SLOPE STABILIZATION BY SOIL NAILING

A PROJECT

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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to

JAYPEE UNIVERSITY OF INFORMATION TECHNOLOGY

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HIMACHAL PRADESH, INDIA

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **"SLOPE STABILIZATION BY SOIL NAILING"** 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 Manik Sood (131620), Lovejeet Singh (131640), Taranjeet Singh(131601) during a period from July 2016 to May 2017 under the supervision of **Mr. Saurabh Rawat**(Assistant Professor), Department of Civil Engineering, Jaypee University of Information Technology, Waknaghat.

The above statement made is correct to the best to for knowledge.

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AUTHOR'S DECLARATION

We hereby declare that we are the sole authors of this report. This is a true copy of the Report, including any required final revisions, as accepted by my examiners.

I understand that my report may be made electronically available to the public.

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ABSTRACT

The basic concept of soil nailing is to reinforce and strengthen the existing ground by installing closely spaced steel bars, called "Nails", into a slope as construction proceeds from top to down. Soil nailing is an in-situ reinforcement technique by steel bars which can withstand tensile forces, shearing forces and bending moments. This process creates a reinforced section that is in itself stable and able to retain the ground behind it. Soil nailing technique is used to support very steep cuts with advantage of strengthening the slope with excessive earth works to provide construction access and working associated with commonly used retaining systems. This technique is commonly used for slope stabilization and retaining walls. Its behaviour is typical and involves essentially two interaction mechanisms: The soil-reinforcement friction and the normal earth pressure on the reinforcement.

The mobilization of the lateral (soil-reinforcement) friction requires frictional properties for the soil, while the mobilization of the normal earth pressure requires a relative rigidity of the inclusions. This report presents comprehensive guidelines for evaluating and using soil reinforcement techniques in natural or cut slopes. In the present research work, nails have been inserted at an angle of 20° from the horizontal. The nails were tested on different slopes angles i.e. 45°, 60° and 90°. Two types of nails of length 15 cm have been used i.e. Screwed Nails and Helical Nails. The tests were performed with and without nails and the results reveal that the strength of the soil is increased in all the cases after the insertion of nails but the screwed nails were more effective than helical nails.

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CHAPTER 1
INTRODUCTION

1.1 General

Soil nailing consists of the passive reinforcement of existing ground by installing closely spaced steel bars (i.e. nails), which may be subsequently encased in grout..

Soil nailing is typically used to stabilize existing slopes or excavations where top-to-bottom construction is advantageous compared to other retaining wall systems. For certain conditions, soil nailing offers a viable alternative from the viewpoint of technical feasibility, construction costs, and construction duration when compared to ground anchor walls, which is another popular top-to bottom retaining system.

An alternative application of passive reinforcement in soil is sometimes used to stabilize landslides. In this case, the reinforcement (sometimes also called “nails”) is installed almost vertically and perpendicular to the base of the slide. In this alternative application, nails are also passive, installed in a closely spaced pattern approximately perpendicular to the nearly horizontal sliding surface, and subjected predominantly to shear forces arising from the landslide movement.

The evaluation of stability of slopes in soil is an important, interesting, and challenging problem in the field of geotechnical engineering. The wide variety of applications of slope engineering include excavations, hill roads, railway lines, embankments, earth dams, reservoirs, open-cut mines and coastal slope stability. Extensive engineering and research studies performed over the past 70 years provide a sound set of soil mechanics principles to understand practical problems of slope stability.

1.2 ORIGIN AND DEVELOPEMENT

Soil nailing technique has been applied to civil engineering project at **Mexico City** back to1960s and has gained popularity in Europe since 1970. During the development of soil nailing technique, cementitious grouted drilled nail, post-grouted driven nail, percussion-driven nail, jet nail, and etc have been devised and improved.

One of the first applications of soil nailing was in 1972 for a railroad widening project near **Versailles, France,** where an 18 m (59 ft) high. In **Germany**, the first use of a soil nail wall was in 1975 (Stocker et al. 1979).
The **United States** first used soil nailing in 1976 for the support of a 13.7 m deep foundation on a dense silty sand.

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

1. Stabilization of railroad and highway cut slopes
2. Excavation retaining structures in urban areas for high-rise building and underground facilities
3. Tunnel portals in steep and unstable stratified slopes
4. Construction and retrofitting of bridge abutments with complex boundaries involving wall support under piled foundations
5. Stabilizing steep cuttings to maximize development space.
6. The stabilizing of existing over-steep embankments.
7. Soil Nailing through existing concrete or masonry structures such as failing retaining walls and bridge abutments to provide long term stability without demolition and rebuild costs.
8. Temporary support can be provided to excavations without the need for bulky and intrusive scaffold type temporary works solution.

1.4 ADVANTAGES AND DISADVANTAGES OF SOIL NAILING

Hereafter, the advantages and disadvantages of soil nailing are briefly discussed.

Advantages:

1. Allow in-situ strengthening on existing slope surface with minimum excavation and backfilling, particularly very suitable for uphill widening, thus it is environmental friendly.

2. Allow excellent working space in front of the excavation face.

3. Sub-vertical cut surface reducing loss of space.
4. Avoid unnecessary temporary works.
5. Only requires light machinery and equipment.
6. Flexible method at constraint site and for any excavation shape.
7. Can be used for strengthening of either natural slope, natural or man-made cut slopes.
8. Thinner facing requirement.

Disadvantages:

1. Nail encroachment to retained ground rendering unusable underground space.
2. Generally larger lateral soil strain during removal of lateral support and ground surface
3. cracking may appear.

Tendency of high ground loss due to drilling technique, particularly at course grained soil.

4. Less suitable for course grained soil and soft clayey soil, which have short self support time, and soils prone to creeping.
5. Lower mobilised nail strength at lower rows of nailing.
6. Lower mobilised nail strength at lower rows of nailing.

1.5 SUITABILITY OF SOIL NAILING WITH RESPECT TO SOIL TYPES

As soil nail construction requires temporary stability in both the staged excavation and also the drilled hole stability, any soils with sufficient temporary self-support of about 2m sub vertical height for minimum of 1 to 2 days and hole stability for minimum four hours are considered suitable ground for soil nailing.

