cohesion

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# ABBREVIATION NOTATION AND NOMENCLATURE

| | |
|---|---|
| IWM | International workshop for micropiles |
| SLD | Service load design |
| LFD | Load factor design |
| DST | Direct shear test |
| UCS | Unconfined compression |
| ASTM | American society for testing and materials |

# Chapter 1

# Introduction

## 1.1 General

A micropile is a small diameter drilled and grouted pile that is typically reinforced. The diameter is usually less than twelve inches and this type of pile would be considered a non-displacement pile. Micropiles can be installed at any angle, where access is restrictive, and in virtually all soil types and ground conditions. Micropiles are used for slope stabilization to provide the necessary restraining forces to structurally support the slope. Battered, and possibly vertical, micropiles are installed through the unstable slope to a designed depth below the failure surface to establish a system. In doing this, the micropiles provide axial, shear, and bending resistance. Most importantly, they help resist the shear forces that develop along the failure surface.

Since mankind started to design and build structures for different usages and environments, foundation systems to support such structures had to be developed in order to match the architectural and structural needs. With the ever-increasing urban expansions, it is not always possible to find good supporting ground at or close to surface level. Therefore, foundations other than spread footings were designed to transfer compression loads down to a suitable load-bearing stratum. Higher and slender structures subjected to wind and seismic loads need foundations capable to support compression as well as uplift and lateral forces. Instead of large, mass concrete foundations, which require large areas and mass excavations, smaller and deeper drilled shaft or pile foundations became a more economical alternative, in which steel reinforcing systems embedded in concrete and cement grout are the major component. Micro Piles belong in this category of foundation elements. They are very simple but unique in design and construction and are becoming more and more popular.

Micropiles have been used effectively in many applications of ground improvement to increase the bearing capacity and reduce the settlements particularly in strengthening the existing foundations. Frictional resistance between the surface of the pile and soil and the associated group/network effects of micropiles are considered as the possible mechanism for improvement. Full-scale field use of micropiles for slope stabilization has proven the method to be technically effective, but uncertainties in load transfer mechanism have prevented more widespread implementation. Designers often adopt conservative position because of these uncertainties, which fuels the perception that use of micropile is cost-prohibitive.

## 1.2 Background of study

Since its original conception in the 1950's by Dr. Fernando Lizzi, a number of micro pile systems using steel-bar reinforcement / cement grout combinations with or without steel pipe casing, have been developed. Lizzi's idea was, to produce a foundation system consisting of small pile groups, which form a reinforced soil mass like the root system of a tree. He called these Pali Radice or "Root Piles" Further developments using different installation methods and reinforcing systems made it necessary to capture them all under a general heading, first "Mini-Piles", which was later changed to "Micro Piles". With the creation of the International Workshop for Micro piles (IWM), first in North America and later internationally, Micro-Pile became a household name in the Geotechnical and foundation industry. They are mainly used as Friction Piles to take tension and / or compression loads.

## 1.3 Advantages

- Fast one-step installation
- Simultaneously drilling and grouting

- Allows use of smaller equipment at lower cost
- Offers higher skin friction
- Vibration free drilling: Bore holes can be drilled without damaging adjacent structures
- Foundation element for any ground condition: Compressive and tensile loads can be transferred to the underground by skin friction along the grout body
- Environmental friendly: Do not require large access roads or drilling platforms
- Offers practical and cost-effective solution to costly alternative pile system as well as a solution to job site with difficult access

## 1.4 Aim

In this study we are optimising the angle of inclination of micropile to resist maximum horizontal load.

## 1.5 Objective

- To find out different physical properties of various soil sample.
- To find out the ultimate vertical resisting force and horizontal resisting force by varying the length of micropile.
- To optimise the angle of inclination of micropile with respect to vertical axis which is best suited for practical use in field.

# Chapter 2

# Literature Review

## 2.1 General

During the literature review for this work, we referred quite a few books on soil, technical and research papers from various national and international journals. This part focuses on the literature of improvement of soil stabilization using micropile.

## 2.2 Relevant Literature

Cantoni and Collotta (1989), This article describes a design method for reticulated micropile structures adopted to stabilise sliding slopes. The method is based on the assumption that the structure behaves as a composite block. This assumption can be considered valid for structures built with closely spaced micropiles having appropriate arrays and well differentiated vertical inclinations. The method analyses the stability of the structure with respect to three possible failure mechanisms, evaluating the relevant partial safety factors which have to be added to the main safety factor considered in the determination of the landslide thrust. The results obtained show that, in spite of the closely spaced array and the large number of micropiles used, the stresses in the components of the structures are close to the allowable values.

Poulos (1995) Canadian Geotechnical Journal has described an approach for the design of piles to reinforce slopes, involving three main steps: (1) evaluating the shear force needed to increase the safety factor to the desired value; (2) evaluating the maximum shear force that each pile can provide to resist sliding of the potentially unstable portion of the slope; and (3) selection of the type and number of piles, and the most suitable location of these piles within the slope. For step 1, stability analyses can be used to assess the required additional shear force for stability. Step 2 involves the use of a computer analysis for the response of a pile to laterally moving soil. This analysis can be implemented via a computer program ERCAP and enables the resisting shear force developed by the piles to be evaluated as a function of pile diameter and flexibility and the relative depth of the soil movement in relation to the pile length. Step (3) involves the use of engineering judgement in conjunction with the analysis results from steps 1 and 2. The paper describes the ERCAP analysis and the characteristics of pile behaviour it reveals. The application of the approach to a highway bypass problem in Newcastle, Australia, is described in detail. In the final design, a total of 64 bored piles 1.2 m in diameter were used over a total length of slope cutting of about 250 m. The pile lengths ranged between 6 and 12 m, with the spacings varying between 3.2 and 6.0 m. Key words: analysis, boundary element, piles, soil–pile interaction, slope stabilization, soil mechanics.

Dr Kelley (2000) has discussed implementation of micropile technology on U.S. transportation projects has been hindered by lack of practical design and construction guidelines. In response to this need, the FHWA sponsored the development of this Micropile Design and Construction Guidelines Implementation Manual. Funding and development of the manual has been a cooperative effort between FHWA, several U.S. micropile specialty contractors, and several State DOT's. This manual is intended as a "practitioner-oriented" document containing sufficient information on micropile design, construction specifications, inspection and testing procedures, cost data, and contracting methods to facilitate and speed the implementation and cost-effective use of micropiles on United States transportation projects. It provides a general definition and historic framework of micropiles. IT also describes the newly developed classifications of micropile type and application and illustrates the use of micropiles for transportation applications. Also, it discusses construction techniques and materials and presents design methodologies for structural foundation support for both Service Load Design (SLD) and Load Factor Design (LFD) which was supposed to present a design methodology for slope stabilization, is not included in this version. Further it describes micropile load testing.

It reviews construction inspection and quality control procedures and discusses contracting methods for micropile applications.

Allen Cadden, *et al* (2004) Discuss about the recent advancement in the field of micropile. Micropiles have been in use for more than 50 years. Originally, they were conceived as innovative solutions to aid in difficult post-war reconstruction efforts. Over the past 20 years, micropile technology has expanded significantly and has evolved from the concept of low capacity micropile networks to the use of single, high capacity elements. These small elements allow engineers to solve some difficult structural support problems involving high loads and restricted access. Engineers and researchers are now giving renewed attention to micropile networks as technically and economically viable solutions to problems of slope stabilization, lateral loading, and seismic retrofit. This paper explores these recent advances and looks beyond to the newest developments and future advances envisioned for micropiles.

Gupta and Desai (2005) explained the construction and installation of micropiles. The objective of the paper is to study an alternate cost effective and economical solution to prevent settlement of existing foundation and to study behaviour of micro piles as strengthening technique of existing structure. The drilling method is selected on the basis of causing minimal disturbance to the ground and nearby sensitive structures and able to achieve the required drilling performance. In all drilling methods, drilling fluid is used as a coolant for the drill bit and as a flushing medium to remove the drill cuttings. Water is the most common drilling fluid compared to other drilling fluid such as drill slurries, polymer, foam and bentonite. Another type of flushing medium is using compressed air, which is commonly used in Malaysia. The paper describes the bearing capacity of the foundation soil is improved using micro piles. Non-linear finite element analysis is carried out to examine the applicability and level of improvement obtained in the field. Densification of soil surrounding the micro piles and the frictional resistance between the micro piles and the foundation were given due consideration in the analysis. The results s Micro piles can be installed in low overhead clearance (less than 3.5 m), in all types of soils and ground condition. Minimal disturbance is caused during construction. Inclined micro piles can be easily constructed. They are able to resist axial and lateral loads. Only small volumes of earth to be excavated due to small diameter. Little disturbance is caused during drilling through an existing structure due to their small diameters. They can be drilled with boring machines that do not cause much noise. Their high flexibility during seismic conditions. How that the methodology used was effective in obtaining the desired level of improvement.

Howe (2010) after research has stated that for stability of slope:
A slope stability analysis was performed for three case studies using micropiles for slope stabilization. All case studies had some significant slope movements prior to the micropiles being designed and constructed. The analysis consisted primarily of the following:
Evaluate the factor of safety of the existing slope by:
Performing stability analysis of the existing slope
Adjusting soil strength parameters until FS=1.0 for back-analysis of soil strength parameters.
Determine the optimum location of the micropile and establish a simple method of doing so.
Determine the batter of the micropile.

Turner (2013) after research found out that When used in a slide stabilizing wall system, micropile walls consists of multiple micropiles battered alternately upslope and downslope and connected at the surface by means of a concrete applying beam running the length of a landslide. The micropiles extend through the slide mass into competent soil or rock beneath the slide. There is currently no consensus regarding the proper design approach for micropile wall systems. The most widely-cited procedure is described in the FHWA/NHI Micropile

Design Manual (Sabatini et. al., 2005). Back analysis of a failed slope is used to determine the additional resistance to sliding that must be provided to achieve a target factor of safety. The micropile wall trial design is evaluated against the required resistance by analysing individual micropiles for axial, shear, and bending strength assuming that each micropile acts as a vertical, free-headed pile. Design loads are determined by modelling soil layers as equivalent springs in a pile *p-y* analysis. Landslide forces are rotated and micropiles are loaded using an equivalent concentrated load acting at the surface. Besides being difficult to implement in practice, it is the authors' observation that the limiting factor that determines micropile design with this approach is the bending resistance of the micropile. However, the authors' experience, as well as that of others as reported in the literature, suggests strongly that micropiles used in this type of system undergo only small bending stresses and instead provide resistance through mobilization of axial forces. For example, consider the findings of three studies in which slide stabilizing micropiles were instrumented to determine axial and bending stresses in the micropiles.

