“An experimental study on soil stabilization using soil nails”

A PROJECT REPORT

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

Under the supervision of

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CERTIFICATE

This is to certify that the work which is being presented in the thesis titled **“An experimental study on soil stabilization using soil nails”** in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Civil Engineering and submitted to the Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out By Rishav Kharwal(131646),Vivek Gandhi(131616),Devasya Singh(131693) during a period from June 2016 to May 2017 under the supervision of **Mr.Saurabh Rawat** Assistant Professor, Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

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ABSTRACT

Soil nailing is an in-situ reinforcement technique by passive bars which can withstand tensile forces, shearing forces and bending moments.

This technique is used for retaining walls and for slope stabilization. Its behaviour is typical of that of composite materials and involves essentially two interaction mechanisms:

The soil- reinforcement friction and the normal earth pressure on the reinforcement. The mobilization of the lateral friction requires frictional properties for the soil, while the mobilization of the normal earth pressure requires a relative rigidity of the inclusions.

Taking into account these mechanisms, multi-criteria at failure design method is proposed. It is derived from the slice methods used in slope stability analysis. The criteria lead to a yielding curve in the shear – tensile forces plane and the consideration of the principle of the maximum plastic work enables to calculate the shear and tensile forces mobilized at failure in each inclusion.

Using a formulation determinate, the slope stability analysis take into account the passive force of reinforcement.

CHAPTER 1

INTRODUCTION

1.1 General

Soil nailing generally consists of the enduring reinforcement of the existing ground by planting or inagurating closely spaced steel bars (i.e. nails).

In soil nailing generally the construction proceeds from top to bottom.To provide continuity shotcreting or concreting is also done on the excavation face. The performance of the structure in a soil nailed wall is generally affected by three components—the native soil,the reinforcement and the facing element.The performance of the structure is also affected by the mutual interactions of these three components.

The principal of soil nailed wall is the development of friction between the compacted earth mass and reinforcing elements.The soil transfers the forces built up in the earth mass to the reinforcement by means of friction. Thus,tension is developed in reinforcement.

Soil Nailing technique is generally classified broadly into two main categories:

1. In-situ soil reinforcement.

2. Remoulded soil reinforcement.

The reinforced earth technique mentioned above follows the remoulded soil reinforcement method where the soil is built up together with the reinforcement, which may comprise of geo-grids, geo-textiles or steel strips. However, since many geotechnical applications require reinforcement that needs to be placed in-situ, such as slopes or excavated walls, rather than built up structures, such as embankments. The former i.e placed in-situ has been developed in current times and it is considerd to be an important aspect of soil reinforcement.Such techniques like soil nailing and dowelling, have received tremendous development over the last 25 years.

1.2 Origin and development

- The very first application of soil nailing was in 1972 for a railroad widening project close to Versailles, France, where an 18 m (59 ft) high soil nailed wall is constructed.
- The origin of soil nailing can be traced to a support system for underground excavations in rock referred to as the New Austrian cut-slope in sand was stabilized using soil nails.
- In Germany,the first soil nailed wall was constructed in the year 1975.
- The United States first used soil nailing in 1976 for the support of a 13.7 m deep foundation excavation in dense silty sands.
- In India use of soil nailing technology is gradually increasing and guidelines have been made by IRC with the help of Indian Institute of Science, Bangalore.

1.3 Applications

- Used for the Stabilization of railroad and highway cut slopes.
- Excavation holding structures in urban areas for high-rise building and underground facilities.
- Tunnel portals in steep and unstable stratified slopes.
- Stabilizing steep cuttings to maximize development space.
- The stabilizing of existing over-steep embankments.
- Soil Nailing through existing concrete or masonry structures like failing retaining walls and bridge abutments to produce future stability without demolition and reconstruct prices.
- Temporary support is provided to excavations while not the requirement for bulky and intrusive scaffold type temporary works solution.

1.4 Advantages

Soil nail walls exhibit numerous advantages. Some of these advantages are described below:

Construction

- Less troubled to traffic and causes less enviournmental effect as compared to alternative construction techniques.
- It usually uses less construction material and also installation of soil nail walls is comparatively fast.

- Soil nailing is very beneficial at sites with remote access because smaller equipments are generally used.

Performance

- Soil nail walls are relatively flexible and can accommodate relatively large total and differential settlements.
- The deflections of soil nail walls are usually within tolerable limits.
- Have performed well during seismic events owing to overall system flexibility.

Cost

- Soil nail walls are much more economical as compared to other retaining walls.
- Shotcrete facing is usually more cost effective.

1.5 Construction Sequences

The following are the typical sequence to construct a soil nail wall using the drill and grout method of nail installation:

- Excavate Initial Cut to a depth slightly below the first row of nails, typically about 1 to 2m depending upon the ability of the soil to stand unsupported for a minimum of 24 to 48 hours.
- Drill Hole for Nail at predetermined locations to a specified length and inclination using a drilling method appropriate for the ground.
- Install and Grout Nails. The nails which are commonly 19 to 35mm bars are inserted into the hole and the drill hole is filled with cement grout to bond the nail bar to the surrounding soil.
- Place Drainage System. A 400mm wide prefabricated synthetic drainage net placed in vertical strips between the nail heads on a horizontal spacing equal to that of the nails, is usually installed against the excavation face before shotcreting to provide drainage.
- Place Construction Facing which consist of mesh reinforced wet-mix shotcrete layer and Bearing Plates which consist of a steel bearing plate and securing nut at each nail head.
- Repeat the Process to Final Grade. Repeat the sequence of excavate, install nail and drainage system and placing of construction facing until the final grade is achieved.
- Place Final Facing. For architectural and long term structural durability reasons, the final facing (commonly the CIP concrete facing) is placed.

The reinforcement principle of the soil nailing method may seem to resemble that of the reinforced earth method. However due to the method of installation, the soil nailing method produces a very different behaviour from that of reinforced earth which is generally marked by the point of maximum displacement. Soil nailing produces greater displacements at the top of the excavation while reinforced earth show larger displacements near the bottom. This shows that the method of installation has a great impact on the mobilization of forces within the system and should be properly understood with the properties and geometry of the materials involved to gain an understanding of the overall behaviour of the system.

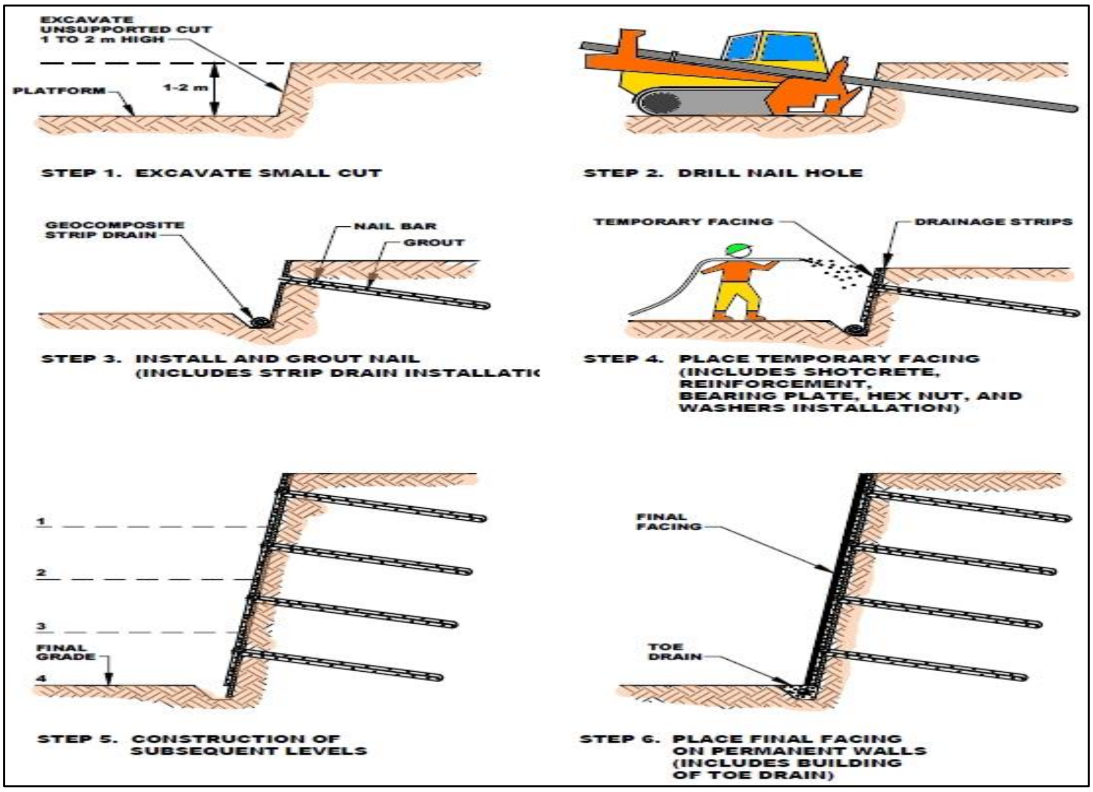

Fig1.1 construction sequence of a soil nail wall

1.6 Components of a soil nail wall

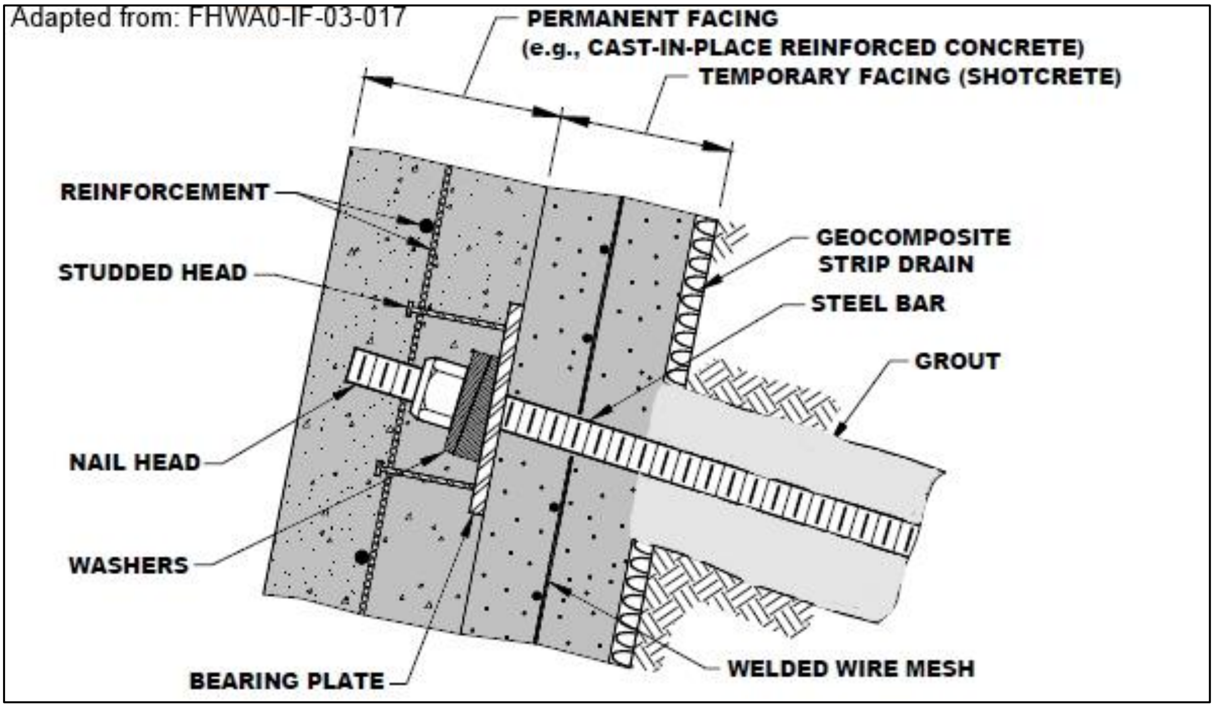

Fig 1.1 Main components of a soil nail wall.

The components of a soil nailed wall are shown above in the (Fig 1.2) they are as follows:

Nail bars : The reinforcing bars used in soil nailing are generally hollow or solid. Threaded bars can also be used. Grade 60 bars often have a nominal tensile strength of 420 MPa or Grade 75 (520 Mpa). Bars with a tensile strength of 665 MPa (Grade 95) and as high as 1,035 MPa (Grade 150) is also thought about for soil nailing, however their use should be limiting. Bars with lower grades are preferred over bars with high grades because they are more ductile, additional susceptible to corrosion, and easily available. Grade 150bars should not be used because of the reason that they are more brittle under shear and more susceptible to stress corrosion than steel at lower grades. Threaded bars applications are available in 19-mm, 22-mm, 25-mm, 29-mm, 32-mm, 36-mm, and 43-mm diameter. These are approximately 18 m (59 ft) in length.

Nail head: The nail head comprises of following main main components:

- the bearing-plate.

-hex nut

-Washers and headed-stud. The bearing plate is made of Grade 250 MPa.

Grout : Grout for is basically a neat cement grout, which is used to fill the vacant space between the nail bar and the surrounding ground. Sand-cement grout may also be utilized in conjunction with open hole-drilling (i.e. for non-caving conditions) for economic reasons. Cement Type I (normal) is used for most of the applications. Cement Type III is grounded finer, it also hardens quicker, and may be used when target grout strength is needed to be achieved quicker. Cement Type II hardens at a slower rate, produces less heat, and is more resistant to the corrosive action of sulphates than Cement Type I. The water/cement ratio for grout used in soil nailing applications usually ranges from 0.4 to 0.5.

Fig 1.3: Grout is being placed with the help of pipes

Centralizers: Centralizers are devices made of polyvinyl chloride (PVC) or other synthetic materials that are installed at various locations along the length of each nail bar to ensure that a minimum thickness of grout completely covers the nail bar. They are installed at regular intervals, typically not exceeding 2.5 m (8 ft), along the length of the nail and at a distance of about 0.5 m (1.5 ft) from each end of the nail.

Corrosion protection elements: In addition to the cement grout, this provides both physical and chemical protection to the nail bars. Protective sheathings made of corrugated synthetic material [HDPE (High Density Polyethylene) or PVC tube) surrounding the nail bar are usually used to provide additional corrosion protection.

Wall facing: Nails are connected at the excavation surface (or slope face) to a facing system, which most commonly consists of a first-stage, temporary facing of shotcrete during construction and, a second-stage, permanent facing of CIP concrete. The purpose of the temporary facing is to support the soil exposed between the nails during excavation, provide initial connection among nails, and provide protection against erosion and sloughing of the soil at the excavation face. The main aim of providing the permanent facing is to provide connection among nails, a more resistant erosion protection, and an aesthetic finish. Temporary facing usually consists of shotcrete and WWM and additional shorter reinforcement bars (referred to as waler bars) around the nail heads. Permanent facing is commonly constructed of CIP reinforced concrete and WWM-reinforced shotcrete.

Drainage system: In order to prevent water pressure from developing behind the wall facing, vertical geo-composite strip drains are generally put in between the temporary facing and the excavation. It also includes a footing drain and weep holes to guide the water collected from the drainage away from the wall face.

1.7 Machineries used in soil nailing

The following tools or machineries are used for soil nailing:

Drilling equipments.
Grout mixing equipments.
Shotcreting equipments.
Compressor.

They can be broadly explained further as follows:

Drilling equipments: It's a rotary air-flushed and water-flushed system. It consists of a down the hole hammer with a tri-cone bit(Fig 1.4). It is vital to acquire drilling instrumentally with ample power and rigid drill rods.

Grout mixing equipments: In order to provide uniform grout mix, high speed shear colloidal mixer ought to be thought-about. Powerful grout pump is important for uninterrupted delivery of grout combine (Fig 1.5). Special grout pump has to be used if fine aggregate has to be used.

Shortcreting equipments: Dry mix methodology would require a valve at the nozzle outlet to manage the amount of water inserting into the high pressurized flow of sand/cement mix (Fig 1.6).In order to control the thickness of the shotcrete, measuring pin shall be put in at fixed vertical and horizontal intervals to guide the nozzle man.

Compressor: The mechanical device shall have minimum capability to deliver the shortcrete at the minimum rate of $9m^3$/min. Sometimes the noise of mechanical device is a problem if the work is at shut proximity to territorial dominion, hospital and faculty.

Fig 1.4: Typical drilling equipment

Fig 1.5: Grout Mixing Instrument

Fig 1.6: Shotcreting is done with the help of a pipe with a nozzle

1.8 Mechainsm of soil nailing behaviour in reinforcement of structure

The purest form of soil nailing, without the use of any pretension or preloading and connected with a weak facing, acts in response to the deformation of the system. This is because the nails are placed as passive inclusions and offers no support to the system when initially installed. However, with excavation of the soil in front of the retained soil, the soil moves in active response to the unloading and undergoes deformation. The deformation of the soil transfers the loading to the nails. Two possible types of interaction are developed.

1. The primary action is the interaction of shear stress along the nail-soil interface, which is subsequently transferred into the nail as tensile forces.

2. The secondary action is the action of shear and bending, which is developed as a result of passive pressure of the earth along the nail. This is observable when shear zones in the soil develop to form active and passive zones.

When loading of the system takes place, the soil nailed wall may approach failure mainly by either breakage due to insufficient structural capacity of the nail, pullout of nail due to lack of adherence at the nail-soil interface, or global instability of the retained slope or structure (external failure). There may be other forms of failure locally due to excessive excavation depth prior to installation of subsequent nail or piping of soil. In general, they may be summarized into four forms:

1. Instability during excavation phases
2. Overall sliding of the reinforced mass
3. Lack of Friction between soil and nails
4. Breakage of the nails

Based on these failure modes, design may be made using limit equilibrium methods to find out safety against different modes of failure. However, the behaviour of soil nails is also subjected to the many variations in design specifications of geometry and layout, coupled with the variation of site and materials used make for a very complicated design process.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter presents the review of developments of the theoretical concepts, analysis methods and model analysis done by various researchers leading to the present design methodology of analysis of unreinforced slope.

2.2 Research work on soil nailing

A kinematic limit analysis for the design of nailed soil structures is developed by *Juran et al. (1990)*. Design of soil- nailed systems has been traditionally done using slope- stability analysis methods. These methods have been developed to incorporate the effect of the available tension and shear resistance of the passive reinforcements on the slope stability. However, they provide only a global safety factor. In this design methodology, a kinematical limit analysis design approach that provides a rational estimate of maximum tension and shear forces mobilized in each reinforcement is presented. This design method enables one to estimate nail forces and to evaluate local stability at the level of each nail.The design approach is also used to analyze the various failure mechanisms observed on model walls and predicted critical model heights are compared with experimental results.This method is used to evaluate the effect of the main design parameters such as inclination and bending stiffness of the nails, embankment slope, facing inclination, soil strength characteristics on the magnitude and location of the maximum nail forces and on the structure stability.The design methodology was evaluated by both full-scale experiments and reduced-scale model tests. The proposed method provides a rational approach to predict the progressive pullout failure, which is generally induced by the sliding of the upper nails.

*Griffiths and Lane (1999)*stated that Finite Element method in conjunction with an elastic-perfectly plastic (Mohr-Coulomb) stress-strain method has been found to be a reliable and robustmethod for assessing the factor of safety of slopes.One of the main advantages of the FE approach isthat the factor of safety emerges naturally from theanalysis without the user having to commit to anyparticular form of the mechanism a priori.The FE approach for determining the factor of safety of slopes has satisfied the criteria for effective computer-aided analysis.

The widespread use of this method should be seriously consideredby geotechnical practitioners as a more powerfulalternative to traditional limit equilibrium methods.

Arash olia and Jinyan liu did their numerical investigation on the behaviour of soil nail wall during the different stages of construction.A well known case in Germany is used in this study.they did 15m deep excavation in a slopping terrain.One side is excavated on city street and other on private houses.The nails are of 25mm and 28mm diameter of deformed steel bars.The excavation was carried out in steps of 1 or 1.1 mm cover the whole length.The 2D plane strain continuous method is used in this study.the most important factor in this study is to idealize the 3D soil nail into a 2D strain plane element.

This study shows that a 2-D FEM can provide reliable results and will be still popular in practice due to its simplicity and easy implementation.

*Wan-Huan ZHOU (2008)*did the pull out test in laboratory and in actual sight conditions and compared the result. The study was to see the FEM results practically they computed stress and strains in nails by using strain gauges and drew bending moment diagram and their studies showed following things.With increase in applied overburden pressure, the time needed to obtain stress equilibrium in the box increases.Grouting pressure increases the earth pressure, but it could not be maintained for a very long time. Higher the applied grouting pressures the longer that grouting pressure is maintained.Saturation increases the vertical effective stress around the soil nail. It appears that the FBG (Fibre Bragg Grating) sensors show higher reliability than the strain gauges for the small strain monitoring.Thickness of the adhered soil was not uniform around the soil nail.

Saytendra Mittal (2005) did experiment on erosion soil and gave graphical representations for the variation of **factor of safety** with angle of internal friction, cohesion of soil and nail inclinations at different height to nail length ratios and found following graph.

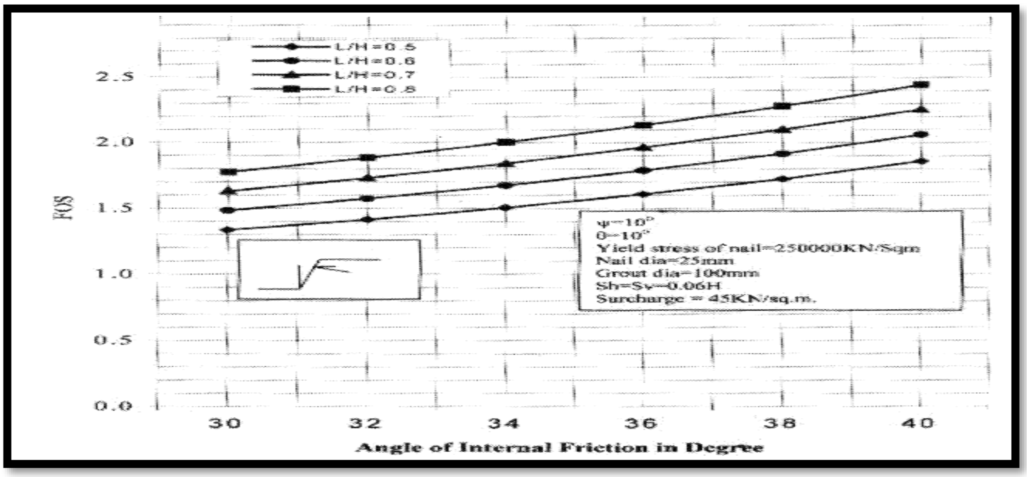

Fig 2.1 Angle of friction vs FOS

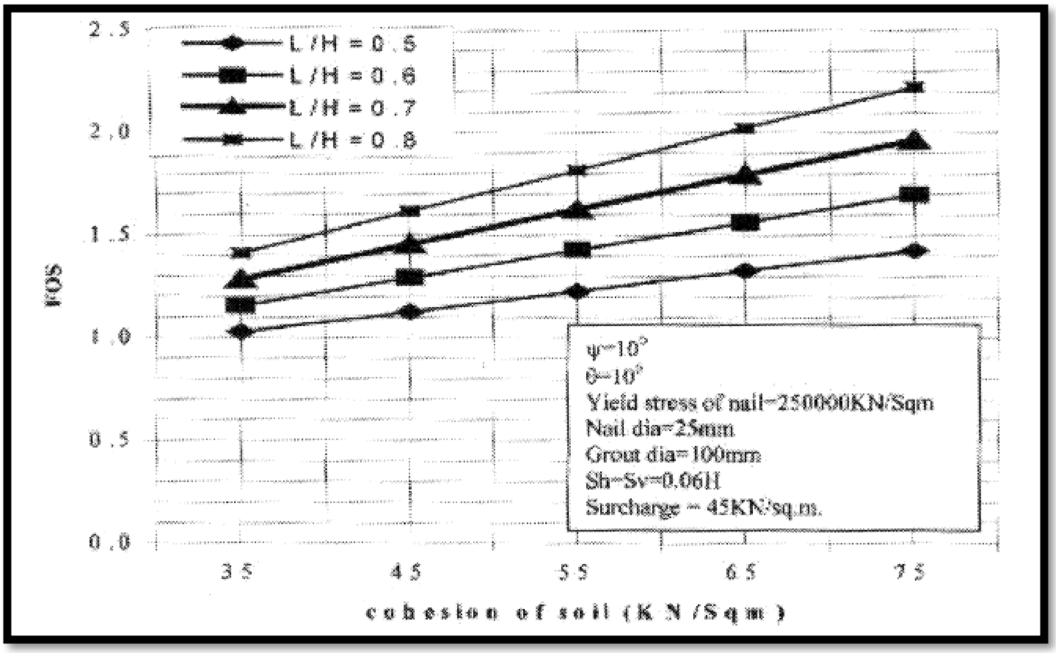

Fig 2.2 Cohesion of soil vs FOS

Saytendra mittel concluded following things from above graphs.