With the above criteria, the following soil types would be suitable for soil nailing:

1. Stiff fine/cohesive soils
2. Cemented granular soil

3. Well graded granular soil with sufficient cohesion of minimum 5kpa as maintained by capillary suction with appropriate moisture content.
4. Most residual soils and weathered rock mass without adverse geological settings(such as weak day lighting discontinuities, highly fractured rock mass ,etc) exposed during staged excavation.
5. Ground profile above ground water level.

1.6 CONSTRUCTION SEQUENCES

The sequence of construction for typical soil nail walls was described in and consisted of:

- Excavation;
- Drilling of nail holes;
- Installation and grouting nails;
- Construction of temporary shotcrete facing;
- Construction of subsequent levels; and
- Construction of a final, permanent facing.

1.7 MACHINERY USED IN SOIL NAILING

The following tools or machineries are used for soil nailing:

- **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 6.1).It is important to procure drilling equipment with sufficient power and rigid drill rods.
- **Grout Mixing Equipments:** In order to produce uniform grout mix, high speed shear colloidal mixer should be considered. Powerful grout pump is essential for uninterrupted delivery of grout mix (Fig 6.2).If fine aggregate is used as filler for economy, special grout pump shall be used.
- **Shotcreting / Guniting Equipments:** Dry mix method will require a valve at the nozzle outlet to control the amount of water injecting into the high pressurized flow of sand/cement mix (Fig 6.3).For controlling the thickness of the shotcrete, measuring pin shall be installed at fixed vertical and horizontal intervals to guide the nozzle man.
- **Compressor:** The compressor shall have minimum capacity to delivered shotcrete at the minimum rate of $9m^3$/min. Sometimes, the noise of compressor can be an issue if the work is at close proximity to residential area, hospital and school.

Fig 1.1: Typical drilling equipment

Fig 1.2: Grout Mixing Instrument

Fig 1.3: Shotcreting is done with the help of a pipe with a nozzle

1.8 OBJECTIVE OF OUR PROJECT

1. To determine the increase in strength of the soil slopes by insertion of different nails at different angles of slope by using **UTM** (Universal Testing Machine).
2. To determine the soil type and properties by **sieve analysis**, **direct shear test(DST)** and **pycnometer test**.

CHAPTER 2
LITERATURE REVIEW

2.1 General

Studies had been done for soil nailed cut considering circular type wedge failure by friction circle method. Effect of variation of parameters such as nail length, nail diameter, nail inclination, wall inclination, angle of internal friction of soil, etc were studied from past few decades to determine the factor of safety of nailed open cuts. It is seen that at sites which are susceptible to rainfall induced erosion, the erosion may be stopped to a greater extent by soil nailing. The use of soil nails for slope strengthening works has been gaining popularity since its first application in 1980's in view of the attractive benefits of simple and fast installation method to reinforce steep cut slopes.

2.2 Research work on soil nailing

<u>Model test and theoretical analysis of reinforced soil slopes with facing panels</u>

The tensile (or compressive in some cases) force acting axially on the reinforcing members for eg: soil nailing bars and geo-textile, is a typical "internal force" within the reinforced soil system. Such internal forces should develop, under given external forces, only when the reinforcement material and the reinforced soil restrain the deformation from each other.

The reinforced soil system at limiting equilibrium state was recently formulated by **Asaoka et al.** (1994 based on the rigid plastic finite element method). In this, a linear constraint condition refer to as "no length change" condition is imposed upon the velocity field in the soil mass at limit state, following the same methodology, an additional condition i.e "no bending" condition is introduced assuming that the flexural rigidity of the reinforcing material is very high compared with the stiffness of fill soil.

Observation of model test:

- **Plain slope (type A):** As soon as loading began some comparatively dry sand rolled down on the slope surface as the loading level was gradually increased, the loading plate inclined towards the slope face and horizontal crack passing through the face was observed on the upper part of the slope surface. Here the test showed that that the failure surface is shallow and is confined near the slope face covering the full height of the slope.

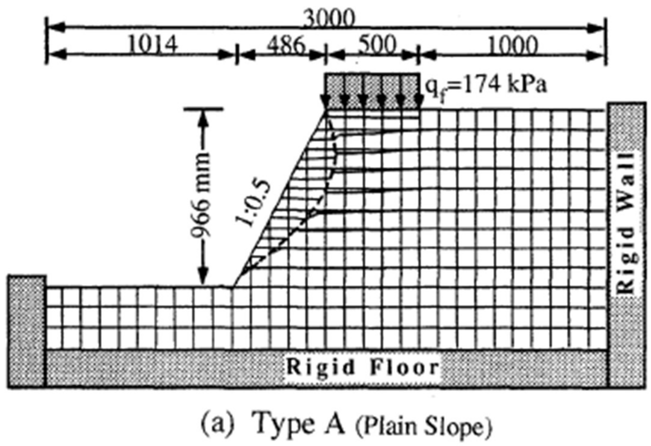


Fig.2.1 Slope with loading conditions

- **Reinforcement with facing (Type C):** Since the rigidity of the facing material was considerably high and the overlap joint between the facing panel was so strong that nothing could be observed outside the slope. It shows that there is no local failure near the facing which is different from reinforcement without facing. Here the type of failure is a block failure.