Boeckmann and Loehr (2013) stated that Based on the results of *p-y* and *t-z* analyses, lateral and axial resistance forces are profiled along the length of the micropile at the sliding depths considered. The resistance forces can be based on ultimate values, or they can be established for some tolerable amount of slope movement. The resistance forces are then included in the slope stability analysis. Details vary among analysis software, but this typically involves specifying the location of the micropile and direction and magnitude of the resisting force. The resistance force used in the computations should be divided by spacing. A variety of full-scale field implementations and large-scale laboratory tests were analysed to develop the procedure outlined in this letter. The field investigations are outlined in Loehr and Brown (2008). The laboratory data were obtained from tests of 1-g model slopes 2.5 m by 4.3 m in plan with heights of 1.6 m as described in Boeckmann (2006) and Bozok (2009). The tests involved incrementally tilting the models until failure so that data are collected up to the limit state.

Mohammad Ali (2013) has explained about use of micropile for expansive clay. Stabilization of Lightweight reinforced concrete structures over expansive soils may be subjected to significant upward movement which may cause undesirable cracks in the structure. Repair activities for these cracks should be repeated annually and in some cases the cost is significant. The design alternatives include the use of stiff mat foundation, drilled pier foundation, isolated footings placed at depths exceeding the depth of seasonal variation of moisture content, soil replacement, and the use of stabilizing agents and micropiles. The type of soil and structure, environmental conditions, estimated surface heave, induced distresses and cost-effectiveness govern the selection and implementation of any of these techniques. The main purpose of this study was to examine the effectiveness of using micropiles as a technique to control upward movement of lightweight structures resting over expansive soils. For this purpose, expansive clay was compacted in a steel box of size 50cm x 50cm x 50cm to a height of 20cm in which small-scale steel model micropiles of diameter 12,16 and 20 mm were inserted in predrilled holes of 25mm diameter surrounded with and without sand. The heads of the model micropiles were fastened to the steel plate (steel plates are used as model footing) of size 25cm x 25cm x 1cm with nut and bolt arrangements. Then the boxes were filled with water and the upward movement of model footings (swelling) was monitored with time. The results showed that the percentage reduction in heave due to micropile reinforcement was more for micropiles surrounded by sand in predrilled holes of 25 mm diameter. The maximum measured reduction in heave was 94 % obtained when four 20 mm diameter micropiles surrounded by sand were used.

Binu Sharma (2014) The paper discusses about the model study of micropile subjected to lateral loading and oblique pull. Micropiles are small diameter cast in situ reinforced grouted piles. Micropiles are mainly applied for structural support and in situ reinforcement. As structural support it can be used for underpinning of distressed historical monuments, seismic retrofit mainly in congested and low headroom areas, resisting uplift dynamic loads. As in situ reinforcement it can be used for slope stabilization, for arresting structural settlement, excavation support in congested areas and as retaining structures. Its wide application makes it necessary to study the soil micropile interaction under various loading conditions. The investigation consists of two model experimental study of single micropiles of different length to diameter ratio installed in sand bed. In the first study the piles were subjected to lateral loading condition and in the second study the piles were subjected to vertical pull and oblique pull condition. Length to diameter ratio has been found to be a major variable influencing ultimate lateral and oblique resistance. The failure mechanism of the piles was found to be influenced by the relative density of the sand bed. The failure mechanism of the piles was also found to be influenced by the angle of inclination of the oblique pull.

G.L. Sivakumar Babu, B. R.Srinivasa Murthy (2014) This research paper discusses about improvemet of soil bearing capacity using micropiles. Micropiles have been used effectively in many applications of ground improvement to increase the bearing capacity and reduce the settlements particularly in strengthening the existing foundations. Frictional resistance between the surface of the pile and soil and the associated group/network effects of micropiles are considered as the possible mechanism for improvement. This paper deals with a case study in which micropiles of 100 mm diameter and 4 m long have been used to improve the bearing capacity of foundation soil and in the rehabilitation of the total building foundation system. The micropiles were inserted around the individual footings at inclination of 700 with the horizontal. The actual design for retrofitting was based on the assumption that the vertical component of the frictional force between the soil and the micropile resists the additional load coming from the structure over and above the bearing capacity. The technique was successful and the structure did not show any signs of distress later. Detailed finite element analysis conducted validated the suggested treatment. The paper describes the case study, the method of treatment adopted in the field and the results of numerical analysis.

Elarabi, H, Abbas A (2014) This technical paper discusses the Micropiles brief history, Micropiles Classification, Drilling Techniques, Grouting, Reinforcement, Design Concept, Testing procedures and Guidelines of Micropiles. The paper provides a simplified step-by-step design approach. These include geotechnical strength limit states, other structural considerations, service limit states, corrosion protection and Micropiles testing procedures.

Hai Shi *et al* (2015) The research article discusses the current approach, which is based on conformal transformation, is to map micropile holes in comparison with unit circle domain. The stress field of soil around a pile plane, as well as the plane strain solution to displacement field distribution, can be obtained by adopting complex variable functions of elastic mechanics. This paper proposes an approach based on Winkler Foundation Beam Model, with the assumption that the soil around the micropiles stemmed from a series of independent springs. The rigidity coefficient of the springs is to be obtained from the planar solution. Based on the deflection curve differential equation of Euler-Bernoulli beams, one can derive the pile deformation and internal force calculation method of micropile composite structures under horizontal load. In the end, we propose reinforcing highway landslides with micropile composite structure and conducting on-site pile pushing tests. The obtained results from the experiment were then compared with the theoretical approach. It has been indicated through validation analysis that the results obtained from the established theoretical approach display a reasonable degree of accuracy and reliability.

# Chapter 3

# Methodology

## 3.1 General

Methodology involves collection of soil sample, study of soil properties by conducting different tests such as particle sieve analysis, Atterberg's limits, water content, specific gravity, direct shear tests, unconfined compression test reinforcing clayey soil and improving the properties of soil by using micropile for suitable design.

## 3.2 Soil Properties

### 3.2.1 Particle Size Distribution (IS: 2720 - Part 4 - 1985)

Soil at any place is composed of particles of a variety of sizes and shapes, sizes ranging from a few microns to a few centimetres are present sometimes in the same soil sample. The distribution of particles of different sizes determines many physical properties of the soil such as its strength, permeability, density etc. Particle size distribution is found out by two methods, first is sieve analysis which is done for coarse grained soils only and the other method is sedimentation analysis used for fine grained soil sample. Both are followed by plotting the results on a semi-log graph. The percentage finer N as the ordinate and the particle diameter i.e. sieve size as the abscissa on a logarithmic scale. The curve generated from the result gives us an idea of the type and gradation of the soil. If the curve is higher up or is more towards the left, it means that the soil has more representation from the finer particles; if it is towards the right, we can deduce that the soil has more of the coarse-grained particles. The soil may be of two types- well graded or poorly graded (uniformly graded). Well graded soils have particles from all the size ranges in a good amount. On the other hand, it is said to be poorly or uniformly graded if it has particles of some sizes in excess and deficiency of particles of other sizes. Sometimes the curve has a flat portion also which means there is an absence of particles of intermediate size, these soils are also known as gap graded or skip graded. For analysis of the particle distribution, we sometimes use $D_{10}$, $D_{30}$, and $D_{60}$ etc. terms which represents a size in mm such that 10%, 30% and 60% of particles respectively are finer than that size. The size of $D_{10}$ also called the effective size or diameter is a very useful data. There is a term called uniformity coefficient Cu which comes from the ratio of $D_{60}$ and $D_{10}$, it gives a measure of the range of the particle size of the soil sample.

**Apparatus**:

Set of fine sieves, 2mm, 1mm, 600micron, 425, 212, 150, and 75 microns, set of coarse sieves, 100mm, 80mm, 40mm, 10mm, and 4.75mm, Weighing balance with accuracy of 0.1% of the mass of the sample, Oven, Mechanical shaker

**Figure 3.1Mechanical shaker**

**Procedure**:

Soil passing 4.75mm I.S. Sieve and retained on 75micron I.S. Sieve contains no fines. Those soils can be directly dry sieved rather than wet sieving.

**Dry Sieving:**

- Take 500gm of the soil sample after taking representative sample by quartering.
- Conduct sieve analysis using a set of standard sieves as given in the data sheet.
- The sieving may be done either by hand or by mechanical sieve shaker for 10 minutes.
- Weigh the material retained on each sieve.
- The percentage retained on each sieve is calculated on the basis of the total weight of the soil sample taken.
- From these results the percentage passing through each of the sieves is calculated.
- Draw the grain size curve for the soil in the semi-logarithmic graph provided.

**Wet Sieving:**

If the soil contains a substantial quantity (say more than 5%) of fine particles, a wet sieve analysis is required. All lumps are broken into individual particles.

- Take 200gm of oven dried soil sample and soaked with water.
- If deflocculating is required, 2% Calgon solution is used instead of water.
- The sample is stirred and left for soaking period of at least 1 hour.
- The slurry is then sieved through 4.75 mm sieve and washed with a jet of water.
- The material retained on the sieve is the gravel fraction, which should be dried in oven and weighed.
- The material passing through 4.75 mm sieve is sieved through 75-micron sieve.
- The material is washed until the water filtered becomes clear.
- The soil retained on 75-micron sieve is collected and dried in oven.
- It is then sieved through the sieve shaker for ten minutes and retained material on each sieve is collected and weighed 10. The material that would have been retained on pan is equal to the total mass of soil minus the sum of the masses of material retained on all sieves.
- Draw the curve for the soil in the semi-logarithmic graph in order to obtain grain size distribution curve.