Soil nailing method does not require skilled labour or high tech tools and it could be adopted at sites where soil stabilization is necessary with low economy.Nails grouted with cement are more effective than the driven nails. Length of nail up to 0.8 times the height of cut is a reasonable length for provides a stable cut.A minimum nail length of 0.7 m performs well in field.The friction circle method may be adopted for design of nailed open cuts. Horizontal and vertical spacing of nails may be kept the same. FOS is higher for inclined nailed wall than that for a vertical wall. FOS increases with nail inclination with horizontal up to 15 degrees, beyond which the FOS decreases.

Nadher Hassan al baghadadi(2013) studies on stabilization of earth slopes by using soil nailing.They studied some of nail parameters which includes:

1.Positions of nail

2.Length of nail

3.Angle of nail inclination

4.Nail spacing.

Nadher Hassan Al-Baghdadi in his research work, Stabilization of Earth Slopes using Soil Nailingpresented a parametric study using commercial computer program “Slide 6“, which utilize different methods for solving slope stability problem. Bishop method was used to analyze un nailed and nailed slopes with granular soil, different slope heights and angles. . Some of nails parameters were studied such as, positions of nail, length of nail, angle of nail inclination, and nail spacing. He reported thatthe optimum length of nails, with spacing larger than to cause block effect, related in obvious manner with height and angle of slope. In the case of spacing which can cause block effect, the increment in length of nails causes increment in F.S. because the failure surface cannot pass through the nails group so it pushed behind the block (nails group), which cause increasing in failure surface length.The best angle of nail inclination is ranged between (5 to 25 degrees) below the horizon. Also, a relationship could be obtained between the nail angle and slope angle and it could be useful indesign procedure. The spacing of nail was found to be (1 m) to give the best improvement of F.S.

*N.Ramya Gandhi and K. Ilamparuthi (2012)*studied on enhancing stability of slope using reinforcementby finite element method. They did this experiment on software and on a slope of 1:1.5. A row of single pile was taken for the experiment. The aim of study was to check the effect of pile **location, length, stiffness and spacing** and concluded that.Effective pile location of the clay slope is 0.2 times the width of the slope from the toe, where as in sandy slope the favourable location, which offers higher factor of safety, is at the mid width of slope.The factor of safety increases with the length of pile. The effective length of the pile is 1 to 2.5 times the height of the slope.Increase in stiffness factor increases the safety factor and maximum factor of safety is obtained for stiffness factor of 0.002 irrespective of slope material. .The safety factor decreases with increase in pile spacing and the optimum spacing is 4D for the sandy slope of 1:1 and the spacing has negligible influence the case of clay slope.

An Experimental Study on Horizontal and Inclined Nails in Sandcarried out by *Javia, Vaibhav et al. (2013)* reported that that horizontally driven nails have more FOS than inclined nails in sand.It is concluded that the ultimate load increases with horizontal nailing as compared to inclined nailing. The experiment showed that the value of FOS is higher for θ= 0° i.e. using horizontal nails in excavations having vertical face in sand for driven nails. Earlier investigators (Juran and Elias, 1990: Sabahit et al., 1996: Patra, 1998,2001: Swami Saran et al., 2005[6]) have also obtained similar results.

2.3 Summary of the Literature Review

Soil nailing has been emerged as an effective technique in recent years, widely used to stabilize the steep slopes. Its design is often controlled by the allowable deformation level especially when buildings and/or other underground facilities exit near the excavation. The majority of slope stability analyses performed in practice still use traditional limitequilibrium approaches involving methods ofslices that have remained essentially unchangedfor decades. The finite elementmethod represents a powerful alternative approach for slope stability analysis which is accurate, versatile and requires fewer assumptions regarding the failuremechanism. Slope failure in the finite elementmodel occurs `naturally' through the zones inwhich the shear strength of the soil is insufficient to resist the shearstresses (Griffiths and Lane, 1999). Therefore a three-dimensional finite element model should be developed for the deformation analysis of nailed soil structures. In this model, the soil nonlinearity, the soil–nail interaction and the staged construction should be considered. The comparison between the kinematical limit equilibrium and the model test has been carried out which resulted in study of parameters like nail stiffness, nail inclinations, soil stiffness and boundary conditions (Juran et al., 1992). Hence a comparable study between the finite element and model testing can also be done in order to study the same parameters which are of great importance with designing schemes.]Experimental study of the soil nails has been well defined.The maximum and minimum effects of reinforcement were obtained for horizontal and inclined upwards placement of nails respectively. The bending and shearing resistance of steel bars did not contribute significantly to the effect of the reinforcement.The loading capacity of a slope decreases with an increase in the slope angles (*β*). The maximum load capacity is found in the slopes with 0º nail inclination for each respective slope angles. The forces on the nails are determined at the centre of the nails and the distribution of forces along the length of the nail is determined. It is observed that the maximum capacity is observed at the top rows of nails.

2.4 Objectives of present study

In the present study, based on the literature review, the following objectives were determined:

- Experimental setup of unreinforce sand soil slope with slope angles of 45^o,60^o and 90^o.
- Study of failure surface of unreinforced soil slope under increasing surcharge load.
- Study of load versus displacement behaviour of unreinforced slopes.
- Study of failure surface of reinforced slope (45^o,60^o and 90^o) with alumminium nails and helical nails.
- Study of load versus settlement behavior of reinforced slopes.

CHAPTER 3

METHODOLOGY

3.1 General

In the project certain equipments were used. A model tank of 60cm X 40cm X60cm. Nails were of stainless steel grooved with threads. On the nails a 120Ω foil strain gauge was soldered which was connected to a wheatstone bridge. During testing this wheatstone bridge was supplied with potential difference of 5V and output voltage was measured by digital multimeter.

Before tthe experiment certain tersts were performed on the soil like sieve analysis, pycnometer test,direct shear test.

3.2 Equipment Used

Various equipments used are-

3.2.1 Model Tank

A model tank of dimension 60cm X 40cm X 60cm was used. It has six flat sides and all angles are right angles. And all of its faces are rectangles. It is also called a cuboid. If at least two of the lengths are equal then it can also be called a square prism or square cuboid. If all three lengths are equal it can be called a cube and each face will be a square. A cube is still a prism. And a cube is one of the Platonic Solids. It is transparent from all four sides. It is filled with soil.

3.2.2 Perpex sheet

It is a transparent thermoplastic often used in sheet form as a lightweight or shatter-resistant alternative to glass. The same material can be utilised as a casting resin, in inks and coatings, and has many other uses. Although not a type of familiar silica-based glass, the substance, like many thermoplastics, is often technically classified as a type of glass (in that it is a non-crystalline vitreous substance) hence its occasional historic designation as acrylic. Chemically, it is the synthetic polymer of methyl methacrylate.

3.2.3 Iron angles

It is fitted at all edges and corners. It is used to give support to a model tank so that when load is applied on it by a machine the model tank doesn't get deform. A pair of two iron angles werefitted on two opposite side of that tank.

Figure 3.1 Model Tank

3.2.4 Nails

Following 2 type of nails are used for conducting experiment:

1. Screwed hollow aluminium nails.
2. Circular rings nails.

3.2.4.1 Screwed hollow aluminium nails.

Screwed hollow aluminum nails of length 15mm with external diameter 10mm. and internal diameter of 8mm are used as shown:

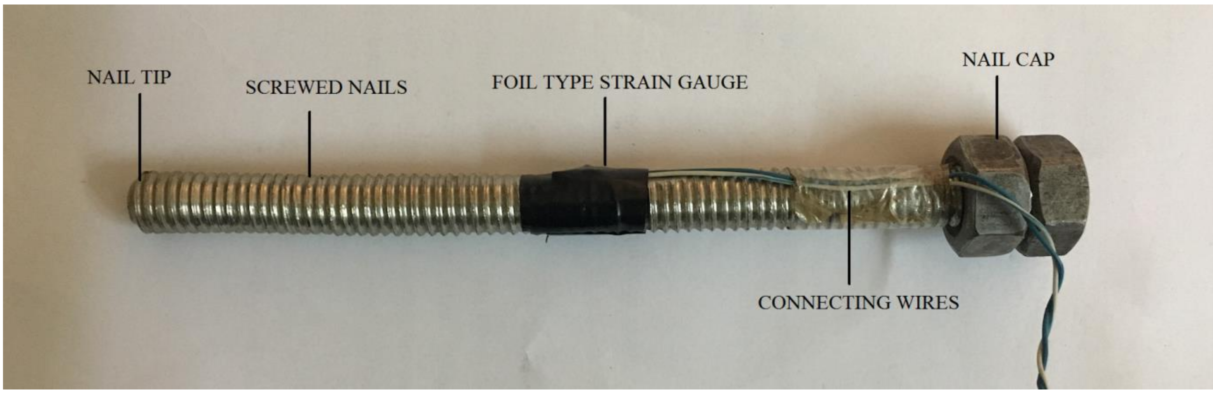

Fig.3.2 hollow screwed aluminium nail.

3.2.4.2 Cylindrical circular rings nails

Hollow cylindrical nails are used with circular rings as shown.

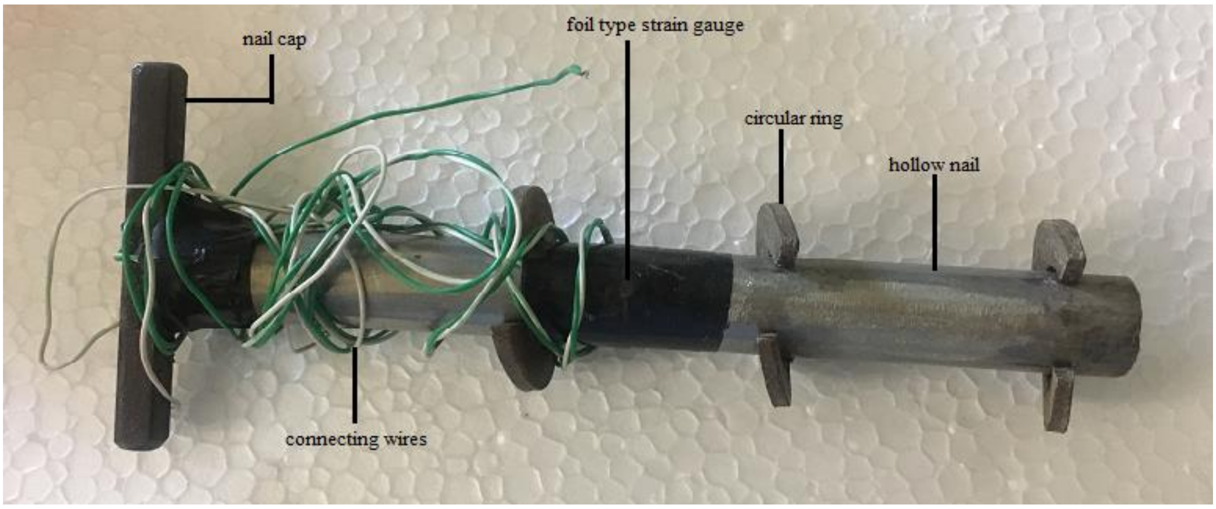

Fig.3.3 cylindrical circular rings nails

3.2.5 Foil Strain Guages

The following foil type strain gauges were used to measure the voltage changes in nail corresponding to the load increments. These foil type strain gauges were ordered.

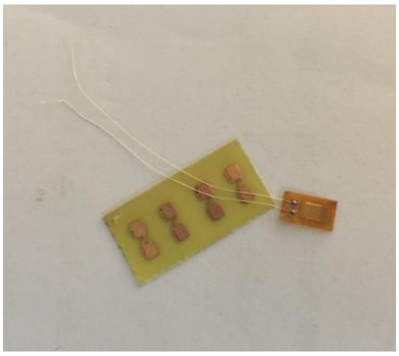

Figure 3.4 foil strain guage

3.2.6 Digital Multimeter

A **multimeter** or a **multitester**, also known as a **VOM** (Volt-Ohm-Milliammeter), is an electronic measuring instrument that combines several measurement functions in one

Digital multimeters (DMM, DVOM) have a numeric display, and may also show a graphical bar representing the measured value. Digital multimeters are now far more common due to their cost and precision, but analog multimeters are still preferable in some cases, for example when monitoring a rapidly varying valueA multimeter can be a hand-held device useful for basic fault finding and field service work, or a bench instrument which can measure to a very high degree of accuracy. They can be used to troubleshoot electrical problems in a wide array of industrial and household devices such as electronic equipment, motor controls, domestic appliances, power supplies, and wiring systems.It was used to measure the resistance .

Figure 3.5 Digital multimeter

3.2.7 Wheat Stone Bridge

One wheat stone bridge is made for one nail which comprises of 3 resistances, aluminium nail and a multimeter.

Wheatstone bridge without connection

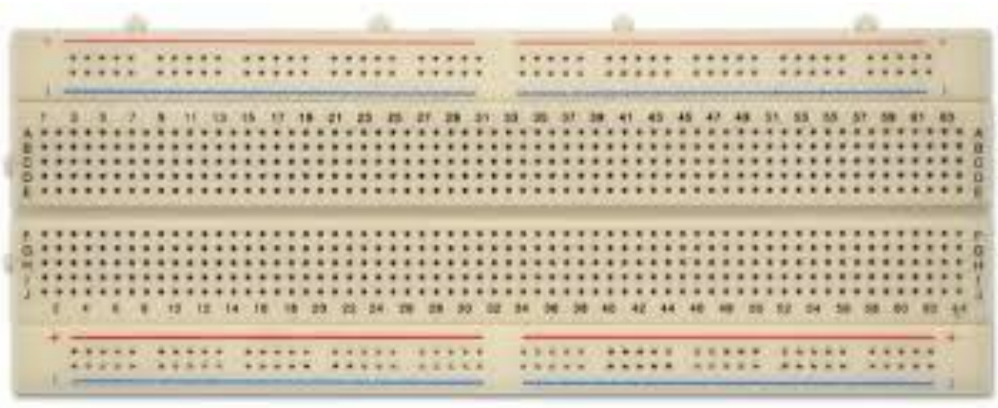

Figure 3.6 Wheatstone bridge without connection

Wheatstone bridge with connection

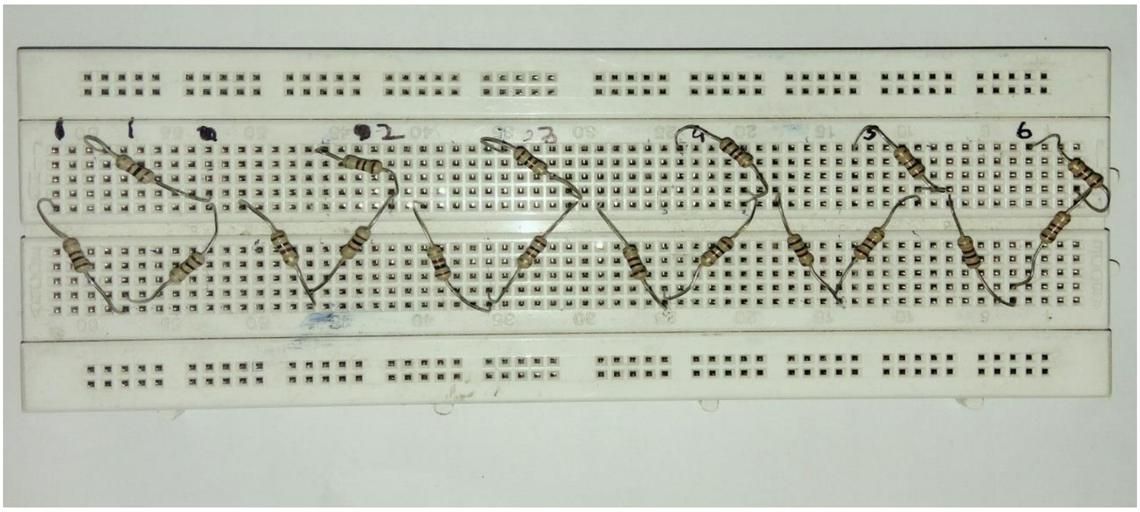

Figure 3.7Wheatstone bridge with connection

3.3 Experiments performed in laboratory

3.3.1 Particle size Distribution

The grain size analysis is widely used in classification of soils. Information obtained from grain size analysis can be used to predict soil water movement.

3.3.2 Specific gravity

The Pycnometer is used for determination of the specific gravity of soil particles of both fine grained and coarse grained soils. The specific gravity of soil is determined using the relation:

$$G = \frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$$

where,

W_1 = 460.5g = Weight of dry and empty pycnometer

W_2 = 540.9g = Weight of pycnometer + dry soil

W_3 = 1307.7g = Weight of pycnometer + soil + water

W_4 = 1255.3g = Weight of pycnometer + water

Result:

The value of Specific Gravity (G) comes out to be 2.87

3.3.3 Direct Shear Test

DST Test is used to determine soil parameters such as cohesion(c) and angle of internal friction. It is a quick test to determine soil parameters.

3.4 Slope preparation

3.4.1 Preparation of 45º Slope

Procedure:

The slope is divided in layers of 5cm and making are done on the model tank. For slope preparation ,density of soil is decided to be 18.393 KN/m^3. First the base of 20cm is prepared which weigh 90 kg . Base is made in layers of 5cm weighing 22.5kg each. After pouring 22.5 kg of soil ,tamping is done to get the desired density. After base of 20cm is prepared, the facing of dimension 42.4cmX40cmXof wooden play as in fig 3.4.1 b) is fixed at the marking of 45^o. The wooden ply has hole for the nails. Vertical spacing of hole on ply=10.6cm. Horizontal spacing of hole =13.3cm. Now the slope is prepared in layers of 5cm. In preparing slope at every 10cm layer, a fine coloured powder is spread along the edges as a tracer. Slope is made till the height of 30cm. When slope reaches to level of a hole, at that point the nail is inserted.

Tamping is done to get the desired density . Nails are at β =0° from horizontal as in fig 3.4.1 (a) the weight of soil for slope is calculated according to the density 18.93 KN/m^3.

FIG 3.10 Preparation of 45° Slope

3.4.2 Preparation of 60° Slope

Procedure:

The slope is divided in layers of 5cm and making are done on the model tank. For slope preparation ,density of soil is decided to be 18.393 Kn/m^3. First the base of 20cm is prepared which weigh 90 kg . Base is made in layers of 5cm weighing 22.5kg each. After pouring 22.5 kg of soil ,tamping is done to get the desired density. After base of 20cm is prepared, the facing of dimension 34cmX40cm of wooden play is fixed at the marking of 60°. The wooden ply has hole for the nails. Vertical spacing of hole on ply=10.6cm. Horizontal spacing of hole =13.3cm. Now the slope is prepared in layers of 5cm. In preparing slope at every 10cm layer, a fine coloured powder is spread along the edges as a tracer. Slope is made till the height of 30cm. When slope reaches to level of a hole, at that point the nail is inserted. Tamping is done to get the desired density . Nails are at β =0° from horizontalas in fig 3.4.2 (a) the weight of soil for slope is calculated according to the density 18.93 KN/m^3.

FIG 3.11 Preparation of 60^o Slope

3.4.3 Preparation of 90^o Slope

Procedure:

The slope is divided in layers of 5cm and making are done on the model tank. For slope preparation ,density of soil is decided to be 18.393 Kn/m^3. First the base of 20cm is prepared which weigh 90 kg . Base is made in layers of 5cm weighing 22.5kg each. After pouring 22.5 kg of soil ,tamping is done to get the desired density. After base of 20cm is prepared, the facing of dimension 30cmX40cm of wooden play is fixed at the marking of 60^o. The wooden ply has hole for the nails. Vertical spacing of hole on ply=10.6cm. Horizontal spacing of hole =13.3cm. Now the slope is prepared in layers of 5cm. In preparing slope at every 10cm layer, a fine coloured powder is spread along the edges as a tracer. Slope is made till the height of 30cm. When slope reaches to level of a hole, at that point the nail is inserted. Tamping is done to get the desired density . Nails are at β =0^{o}from horizontalas in fig 3.4.2 (a) the weight of soil for slope is calculated according to the density 18.93 KN/m^3.

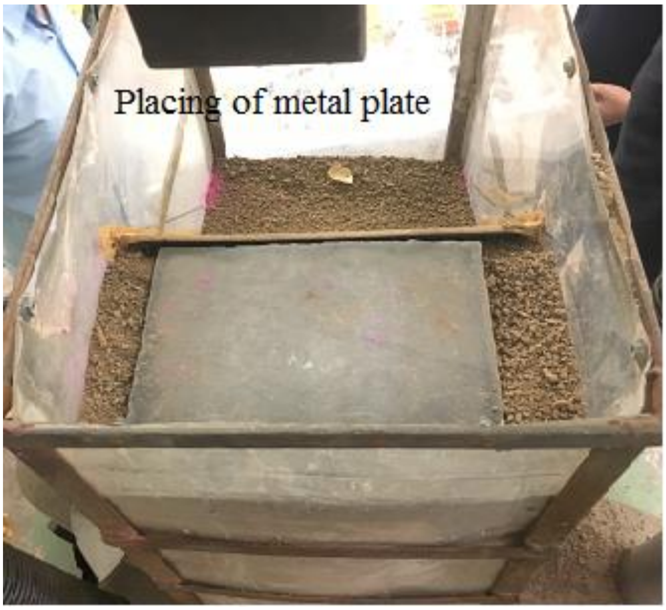

Fig 3.12 Preparation of 90^o Slope

3.5 Testing procedure

Slope is made. 6 nails with strain gauges connected with wire . Each strain gauges is fixed nails with separate wheat stone bridges. Load is applied by UTM. As load increases resistance in strain gauges changes which is measured by multimeter so R_g is measured by formula.

$$\frac{\text{Vout}}{\text{Vin}} = \left(\left(\frac{\text{R3}}{\text{R3} + \text{Rg}}\right) + \left(\frac{\text{R2}}{\text{R2} + \text{R1}}\right)\right)$$

Input voltage is given in Table 1

Resistor	1	2	3	4	5	6
R1	101.2	100.6	101.4	99.8	101.8	101.2
R2	101.6	101.7	103.4	100.9	99.7	99.5
R3	100.2	104.7	102.5	98.5	101.8	100.6

R1,R2 &R3= Resistor arms of Wheatstone bridge

R_g= Strain gauge on nail

Fig 3.11 Multimeter connection

The soil is filled in the box to prepare a base of around 20cm. Then the slope of different angles is prepared. We have done testing on slope angles of 45°, 60° and 90°. After preparing the base, the soil is filled in the box in layers and then tamped. The process continues until the box is filled to the top but the space for the metal plate is left at the top. The horizontal layer of some colored material is added to the sides of the box at each horizontal level of nail pair. After the slope is prepared metal plate is placed over the the top of the slope. Then the box placed on the **UTM** (Universal Testing Machine). Then six wheat stone bridge connections are made on breadboard using 3 resistances, a nail and a multimeter for one wheat stone bridge. Then the voltage is applied across each wheat stone bridge connection individually using USB cables connected to the laptops. The readings of the multimeter will give the values of output voltage.