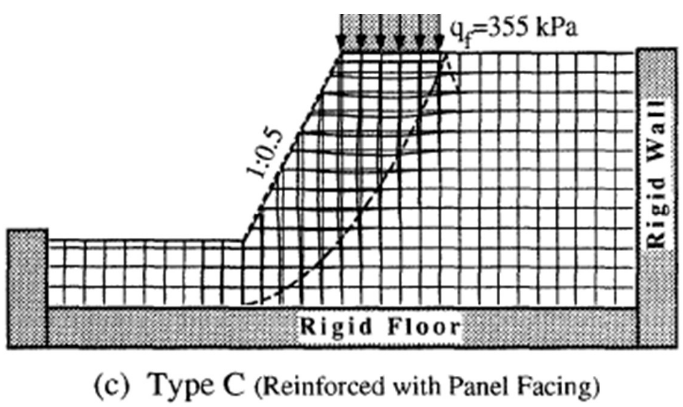


Fig.2.2 Slope with loading conditions

Conclusion :

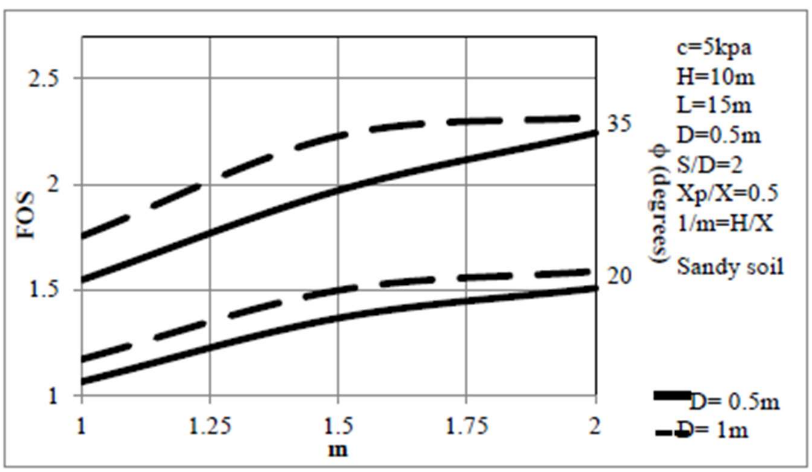
Here the test was performed on different slope inclinations and different facing conditions with reinforcement. Different test gave different types of failure patterns. The test on which he used reinforcement along with facing showed block failure. \

Studies on enhancing stability of slope using reinforcement

N.Ramya Gandhi and K. Ilamparuthi (2012) studied on enhancing stability of slope using reinforcement by 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**.

Effect of slope angle

The effect of slope angle is analyzed for two types of soils of clay and sand and piles of two different stiffnesses (ie. D=0.5m and 1.0m). From the analysis, it is inferred that the safety factor increases with decrease in slope angle both in clay and sandy slopes and for the given slope angle, if the stiffness of pile increases the factor of safety also increases as shown below. But the increase is insufficient in clay when compared to sand slope.



Conclusion:

- 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.

Two case studies on soil nailed slope failures

Liew,Shaw shong & Liong, Chee-How

The first failure site is underlain by completely weathered shale facies, with the existence of mudstone and siltstone the failure consisted of 7 upper berms 1V:1H cut slope(total of 42 m in height) and 5 lower berms of 4V:1H soil nailed slope(total of 30 m in height) reinforced with 12 m length soil nails. When the slope failure occurred, all the soil nails except for the soil nails at the lowest berm had been installed.
The geology of the second failure area consists primarily of wethered metamorphic rock with massive granitic intrusion. The failure involved a steep soil nailed slope(4V:1H) upto a total slope height of seven and a half berms, with the max. Height of abt 45m. The top slope was reinforced with 6 m length soil nails, and lower slope were reinforced with 12 m length soil nails.

Conclusion:

- It is necessary to carry out sub surface investigation at high cut area esp. If soil nailed slope is to be constructed. Inspection and examination on the exposed slope material and geological structures should also be carried out during various stages of construction. If the sub soil profile, geological structures or ground water table are found to be different from the design model, then the design shall be reviewed with the updated info. This design feedbacks and verifications are crucial in order to ensure safety of a soil nailed slope. Sometimes, further design optimisation is possible if the ground condition is more favourable.
- Engineering assessment shall be carried out for all 4 potential failure modes: nail tendon failure, nail pullout failure, facing failure and overall failure for the design of soil nailed slope. The design of the facing is often neglected by designers thinking that

it is sole purpose of the facing is to protect against surface erosion only and neglect its role as a structural element to resist the earth pressure. It should be noted that the design of facing is esp.critical when the soil nailed slope is high and steep, the facing should be designed to resist the earth pressures, bending moment and punching shear force from the pulling of soil nail under the earth pressure. In adequate facing design could lead to failure of soil nailed slope as depicted above.

Studies were done by **C.R. Patra and P.K. Basudhar(2005)** and their study was to check slope stability at different angels with horizontal and different lengths of nails at different heights from toe of slope and conclusions are as follows.

- Nails oriented upwards with larger lengths in the upper part of the slope generally leads to more stability. But the value of the upward inclination of the nails ranges very small from nearly zero to a maximum of 6 degrees.
- If Other nail parameters kept constant unequal spacing of the nails with decreasing values of their lengths from top to bottom of the slope results in the optimal design.
- The savings in the above method is about 8 to 27%

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.

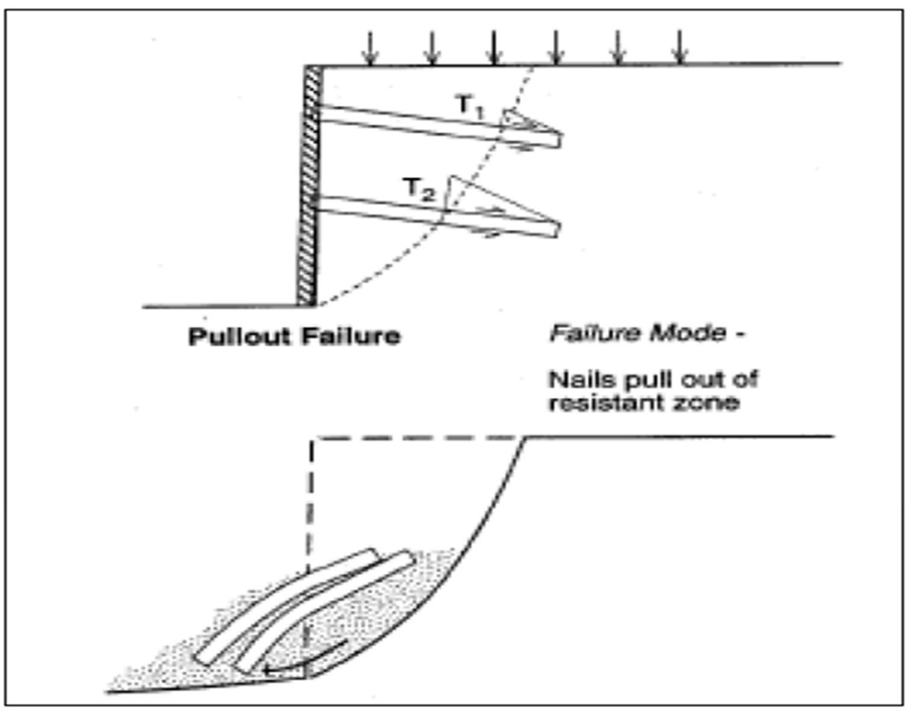
- With increase in applied overburden pressure, the time needed to obtain stress equilibrium in the box increases.
- Grouting pressure increases the earth pressure, but it could not be maintained for a very long time. Higher the applied grouting pressures the longer that grouting pressure is maintained.
- 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.