### 3.2.2 Specific gravity (IS: 2720 - Part 4 - 1985)

Specific gravity of a substance denotes the number of times that substance is heavier than water. In simpler words we can define it as the ratio between the mass of any substance of a definite volume divided by mass of equal volume of water. In case of soils, specific gravity is the number of times the soil solids are heavier than equal volume of water. Different types of soil have different specific gravities, general range for specific gravity of soils

**Table 3.1 Specific Gravity of different soil samples**

| | |
|---|---|
| Sand | 2.63-2.67 |
| Silt | 2.65-2.7 |
| Clay | 2.67-2.9 |
| Organic soil | Less than 2 |

### 3.2.3 Shear strength Parameters

Shearing stresses are induced in a loaded soil and when these stresses reach their limiting value, deformation starts in the soil which leads to failure of the soil mass. The shear strength of a soil is its resistance to the deformation caused by the shear stresses acting on the loaded soil. The shear strength of a soil is one of the most important characteristics. There are several experiments which are used to determine shear strength such as Direct Shear Test (DST) or Unconfined Compression Test (UCS) etc.

The shear resistance offered is made up of three parts:

The structural resistance to the soil displacement caused due to the soil particles getting interlocked, the frictional resistance at the contact point of various particles, and Cohesion or adhesion between the surface of the particles. In case of cohesion less soils, the shear strength is entirely dependent upon the frictional resistance, while in others it comes from the internal friction as well as the cohesion. Methods for measuring shear strength:

### 3.2.4 Direct Shear Test (IS: 2720 – Part 13 – 1986)

This is the most common test used to determine the shear strength of the soil. In this experiment the soil is put inside a shear box closed from all sides and force is applied from one side until the soil fails. The shear stress is calculated by dividing this force with the area of the soil mass. This test can be performed in three conditions- undrained, drained and consolidated undrained depending upon the setup of the experiment.

**Apparatus**:

Shear box, Box container, Porous stone and grid plate, Tamper, Balance, Sieve(4.75mm) Loading frame, Proving ring, Dial gauge.

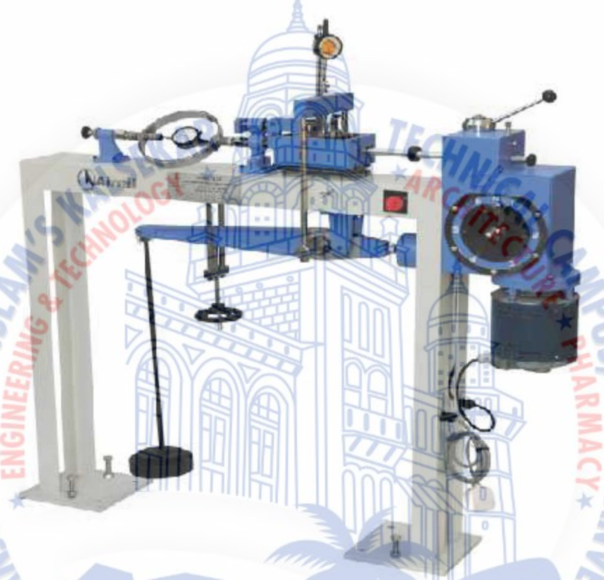

**Figure 3.2Loading Frame**

**Procedure**:

- Carefully assemble the shear box, keeping the grid plate at the bottom. The serrations of the grid plate should be placed a right to the direction of shear.
- Place the soil sample in the shear box to about 5mm from the top and place the grid plate and loading block on top of the soil.
- Mount the shear box assembly on the load frame. Set the lower part of the shear box to bear against the load jack and upper part of the box to bear against proving ring. Set the dial of proving ring to zero. Attach the dial gauge to measure the shear displacement.
- Put the loading yoke on top of loading block. Put Normal weight (0.5 Kg/Cm2. 1.0 Kg/Cm2, 1.5 Kg/Cm2 and 2.0 Kg/Cm2 in individual trial) on the hanger of loading yoke. Remove the shear box pins.

- Starts the horizontal (shear) loading so adjusted (1.25mm/m) that no drainage is occurred in the sample during test. Take the reading of load dial (of proving ring) and shear displacement dial. Conduct the test till failure of sample.
- Repeat the test for vertical load of 0.5 kg, 1kg, 1.5 kg, and 2 kg.

### 3.2.5 Unconfined Compression Test (IS: 2720 – Part 10 – 1991)

**Unconfined Compression Test (UCS test)**: This test is a specific case of triaxial test where the horizontal forces acting are zero. There is no confining pressure in this test and the soil sample tested is subjected to vertical loading only. The specimen used is cylindrical and is loaded till it fails due to shear

**Apparatus**:

Unconfined compressive test, proving ring type. Proving ring, capacity 1 KN, accuracy 1 N, Dial gauge, accuracy 0.01 mm, Weighing balance, Oven, Stopwatch, Sampling tube, Split mould, 38mm diameter, 76mm long, Sample extractor, Knife, Vernier callipers, Large mould.

**Figure 3.3Unconfined Compression Tester**

**Procedure**:

- Soil which is to be tested is mixed with water. This sample is than filled in the mould which is oiled in advance. The mould is having the same internal diameter as that of specimen which is to be tested.
- The mould is opened carefully and sample is taken out

- Prepare two or three such samples for testing.
- Measure the initial length and diameter of the specimen.
- Put the specimen on bottom of the loading device. Adjust upper plate to make contact with the specimen. Set the dial gauge (compression) at zero. The dial gauge reading provides the deformation in the sample and in turn strain.
- Compress the specimen until crakes are developed or the strain curve is well past its peak or until a vertical deformation of 20% is reached. Take the dial reading approximately at every 1 mm deformation of the specimen.
- The proving ring reading provides the corresponding load in- turn axial stress on the sample.
- Repeat of the specimen.
- Determine water content of each sample.

### 3.2.6 Triaxial Test (IS – 2720 – Part 11 – 1981)

**Apparatus**:

Triaxial cell, apparatus for applying and maintaining the desire fluid pressure in the cell, compression machine for application of deviator stress, dial gauge, split mould, rubber membrane stretcher, balance, stop watch, trimmer, etc.

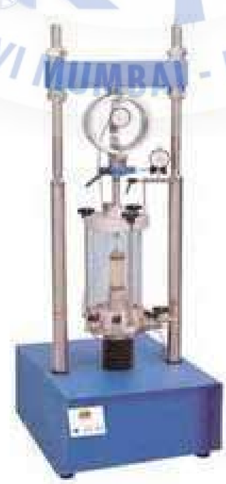

**Figure 3.4 Triaxial Test Apparatus**

**Procedure**:

**Sample Preparation:**

- Mix the soil with water at desired water (optimum) content. Compact the soil properly in the split mould, which should be oiled properly. Trim the excess soil and take out the specimen from mould carefully.
- Determine the water content of this soil.
- Place the specimen on one of the end caps and put the other end cap on the top of the specimen.
- Place the rubber membrane all around the specimen with the help membrane stretcher.
- Seal the rubber membrane with caps by means of rubber rings

**Compression Test:**

- Place the specimen on the pedestal in the triaxial cell.
- Assemble the cell with the loading ring.
- Admit the operation fluid (water) in the cell and raise its pressure to the desired value.
- Adjust the loading machine to bring the loading ram a short distance away from the seat on the cap of the specimen. Read the initial reading of load from the digital display unit/measuring dial gauge. Bring the loading ram just in contact with the seat on the top of specimen. Read the initial reading of dial gauge measuring axial compression.
- Repeat the test on three of four specimen of same water content and same soil under different cell pressure.

### 3.2.7 Determination of water content (IS 2710 - Part – 2 - 1973)

**Apparatus**:

Cylindrical metal mould shall be either of 100mm diameter and 1000cm3 volume or 150mm diameter and 2250cm3 volume and shall confirm to IS: 10074 – 1982. Balance of capacity 500grams and sensitivity 0.01gram. Balance of capacity 15Kg and sensitivity one gram. Thermostatically controlled oven with capacity up to 250 0C. Airtight containers. Steel straight edge about 30cm in length and having one bevelled edge. 4.75mm, 19mm and 37.5mm IS sieves confirming to IS 460 (Part 1). Mixing tools such as tray or pan, spoon, trowel and spatula or suitable mechanical device for thoroughly mixing the sample of soil with additions of water. Heavy compaction rammer confirming to IS: 9189 -1979

**Procedure**:

Clean the container with lid, dry and weigh ($W_1$). Take the required quantity of the soil specimen in the container crumbled and placed loosely, and weigh with lid ($W_2$). Then keep it in an oven with the lid removed and maintain the temperature of the oven at 110 ± 5°C. Dry the specimen in the oven for 24 h. Every time the container is taken out for weighing. Replace the lid on the container and cool the container in a desiccator. Record the final mass ($W_3$) of the container with lid with dried soil sample. Oven-drying at 110 ± 5°C does not result in reliable water content values for soil containing gypsum or other minerals having loosely bound water of hydration or for soil containing significant amounts of organic material. Reliable water content values for these soils can be obtained by drying in an oven at approximately 60 to 80°C.

### 3.2.8 Liquid Limit (IS 2720 - Part 5 – 1985.)

It is the water content of the soil between the liquid state and plastic state of the soil. It can be defined as the minimum water content at which the soil, though in liquid state, shows small shearing strength against flowing. It is measured by the Casagrande's apparatus and is denoted by $W_L$.

**Apparatus**:

Casagrande's liquid limit device, Grooving tools of both standard and ASTM types, Oven Evaporating dish, Spatula, IS Sieve of size 425 $\mu m$, Weighing balance, with $0.01 g$ accuracy.

**Figure 3.5 Casagrande's liquid limit device**

**Procedure**:

- Place a portion of the paste in the cup of the liquid limit device.
- Level the mix so as to have a maximum depth of 1cm.
- Draw the grooving tool through the sample along the symmetrical axis of the cup, holding the tool perpendicular to the cup.
- For normal fine-grained soil: The Casagrande's tool is used to cut a groove 2mm wide at the bottom, 11mm wide at the top and 8mm deep.
- For sandy soil: The ASTM tool is used to cut a groove 2mm wide at the bottom, 13.6mm wide at the top and 10mm deep.
- After the soil pat has been cut by a proper grooving tool, the handle is rotated at the rate of about 2 revolutions per second and the no. of blows counted, till the two parts of the soil sample come into contact for about 10mm length.
- Take about 10g of soil near the closed groove and determine its water content
- The soil of the cup is transferred to the dish containing the soil paste and mixed thoroughly after adding a little more water. Repeat the test.
- By altering the water content of the soil and repeating the foregoing operations, obtain at least 5 readings in the range of 15 to 35 blows. Don't mix dry soil to change its consistency.