Input voltage is measured across each wheat stone bridge connection and is noted down.

Then the **UTM** machine is started and the load is applied gradually. When sufficient load is applied on the nail (or strain gauge) the readings of the multimeter will start to change. As the load increases the readings of the multimeter also changes. The readings of the multimeter for the nails inserted on the top of the slope will change first as they will experience the load first and then the nails below.

The readings of the all the multimeters, load applied and the deflection are taken at an interval of 10 seconds. The experiment will continue for 120-140 seconds.

Now as we have the values of input voltage, output voltage, known resistances at an interval of 10 seconds for each wheat stone bridge connection the values of the resistance of each nail can be calculated using the formula below:

$$R_{g_x} = \frac{V_{in}R_1R_3 - V_{out_x}R_1R_3 - V_{out_x}R_2R_3}{V_{out_x}(R_1 + R_2) + V_{in}R_2}$$

where,

R_{g_x} = Resistance of the nail at any interval x,

R_1, R_2, R_3 = Known Resistances,

V_{in} = Input Voltage,

V_{out_x} = Output Voltage at any interval x

Then using this value of resistance, strain in the nail is calculated at each interval using the formula below:

$$\in_x = \left| \frac{R_{g_x} - R_{g_0}}{R_{g_0}/1.8} \right|$$

where,

$\in_x$ = Strain in nail (or strain gauge) at any interval x.

R_{g_x} = Resistance of nail at any interval x,

R_{g_0} = Initial resistance of nail without any load applied.

Now the value of axial force in the nail at each interval is calculated by using the formula below:

$$F_x = \in_x \; Y_{Al} \; A$$

$$A = \pi(r1^2 - r2^2)$$

where,

F_x = Axial force in the nail at any interval x,

$\in_x$ = Strain in nail (or strain gauge) at any interval x,

Y_{Al} = Young's Modulus of Aluminium,

A = Cross Sectional area of the nail

r1 = Outer diameter of the nail

r2 = Inner diameter of the nail

- Graph between ‘Force in nail’ and ‘Strain in nail’ is plotted for all the six nails.
- Also the graph between ‘Load’ and ‘Strain in nail’ is plotted for all the six nails.
- Then graph between load and corresponding settlement is plotted.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

As per the described methodologies, the preliminary tests and experiments were carried out on the soil sample to study the various parameters and characteristics of the sample that was to be used for the modelling of slope. The results obtained in different tests have been discussed below.

Unreinforced and reinforced slopes prepared were subjected to gradually increasing surcharge using UTM. Their corresponding failure patterns were observed and studied. Load versus settlement curves were formed for both unreinforced and reinforced slope models of 45^o, 60^o and 90 nail forces were calculated through measured values of strain on different nails using strain gages which is given below.

4.2 Particle size distribution analysis (Sieve Analysis)

Particle size distribution curve plotted between % finer and particle size (mm) is shown in fig 4.1.

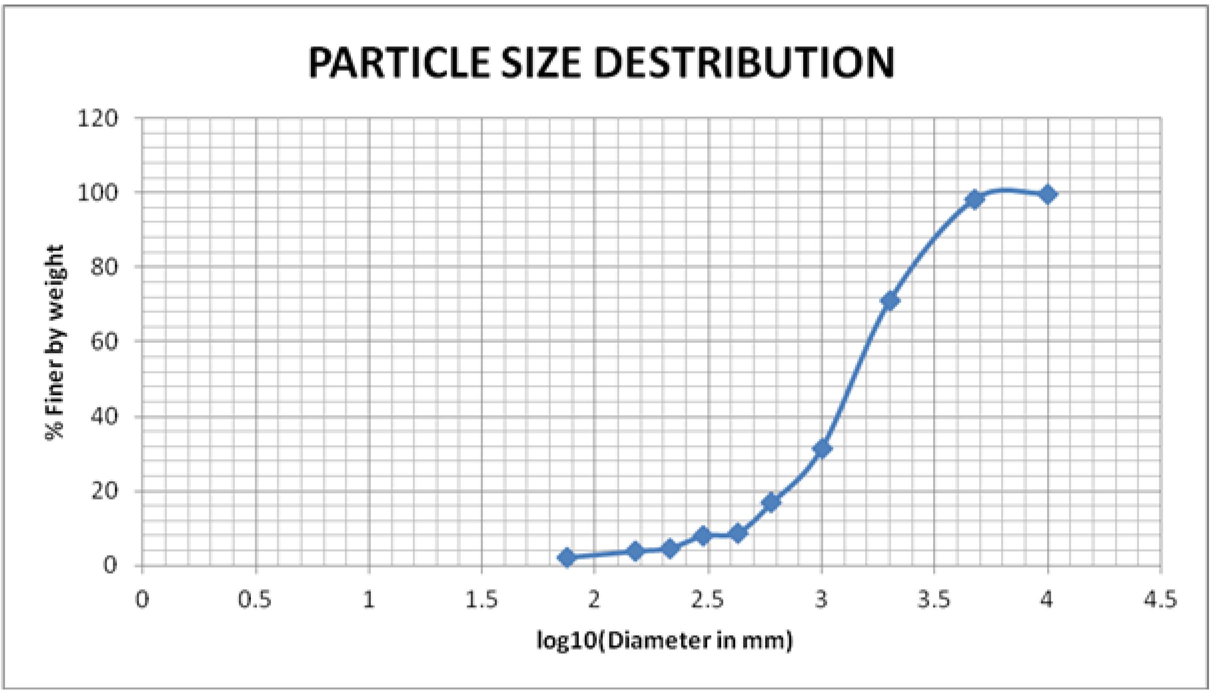

Fig 4.1 Particle size distribution curve

4.3 Specific gravity of soil (Pycnometer test)

Specific gravity of soil sample was found using pycnometer test in the laboratory.

G =The value of Specific Gravity (G) comes out to be 2.87

Now, the value of specific gravity of soil sample to be used in modeling of slope came out to be **2.87**. This value of specific gravity shows that soil sample is **sand.**

4.4 Direct Shear Test (for shear parameters)

Direct Shear test was carried on the soil sample which was found out to be sand by grain size distribution to find out the shear parameters of the soil, i.e. Cohesion (c) and friction angle (ϕ). The test was carried out for three normal stresses of 0.5 kg/cm^2, 0.75 kg/cm^2 and 1 kg/cm^2. From experiment value of cohesion(c)=**0.08kg/cm^2.**

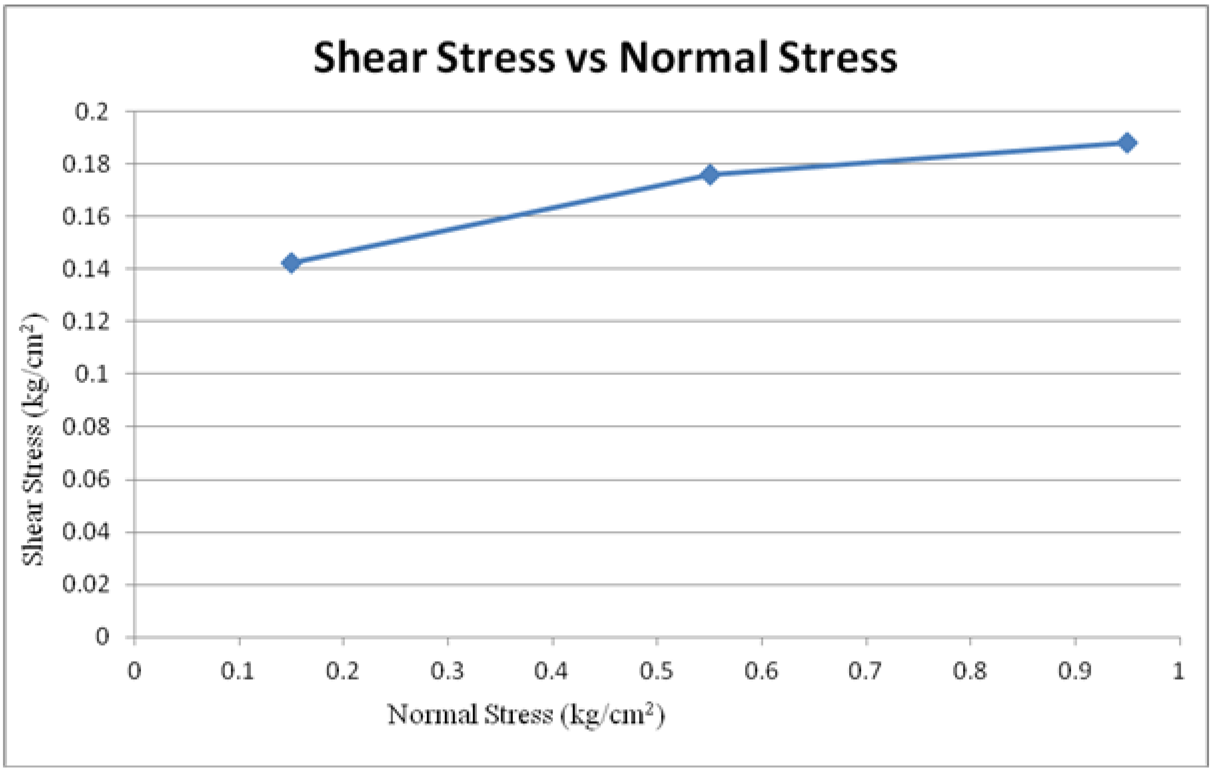

Fig 4.2 shear stress vs. normal stress

4.5 Load versus Settlement curves for slopes

After applying load on slopes using Universal Testing Machine (UTM), load and deflection values were observed and corresponding load vs. settlement curves were obtained for the slopes, i.e. 45^o, 60^{o}90 ^{o}which are shown in figures below.

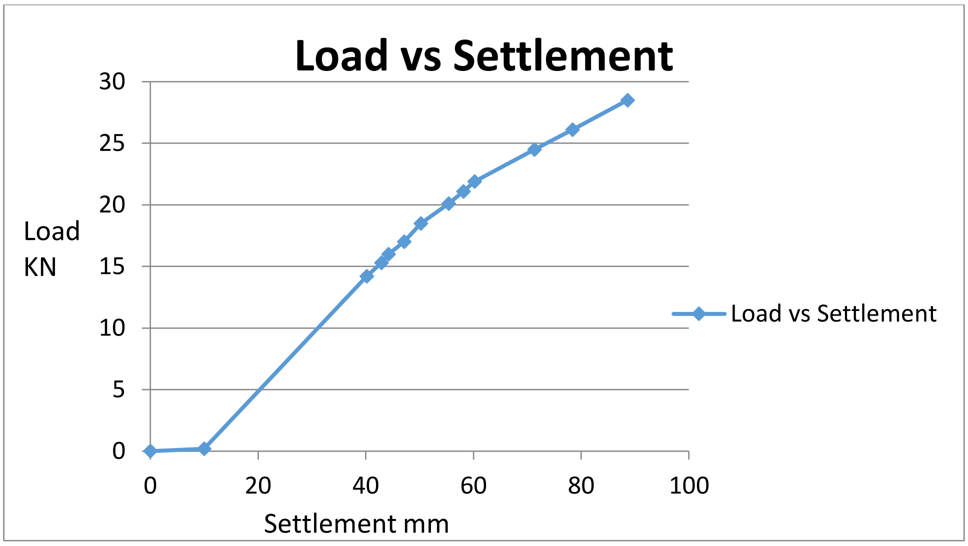

Fig 4.5.1 For 45^o with helical nails

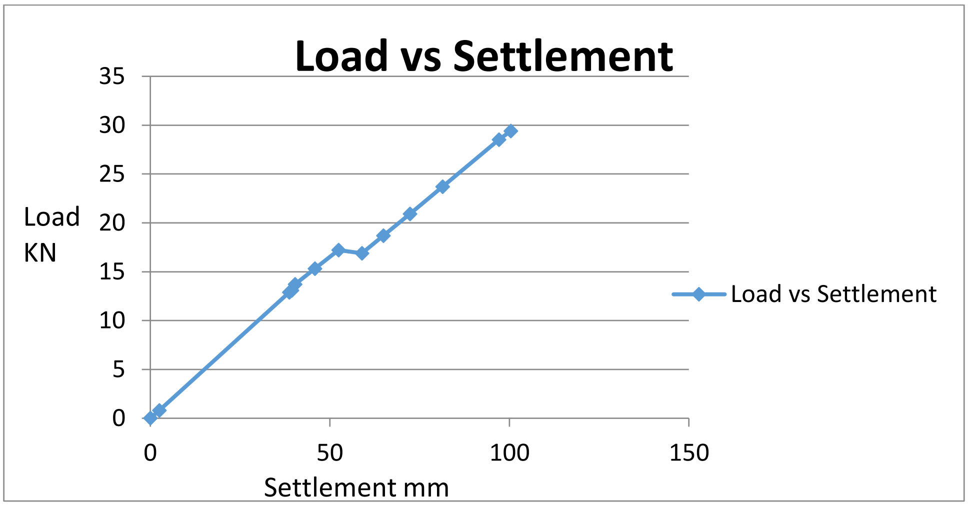

Fig 4.5.2 For 60 ^{o} with helical nails

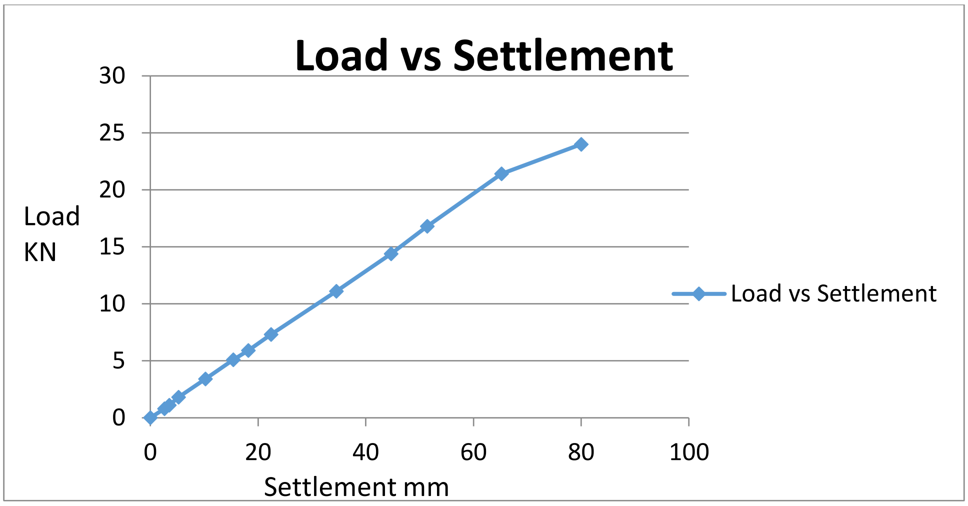

Fig 4.5.3 For 90 ° with helical nails

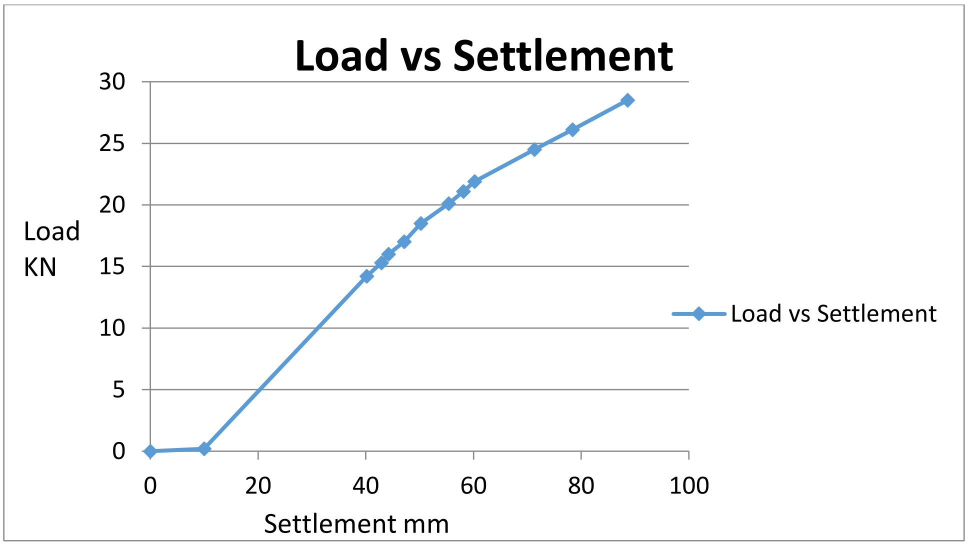

Fig 4.5.4 For 45° with alumminium nails

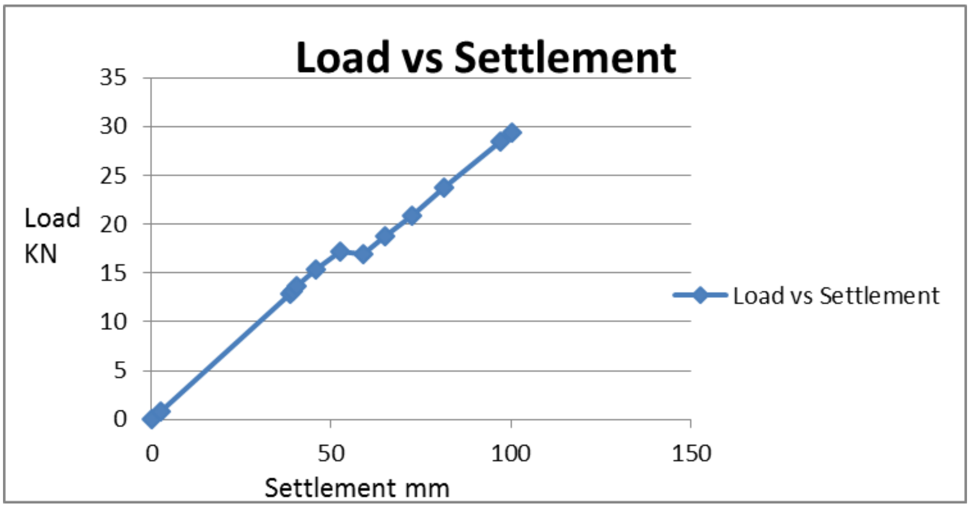

Fig 4.5.5 For 60^o with alumminium nails

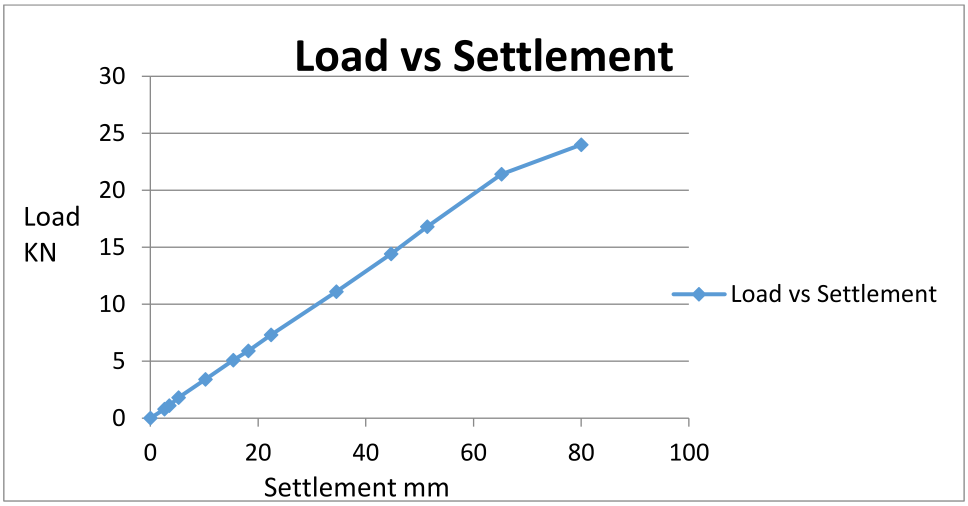

Fig 4.5.6 For 90^o with alumminium nails

From the load vs. settlement curves of unreinforced slopes, the values of load carrying capacity of 45^o,60^o,90^o slopes for alumminium nails are **38.7 kN** and **37.7kN**. **29.3 kN.**

Settlements in the slopes were found out to be **125 mm**,**110mm**and **80mm**for 45^o,90^o and 60^o unreinforced slopes.

From the load vs. settlement curves of reinforced slopes, the values of load carrying capacity of 45^o, 60^o, 90^o slopes for helical nails are **33.7 N** and**31.8kN.24kN.**

Settlements in the slopes were found out to be **80 mm110 mm** and **125mm** for 45^o,60^o and 90^o respectively.

It is seen that reinforced slopes have more load carrying capacities than unreinforced slopes. Also, load carrying capacity decreases with increase in steepness of slopes.