Types of failure modes

Tan, Yean-Chin and chow, Chee-Meng(1988) did studies on the type of failure modes of soil nails and categorised them into four types

- Pullout failure
- Nail tendon failure
- Face failure
- Overall failure

Pullout failure is a result from insufficient embedded length into the resistant zone as seen in figure.



Pullout failure mode (from FHWA 1998).

Fig. 2.3 Pullout failure of nails

Nail tendon failure occurs when there is in adequate tensile strength of nails hence resistance force exceeds the tensile strength of nail and nail break into two pieces .This could be protected by providing adequate cover to nails to prevent it from corrosion.

+

Fig.2.4 Nail tendon failre

Face failure mode for soil nail is generally neglected and due to inadequate thickness of shortcrete nail protrudes out from slope after failure. This failure is prevented by putting steel plate with facing correctly as shown in figure.

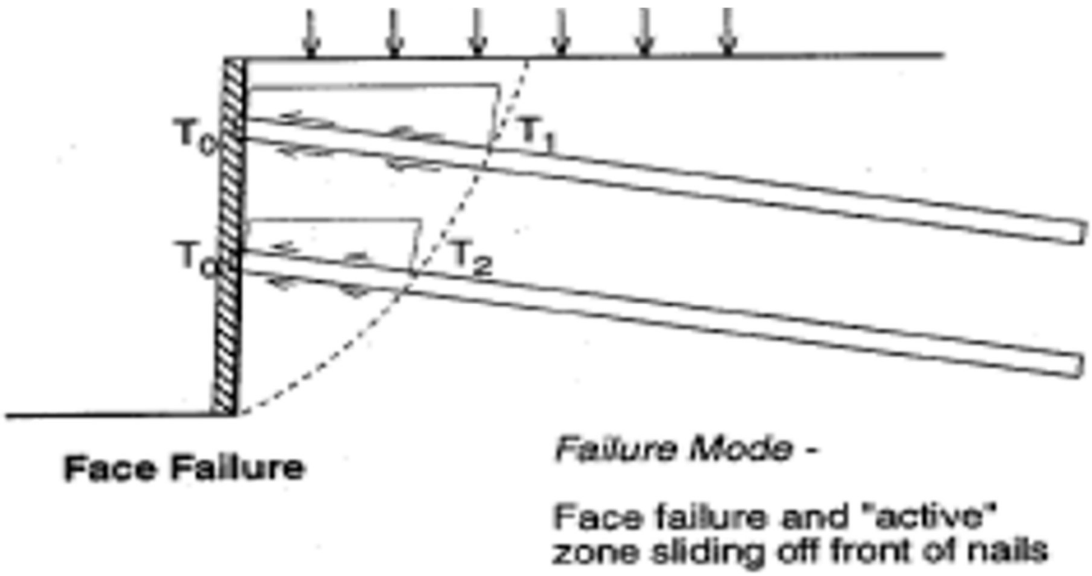
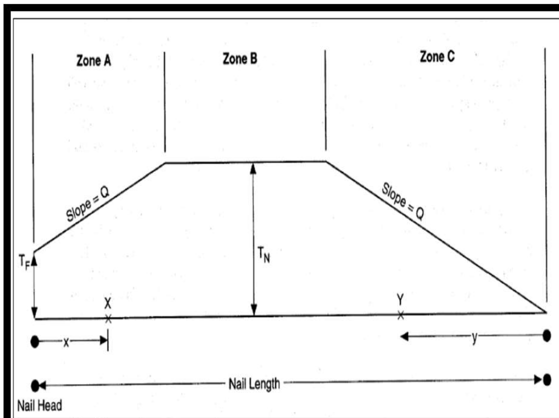
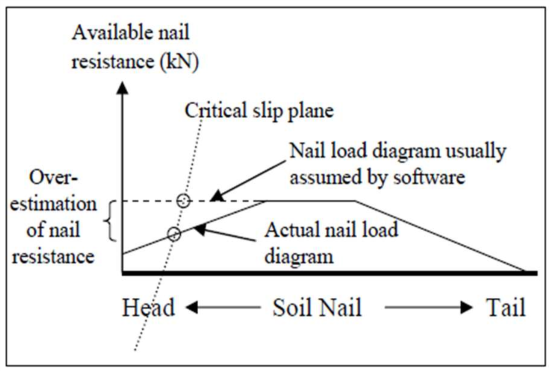


Fig.2.5 Face failure

Over all failure computation is based on limit equilibrium method and it is discovered that overall strength is governed by three kind if forces. Based on these three strengthening parameters nail load diagram is made which contains three zones A, B and C .Zone A is governed by the strength of the facing, zone B is governed by nail tensile capacity and zone C is governed by ground-grout bond strength. All of these zones plotted graphically with respect to nail length forms the nail load diagram and failure occurs when any of force exceeds the nail load envelope. Best designing is said when failure envelope passes through zone A so that tensile strength gets mobilised .Nail load diagram is shown as follows.