- Liquid limit is determined by plotting a ‘flow curve’ on a semi-log graph, with no. of blows as abscissa (log scale) and the water content as ordinate and drawing the best straight line through the plotted points

### 3.2.9 Plastic Limit Test (IS – 2720 – Part6 – 1986)

This limit lies between the plastic and semi-solid state of the soil. It is determined by rolling out a thread of the soil on a flat surface which is non-porous. It is the minimum water content at which the soil just begins to crumble while rolling into a thread of approximately 3mm diameter. Plastic limit is denoted by $W_P$.

**Apparatus**:

Porcelain evaporating dish about 120mm diameter, Spatula, Container to determine moisture content, Container to determine moisture content, Oven, Ground glass plate of $20cm\ x\ 15cm$, Rod of 3mm dia. and about 10cm long.

**Figure 3.6 Plastic limit apparatus**

**Procedure**:

- Take about 8g of the soil and roll it with fingers on a glass plate. The rate of rolling should be between 80 to 90 strokes per minute to form a 3mm dia.

- If the dia. of the threads can be reduced to less than 3mm, without any cracks appearing, it means that the water content is more than its plastic limit. Knead the soil to reduce the water content and roll it into a thread again.
- Repeat the process of alternate rolling and kneading until the thread crumbles.
- Collect and keep the pieces of crumbled soil thread in the container used to determine the moisture content.
- Repeat the process at least twice more with fresh samples of plastic soil each time.

### 3.2.10 Shrinkage Limit Test (IS 2720-1972)

This limit is achieved when further loss of water from the soil does not reduce the volume of the soil. It can be more accurately defined as the lowest water content at which the soil can still be completely saturated. It is denoted by $W_s$

**Apparatus**:

Oven, Sieve 425-micron, Mercury, Desiccator, Weighing balance, with 0.01g accuracy

**Figure 3.7 Shrinkage limit apparatus**

**Procedure**:

- 100 gm. of soil sample from a thoroughly mixed portion of the material passing through 425 microns IS sieve is taken.
- About 30 gm. of above soil sample is placed in the evaporating dish and thoroughly mixed with distilled water to make a paste.
- The weight of the clean empty shrinkage dish is determined and recorded.

- The dish is filled in three layers by placing approximately 1/3rd of the amount of wet soil with the help of spatula.
- Then the dish with wet soil is weighed and recorded immediately.
- The wet soil cake is air dried until the colour of the pat turns from dark to light. Then it is oven dried at a temperature of 1050 C to 1100 C for 12 to 16 hours. The weight of the dish with dry sample is determined and recorded. Then the weight of oven dry soil pat is calculated ($W_0$).
- The shrinkage dish is placed in the evaporating dish and the dish is filled with mercury, till it overflows slightly. Then it is being pressed with plain glass plate firmly on its top to remove excess mercury. The mercury from the shrinkage dish is poured into a measuring jar and the volume of the shrinkage dish is calculated. This volume is recorded as the volume of the wet soil pat (V).
- A glass cup is placed in a suitable large container and the glass cup removed by covering the cup with glass plate with prongs and pressing it. The outside of the glass cup is wiped to remove the adhering mercury. Then it is placed in the evaporating dish which is clean and empty.
- Then the oven dried soil pat is placed on the surface of the mercury in the cup and pressed by means of the glass plate with prongs, the displaced mercury being collected in the evaporating dish.
- The mercury so displaced by the dry soil pat is weighed and its volume ($V_o$) is calculated by dividing this weight by unit weight of mercury.

## 3.3 Analysis of Micropile

The project has been divided into following stages in order to obtain the required objectives:

- Review available project information.
- Requirements of the job, pile loading requirements, pile layout constraints.
- Review geotechnical data.
- Obtain geotechnical/geological subsurface profile.
- Obtain soil properties
- Determination of different soil parameters
- Implementation of the available soil parameters for micropile analysis.

- FHWA-SA-97-070 (v00-06) 5 – 3 (Reference Manual)
- Complete initial geotechnical pile analysis. (with reference of FHWA-SA-97-070(v00-06)-5 -3)
- Determination of $P_{ult}$ (ultimate frictional resistance) using bond stress, length of micropile above slip surface ($L_{above}$) and diameter of micropile (d).

$$P_{ult} = \alpha_{bond\ stress} \times L_{above} \times \pi \times d$$

- Determination of $L_{below}$ (length of pile below slips surface).

$$L_{below} = P_{ult} \times F.S / \alpha_{bond\ stress} \times \pi \times d$$

- Determination of $H_{req}$(required shear force) using Cohesive strength of soil (C) and length of micropile (L).

$$H_{req} = C \times L$$

- Determination of $H_{ult}$ (capacity of micropile) using $P_{ult}$ and angle of inclination of micropile ($\Psi$)

$$H_{ult} = P_{ult} \times cos\Psi + P_{ult} \times sin\Psi$$

- Preparation of comparative study for micropile analysis for different soil samples.
- Determination of optimum angle of inclination of micropile for different soil samples.

**Table 3.2 Grout to Grout bond Ultimate Strength.**

| Soil / Rock Description | Grout-to-Ground Bond Ultimate Strengths, kPa | | | |
|---|---|---|---|---|
| | Type A | Type B | Type C | Type D |
| Silt & Clay (some sand) (soft, medium plastic) | 35-70 | 35-95 | 50-120 | 50-145 |
| Silt & Clay (some sand) (stiff, dense to very dense) | 50-120 | 70-190 | 95-190 | 95-190 |
| Sand (some silt) (fine, loose-medium dense) | 70-145 | 70-190 | 95-190 | 95- 240 |
| Sand (some silt, gravel) (fine-coarse, med.-very dense) | 95-215 | 120-360 | 145-360 | 145-385 |
| Gravel (some sand) (medium-very dense) | 95-265 | 120-360 | 145-360 | 145-385 |
| Glacial Till (silt, sand, gravel) (medium-very dense, cemented) | 95-190 | 95-310 | 120-310 | 120-335 |
| Soft Shales (fresh-moderate fracturing, little to no weathering) | 205-550 | N/A | N/A | N/A |
| Slates and Hard Shales (fresh moderate fracturing, little to no weathering) | 515-1,380 | N/A | N/A | N/A |
| Limestone (fresh-moderate fracturing, little to no weathering) | 1,035-2,070 | N/A | N/A | N/A |
| Sandstone (fresh-moderate fracturing, little to no weathering) | 520-1,725 | N/A | N/A | N/A |
| Granite and Basalt (fresh moderate fracturing, little to no weathering) | 1,380-4,200 | N/A | N/A | N/A |

# Chapter 4

## Result & Discussion

According to FHWA 2005 manual of Micropile Design and Construction. We have analysed the best suited angle of micropile for installation so that it can bear maximum horizontal force and the slope is also stable in all condition. Also, we are varying the length of micropile which it is directly proportional to the resisting force (Vertical) of micropile, therefore we have calculated for 10 different soils with each of five (5) different length and have got the optimum angle of inclination of micropile with respect to vertical are as follows.

# 4.1 Laboratory Results of Soil Properties of Different Locations

**Table 4.1 Laboratory test results on collected different soil samples**

| Parameters | | Values | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Locations | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Field Moisture Content (%) | | 21.48 | 26.63 | 27.19 | 21.93 | 23.59 | 9.33 | 27.77 | 27.23 | 27.28 | 28.03 |
| Specific Gravity | | 2.67 | 2.83 | 2.8 | 2.59 | 2.8 | 2.66 | 2.8 | 2.86 | 2.73 | 2.89 |
| Atterberg Limits | Liquid Limit (%) | 45 | 64 | 66 | 49 | 48 | 40 | 42 | 35 | 43 | 41 |
| | Plastic Limit (%) | 19 | 29 | 30 | 20 | 23 | 20 | 23 | 21 | 19 | 22 |
| | Shrinkage Limit (%) | 26 | 35 | 36 | 29 | 25 | 20 | 21 | 14 | 24 | 19 |
| Particle Size Distribution | Gravel (%) | 2 | 14 | 12 | 9 | 9 | 1 | 0 | 4 | 4 | 4 |
| | Sand (%) | 16 | 32 | 28 | 25 | 35 | 18 | 19 | 29 | 32 | 39 |
| | Silt+Clay (%) | 82 | 54 | 60 | 66 | 56 | 81 | 81 | 67 | 64 | 57 |
| Soil Classification | | CI | CH | CH | CI | SM | CL | CI | CI | CI | CI |
| Shear properties | Cohesion $(kN/m^2)$ | 74.56 | 125.6 | 141.3 | 82.4 | 75.54 | 68.67 | 90.25 | 94.18 | 94.17 | 104.9 |
| | Angle of internal Friction (ϕ) | 13.2 | 10.7 | 8.9 | 12.3 | 11.4 | 31.9 | 13.4 | 9.3 | 2.4 | 9.5 |

## 4.2 Optimum Results of $H_{ult}$ for Different Soil Samples

### 4.2.1 Sample Number: 01.

**Table 4.2 Values of $H_{ult}$ for sample number: 01**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=235.5 | 235.5 | 255.1 | 272.8 | 301.8 | 306.6 | 308.8 | 310.9 | 313.0 | 314.9 | 316.8 | 318.5 | 320.2 | 321.7 | 323.2 | 324.5 | 325.8 | 325.8 | 325.8 | 325.8 | 325.8 | 325.8 |
| Pult=471 | 471.0 | 510.2 | 545.6 | 603.7 | 613.1 | 617.6 | 621.9 | 625.9 | 629.8 | 633.5 | 637.0 | 640.3 | 643.4 | 646.3 | 649.0 | 651.5 | 651.5 | 651.5 | 651.5 | 651.5 | 651.5 |
| Pult=706.5 | 706.5 | 765.3 | 818.4 | 905.5 | 919.7 | 926.4 | 932.8 | 938.9 | 944.7 | 950.2 | 955.5 | 960.4 | 965.1 | 969.5 | 973.5 | 977.3 | 977.3 | 977.3 | 977.3 | 977.3 | 977.3 |
| Pult=942 | 942.0 | 1020.4 | 1091.2 | 1207.4 | 1226.3 | 1235.2 | 1243.7 | 1251.9 | 1259.6 | 1267.0 | 1274.0 | 1280.6 | 1286.8 | 1292.6 | 1298.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 |
| Pult=1177.5 | 1177.5 | 1275.5 | 1364.0 | 1509.2 | 1532.9 | 1544.0 | 1554.6 | 1564.8 | 1574.5 | 1583.7 | 1592.5 | 1600.7 | 1608.5 | 1615.8 | 1622.6 | 1628.9 | 1628.9 | 1628.9 | 1628.9 | 1628.9 | 1628.9 |