4.6 Load vs. nail strain curves

4.6.1 For 45^0 slope with nail at 0^0 inclination

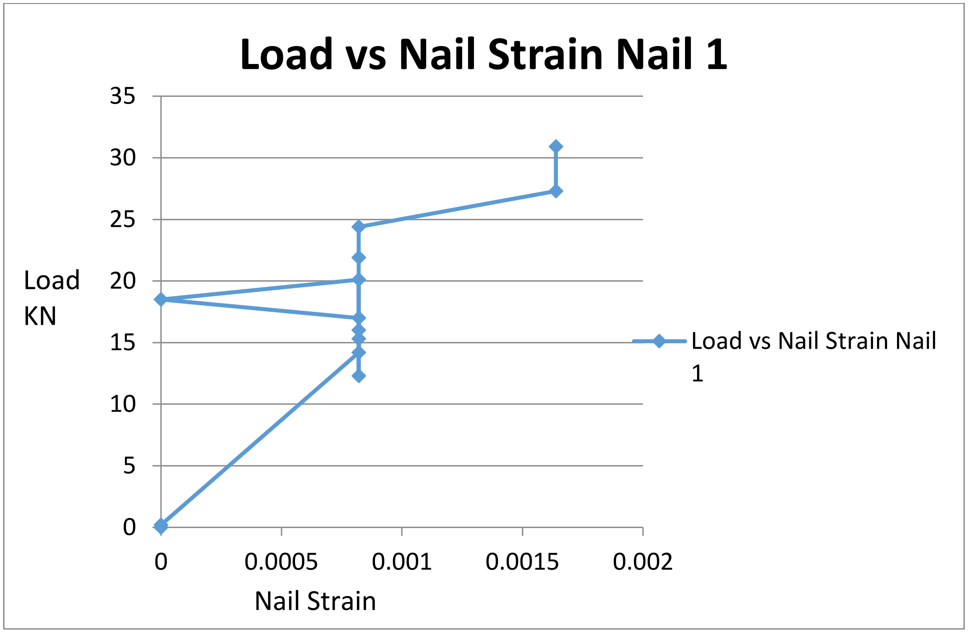

Fig 4.6.1 load vs. nail strain(nail 1)

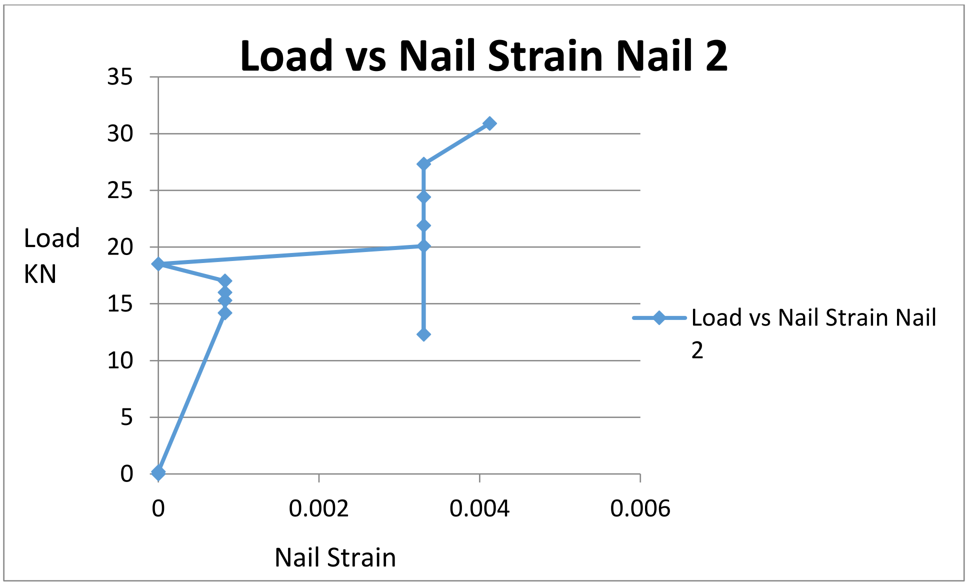

Fig 4.6.2 load vs. nail strain(nail 2)

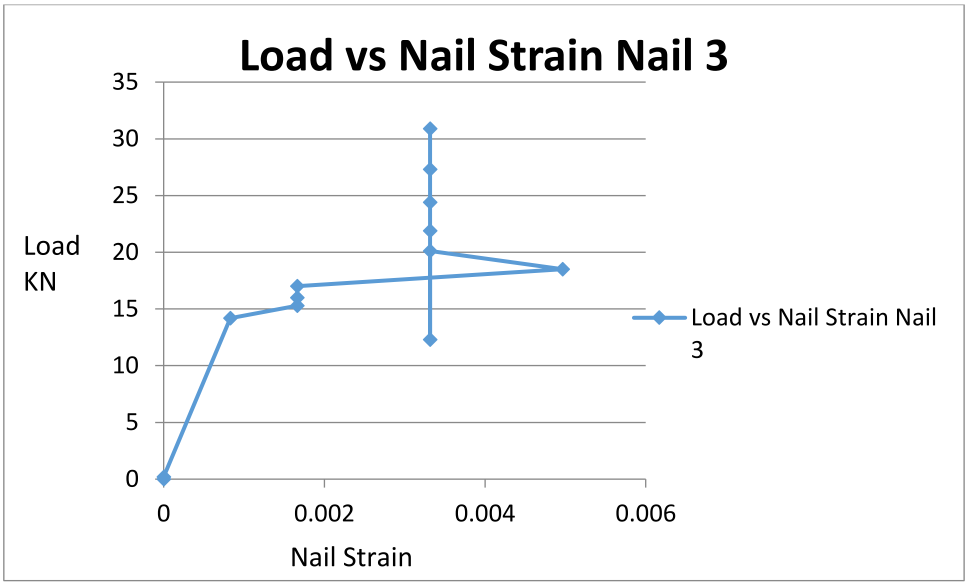

Fig 4.6.3 load vs. nail strain(nail 3)

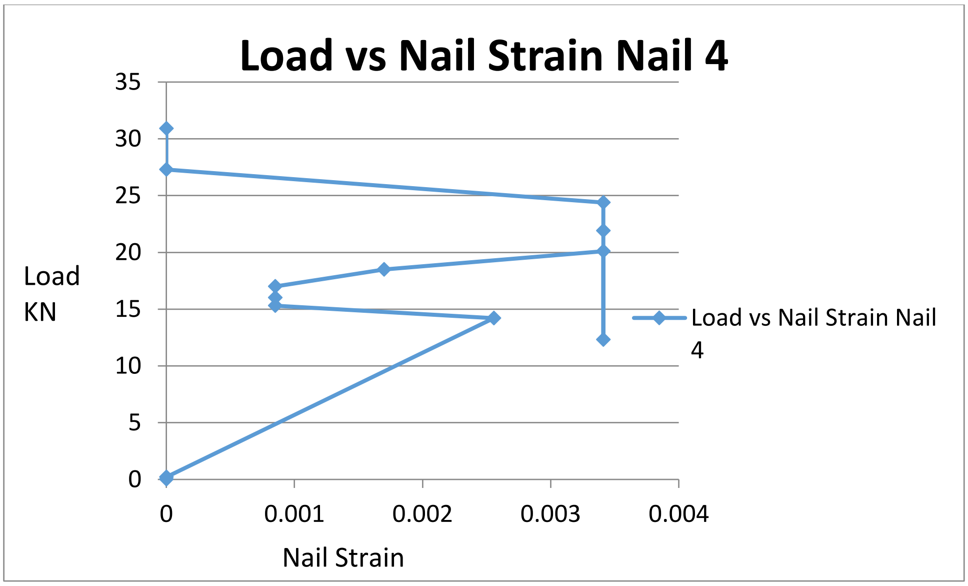

Fig 4.6.4 load vs. nail strain(nail 4)

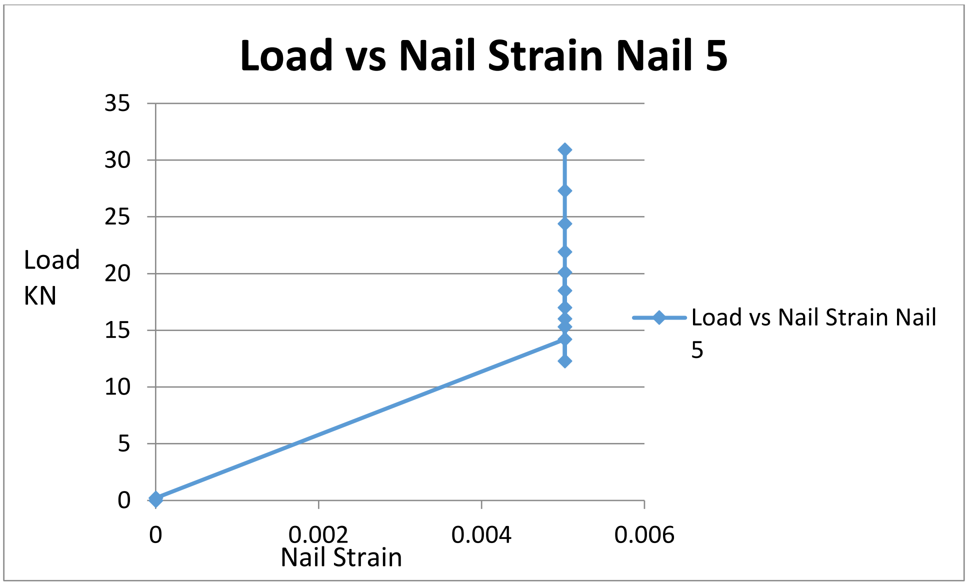

Fig 4.6.5 load vs. nail strain(nail 5)

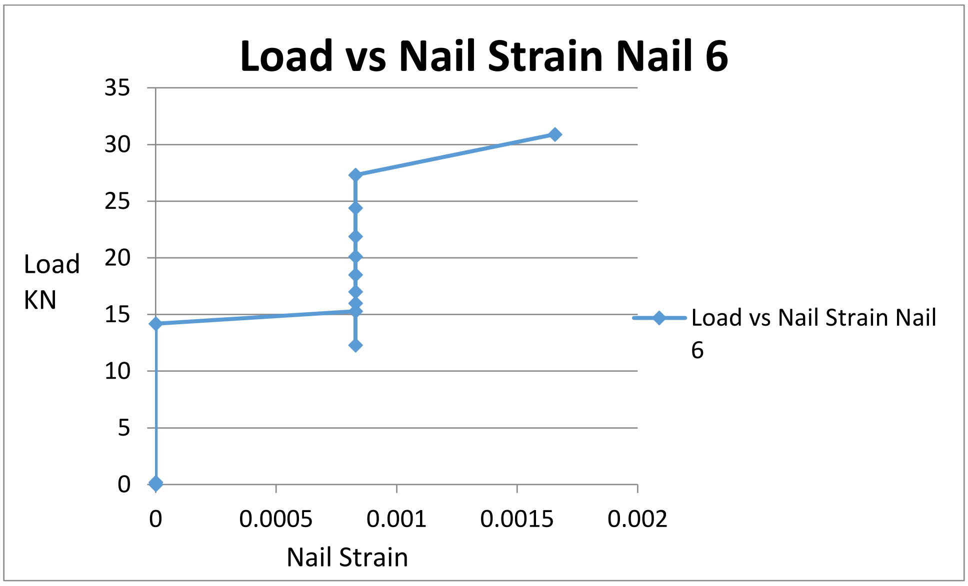

Fig 4.6.6 load vs. nail strain(nail 6)

4.6.2 For 60^0 slope with nail at 0^0 inclination

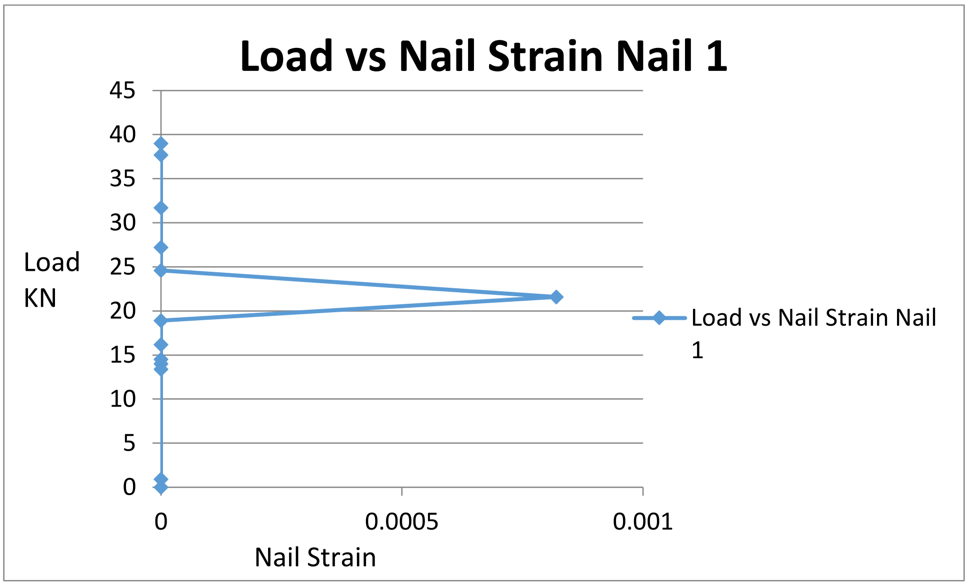

Fig4.6.7 load vs nail strain (nail 1)

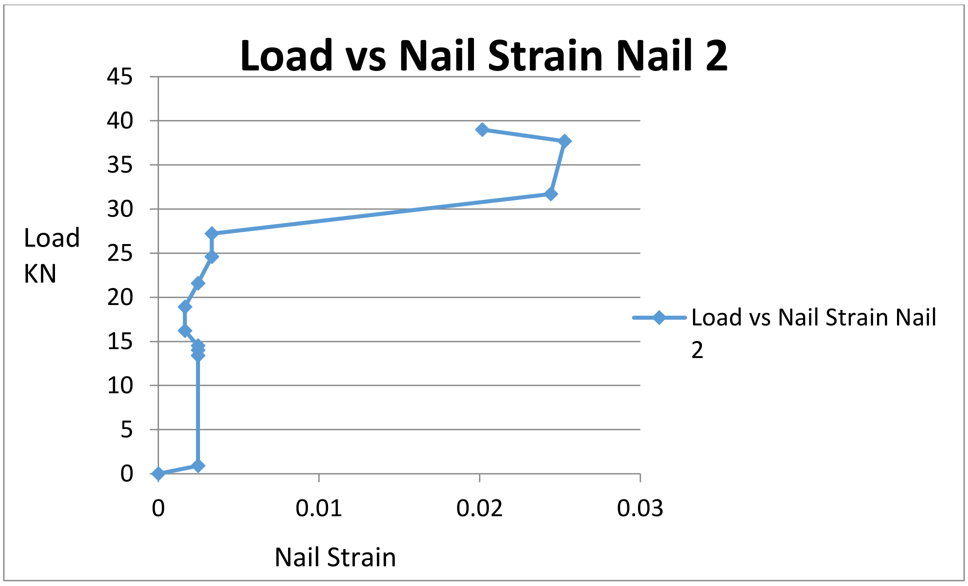

Fig4.6.8 load vs nail strain (nail 2)

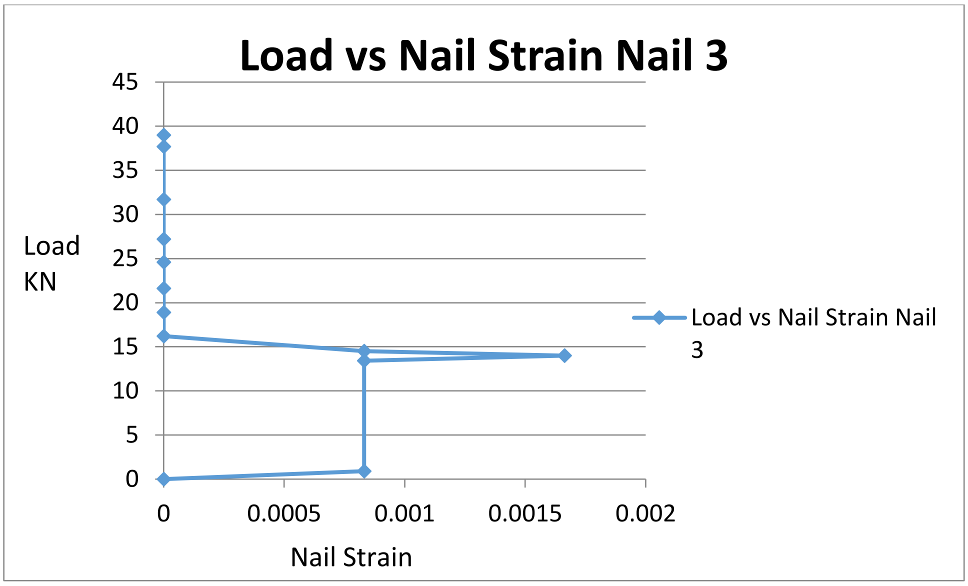

Fig4.6.9 load vs nail strain (nail 3)

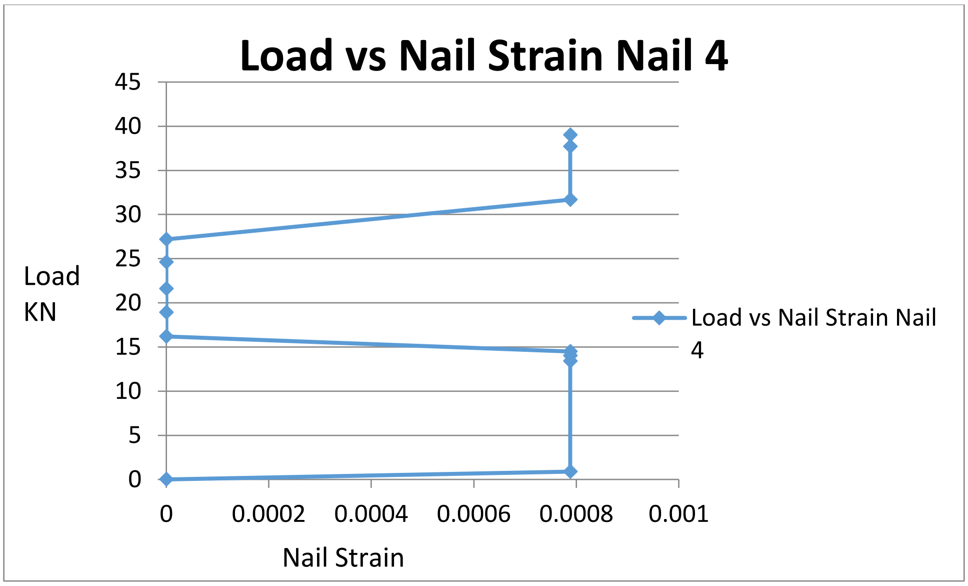

Fig4.6.10 load vs nail strain (nail 4)

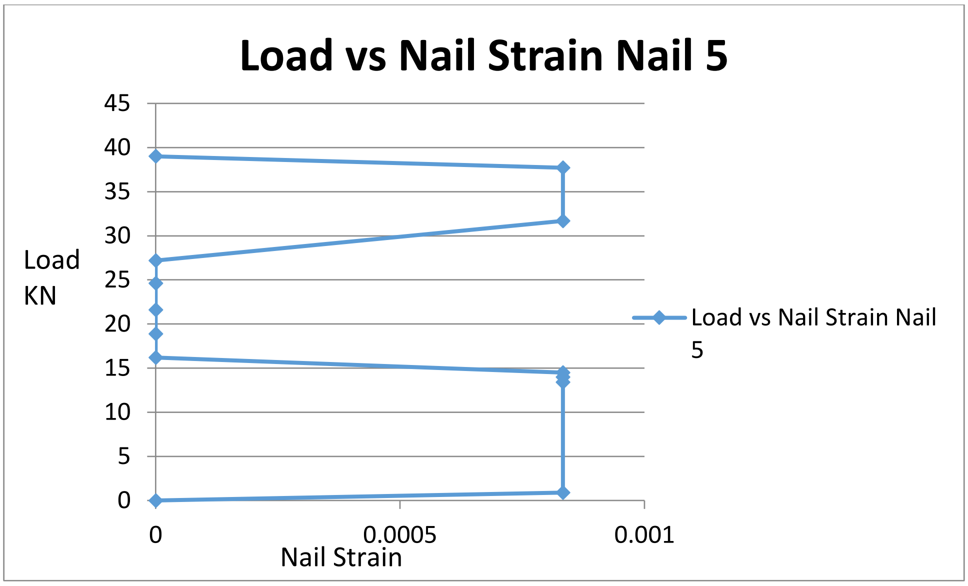

Fig4.6.11 load vs nail strain (nail 5)

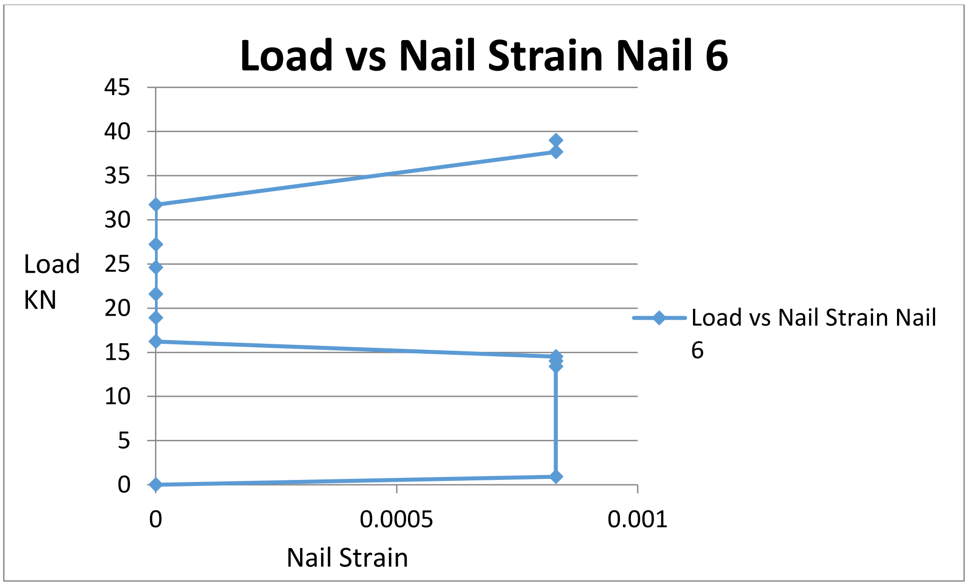

Fig4.6.12 load vs nail strain (nail 6)

4.6.3 For 90^0 slope with nail at 0^0 inclination

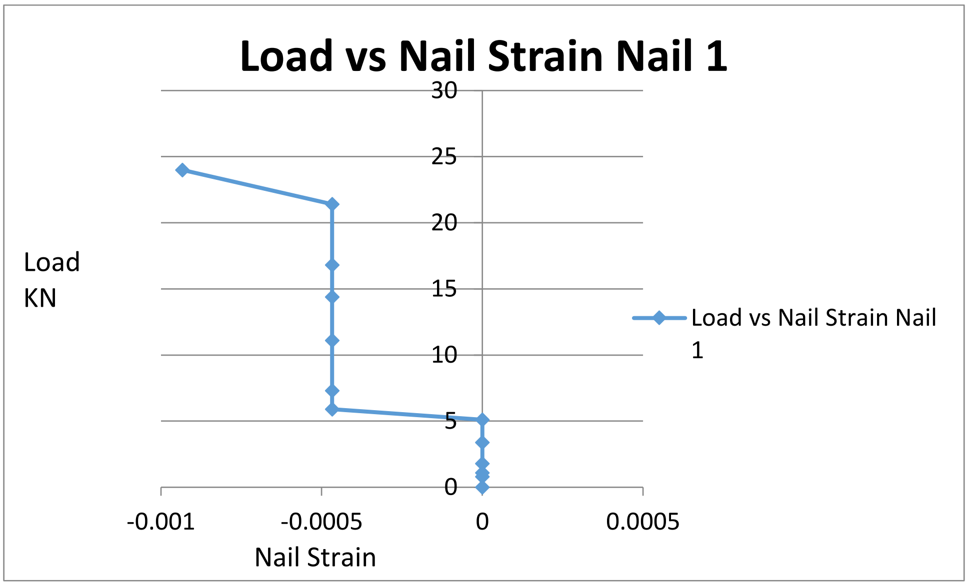

Fig 4.6.13 load vs. nail stain(nail 1)