Nail load diagram (from FHWA 1998).



Overestimation of nail resistance if shotcrete facing strength not taken into consideration.

Construction sequence

To avoid the above failure it is important have accuracy in work and an construction sequence is generated to do soil nailing which is.

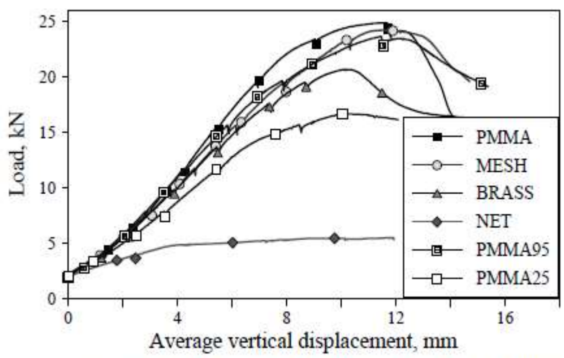
- Excavation to one level or maximum two levels from the top of slope.
- Installation of soil nails and horizontal drains and shortcreting with BRC reinforcement.
- Excavate to next level of soil nails then install soil nails and horizontal drains and shortcrete with BRC reinforcement.

Paolo Simonini, Alberto Bisson and Prof. Simonetta Cola (2013) represented a conference paper on soil nailing with different types of facing .They classified facing in three categories

- **Hard facing -** It stabilises the slope by sustaining the expected destabilising forces.
- **Flexible facing** is designed to provide the necessary restrains to the areas of slope face between the bearing plates as well as the erosion control.

- **Soft facing** with the function of controlling slope erosion in conjunction of vegetation.

  They used PMMA, mesh, brass net, PMMA95, PMMA25 (poly methyl 2 methyl propenoate)of different flexional and axial stiffness and experimental results showed that not only it affects the load bearing of soil but tensile stresses on nails are also influenced as shown in following graph.



Load on the plate vs. mean settlements during loading phase up to collapse.

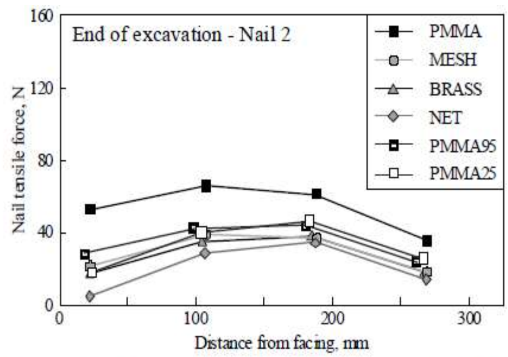
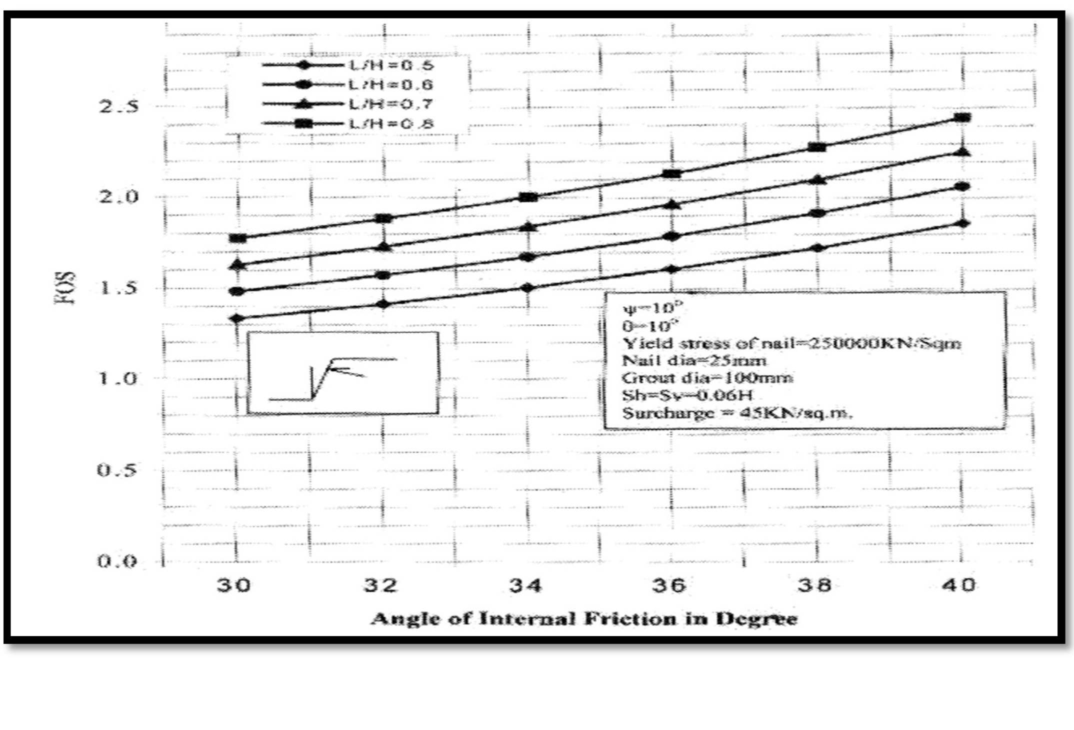
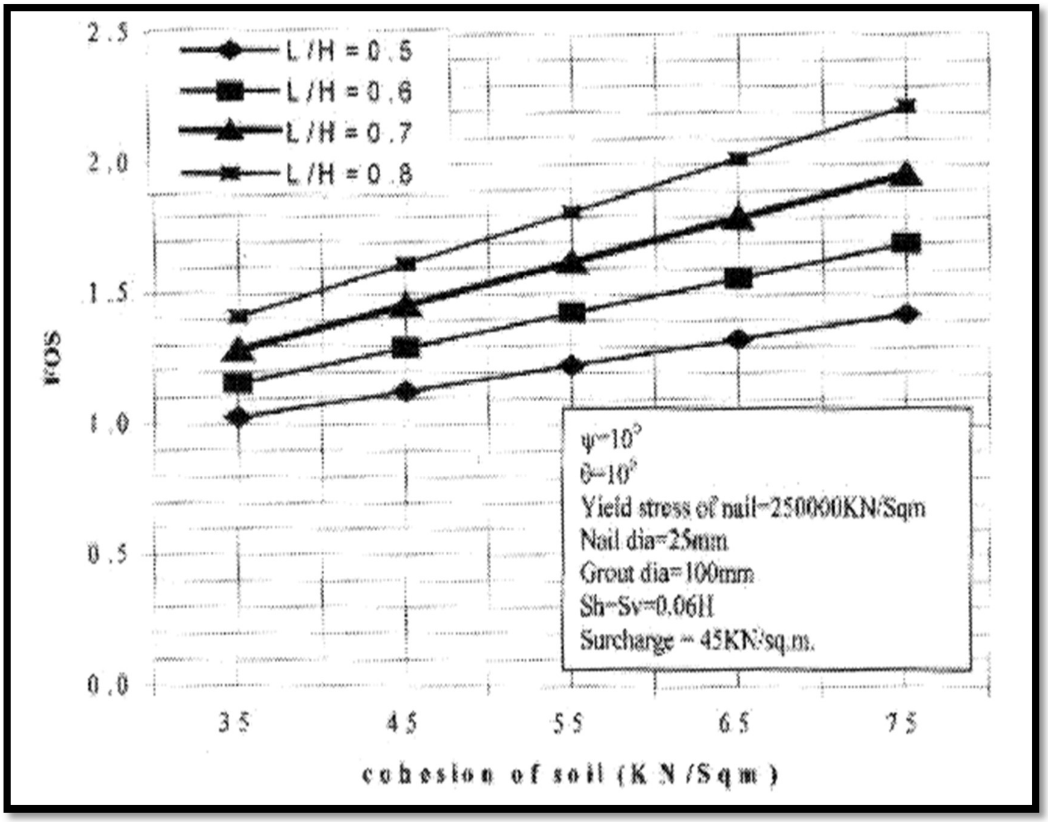