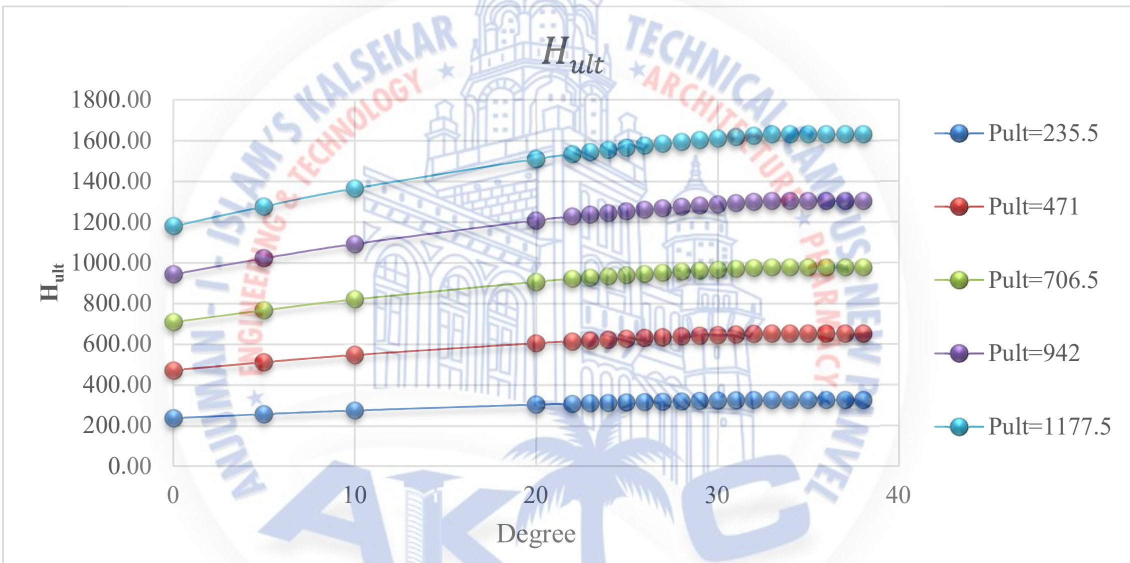


**Figure 4.1 Graphical Representation of Sample number: 01**

The above Graph of soil sample having $C = 74.56\ kN/m^2$ and $\emptyset = 13.2°$c represents optimum value of $H_{ult}(kN/m)$ for different angles

### 4.2.2 Sample Number: 02.

**Table 4.3 Value of $H_{ult}$ for sample number: 02**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=353.25 | 353.3 | 382.7 | 409.2 | 452.8 | 459.9 | 463.2 | 466.4 | 469.4 | 472.4 | 475.1 | 477.7 | 480.2 | 482.6 | 484.7 | 486.8 | 488.7 | 488.7 | 488.7 | 488.7 | 488.7 | 488.7 |
| Pult=706.5 | 706.5 | 765.3 | 818.4 | 905.5 | 919.7 | 926.4 | 932.8 | 938.9 | 944.7 | 950.2 | 955.5 | 960.4 | 965.1 | 969.5 | 973.5 | 977.3 | 977.3 | 977.3 | 977.3 | 977.3 | 977.3 |
| Pult=1059.75 | 1059.8 | 1148.0 | 1227.6 | 1358.3 | 1379.6 | 1389.6 | 1399.2 | 1408.3 | 1417.1 | 1425.4 | 1433.2 | 1440.7 | 1447.7 | 1454.2 | 1460.3 | 1466.0 | 1466.0 | 1466.0 | 1466.0 | 1466.0 | 1466.0 |
| Pult=1413 | 1413.0 | 1530.6 | 1636.8 | 1811.1 | 1839.4 | 1852.8 | 1865.6 | 1877.8 | 1889.4 | 1900.5 | 1911.0 | 1920.9 | 1930.2 | 1938.9 | 1947.1 | 1954.6 | 1954.6 | 1954.6 | 1954.6 | 1954.6 | 1954.6 |
| Pult=1766.25 | 1766.3 | 1913.3 | 2046.0 | 2263.8 | 2299.3 | 2316.0 | 2332.0 | 2347.2 | 2361.8 | 2375.6 | 2388.7 | 2401.1 | 2412.7 | 2423.7 | 2433.8 | 2443.3 | 2443.3 | 2443.3 | 2443.3 | 2443.3 | 2443.3 |

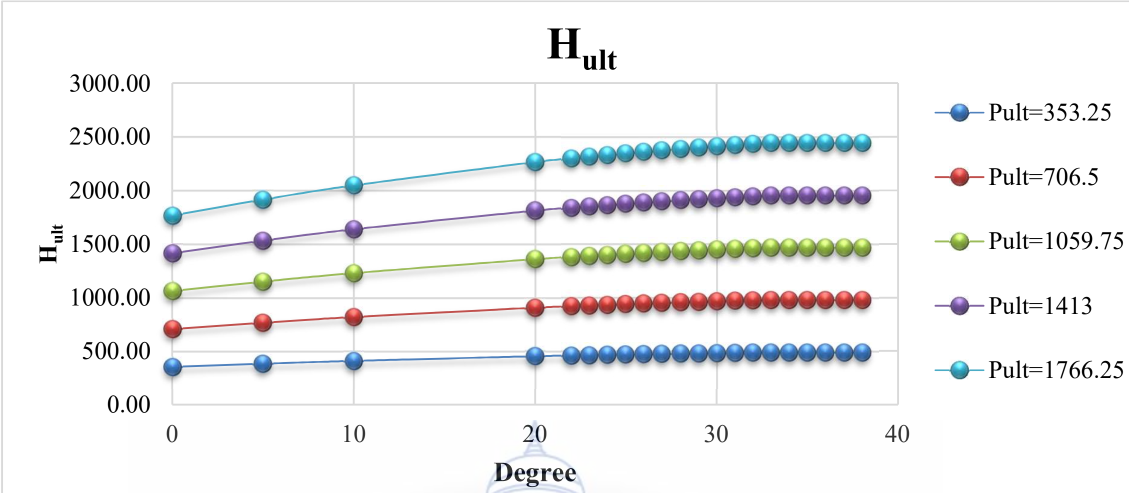


**Figure 4.2 Graphical Representation of Sample number: 02**

The above Graph of soil sample having $C = 125.6\ kN/m^2$ and $\emptyset = 10.7°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles

### 4.2.3 Sample Number: 03.

**Table 4.4 Value of $H_{ult}$ for sample number: 03**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=417 | 417.0 | 510.2 | 545.6 | 603.7 | 613.1 | 617.6 | 621.9 | 625.9 | 629.8 | 633.5 | 637.0 | 640.3 | 643.4 | 646.3 | 649.0 | 651.5 | 651.5 | 651.5 | 651.5 | 651.5 | 651.5 |
| Pult=942 | 942.0 | 1020.4 | 1091.2 | 1207.4 | 1226.3 | 1235.2 | 1243.7 | 1251.9 | 1259.6 | 1267.0 | 1274.0 | 1280.6 | 1286.8 | 1292.6 | 1298.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 |
| Pult=1413 | 1413.0 | 1530.6 | 1636.8 | 1811.1 | 1839.4 | 1852.8 | 1865.6 | 1877.8 | 1889.4 | 1900.5 | 1911.0 | 1920.9 | 1930.2 | 1938.9 | 1947.1 | 1954.6 | 1954.6 | 1954.6 | 1954.6 | 1954.6 | 1954.6 |
| Pult=1884 | 1844.0 | 2040.9 | 2182.4 | 2414.8 | 2452.6 | 2470.4 | 2487.4 | 2503.7 | 2519.2 | 2534.0 | 2548.0 | 2561.2 | 2573.6 | 2585.2 | 2596.1 | 2606.2 | 2606.2 | 2606.2 | 2606.2 | 2606.2 | 2606.2 |
| Pult=2355 | 2355.0 | 2551.1 | 2728.0 | 3018.4 | 3065.7 | 3088.0 | 3109.3 | 3129.6 | 3149.0 | 3167.5 | 3185.0 | 3201.5 | 3217.0 | 3231.5 | 3245.1 | 3257.7 | 3257.7 | 3257.7 | 3257.7 | 3257.7 | 3257.7 |

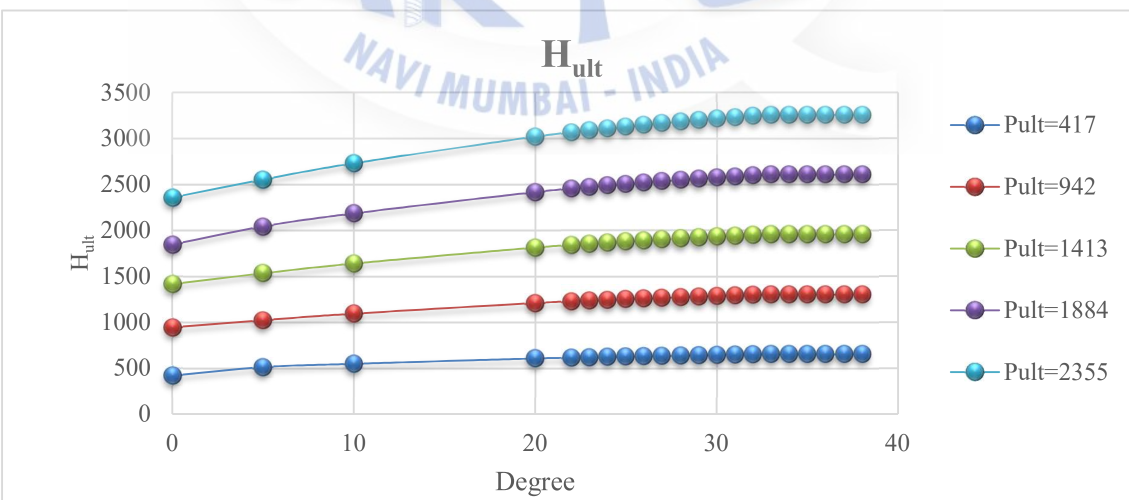


**Figure 4.3 Graphical Representation of Sample number: 03**

The above Graph of soil sample having $C = 141.3\ kN/m^2$ and $\emptyset = 8.9°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles