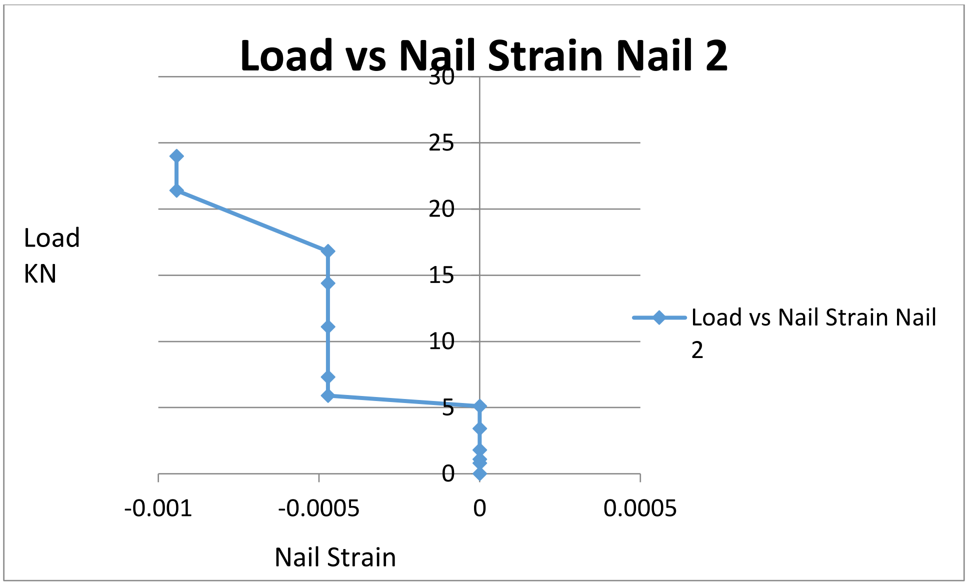

Fig 4.6.14 load vs. nail stain(nail 2)

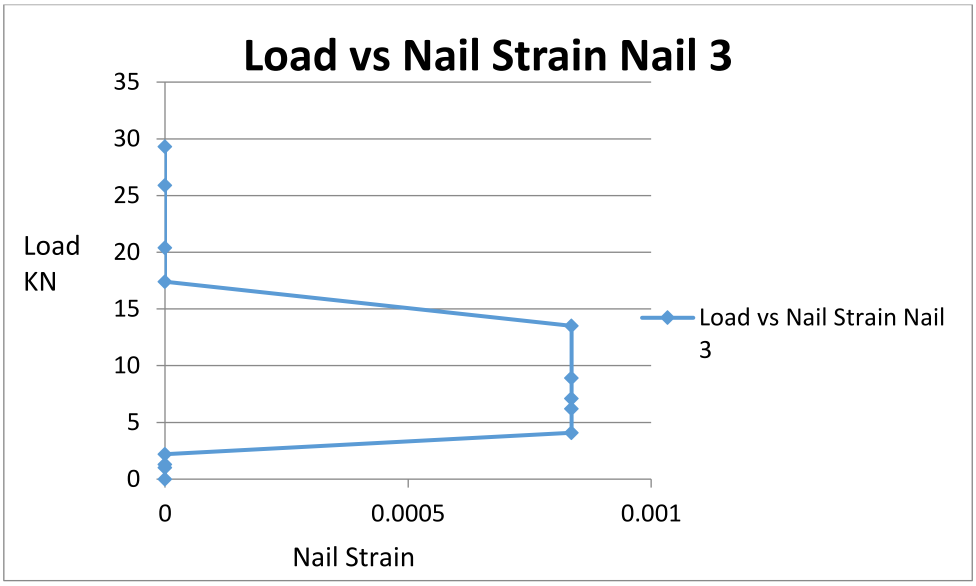

Fig 4.6.15 load vs. nail stain(nail 3)

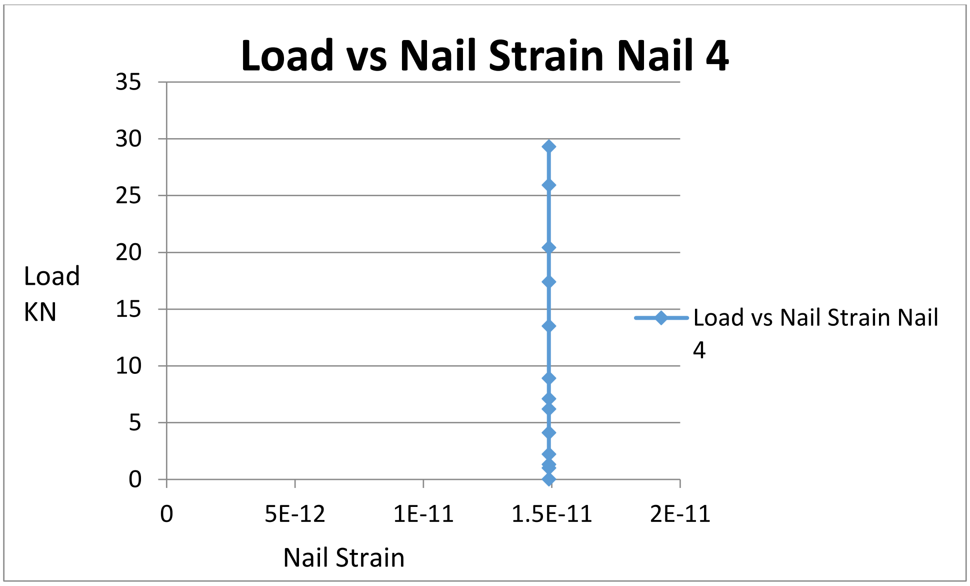

Fig 4.6.16 load vs. nail stain(nail4)

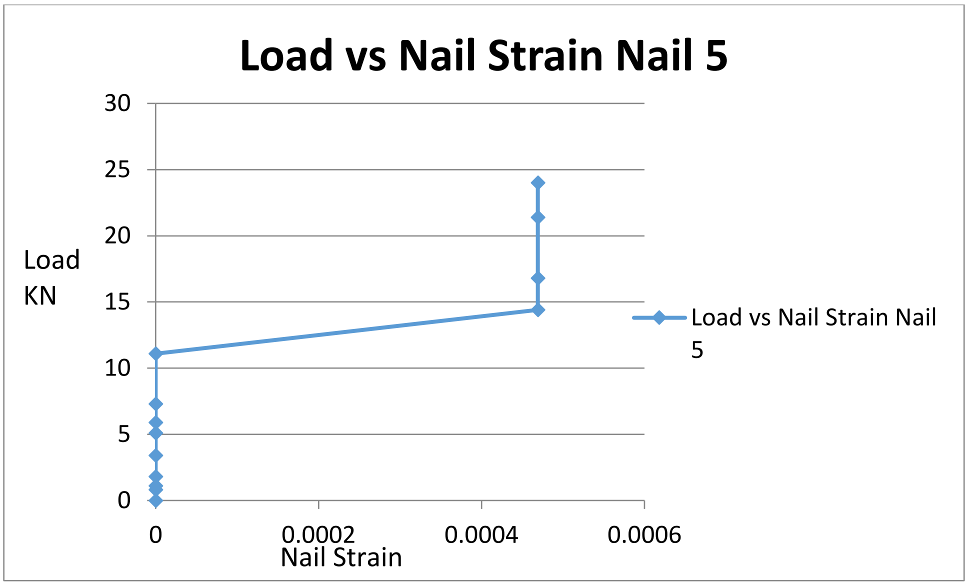

Fig 4.6.17 load vs. nail stain(nail5)

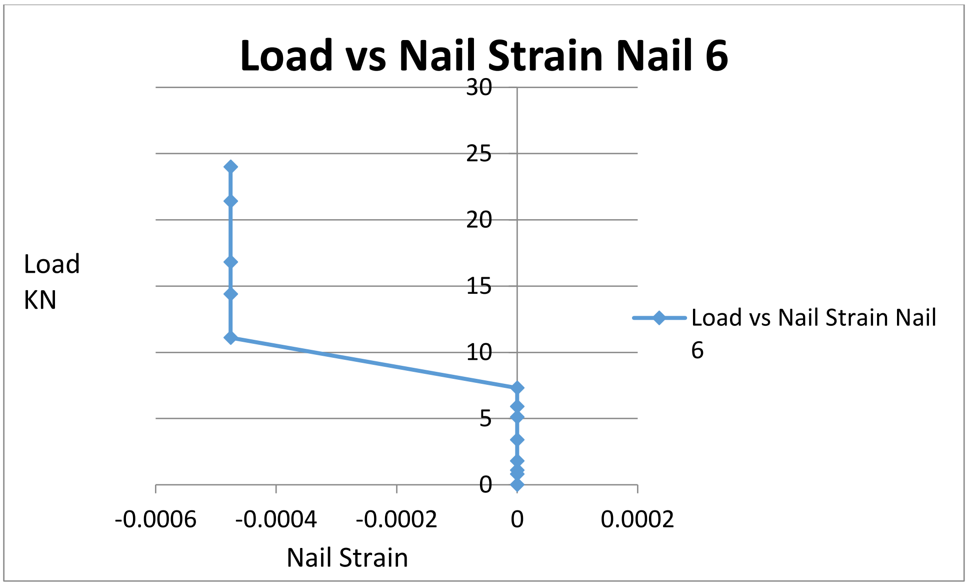

Fig 4.6.18 load vs. nail stain(nail6)

4.6.4 For 45^0 slope with helical nail

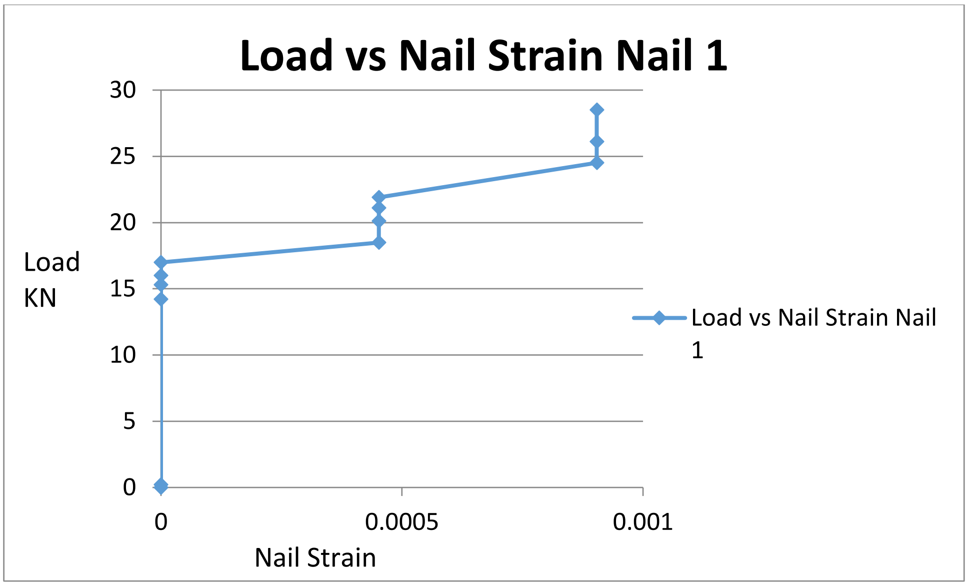

Fig 4.6.19 load vs. nail strain (nail 1)

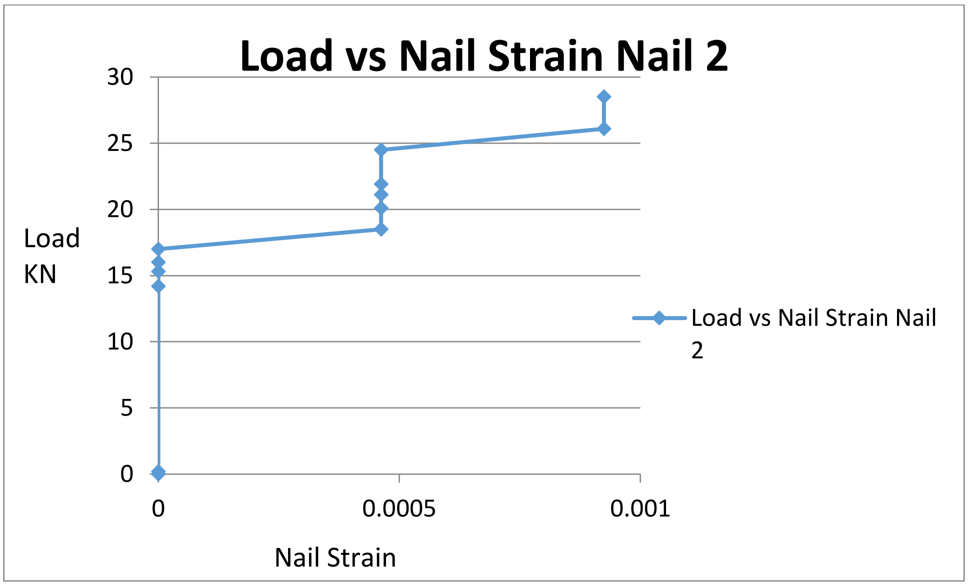

Fig 4.6.20 load vs. nail strain (nail 2)

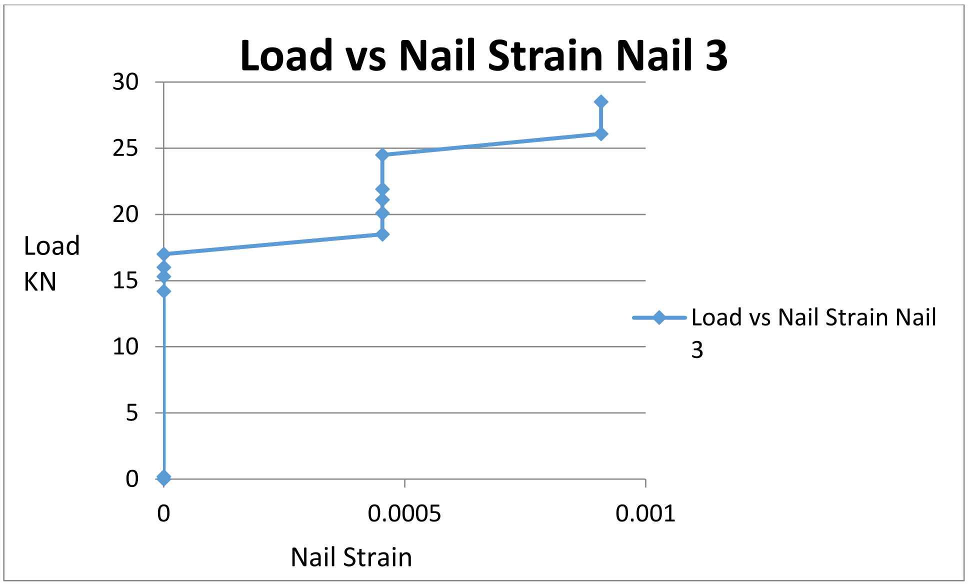

Fig 4.6.21 load vs. nail strain (nail 3)

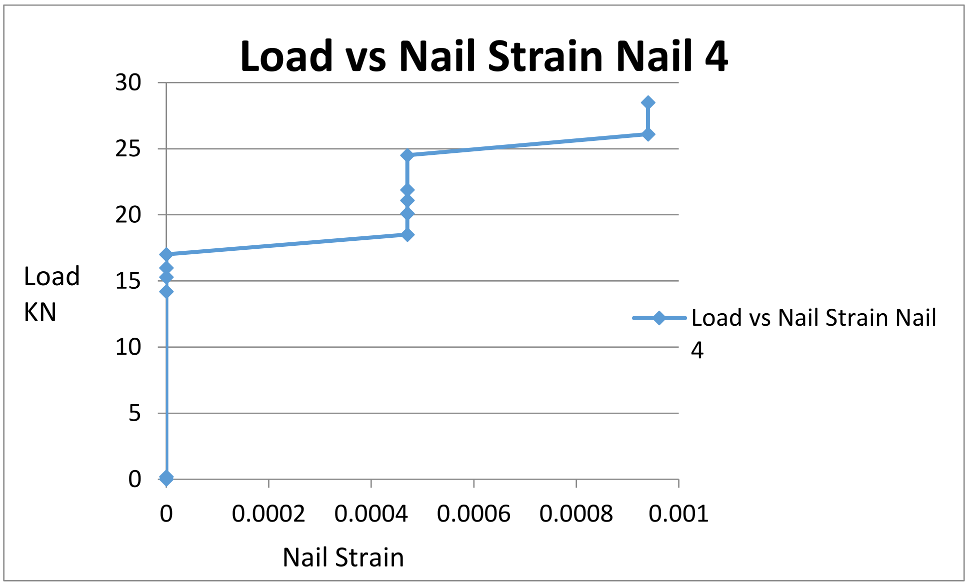

Fig 4.6.22 load vs. nail strain (nail 4)

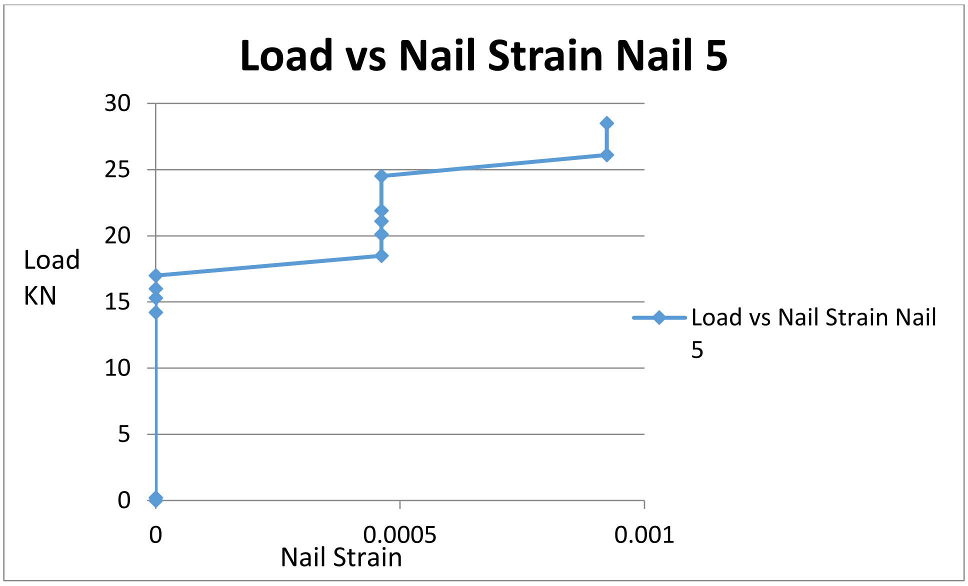

Fig 4.6.23 load vs. nail strain (nail 5)

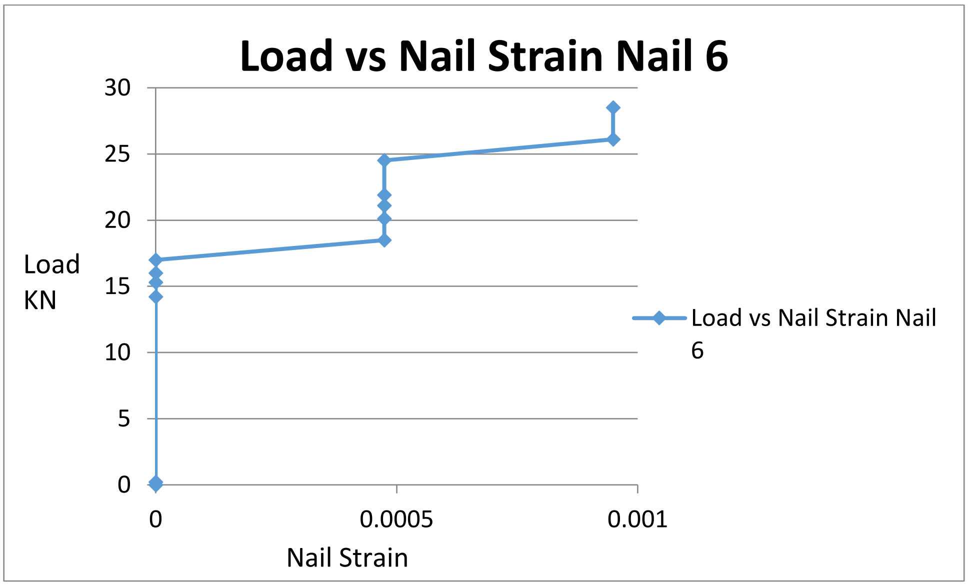

Fig 4.6.24 load vs. nail strain (nail 6)

4.6.5 For 60^0 slope with helical nail

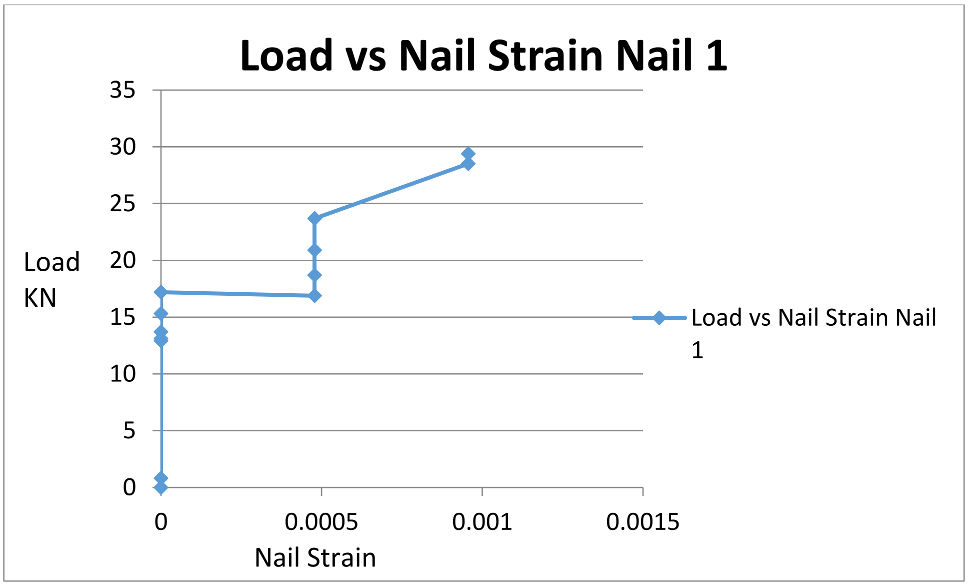

Fig 4.6.25 load vs. nail strain (nail 1)

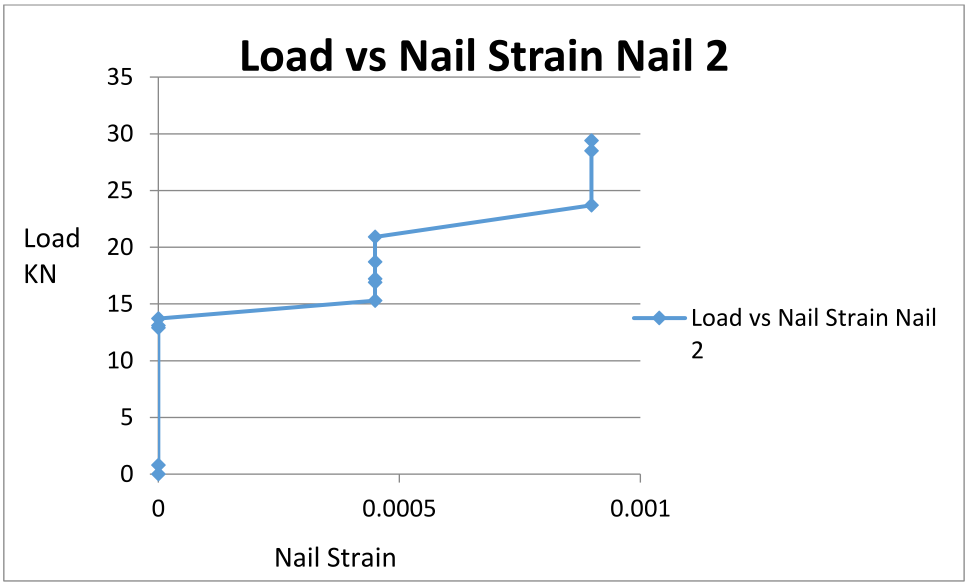

Fig 4.6.26 load vs. nail strain (nail 2)