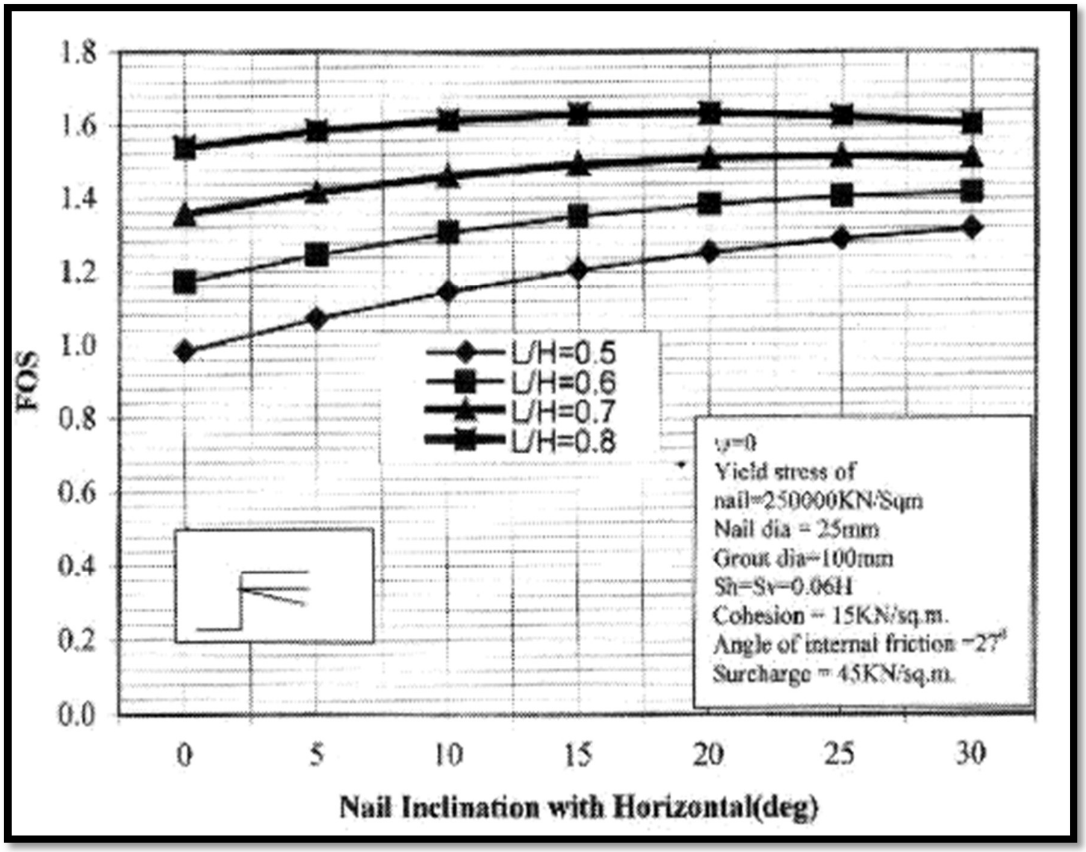
Figure 3. Distribution of tensile force along the monitored nails at the end of excavation

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.





2.5
2.0
1.5
1.0
0.5
0.0
L/H = 0.5
L/H = 0.6
L/H = 0.7
L/H = 0.8
FOS
ψ=10°
θ=10°
Yield stress of nail=250000KN/Sqm
Nail dia=25mm
Grout dia=100mm
Sh=Sv=0.06H
Surcharge = 45KN/sq.m.
35
45
55
65
75
cohesion of soil (KN/Sqm)



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.

SOIL NAILING FOR SLOPE STRENGTHENING:

Liew shaw-shong

Gue and partners Sdn Bhd, kuala-lumpur, Malaysia

Passive soil nailing technique has gained popularity for temporary and permanent slope strengthening works at both in –situ cut slopes of virtually ant formations and also man-made filled slopes in Malaysia. However, there are still many misconception and myth in the design and construction of soil nails.