### 4.2.4 Sample Number: 04.

**Table 4.5 Value of $H_{ult}$ for sample number: 04**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=588.8 | 588.7 | 637.8 | 682.0 | 754.6 | 766.4 | 772.0 | 777.3 | 782.4 | 787.3 | 791.9 | 796.2 | 800.4 | 804.3 | 807.9 | 811.3 | 814.4 | 814.4 | 814.4 | 814.4 | 814.4 | 814.42 |
| Pult=1177.5 | 1177.5 | 1275.5 | 1364.0 | 1509.2 | 1532.9 | 1544.0 | 1554.6 | 1564.8 | 1574.5 | 1583.7 | 1592.5 | 1600.7 | 1608.5 | 1615.8 | 1622.6 | 1628.9 | 1628.9 | 1628.9 | 1628.9 | 1628.9 | 1628.9 |
| Pult=1766.3 | 1766.3 | 1913.3 | 2046.0 | 2263.8 | 2299.3 | 2316.0 | 2332.0 | 2347.2 | 2361.8 | 2375.6 | 2388.7 | 2401.1 | 2412.7 | 2423.7 | 2433.8 | 2443.3 | 2443.3 | 2443.3 | 2443.3 | 2443.3 | 2443.3 |
| Pult=2355.0 | 2355.0 | 2551.1 | 2728.0 | 3018.4 | 3065.7 | 3088.0 | 3109.3 | 3129.6 | 3149.0 | 3167.5 | 3185.0 | 3201.5 | 3217.0 | 3231.5 | 3245.1 | 3257.7 | 3257.7 | 3257.7 | 3257.7 | 3257.7 | 3257.7 |
| Pult=2943.8 | 2943.8 | 3188.8 | 3410.0 | 3773.0 | 3832.2 | 3860.0 | 3886.6 | 3912.0 | 3936.3 | 3959.3 | 3981.2 | 4001.8 | 4021.2 | 4039.4 | 4056.4 | 4072.1 | 4072.1 | 4072.1 | 4072.1 | 4072.1 | 4072.1 |

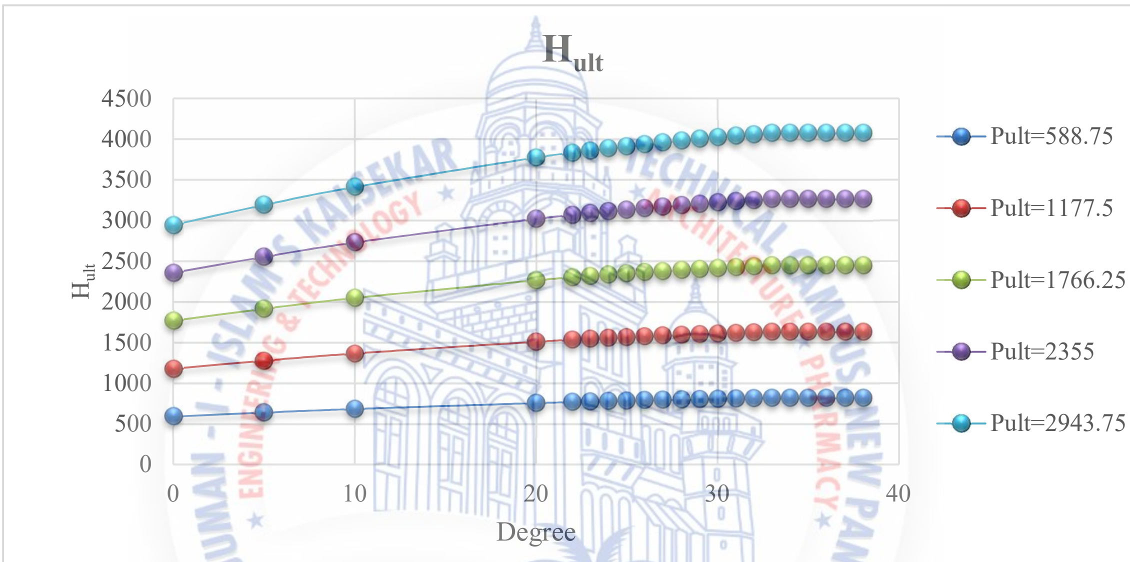


**Figure 4.4 Graphical Representation of Sample number: 04**

The above Graph of soil sample having $C = 82.4\ kN/m^2$ and $\emptyset = 12.3°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles

### 4.2.5 Sample Number: 05.

**Table 4.6 Value of $H_{ult}$ for sample number: 05**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=706.5 | 706.5 | 765.3 | 818.4 | 905.5 | 919.7 | 926.4 | 932.8 | 938.9 | 944.7 | 950.2 | 955.5 | 960.4 | 965.1 | 969.5 | 973.5 | 977.3 | 977.3 | 977.3 | 977.3 | 977.3 | 977.31 |
| Pult=1413 | 1413.0 | 1530.6 | 1636.8 | 1811.1 | 1839.4 | 1852.8 | 1865.6 | 1877.8 | 1889.4 | 1900.5 | 1911.0 | 1920.9 | 1930.2 | 1938.9 | 1947.1 | 1954.6 | 1954.6 | 1954.6 | 1954.6 | 1954.6 | 1954.6 |
| Pult=2119.5 | 2119.5 | 2296.0 | 2455.2 | 2716.6 | 2759.1 | 2779.2 | 2798.3 | 2816.7 | 2834.1 | 2850.7 | 2866.5 | 2881.3 | 2895.3 | 2908.4 | 2920.6 | 2931.9 | 2931.9 | 2931.9 | 2931.9 | 2931.9 | 2931.9 |
| Pult=2826 | 2826.0 | 3061.3 | 3273.6 | 3622.1 | 3678.9 | 3705.6 | 3731.1 | 3755.6 | 3778.8 | 3801.0 | 3821.9 | 3841.8 | 3860.4 | 3877.9 | 3894.1 | 3909.2 | 3909.2 | 3909.2 | 3909.2 | 3909.2 | 3909.2 |
| Pult=3532.5 | 3532.5 | 3826.6 | 4092.1 | 4527.7 | 4598.6 | 4631.9 | 4663.9 | 4694.4 | 4723.5 | 4751.2 | 4777.4 | 4802.2 | 4825.5 | 4847.3 | 4867.7 | 4886.5 | 4886.5 | 4886.5 | 4886.5 | 4886.5 | 4886.5 |

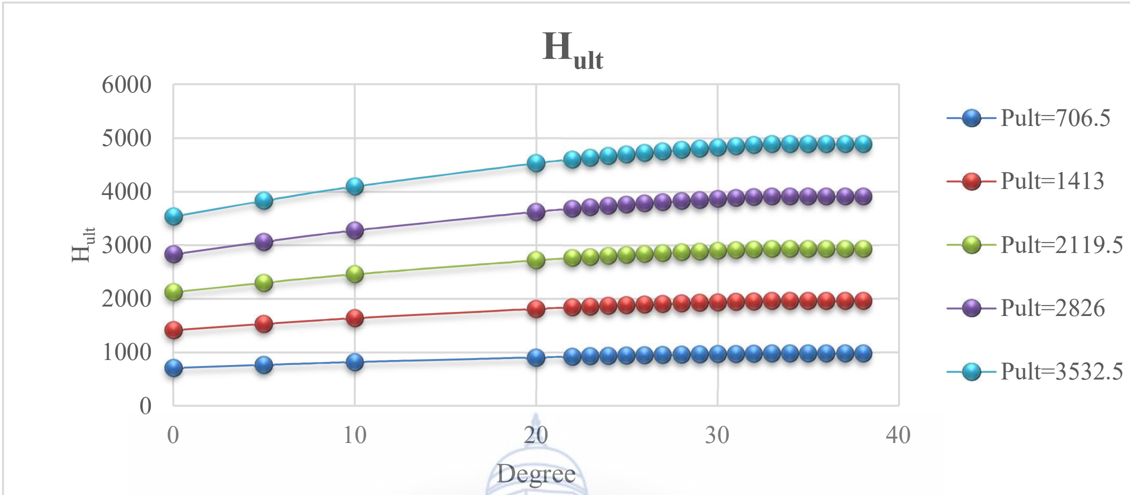


**Figure 4.5 Graphical Representation of Sample number: 05**

The above Graph of soil sample having $C = 75.54\ kN/m^2$ and $\emptyset = 11.4°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles.