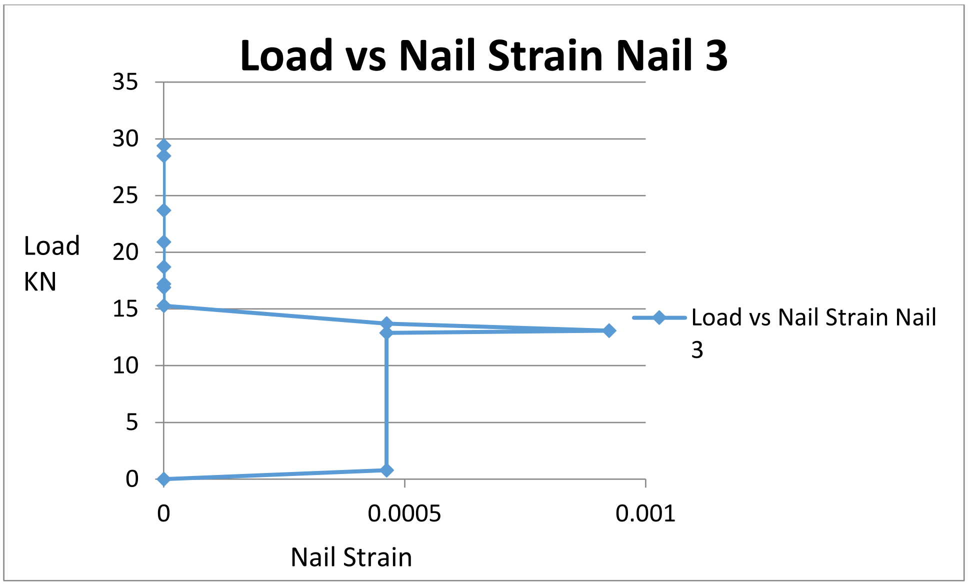

Fig 4.6.27 load vs. nail strain (nail 3)

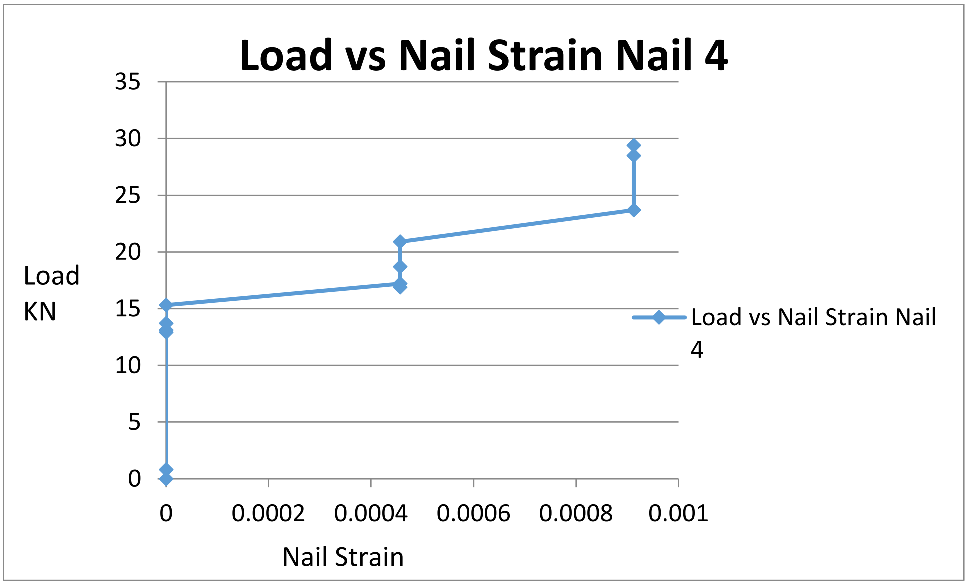

Fig 4.6.28 load vs. nail strain (nail 4)

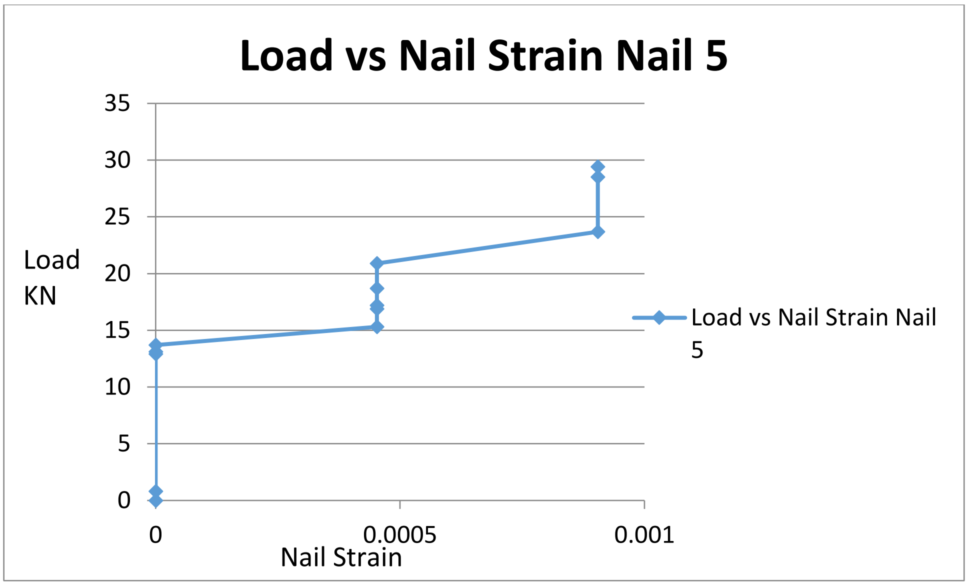

Fig 4.6.29 load vs. nail strain (nail 5)

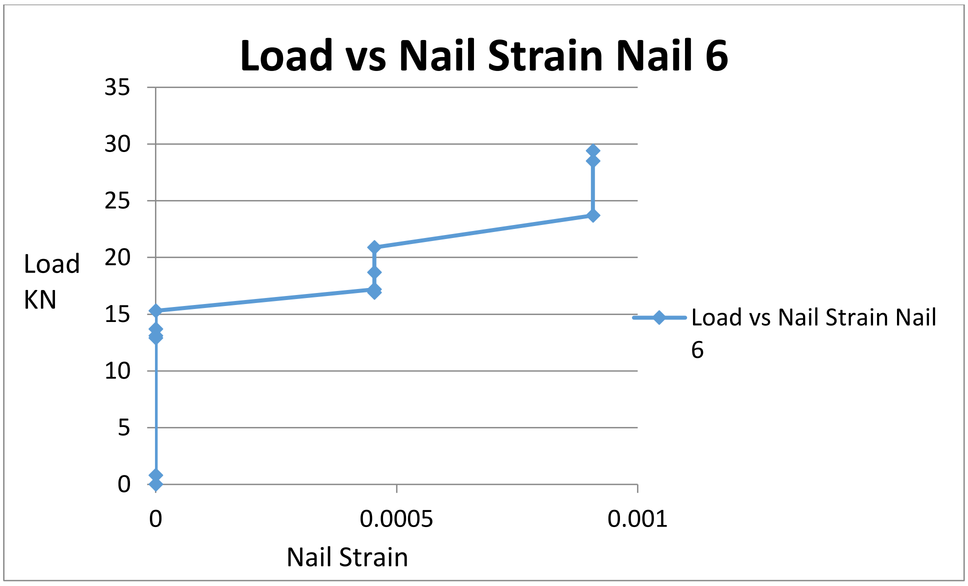

Fig 4.6.30 load vs. nail strain (nail 6)

4.6.6 For 90^0 slope with helical nail

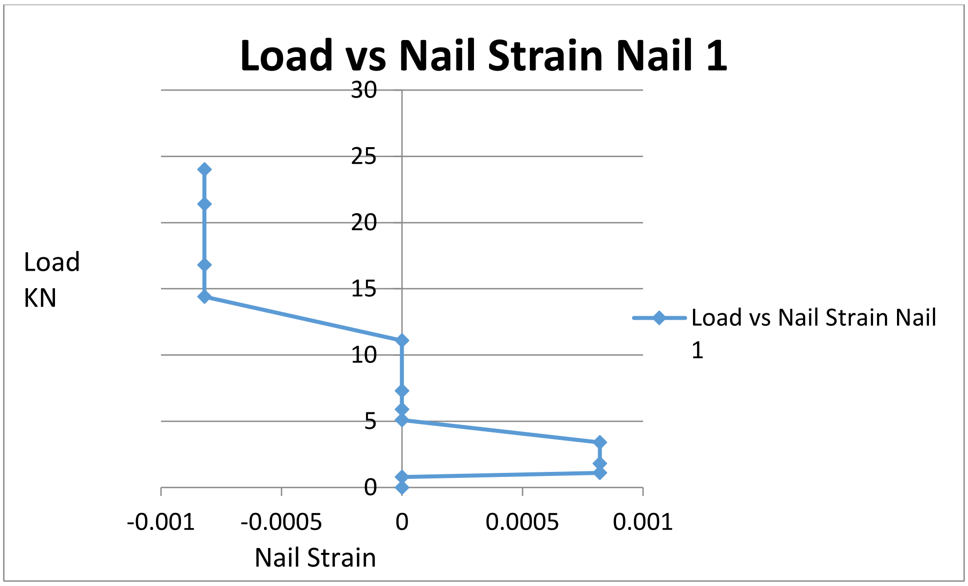

Fig 4.6.31 load vs. nail strain (nail1)

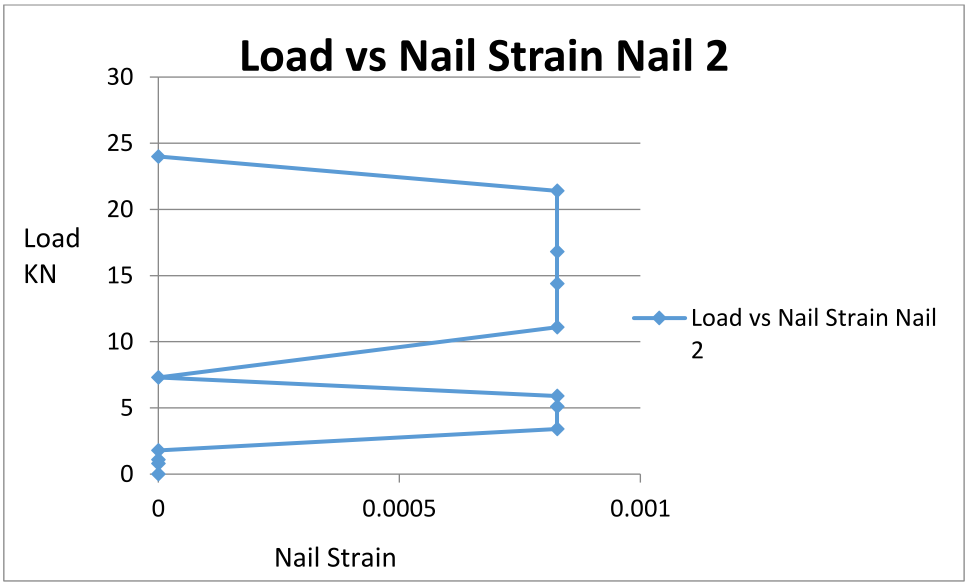

Fig 4.6.32 load vs. nail strain (nail1)

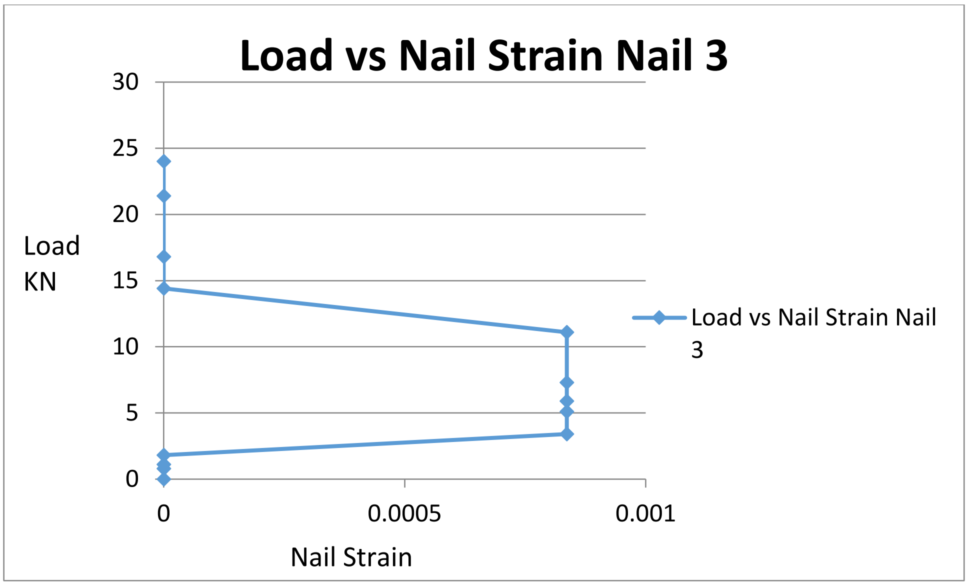

Fig4.6.33 load vs. nail strain (nail3)

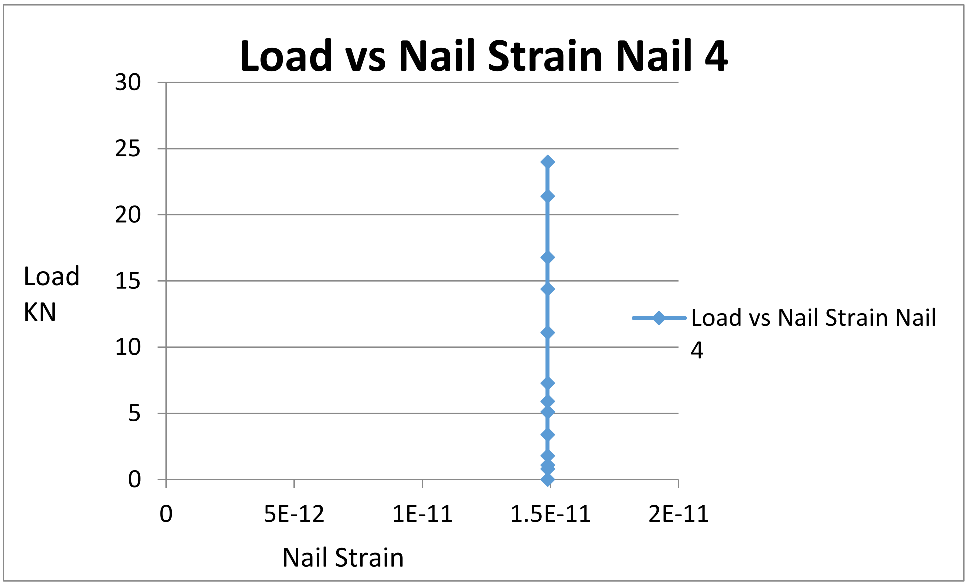

Fig 4.6.34 load vs. nail strain (nail4)

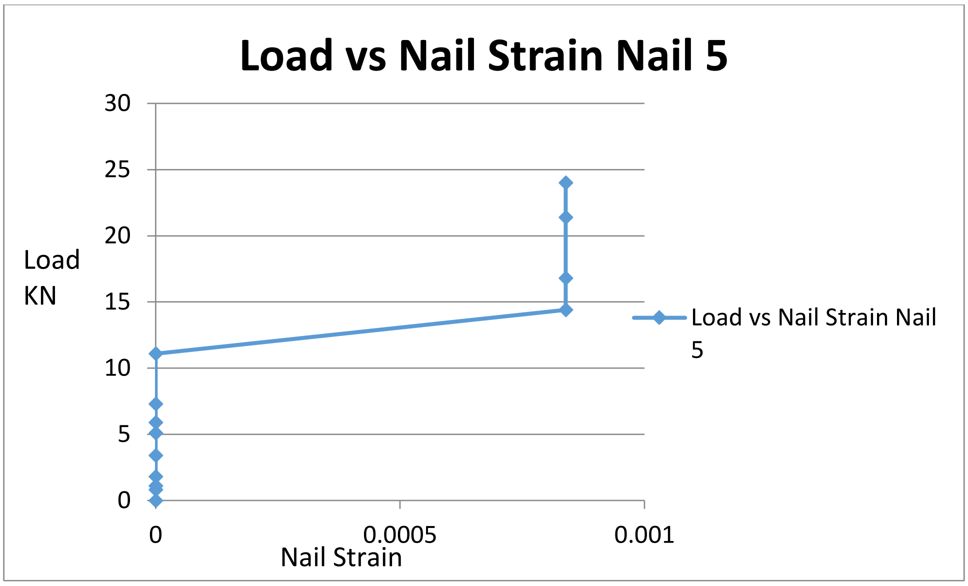

Fig 4.6.35 load vs. nail strain (nail5)

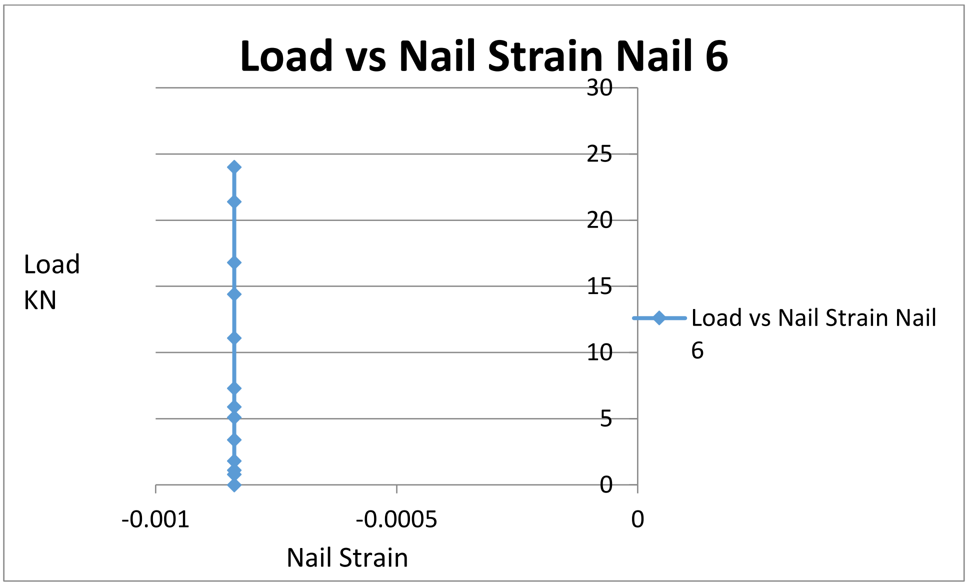

Fig 4.6.36 load vs. nail strain (nail6)

Strains in the nails do not come immediately after the application of load and for different nails at different locations trains come at different times. This shows that while first bonds with the nail on application of load and when perfect grip is made then soil and nail body get mobilized as one body and stress is generated in starts transferring to Nail from soil.

In every slope strain is generated first in lower nails then in upper nail this may be because due to surcharge grip is established first in bottom nails.

CHAPTER 5

CONCLUSIONS

5.1 General

In this major project report an attempt has been made to assess the soil nailing process in stability of slopes through comprehensive experimental and lab studies. This chapter presents the overview and the salient conclusions drawn from the work carried out under this project. Also, future scope of the project is discussed in this chapter.

5.2 Conclusions and remarks

Following conclusions were drawn from the work carried out:

- From Particle Size Distribution (PSD) curve, it was observed that the soil was **sand.** Furtherthe value of coefficient of curvature (C_c) showed that soil **was well graded** sand which was used for modeling of unreinforced and reinforced slopes with slope angles 45^o,60^o and 90^o .The specific gravity of the soil sample used was found out to be **2.87** by carrying out pycnometer test for specific gravity and soil was classified as **sand**. Also. the direct shear test results gave value of c as **0.08kg/cm^2** showing that it was loose sand and had small cohesion value due to addition of water.

- The **failure patterns** observed in the slopes were found to be only slip-surface failure for the 45^o unreinforced slope and that of 60^o and 90^o slope model was observed as toe failure. For reinforced slopes of angles 45^o, 60^o and 90^o the **failure patterns** observed were slip-surface failure and toe failure respectively.

- The load carrying capacity of reinforced slopes with thredded aluminium nails and helical nails as reinforcement is greater than as compared to unreinforced slopes which was observed from load versus settlement curves.The ultimate load increases after reinforcement with nails. Also, the ultimate load decreases with increasing steepness.

- **Nail forces** which were measured were found to be **maximum** for **bottom nails** at any point of surcharge loading for both the slopes tested and the **minimum forces** were generated in **top** row of nails for both the cases as observed from nail force vs. time graph plotted. Earlier investigators as mentioned in chapter 2 have received similar results.

- Here, modeling of slope is done in a model box of Perspex sheet, i.e. slope is supported by Perspex sheet from four sides. So, it is observed that due to change in the boundary conditions for preparing and analysing the unreinforced and reinforced slopes, results may slightly differ from results at actual site conditions where soil will be surrounded by soil or ground.

5.3 Future Scope of the work

In the present study stability of slopes using thredded aluminnium nails and helical soil nails has been demonstrated. For more reseach work following work can be carried out:

- Study of failure mechnism, load-displacememt behaviour of soil slopes with different soil-nail inclination under increase in surcharge loading.
- Soil nails under short term and long term loading.
- Dynamic analysis of soil nailed slopes.

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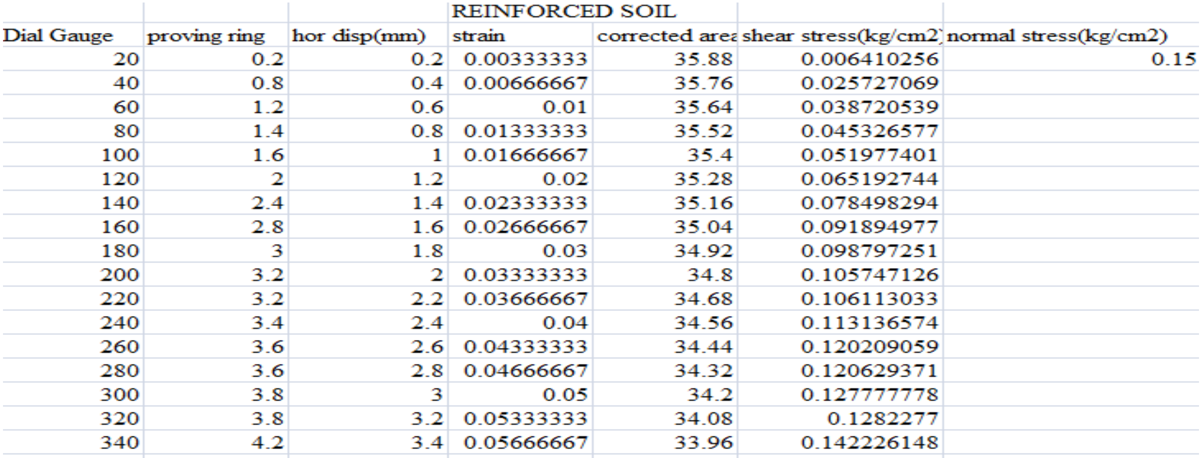
ANNEXURE A: Lab Experiments done on soil

A.1.3 Direct Shear Test

DST Test is used to determine soil parameters such as cohesion(c) and angle of internal friction. It is a quick test to determine soil parameters.