Design of soil nails

The following documents have been widely referred by designers in designing the soil nailing strengthening works.

a) BS 8006:1995 Code of practice for strengthened\reinforcement soils and other fills.
b) Federal Highway Administration(FHWA): Manual for design and construction monitoring of soil nail walls.
c) BS 8081:1989 Code of practice for ground anchorage.

Conclusion:

This paper briefly overviews the methodology and design philosophy of soil nails.

CHAPTER 3
METHODOLOGY

3.1 General

In this chapter, there is a detailed procedure of our project, material and instruments, along with the complete set of formulas required for all calculations required for our experiment.

3.2 Material and Instrument used

3.2.1 Box

We have used a box of size 60x40x60 cm made of perprex sheet and steel angles at the edges. The perplex sheet used is 2mm thick. The boxes we got manufactured from a welding shop near Shimla. The sheet is fixed from all its edges to a angle with bolts. 2 such boxes we got manufactured for our project work.

Fig. 3.1 Box ready for experiment

3.2.2 Soil

Soil used is sandy soil. The soil is a mountaneous soil, which we got from a crusher in **Domehar** village in **Waknaghat.**

Fig.3.2 Soil used for testing

3.2.3 Nails

Following 2 type of nails are used for conducting experiment:

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

3.2.3.1 Screwed hollow aluminium nails.

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

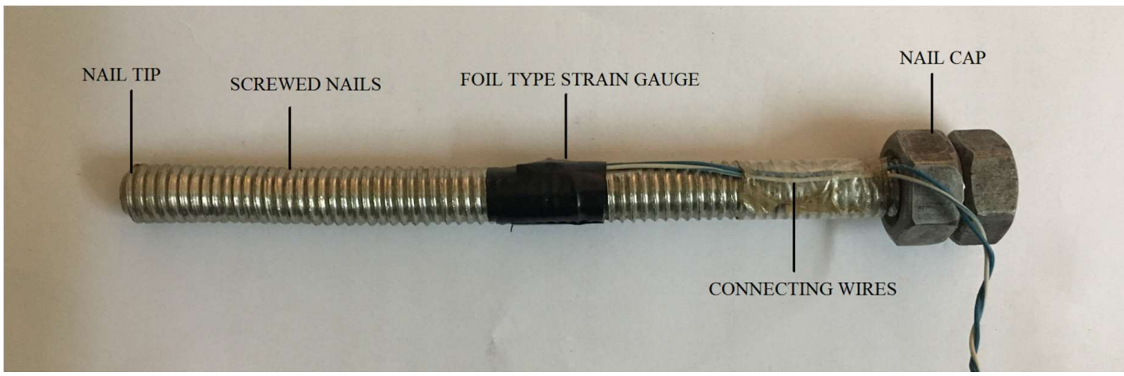


Fig.3.3 Hollow screwed aluminium nail.

3.2.3.2 Cylindrical circular rings nails

Hollow cylindrical nails are used with circular rings as shown.

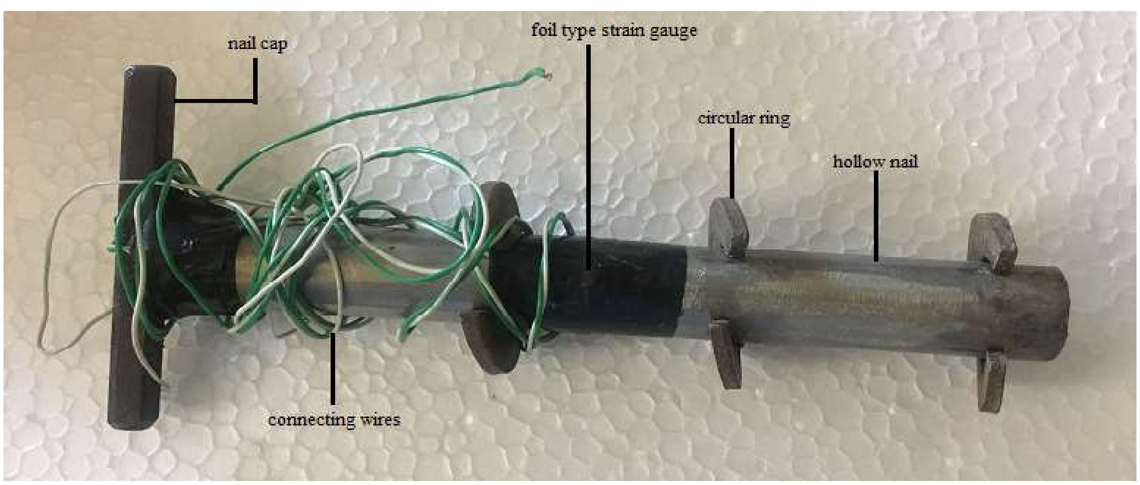


Fig.3.4 Hollow cylindrical circular rings nail.

3.2.4 Strain Gauges

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.

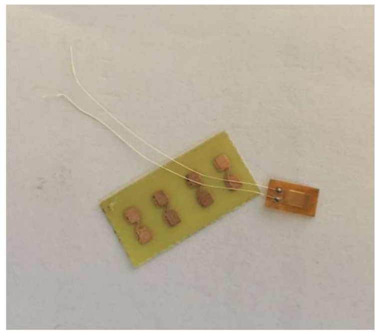


Fig.3.5 Foil type strain gauges

3.2.5 Connecting wires

The following copper wires were used for connecting the strain gauges (attached to the nails) with the multimeter.

Fig.3.6 Connecting wires

3.2.6 Bread Board

Bread board is used for assembling the connection for 6 nails altogether.

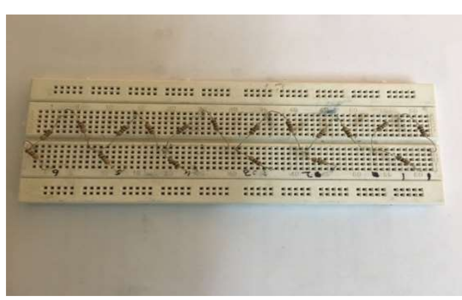


Fig.3.7 Bread board

3.2.7 Resistances

We have used resistances for making wheat stone bridge.