## 4.2.6 Sample Number: 06.

**Table 4.7 Value of $H_{ult}$ for sample number: 06**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pult=824.25** | 824.3 | 892.9 | 954.8 | 1056.5 | 1073.0 | 1080.8 | 1088.2 | 1095.4 | 1102.2 | 1108.6 | 1114.7 | 1120.5 | 1126.0 | 1131.0 | 1135.8 | 1140.2 | 1140.2 | 1140.2 | 1140.2 | 1140.2 | 1140.2 |
| **Pult=1648.5** | 1648.5 | 1785.8 | 1909.6 | 2112.9 | 2146.0 | 2161.6 | 2176.5 | 2190.7 | 2204.3 | 2217.2 | 2229.5 | 2241.0 | 2251.9 | 2262.1 | 2271.6 | 2280.4 | 2280.4 | 2280.4 | 2280.4 | 2280.4 | 2280.4 |
| **Pult=2472.75** | 2472.8 | 2678.6 | 2864.4 | 3169.4 | 3219.0 | 3242.4 | 3264.7 | 3286.1 | 3306.5 | 3325.8 | 3344.2 | 3361.5 | 3377.8 | 3393.1 | 3407.4 | 3420.6 | 3420.6 | 3420.6 | 3420.6 | 3420.6 | 3420.6 |
| **Pult=3297** | 3297.0 | 3571.5 | 3819.2 | 4225.8 | 4292.0 | 4323.2 | 4353.0 | 4381.5 | 4408.6 | 4434.5 | 4458.9 | 4482.0 | 4503.8 | 4524.2 | 4543.2 | 4560.8 | 4560.8 | 4560.8 | 4560.8 | 4560.8 | 4560.8 |
| **Pult=4121.25** | 4121.3 | 4464.4 | 4774.1 | 5282.3 | 5365.0 | 5403.9 | 5441.2 | 5476.8 | 5510.8 | 5543.1 | 5573.7 | 5602.6 | 5629.7 | 5655.2 | 5679.0 | 5701.0 | 5701.0 | 5701.0 | 5701.0 | 5701.0 | 5701 |

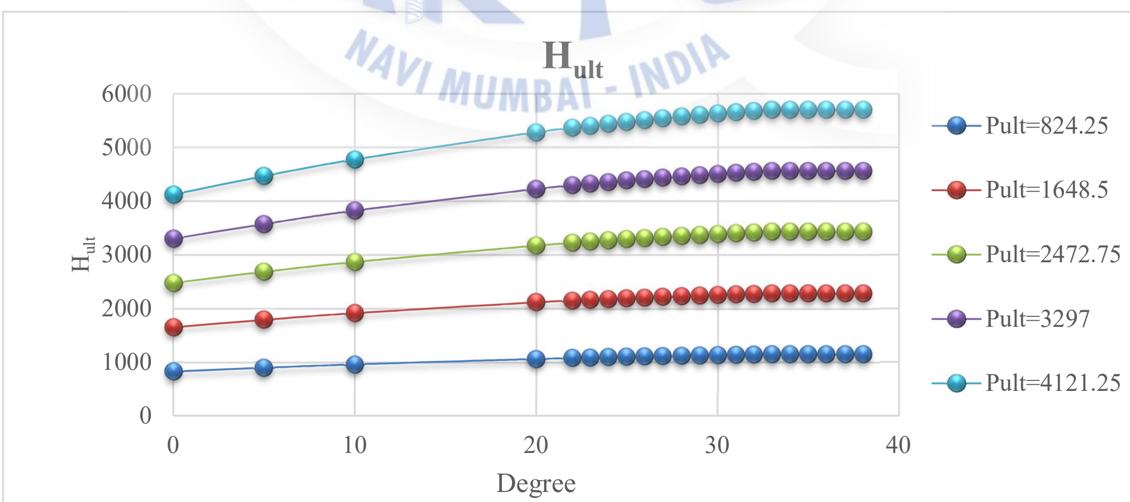


**Figure 4.6 Graphical Representation of Sample number: 06**

The above Graph of soil sample having $C = 68.67\ kN/m^2$ and $\emptyset = 31.9°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles.

### 4.2.7 Sample Number: 07.

**Table 4.8 Value of $H_{ult}$ for sample number: 07**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=942 | 942.0 | 1020.4 | 1091.2 | 1207.4 | 1226.3 | 1235.2 | 1243.7 | 1251.9 | 1259.6 | 1267.0 | 1274.0 | 1280.6 | 1286.8 | 1292.6 | 1298.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 | 1303.1 |
| Pult=1884 | 1884.0 | 2040.9 | 2182.4 | 2414.8 | 2452.6 | 2470.4 | 2487.4 | 2503.7 | 2519.2 | 2534.0 | 2548.0 | 2561.2 | 2573.6 | 2585.2 | 2596.1 | 2606.2 | 2606.2 | 2606.2 | 2606.2 | 2606.2 | 2606.2 |
| Pult=2826 | 2826.0 | 3061.3 | 3273.6 | 3622.1 | 3678.9 | 3705.6 | 3731.1 | 3755.6 | 3778.8 | 3801.0 | 3821.9 | 3841.8 | 3860.4 | 3877.9 | 3894.1 | 3909.2 | 3909.2 | 3909.2 | 3909.2 | 3909.2 | 3909.2 |
| Pult=3768 | 3768.0 | 4081.7 | 4364.9 | 4829.5 | 4905.2 | 4940.7 | 4974.8 | 5007.4 | 5038.4 | 5068.0 | 5095.9 | 5122.3 | 5147.2 | 5170.5 | 5192.2 | 5212.3 | 5212.3 | 5212.3 | 5212.3 | 5212.3 | 5212.3 |
| Pult=4710 | 4710.0 | 5102.1 | 5456.1 | 6036.9 | 6131.4 | 6175.9 | 6218.5 | 6259.2 | 6298.1 | 6334.9 | 6369.9 | 6402.9 | 6434.0 | 6463.1 | 6490.2 | 6515.4 | 6515.4 | 6515.4 | 6515.4 | 6515.4 | 6515.4 |

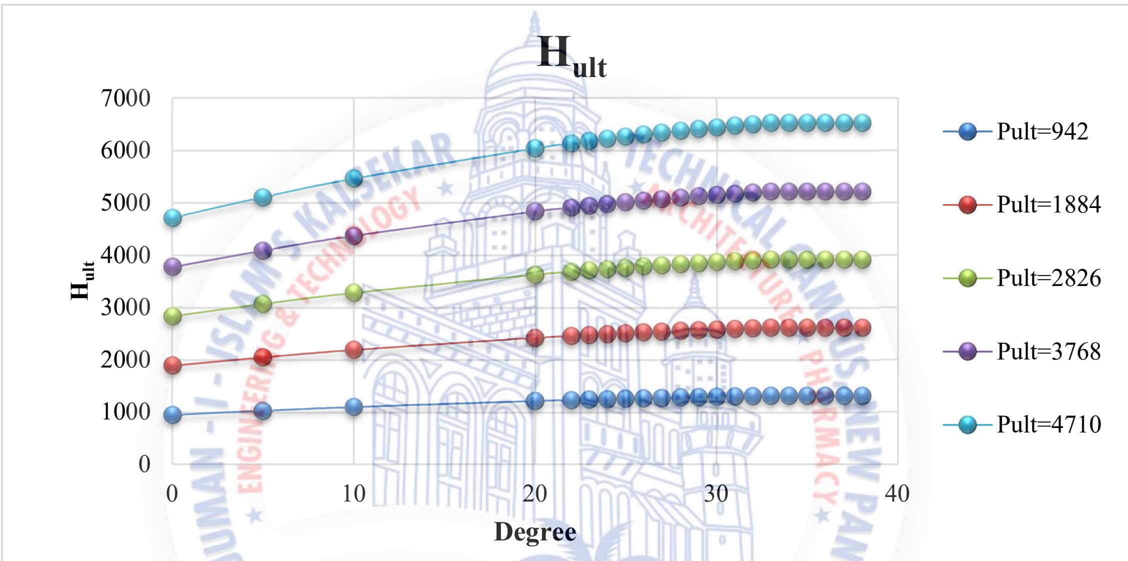


**Figure 4.7 Graphical Representation of Sample number: 07**

The above Graph of soil sample having $C = 90.25\ kN/m^2$ and $\emptyset = 13.4°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles

### 4.2.8 Sample Number: 08.

**Table 4.9 Value of $H_{ult}$ for sample number: 08**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=1059.75 | 1059.8 | 1148.0 | 1227.6 | 1358.3 | 1379.6 | 1389.6 | 1399.2 | 1408.3 | 1417.1 | 1425.4 | 1433.2 | 1440.7 | 1447.7 | 1454.2 | 1460.3 | 1466.0 | 1466.0 | 1466.0 | 1466.0 | 1466.0 | 1466 |
| Pult=2119.5 | 2119.5 | 2296.0 | 2455.2 | 2716.6 | 2759.1 | 2779.2 | 2798.3 | 2816.7 | 2834.1 | 2850.7 | 2866.5 | 2881.3 | 2895.3 | 2908.4 | 2920.6 | 2931.9 | 2931.9 | 2931.9 | 2931.9 | 2931.9 | 2931.9 |
| Pult=3179.25 | 3179.3 | 3443.9 | 3682.8 | 4074.9 | 4138.7 | 4168.8 | 4197.5 | 4225.0 | 4251.2 | 4276.1 | 4299.7 | 4322.0 | 4342.9 | 4362.6 | 4380.9 | 4397.9 | 4397.9 | 4397.9 | 4397.9 | 4397.9 | 4397.9 |
| Pult=4239 | 4239.0 | 4591.9 | 4910.5 | 5433.2 | 5518.3 | 5558.3 | 5596.7 | 5633.3 | 5668.2 | 5701.4 | 5732.9 | 5762.6 | 5790.6 | 5816.8 | 5841.2 | 5863.9 | 5863.9 | 5863.9 | 5863.9 | 5863.9 | 5863.9 |
| Pult=5298.75 | 5298.8 | 5739.9 | 6138.1 | 6791.5 | 6897.9 | 6947.9 | 6995.8 | 7041.7 | 7085.3 | 7126.8 | 7166.1 | 7203.3 | 7238.2 | 7271.0 | 7301.5 | 7329.8 | 7329.8 | 7329.8 | 7329.8 | 7329.8 | 7329.8 |

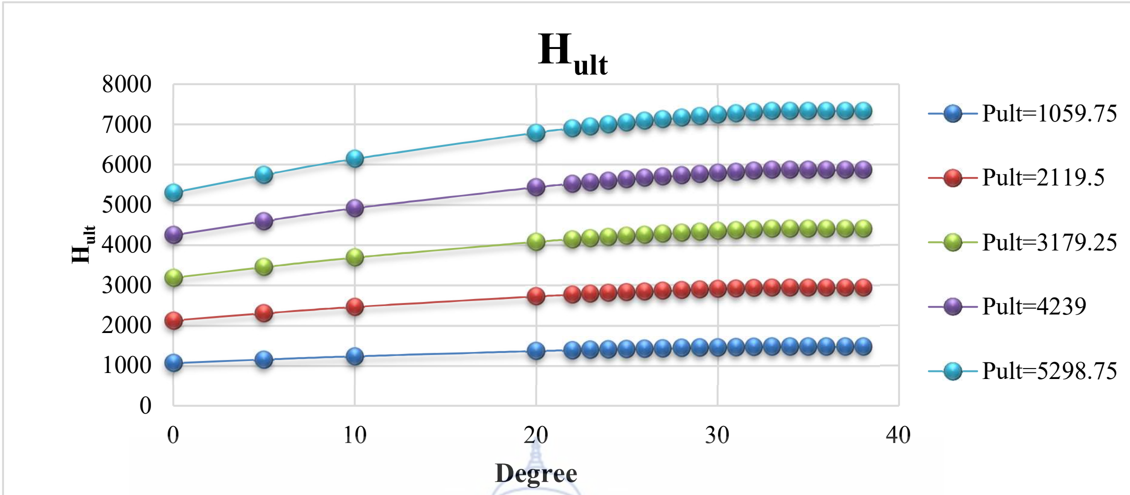


**Figure 4.8 Graphical Representation of Sample number: 08**

The above Graph of soil sample having $C = 94.18\ kN/m^2$ and $\emptyset = 9.3°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles