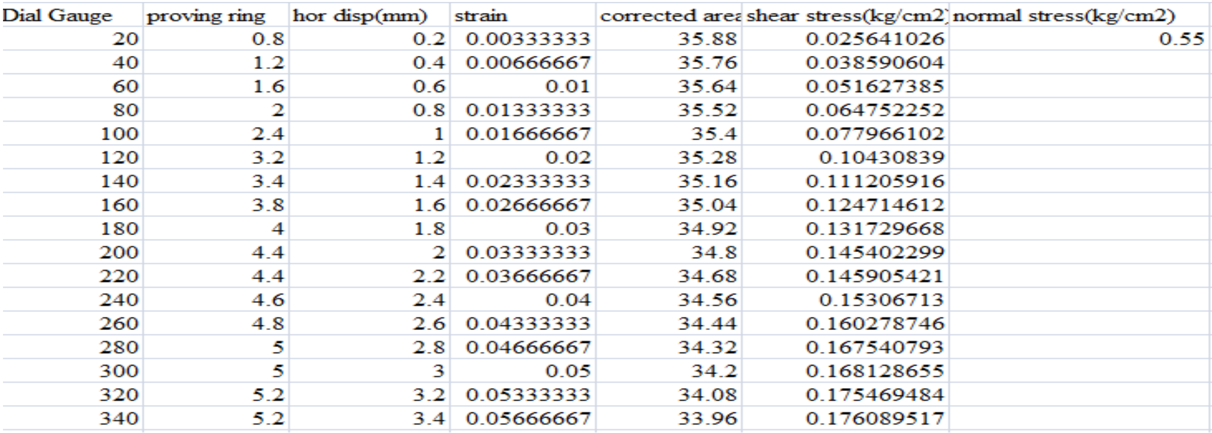
The result of the experiment on reinforced as well as simple soil sample was conducted as result are as below:

A.1.3.1 Values of experiment carried on reinforced soil



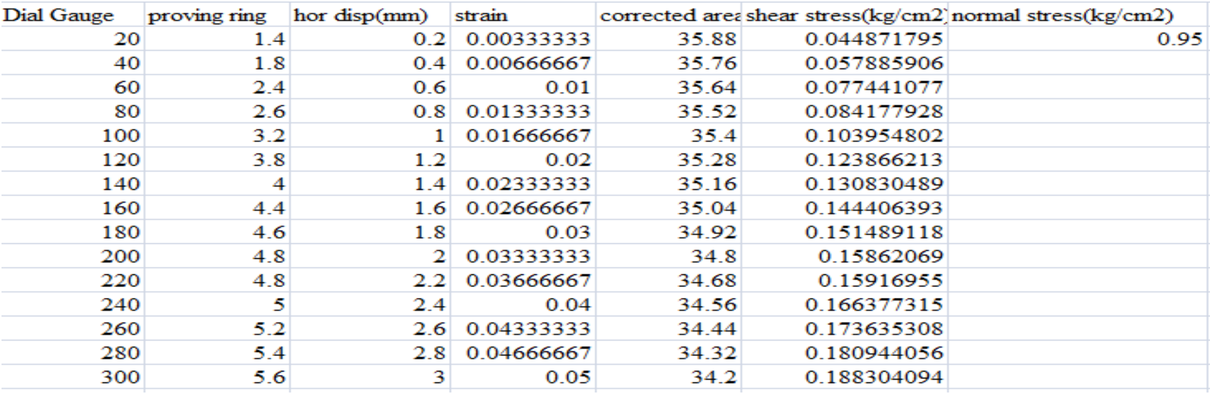
			REINFORCED SOIL			
Dial Gauge	proving ring	hor disp(mm)	strain	corrected area	shear stress(kg/cm2)	normal stress(kg/cm2)
20	0.2	0.2	0.00333333	35.88	0.006410256	0.15
40	0.8	0.4	0.00666667	35.76	0.025727069	
60	1.2	0.6	0.01	35.64	0.038720539	
80	1.4	0.8	0.01333333	35.52	0.045326577	
100	1.6	1	0.01666667	35.4	0.051977401	
120	2	1.2	0.02	35.28	0.065192744	
140	2.4	1.4	0.02333333	35.16	0.078498294	
160	2.8	1.6	0.02666667	35.04	0.091894977	
180	3	1.8	0.03	34.92	0.098797251	
200	3.2	2	0.03333333	34.8	0.105747126	
220	3.2	2.2	0.03666667	34.68	0.106113033	
240	3.4	2.4	0.04	34.56	0.113136574	
260	3.6	2.6	0.04333333	34.44	0.120209059	
280	3.6	2.8	0.04666667	34.32	0.120629371	
300	3.8	3	0.05	34.2	0.127777778	
320	3.8	3.2	0.05333333	34.08	0.1282277	
340	4.2	3.4	0.05666667	33.96	0.142226148	

Table A.2 readings of 1st test



Dial Gauge	proving ring	hor disp(mm)	strain	corrected area	shear stress(kg/cm2)	normal stress(kg/cm2)
20	0.8	0.2	0.00333333	35.88	0.025641026	0.55
40	1.2	0.4	0.00666667	35.76	0.038590604	
60	1.6	0.6	0.01	35.64	0.051627385	
80	2	0.8	0.01333333	35.52	0.064752252	
100	2.4	1	0.01666667	35.4	0.077966102	
120	3.2	1.2	0.02	35.28	0.10430839	
140	3.4	1.4	0.02333333	35.16	0.111205916	
160	3.8	1.6	0.02666667	35.04	0.124714612	
180	4	1.8	0.03	34.92	0.131729668	
200	4.4	2	0.03333333	34.8	0.145402299	
220	4.4	2.2	0.03666667	34.68	0.145905421	
240	4.6	2.4	0.04	34.56	0.15306713	
260	4.8	2.6	0.04333333	34.44	0.160278746	
280	5	2.8	0.04666667	34.32	0.167540793	
300	5	3	0.05	34.2	0.168128655	
320	5.2	3.2	0.05333333	34.08	0.175469484	
340	5.2	3.4	0.05666667	33.96	0.176089517	

Table A.3 readings of 2nd test

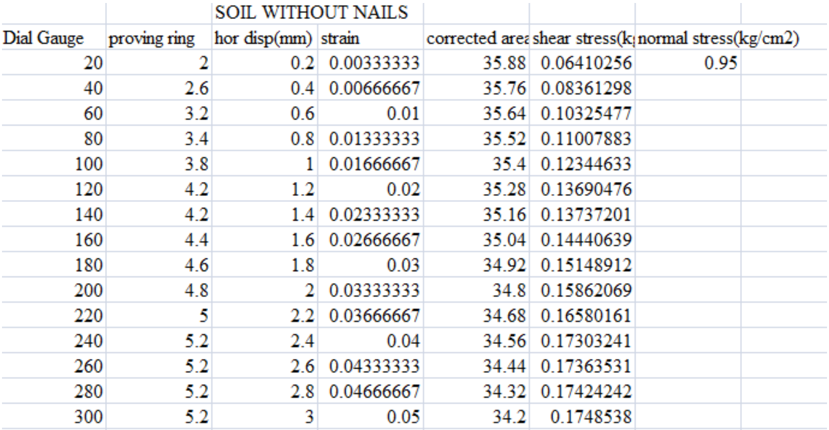


Dial Gauge	proving ring	hor disp(mm)	strain	corrected are	shear stress(kg/cm2)	normal stress(kg/cm2)
20	1.4	0.2	0.00333333	35.88	0.044871795	0.95
40	1.8	0.4	0.00666667	35.76	0.057885906	
60	2.4	0.6	0.01	35.64	0.077441077	
80	2.6	0.8	0.01333333	35.52	0.084177928	
100	3.2	1	0.01666667	35.4	0.103954802	
120	3.8	1.2	0.02	35.28	0.123866213	
140	4	1.4	0.02333333	35.16	0.130830489	
160	4.4	1.6	0.02666667	35.04	0.144406393	
180	4.6	1.8	0.03	34.92	0.151489118	
200	4.8	2	0.03333333	34.8	0.15862069	
220	4.8	2.2	0.03666667	34.68	0.15916955	
240	5	2.4	0.04	34.56	0.166377315	
260	5.2	2.6	0.04333333	34.44	0.173635308	
280	5.4	2.8	0.04666667	34.32	0.180944056	
300	5.6	3	0.05	34.2	0.188304094	

Table A.4 readings of 3rd test.

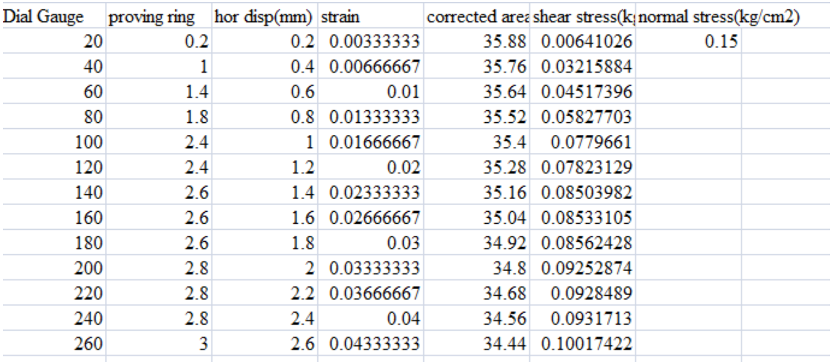
From experiment value of cohesion (c) = **0.08kg/cm^2.**

A.1.3.2 Values of experiment carried on soil without nails



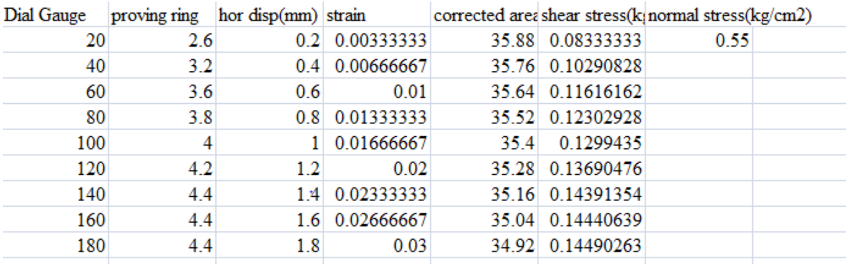
		SOIL WITHOUT NAILS				
Dial Gauge	proving ring	hor disp(mm)	strain	corrected are	shear stress(k	normal stress(kg/cm2)
20	2	0.2	0.00333333	35.88	0.06410256	0.95
40	2.6	0.4	0.00666667	35.76	0.08361298	
60	3.2	0.6	0.01	35.64	0.10325477	
80	3.4	0.8	0.01333333	35.52	0.11007883	
100	3.8	1	0.01666667	35.4	0.12344633	
120	4.2	1.2	0.02	35.28	0.13690476	
140	4.2	1.4	0.02333333	35.16	0.13737201	
160	4.4	1.6	0.02666667	35.04	0.14440639	
180	4.6	1.8	0.03	34.92	0.15148912	
200	4.8	2	0.03333333	34.8	0.15862069	
220	5	2.2	0.03666667	34.68	0.16580161	
240	5.2	2.4	0.04	34.56	0.17303241	
260	5.2	2.6	0.04333333	34.44	0.17363531	
280	5.2	2.8	0.04666667	34.32	0.17424242	
300	5.2	3	0.05	34.2	0.1748538	

Table A.5 reading



Dial Gauge	proving ring	hor disp(mm)	strain	corrected are	shear stress(k	normal stress(kg/cm2)
20	0.2	0.2	0.00333333	35.88	0.00641026	0.15
40	1	0.4	0.00666667	35.76	0.03215884	
60	1.4	0.6	0.01	35.64	0.04517396	
80	1.8	0.8	0.01333333	35.52	0.05827703	
100	2.4	1	0.01666667	35.4	0.0779661	
120	2.4	1.2	0.02	35.28	0.07823129	
140	2.6	1.4	0.02333333	35.16	0.08503982	
160	2.6	1.6	0.02666667	35.04	0.08533105	
180	2.6	1.8	0.03	34.92	0.08562428	
200	2.8	2	0.03333333	34.8	0.09252874	
220	2.8	2.2	0.03666667	34.68	0.0928489	
240	2.8	2.4	0.04	34.56	0.0931713	
260	3	2.6	0.04333333	34.44	0.10017422	

Table A.6 reading

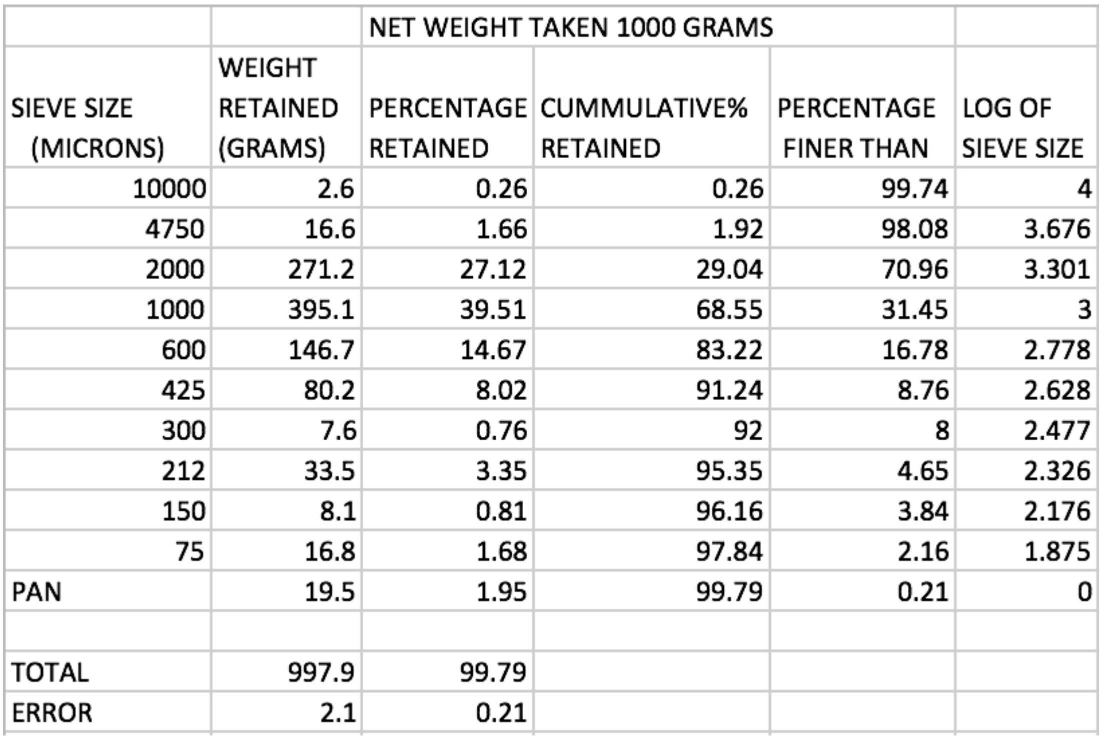


Dial Gauge	proving ring	hor disp(mm)	strain	corrected are	shear stress(k	normal stress(kg/cm2)
20	2.6	0.2	0.00333333	35.88	0.08333333	0.55
40	3.2	0.4	0.00666667	35.76	0.10290828	
60	3.6	0.6	0.01	35.64	0.11616162	
80	3.8	0.8	0.01333333	35.52	0.12302928	
100	4	1	0.01666667	35.4	0.1299435	
120	4.2	1.2	0.02	35.28	0.13690476	
140	4.4	1.4	0.02333333	35.16	0.14391354	
160	4.4	1.6	0.02666667	35.04	0.14440639	
180	4.4	1.8	0.03	34.92	0.14490263	

Table A.7 reading

B.1.1 Particle size Distribution

The grain size analysis is widely used in classification of soils. Information obtained from grain size analysis can be used to predict soil water movement.



		NET WEIGHT TAKEN 1000 GRAMS			
SIEVE SIZE (MICRONS)	WEIGHT RETAINED (GRAMS)	PERCENTAGE RETAINED	CUMMULATIVE% RETAINED	PERCENTAGE FINER THAN	LOG OF SIEVE SIZE
10000	2.6	0.26	0.26	99.74	4
4750	16.6	1.66	1.92	98.08	3.676
2000	271.2	27.12	29.04	70.96	3.301
1000	395.1	39.51	68.55	31.45	3
600	146.7	14.67	83.22	16.78	2.778
425	80.2	8.02	91.24	8.76	2.628
300	7.6	0.76	92	8	2.477
212	33.5	3.35	95.35	4.65	2.326
150	8.1	0.81	96.16	3.84	2.176
75	16.8	1.68	97.84	2.16	1.875
PAN	19.5	1.95	99.79	0.21	0
TOTAL	997.9	99.79			
ERROR	2.1	0.21			

Table.B.1 Observations of particle size distribution

ANNEXURE B: Tests performed with nails

B.1 Screwed Aluminum Nails

B.1.1 45° slope

Calculations: Screwed Nails – 45° slope

Table B.1

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out) 2	Nail 2	Strain 2
0	263	68.3228	2.64613E-08	211	76.0391	1.21989E-11
10	263	68.3228	2.64613E-08	211	76.0391	1.21989E-11
20	264	68.2217	0.00081971	212	75.9268	0.000826998
30	264	68.2217	0.00081971	212	75.9268	0.000826998
40	264	68.2217	0.00081971	212	75.9268	0.000826998
50	264	68.2217	0.00081971	212	75.9268	0.000826998
60	263	68.3228	2.64613E-08	211	76.0391	1.21989E-11
70	264	68.2217	0.00081971	215	75.5878	0.003301805
80	264	68.2217	0.00081971	215	75.5878	0.003301805
90	264	68.2217	0.00081971	215	75.5878	0.003301805
100	264	68.2217	0.00081971	215	75.5878	0.003301805
110	265	68.1209	0.001638413	215	75.5878	0.003301805
120	265	68.1209	0.001638413	216	75.47505	0.004124685
130	266	68.0202	0.002456138	216	75.47505	0.004124685
140	265	68.1209	0.001638413	216	75.47505	0.004124685

V(out) 3	Nail 3	Strain 3	V(out) 4	Nail 4	Strain 4

243	70.46412326	7.29022E-12	276	64.62286799	2.42926E-11
243	70.46412326	7.29022E-12	276	64.62286799	2.42926E-11
242	70.56955541	0.000831252	273	64.92026949	0.002556727
241	70.67511618	0.001663517	277	64.52397456	0.000850176
241	70.67511618	0.001663517	277	64.52397456	0.000850176
241	70.67511618	0.001663517	277	64.52397456	0.000850176
249	69.8342181	0.004966319	278	64.42520097	0.001699321
247	70.04367609	0.003314903	272	65.01964445	0.003411043
247	70.04367609	0.003314903	272	65.01964445	0.003411043
247	70.04367609	0.003314903	272	65.01964445	0.003411043
247	70.04367609	0.003314903	272	65.01964445	0.003411043
247	70.04367609	0.003314903	276	64.62286799	2.42926E-11
247	70.04367609	0.003314903	276	64.62286799	2.42926E-11
247	70.04367609	0.003314903	276	64.62286799	2.42926E-11
247	70.04367609	0.003314903	276	64.62286799	2.42926E-11

V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
167	81.08270558	1.81002E-11	216	74.47924775	2.02473E-11
167	81.08270558	1.81002E-11	216	74.47924775	2.02473E-11
161	81.81573642	0.005022518	216	74.47924775	2.02473E-11
161	81.81573642	0.005022518	217	74.36811424	0.000828967
161	81.81573642	0.005022518	217	74.36811424	0.000828967
161	81.81573642	0.005022518	217	74.36811424	0.000828967
161	81.81573642	0.005022518	217	74.36811424	0.000828967
161	81.81573642	0.005022518	217	74.36811424	0.000828967
161	81.81573642	0.005022518	217	74.36811424	0.000828967
161	81.81573642	0.005022518	217	74.36811424	0.000828967
161	81.81573642	0.005022518	217	74.36811424	0.000828967

161	81.81573642	0.005022518	217	74.36811424	0.000828967
161	81.81573642	0.005022518	218	74.25712173	0.001656882
161	81.81573642	0.005022518	218	74.25712173	0.001656882
161	81.81573642	0.005022518	218	74.25712173	0.001656882

Table B.1

Nail Forces (KN)			
Time (Seconds)	**Nail 1**	**Nail 2**	**Nail 3**
0	0.000315897	1.45631E-07	8.7031E-08
10	0.000315897	1.45631E-07	8.7031E-08
20	9.785735858	9.872740621	9.923525471
30	9.785735858	9.872740621	19.85915622
40	9.785735858	9.872740621	19.85915622
50	9.785735858	9.872740621	19.85915622
60	0.000315897	1.45631E-07	59.28817398
70	9.785735858	39.41711786	39.57348921
80	9.785735858	39.41711786	39.57348921
90	9.785735858	39.41711786	39.57348921
100	9.785735858	39.41711786	39.57348921
110	19.55945617	39.41711786	39.57348921
120	19.55945617	49.24070526	39.57348921

Table B.1

	Soil Stress Strain		
Time (Seconds)	**Load (KN)**	**Displacement (mm)**	**Stress (KN/m^2**
0	0	0	0
10	0.2	0	2.5
20	14.2	0	177.5
30	15.3	0	191.25
40	16	0	200
50	17	0	212.5
60	18.5	0	231.25
70	20.1	10	251.25
80	12.3	30.5	153.75
90	21.9	45.3	273.75
100	24.4	59.6	305
110	27.3	90.3	341.25
120	30.9	112	386.25
130	34.8	117	435

140	38.7	125	483.75

Table B.1

B.1.2 60° slope

Calculations: Screwed Nails – 60° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2
0	263	68.3228	2.646E-08	209	76.26640991	1.3815E-11
10	263	68.3228	2.646E-08	212	75.92640833	0.0024761
20	263	68.3228	2.646E-08	212	75.92640833	0.0024761
30	263	68.3228	2.646E-08	212	75.92640833	0.0024761
40	263	68.3228	2.646E-08	212	75.92640833	0.0024761
50	263	68.3228	2.646E-08	211	76.03960055	0.0016527
60	263	68.3228	2.646E-08	211	76.03960055	0.0016527
70	264	68.2217	0.000817	212	75.92640833	0.0024761
80	263	68.3228	2.646E-08	205	76.72173574	0.00331678
90	263	68.3228	2.646E-08	205	76.72173574	0.00331678
100	263	68.3228	2.646E-08	180	79.62010959	0.02442971
110	263	68.3228	2.646E-08	179	79.73796651	0.02528823
120	263	68.3228	2.646E-08	185	79.0330708	0.02015348
130	263	68.3228	2.646E-08	185	79.0330708	0.02015348
140	263	68.3228	2.646E-08	185	79.0330708	0.02015348

V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4
251	69.62526804	5.50516E-13	277	64.52397456	8.07178E-12
252	69.5209829	0.000832114	278	64.42520097	0.000788137
252	69.5209829	0.000832114	278	64.42520097	0.000788137
253	69.41682405	0.001663221	278	64.42520097	0.000788137
252	69.5209829	0.000832114	278	64.42520097	0.000788137
251	69.62526804	5.50516E-13	277	64.52397456	8.07178E-12
251	69.62526804	5.50516E-13	277	64.52397456	8.07178E-12
251	69.62526804	5.50516E-13	277	64.52397456	8.07178E-12

251	69.62526804	5.50516E-13	277	64.52397456	8.07178E-12
251	69.62526804	5.50516E-13	277	64.52397456	8.07178E-12
251	69.62526804	5.50516E-13	278	64.42520097	0.000788137
251	69.62526804	5.50516E-13	278	64.42520097	0.000788137
251	69.62526804	5.50516E-13	278	64.42520097	0.000788137
251	69.62526804	5.50516E-13	278	64.42520097	0.000788137
251	69.62526804	5.50516E-13	278	64.42520097	0.000788137

V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
167	81.08270558	1.81002E-11	222	73.81455628	1.19992E-11
168	80.96110242	0.00083319	223	73.70426474	0.000830095
168	80.96110242	0.00083319	223	73.70426474	0.000830095
168	80.96110242	0.00083319	223	73.70426474	0.000830095
168	80.96110242	0.00083319	223	73.70426474	0.000830095
167	81.08270558	1.81002E-11	222	73.81455628	1.19992E-11
167	81.08270558	1.81002E-11	222	73.81455628	1.19992E-11
167	81.08270558	1.81002E-11	222	73.81455628	1.19992E-11
167	81.08270558	1.81002E-11	222	73.81455628	1.19992E-11
167	81.08270558	1.81002E-11	222	73.81455628	1.19992E-11
168	80.96110242	0.00083319	222	73.81455628	1.19992E-11
168	80.96110242	0.00083319	223	73.70426474	0.000830095
167	81.08270558	1.81002E-11	223	73.70426474	0.000830095
167	81.08270558	1.81002E-11	223	73.70426474	0.000830095
167	81.08270558	1.81002E-11	223	73.70426474	0.000830095

Table B.2

Nail Forces (KN)						
Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0.0003159	1.6493E-07	6.57209E-09	9.63613E-08	2.16081E-07	1.43247E-07
10	0.0003159	29.5670912	9.933824986	9.408815331	9.946667212	9.909714478
20	0.0003159	29.5670912	9.933824986	9.408815331	9.946667212	9.909714478
30	0.0003159	29.5670912	19.85562009	9.408815331	9.946667212	9.909714478
40	0.0003159	29.5670912	9.933824986	9.408815331	9.946667212	9.909714478

50	0.0003159	19.723711	6.57209E-09	9.63613E-08	2.16081E-07	1.43247E-07
60	0.0003159	19.723711	6.57209E-09	9.63613E-08	2.16081E-07	1.43247E-07
70	9.7857359	29.5670912	6.57209E-09	9.63613E-08	2.16081E-07	1.43247E-07
80	0.0003159	39.5958751	6.57209E-09	9.63613E-08	2.16081E-07	1.43247E-07
90	0.0003159	39.5958751	6.57209E-09	9.63613E-08	2.16081E-07	1.43247E-07
100	0.0003159	291.643183	6.57209E-09	9.408815331	9.946667212	1.43247E-07
110	0.0003159	301.892213	6.57209E-09	9.408815331	9.946667212	9.909714478
120	0.0003159	240.593335	6.57209E-09	9.408815331	2.16081E-07	9.909714478

Table B.2

	Soil Stress Strain		
Time (Seconds)	Load (KN)	Displacement (mm)	Stress (KN/m^2
0	0	0	0
10	0.9	0	11.25
20	13.4	0	167.5
30	14	0	175
40	14.5	0	181.25
50	16.2	0	202.5
60	18.9	0	236.25
70	21.6	0	270
80	24.6	0	307.5
90	27.2	0	340
100	31.7	0	396.25
110	37.7	0	471.25

Table B.2

B.1.3 90° slope

Calculations: Screwed Nails – 90° slope

Time (Seconds)	**V(out)1**	**Nail 1**	**Strain 1**	**V(out)2**	**Nail 2**	**Strain 2**
0	264	68.22137218	3.17232E-11	206	76.60769022	2.74726E-11
10	264	68.22137218	3.17232E-11	206	76.60769022	2.74726E-11
20	263	68.32217675	0.000820894	206	76.60769022	2.74726E-11
30	263	68.32217675	0.000820894	206	76.60769022	2.74726E-11
40	263	68.32217675	0.000820894	205	76.72173574	0.000827053
50	264	68.22137218	3.17232E-11	205	76.72173574	0.000827053
60	264	68.22137218	3.17232E-11	205	76.72173574	0.000827053
70	264	68.22137218	3.17232E-11	206	76.60769022	2.74726E-11
80	264	68.22137218	3.17232E-11	205	76.72173574	0.000827053
90	265	68.12068813	0.000819913	205	76.72173574	0.000827053
100	265	68.12068813	0.000819913	205	76.72173574	0.000827053
110	265	68.12068813	0.000819913	205	76.72173574	0.000827053
120	265	68.12068813	0.000819913	206	76.60769022	2.74726E-11
130	265	68.12068813	0.000819913	206	76.60769022	2.74726E-11
140	265	68.12068813	0.000819913	206	76.60769022	2.74726E-11

V(out)3	**Nail 3**	**Strain 3**	**V(out)4**	**Nail 4**	**Strain 4**
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
250	69.63509852	0.000836362	278	64.5254174	1.48853E11
250	69.63509852	0.000836362	278	64.5254174	1.48853E11
250	69.63509852	0.000836362	278	64.5254174	1.48853E11
250	69.63509852	0.000836362	278	64.5254174	1.48853E11
250	69.63509852	0.000836362	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E11
V(out)5	**Nail 5**	**Strain 5**	**V(out)6**	**Nail 6**	**Strain 6**
162	81.54518191	2.92545E-11	225	73.30239758	0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	0.000836903

162	81.54518191	2.92545E-11	225	73.30239758	0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	0.000836903
163	81.42205169	0.000838868	225	73.30239758	0.000836903
163	81.42205169	0.000838868	225	73.30239758	0.000836903
163	81.42205169	0.000838868	225	73.30239758	0.000836903
163	81.42205169	0.000838868	225	73.30239758	0.000836903
163	81.42205169	0.000838868	225	73.30239758	0.000836903
163	81.42205169	0.000838868	225	73.30239758	0.000836903

Table B.3

Helical nails

B.2.1 45° slope

Calculations: Helical Nails – 45° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2
0	236	82.45778	1.09781E-08	246	84.5185571	8.11504E-12
10	236	82.45778	1.09781E-08	246	84.5185571	8.11504E-12
20	236	82.45778	1.09781E-08	246	84.5185571	8.11504E-12
30	236	82.45778	1.09781E-08	246	84.5185571	8.11504E-12
40	236	82.45778	1.09781E-08	246	84.5185571	8.11504E-12
50	236	82.45778	1.09781E-08	246	84.5185571	8.11504E-12
60	237	82.39067	0.000452141	247	84.44821312	0.000462384
70	237	82.39067	0.000452141	247	84.44821312	0.000462384
80	237	82.39067	0.000452141	247	84.44821312	0.000462384
90	237	82.39067	0.000452141	247	84.44821312	0.000462384
100	238	82.32361	0.000903939	247	84.44821312	0.000462384
110	238	82.32361	0.000903939	248	84.37792128	0.000924424
120	238	82.32361	0.000903939	248	84.37792128	0.000924424
130	238	82.32361	0.000903939	248	84.37792128	0.000924424
140	238	82.32361	0.000903939	248	84.37792128	0.000924424

V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4
239	82.79711978	2.04245E-11	247	79.17197643	1.78328E-11
239	82.79711978	2.04245E-11	247	79.17197643	1.78328E-11
239	82.79711978	2.04245E-11	247	79.17197643	1.78328E-11
239	82.79711978	2.04245E-11	247	79.17197643	1.78328E-11
239	82.79711978	2.04245E-11	247	79.17197643	1.78328E-11

239	82.79711978	2.04245E-11	247	79.17197643	1.78328E-11
240	82.7294726	0.000453902	248	79.1049836	0.000470094
240	82.7294726	0.000453902	248	79.1049836	0.000470094
240	82.7294726	0.000453902	248	79.1049836	0.000470094
240	82.7294726	0.000453902	248	79.1049836	0.000470094
240	82.7294726	0.000453902	248	79.1049836	0.000470094
241	82.6618748	0.000907472	249	79.03804128	0.000939833
241	82.6618748	0.000907472	249	79.03804128	0.000939833
241	82.6618748	0.000907472	249	79.03804128	0.000939833
241	82.6618748	0.000907472	249	79.03804128	0.000939833

V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
254	84.26988002	1.52182E-11	250	82.75084108	7.25791E-12
254	84.26988002	1.52182E-11	250	82.75084108	7.25791E-12
254	84.26988002	1.52182E-11	250	82.75084108	7.25791E-12
254	84.26988002	1.52182E-11	250	82.75084108	7.25791E-12
254	84.26988002	1.52182E-11	250	82.75084108	7.25791E-12
254	84.26988002	1.52182E-11	250	82.75084108	7.25791E-12
255	84.19985526	0.000461644	251	82.68014448	0.000474628
255	84.19985526	0.000461644	251	82.68014448	0.000474628
255	84.19985526	0.000461644	251	82.68014448	0.000474628
255	84.19985526	0.000461644	251	82.68014448	0.000474628
255	84.19985526	0.000461644	251	82.68014448	0.000474628
256	84.12988317	0.00092294	252	82.60950238	0.000948891
256	84.12988317	0.00092294	252	82.60950238	0.000948891
256	84.12988317	0.00092294	252	82.60950238	0.000948891
256	84.12988317	0.00092294	252	82.60950238	0.000948891

Table B.4

Nail Forces (KN)						
Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0.000131	9.69E-08	2.43829E-07	2.12889E-07	1.81676E-07	8.66453E-08
10	0.000131	9.69E-08	2.43829E-07	2.12889E-07	1.81676E-07	8.66453E-08
20	0.000131	9.69E-08	2.43829E-07	2.12889E-07	1.81676E-07	8.66453E-08
30	0.000131	9.69E-08	2.43829E-07	2.12889E-07	1.81676E-07	8.66453E-08
40	0.000131	9.69E-08	2.43829E-07	2.12889E-07	1.81676E-07	8.66453E-08
50	0.000131	9.69E-08	2.43829E-07	2.12889E-07	1.81676E-07	8.66453E-08
60	5.397681	5.519959	5.418703773	5.612001431	5.511124802	5.666137019

70	5.397681	5.519959	5.418703773	5.612001431	5.511124802	5.666137019
80	5.397681	5.519959	5.418703773	5.612001431	5.511124802	5.666137019
90	5.397681	5.519959	5.418703773	5.612001431	5.511124802	5.666137019
100	10.79127	5.519959	5.418703773	5.612001431	5.511124802	5.666137019
110	10.79127	11.03583	10.83345278	11.21977213	11.01810328	11.3279063
120	10.79127	11.03583	10.83345278	11.21977213	11.01810328	11.3279063

Table B.4

Nail Forces (KN)						
Time (Seconds)	**Nail 1**	**Nail 2**	**Nail 3**	**Nail 4**	**Nail 5**	**Nail 6**
0	3.78714E-07	3.27969E-07	4.35788E-07	1.77701E-07	3.49241E-07	9.990986939
10	3.78714E-07	3.27969E-07	4.35788E-07	1.77701E07	3.49241E-07	9.990986939
20	9.799879082	3.27969E-07	4.35788E-07	1.77701E07	3.49241E-07	9.990986939
30	9.799879082	3.27969E-07	4.35788E-07	1.77701E07	3.49241E-07	9.990986939
40	9.799879082	9.873401864	9.984535164	1.77701E07	3.49241E-07	9.990986939
50	3.78714E-07	9.873401864	9.984535164	1.77701E07	3.49241E-07	9.990986939
60	3.78714E-07	9.873401864	9.984535164	1.7770107	3.49241E-07	9.990986939
70	3.78714E-07	3.27969E-07	9.984535164	1.77701E07	3.49241E-07	9.990986939
80	3.78714E-07	9.873401864	9.984535164	1.77701E07	3.49241E 07	9.990986939
90	9.7881629	9.873401864	4.35788E-07	1.77701E07	10.0144549	9.990986939
100	9.7881629	9.873401864	4.35788E-07	1.77701E07	10.0144549	9.990986939
110	9.7881629	9.873401864	4.35788E-07	1.77701E-07	10.0144549	9.990986939
120	9.7881629	3.27969E-07	4.35788E-07	1.77701E-07	10.0144549	9.990986939

Table B.4

	Soil Stress Strain	
Time (Seconds)	**Load (KN)**	**Stress (KN/m^2**
0	0	0
10	1	12.5
20	1.3	16.25
30	2.2	27.5

40	4.1	51.25
50	6.2	77.5
60	7.1	88.75
70	8.9	111.25
80	13.5	168.75
90	17.4	217.5
100	20.4	255
110	25.9	323.75
120	29.3	366.25

Table B.4

Time (Seconds)	Load (KN)	Displacement (mm)	Stress (KN/m^2
0	0	0	0
10	0.2	10	2.5
20	14.2	40.2	177.5
30	15.3	42.9	191.25
40	16	44.2	200
50	17	47.1	212.5
60	18.5	50.2	231.25
70	20.1	55.4	251.25
80	21.1	58.1	263.75
90	21.9	60.2	273.75
100	24.5	71.3	306.25
110	26.1	78.4	326.25
120	28.5	88.6	356.25
130	31.2	100.1	390
140	33.7	125	421.25

TABLE B.4

B.2.2 60° slope

Calculations: helical Nails – 60° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2
0	245	80.95619	2.20613E-08	253	84.52546744	1.83443E-11
10	245	80.95619	2.20613E-08	253	84.52546744	1.83443E-11
20	245	80.95619	2.20613E-08	253	84.52546744	1.83443E-11
30	245	80.95619	2.20613E-08	253	84.52546744	1.83443E-11
40	245	80.95619	2.20613E-08	253	84.52546744	1.83443E-11

50	245	80.95619	2.20613E-08	254	84.45709135	0.000449412
60	245	80.95619	2.20613E-08	254	84.45709135	0.000449412
70	246	80.88653	0.000478004	254	84.45709135	0.000449412
80	246	80.88653	0.000478004	254	84.45709135	0.000449412
90	246	80.88653	0.000478004	254	84.45709135	0.000449412
100	246	80.88653	0.000478004	255	84.38876452	0.000898499
110	247	80.81693	0.000955662	255	84.38876452	0.000898499
120	247	80.81693	0.000955662	255	84.38876452	0.000898499
130	247	80.81693	0.000955662	255	84.38876452	0.000898499
140	247	80.81693	0.000955662	255	84.38876452	0.000898499

V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4
251	81.71241928	1.95676E-11	266	78.43685288	1.6598E-11
252	81.64446376	0.000462024	266	78.43685288	1.6598E-11
252	81.64446376	0.000462024	266	78.43685288	1.6598E-11
253	81.57655836	0.000923706	266	78.43685288	1.6598E-11
252	81.64446376	0.000462024	266	78.43685288	1.6598E-11
251	81.71241928	1.95676E-11	266	78.43685288	1.6598E-11
251	81.71241928	1.95676E-11	267	78.37240699	0.00045646
251	81.71241928	1.95676E-11	267	78.37240699	0.00045646
251	81.71241928	1.95676E-11	267	78.37240699	0.00045646
251	81.71241928	1.95676E-11	267	78.37240699	0.00045646
251	81.71241928	1.95676E-11	268	78.30800802	0.000912587
251	81.71241928	1.95676E-11	268	78.30800802	0.000912587
251	81.71241928	1.95676E-11	268	78.30800802	0.000912587
251	81.71241928	1.95676E-11	268	78.30800802	0.000912587
251	81.71241928	1.95676E-11	268	78.30800802	0.000912587

V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
250	84.88823659	1.28138E-11	254	83.25113504	2.39457E-11
250	84.88823659	1.28138E-11	254	83.25113504	2.39457E-11
250	84.88823659	1.28138E-11	254	83.25113504	2.39457E-11
250	84.88823659	1.28138E-11	254	83.25113504	2.39457E-11
250	84.88823659	1.28138E-11	254	83.25113504	2.39457E-11
251	84.81909807	0.000452481	254	83.25113504	2.39457E-11
251	84.81909807	0.000452481	255	83.18314473	0.000453716
251	84.81909807	0.000452481	255	83.18314473	0.000453716
251	84.81909807	0.000452481	255	83.18314473	0.000453716
251	84.81909807	0.000452481	255	83.18314473	0.000453716
252	84.75001075	0.000904626	256	83.11520468	0.000907097
252	84.75001075	0.000904626	256	83.11520468	0.000907097
252	84.75001075	0.000904626	256	83.11520468	0.000907097
252	84.75001075	0.000904626	256	83.11520468	0.000907097

252	84.75001075	0.000904626	256	83.11520468	0.000907097

Table B.5

Nail Forces (KN)						
Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0.000263	2.19E-07	2.33599E-07	1.98148E-07	1.52971E-07	2.85865E-07
10	0.000263	2.19E-07	5.515661723	1.98148E-07	1.52971E-07	2.85865E-07
20	0.000263	2.19E-07	5.515661723	1.98148E-07	1.52971E-07	2.85865E-07
30	0.000263	2.19E-07	11.02725575	1.98148E-07	1.52971E-07	2.85865E-07
40	0.000263	2.19E-07	5.515661723	1.98148E-07	1.52971E-07	2.85865E-07
50	0.000263	5.365098	2.33599E-07	1.98148E-07	5.401737837	2.85865E-07
60	0.000263	5.365098	2.33599E-07	5.449241487	5.401737837	5.416488709
70	5.706432	5.365098	2.33599E-07	5.449241487	5.401737837	5.416488709
80	5.706432	5.365098	2.33599E-07	5.449241487	5.401737837	5.416488709
90	5.706432	5.365098	2.33599E-07	5.449241487	5.401737837	5.416488709
100	5.706432	10.72633	2.33599E-07	10.89451466	10.79947633	10.82897302
110	11.40874	10.72633	2.33599E-07	10.89451466	10.79947633	10.82897302
120	11.40874	10.72633	2.33599E-07	10.89451466	10.79947633	10.82897302

Table B.5

Time (Seconds)	Load (KN)	Displacement (mm)	Stress (KN/m^2
0	0	0	0
10	0.8	2.5	10
20	12.9	38.7	161.25
30	13.1	39.4	163.75
40	13.7	40.3	171.25
50	15.3	45.8	191.25
60	17.2	52.4	215
70	16.9	58.9	211.25
80	18.7	64.9	233.75
90	20.9	72.3	261.25
100	23.7	81.4	296.25
110	28.5	97.1	356.25
120	29.4	100.4	367.5
130	30.2	103.7	377.5
140	31.8	110	397.5

Table B.5

B.2.3 90° slope

Stress Calculations: helical Nails – 90° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2
0	264	68.22137	1.77209E-08	206	76.60769022	2.74726E-11
10	264	68.22137	1.77209E-08	206	76.60769022	2.74726E-11
20	263	68.32218	0.000820912	206	76.60769022	2.74726E-11
30	263	68.32218	0.000820912	206	76.60769022	2.74726E-11
40	263	68.32218	0.000820912	205	76.72173574	0.000827053
50	264	68.22137	1.77209E-08	205	76.72173574	0.000827053
60	264	68.22137	1.77209E-08	205	76.72173574	0.000827053
70	264	68.22137	1.77209E-08	206	76.60769022	2.74726E-11
80	264	68.22137	1.77209E-08	205	76.72173574	0.000827053
90	265	68.12069	-0.000819895	205	76.72173574	0.000827053
100	265	68.12069	-0.000819895	205	76.72173574	0.000827053
110	265	68.12069	-0.000819895	205	76.72173574	0.000827053
120	265	68.12069	-0.000819895	206	76.60769022	2.74726E-11
130	265	68.12069	-0.000819895	206	76.60769022	2.74726E-11
140	265	68.12069	-0.000819895	206	76.60769022	2.74726E-11

V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
250	69.63509852	0.000836362	278	64.5254174	1.48853E-11
250	69.63509852	0.000836362	278	64.5254174	1.48853E-11
250	69.63509852	0.000836362	278	64.5254174	1.48853E-11
250	69.63509852	0.000836362	278	64.5254174	1.48853E-11
250	69.63509852	0.000836362	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11
251	69.53042381	3.65041E-11	278	64.5254174	1.48853E-11

V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903

162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903
162	81.54518191	2.92545E-11	225	73.30239758	-0.000836903
163	81.42205169	0.000838868	225	73.30239758	-0.000836903
163	81.42205169	0.000838868	225	73.30239758	-0.000836903
163	81.42205169	0.000838868	225	73.30239758	-0.000836903
163	81.42205169	0.000838868	225	73.30239758	-0.000836903
163	81.42205169	0.000838868	225	73.30239758	-0.000836903
163	81.42205169	0.000838868	225	73.30239758	-0.000836903

Table B.6

Nail Forces (KN)						
Time (Seconds)	**Nail 1**	**Nail 2**	**Nail 3**	**Nail 4**	**Nail 5**	**Nail 6**
0	0.000212	3.28E-07	4.35788E-07	1.77701E-07	3.49241E-07	-9.990986939
10	0.000212	3.28E-07	4.35788E-07	1.77701E-07	3.49241E-07	-9.990986939
20	9.800091	3.28E-07	4.35788E-07	1.77701E-07	3.49241E-07	-9.990986939
30	9.800091	3.28E-07	4.35788E-07	1.77701E-07	3.49241E-07	-9.990986939
40	9.800091	9.873402	9.984535164	1.77701E-07	3.49241E-07	-9.990986939
50	0.000212	9.873402	9.984535164	1.77701E-07	3.49241E-07	-9.990986939
60	0.000212	9.873402	9.984535164	1.77701E-07	3.49241E-07	-9.990986939
70	0.000212	3.28E-07	9.984535164	1.77701E-07	3.49241E-07	-9.990986939
80	0.000212	9.873402	9.984535164	1.77701E-07	3.49241E-07	-9.990986939
90	-9.78795	9.873402	4.35788E-07	1.77701E-07	10.0144549	-9.990986939

Table B.6

Time (Seconds)	**Load (KN)**	**Displacement (mm)**	**Stress (KN/m^2**
0	0	0	0
10	0.8	2.6	10
20	1.1	3.5	13.75
30	1.8	5.2	22.5
40	3.4	10.2	42.5
50	5.1	15.4	63.75

60	5.9	18.2	73.75
70	7.3	22.4	91.25
80	11.1	34.5	138.75
90	14.4	44.7	180
100	16.8	51.4	210
110	21.4	65.2	267.5
120	24	80	300

Table B.6