### 4.2.9 Sample Number: 09.

**Table 4.10 Value of $H_{ult}$ for sample number: 09**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=1177.5 | 1177.5 | 1275.5 | 1364.0 | 1509.2 | 1532.9 | 1544.0 | 1554.6 | 1564.8 | 1574.5 | 1583.7 | 1592.5 | 1600.7 | 1608.5 | 1615.8 | 1622.6 | 1628.9 | 1628.9 | 1628.9 | 1628.9 | 1628.9 | 1628.9 |
| Pult=2355 | 2355.0 | 2551.1 | 2728.0 | 3018.4 | 3065.7 | 3088.0 | 3109.3 | 3129.6 | 3149.0 | 3167.5 | 3185.0 | 3201.5 | 3217.0 | 3231.5 | 3245.1 | 3257.7 | 3257.7 | 3257.7 | 3257.7 | 3257.7 | 3257.7 |
| Pult=3532.5 | 3532.5 | 3826.6 | 4092.1 | 4527.7 | 4598.6 | 4631.9 | 4663.9 | 4694.4 | 4723.5 | 4751.2 | 4777.4 | 4802.2 | 4825.5 | 4847.3 | 4867.7 | 4886.5 | 4886.5 | 4886.5 | 4886.5 | 4886.5 | 4886.5 |
| Pult=4710 | 4710.0 | 5102.1 | 5456.1 | 6036.9 | 6131.4 | 6175.9 | 6218.5 | 6259.2 | 6298.1 | 6334.9 | 6369.9 | 6402.9 | 6434.0 | 6463.1 | 6490.2 | 6515.4 | 6515.4 | 6515.4 | 6515.4 | 6515.4 | 6515.4 |
| Pult=5887.5 | 5887.5 | 6377.7 | 6820.1 | 7546.1 | 7664.3 | 7719.9 | 7773.2 | 7824.1 | 7872.6 | 7918.7 | 7962.4 | 8003.6 | 8042.5 | 8078.9 | 8112.8 | 8144.2 | 8144.2 | 8144.2 | 8144.2 | 8144.2 | 8144.2 |

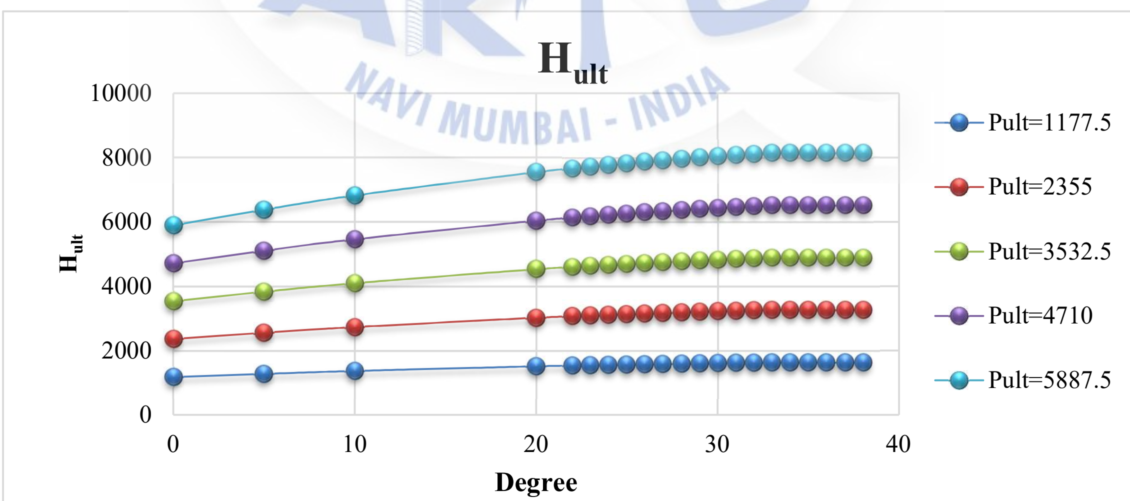


**Figure 4.9 Graphical Representation of Sample number: 09**

The above Graph of soil sample having $C = 94.17\ kN/m^2$ and $\emptyset = 2.4°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles

### 4.2.10 Sample Number: 10.

**Table 4.11 Value of $H_{ult}$ for sample number: 10**

| Degree | 0 | 5 | 10 | 20 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pult=1295.25 | 1295.3 | 1403.1 | 1500.4 | 1660.1 | 1686.1 | 1698.4 | 1710.1 | 1721.3 | 1732.0 | 1742.1 | 1751.7 | 1760.8 | 1769.3 | 1777.4 | 1784.8 | 1791.7 | 1791.7 | 1791.7 | 1791.7 | 1791.7 | 1791.7 |
| Pult=2590.5 | 2590.5 | 2806.2 | 3000.8 | 3320.3 | 3372.3 | 3396.8 | 3420.2 | 3442.6 | 3463.9 | 3484.2 | 3503.4 | 3521.6 | 3538.7 | 3554.7 | 3569.6 | 3583.5 | 3583.5 | 3583.5 | 3583.5 | 3583.5 | 3583.5 |
| Pult=3885.75 | 3885.8 | 4209.3 | 4501.3 | 4980.4 | 5058.4 | 5095.1 | 5130.3 | 5163.9 | 5195.9 | 5226.3 | 5255.2 | 5282.4 | 5308.0 | 5332.1 | 5354.4 | 5375.2 | 5375.2 | 5375.2 | 5375.2 | 5375.2 | 5375.2 |
| Pult=5181 | 5181.0 | 5612.3 | 6001.7 | 6640.6 | 6744.6 | 6793.5 | 6840.4 | 6885.2 | 6927.9 | 6968.4 | 7006.9 | 7043.2 | 7077.4 | 7109.4 | 7139.3 | 7166.9 | 7166.9 | 7166.9 | 7166.9 | 7166.9 | 7166.9 |
| Pult=6476.25 | 6476.3 | 7015.4 | 7502.1 | 8300.7 | 8430.7 | 8491.9 | 8550.5 | 8606.5 | 8659.8 | 8710.5 | 8758.6 | 8804.0 | 8846.7 | 8886.8 | 8924.1 | 8958.7 | 8958.7 | 8958.7 | 8958.7 | 8958.7 | 8958.7 |

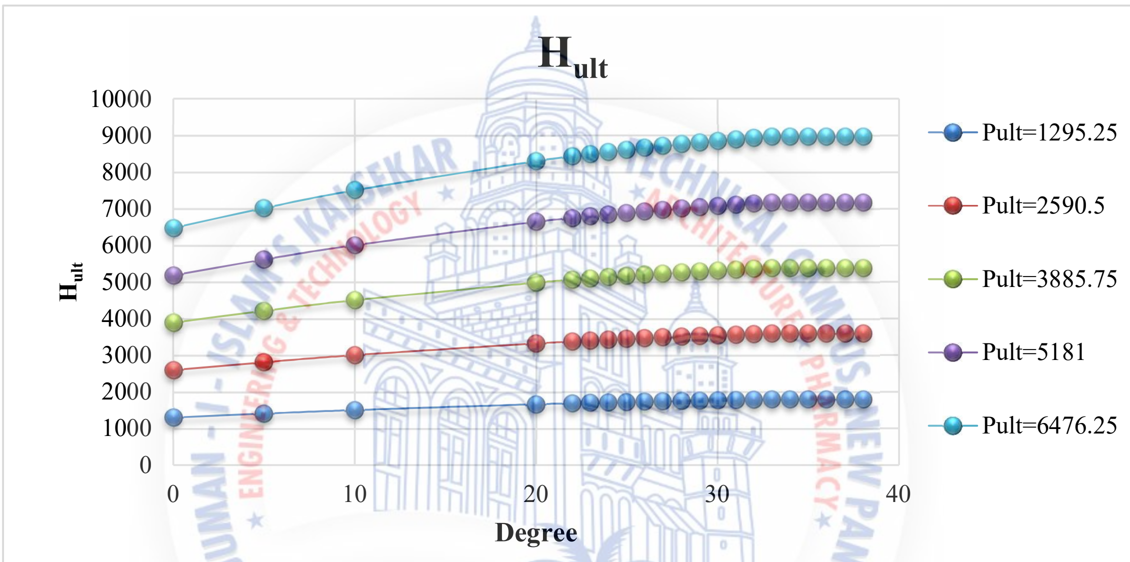


**Figure 4.10 Graphical Representation of Sample number: 10**

The above Graph of soil sample having $C = 104.9\ kN/m^2$ and $\emptyset = 9.5°c$ represents optimum value of $H_{ult}(kN/m)$ for different angles

# Chapter 5

# Conclusion

## 5.1 Conclusion.

According to FHWA 2005 manual of micropile design and construction an analysis was performed to find out best suited angle of micropile for installation so that it can bear maximum horizontal force and the slope is also stable in all the conditions. Also, the lengths of micropile were varied which is directly proportional to the resisting vertical force of micropile.

After analysis, it was found that the optimum angle for installation of micropile for different soil samples is 32̊ which gives the best resistance against the horizontal force acting on the micropile. Further increase in the angle of inclination of the micropile give a constant value for the horizontal resisting force. These results apply for all the ten types of soil sample having different cohesion (c) and angle of internal friction (ϕ)

## 5.2 Future Scope.

- Micropile behaviour can be studied as a strengthening technique

- Further study can be done on the parameters like spacing of micropile for better analysis and design of micropile for stabilising the soil
- Micropile parameters can be studied to find out an alternate cost effective and economical solution

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