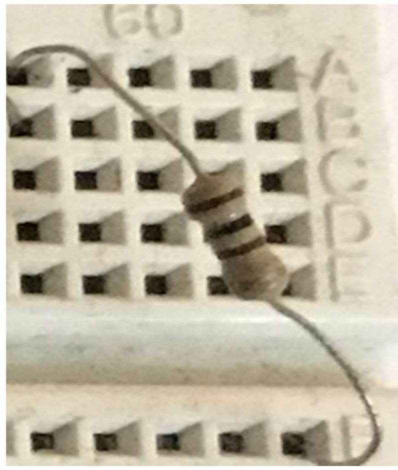


Fig.3.8 Resistance

3.2.8 Wheat Stone Bridge

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

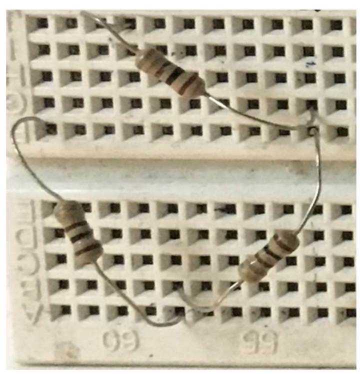


Fig.3.9 Wheat stone bridge

3.2.9 Wooden board

The following facing was used which is made up of plyboard and different facing was used for different slope angles. The following are the numbered holes for respective nails.

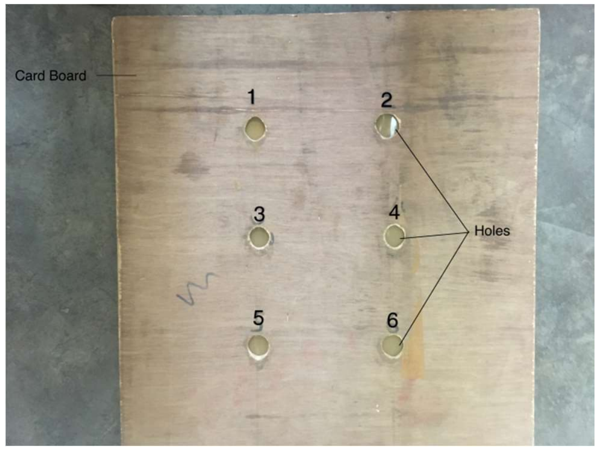


Fig.3.10 Wooden facing

3.3 Procedure

3.3.1 Preparation of Slope

First of all the box is picked up and placed properly on UTM.

Firstly, the base is prepared which is made up of 2 layers of sand each layer of 10 cms tamped manually with hand and trowel to keep the density in required limits.

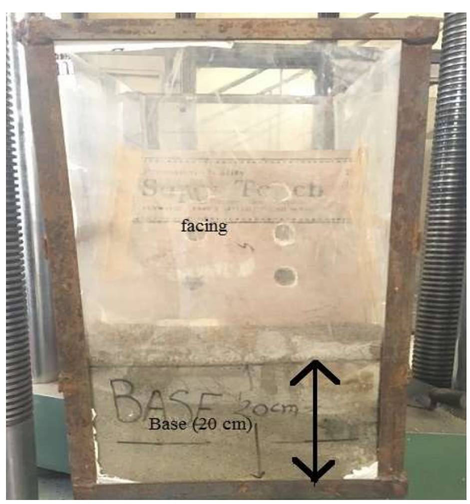


Fig.3.11 Base Prepared

After completing the base, mark the box from outside with a temporary marker, making various angles such as 45deg, 60deg & 90 deg, then take a wooden facing and align it with marked slope and place it there with a help of brown tape.

Fig.3.12 placing of facing

Then put soil in required place and make a correspondong slope with facing placed at proper place. Then after interval of 10 cms or when soil is tamped upto nail holes, place the layer of tracer (Gulal) of thickness upto 1mm. This tracer marks the layer before the test. Then tamp the remaining soil and complete the slope.

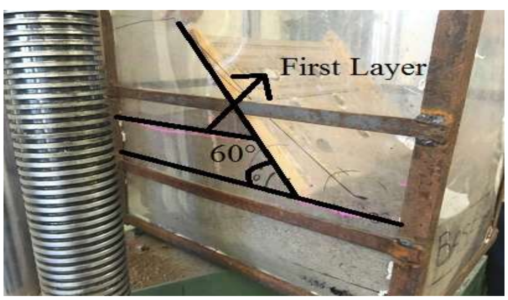


Fig.3.13 preparation of first layer

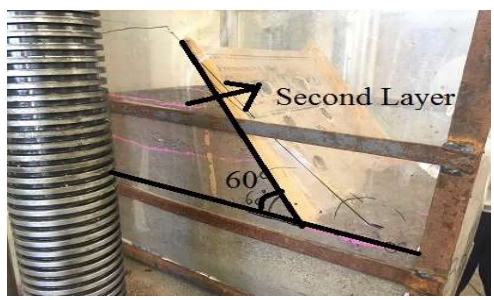


Fig.3.14 preparation of second layer

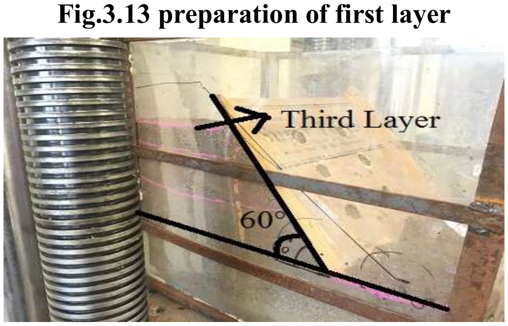


Fig.3.15 preparation of third layer

Fig.3.16 marking with tracer

Then place the metal plate on the top of slope to distribute the load evenly on the slope from UTM.

Fig.3.17 prepared slope

3.3.2 General

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 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 DISCUSSION

4.1 General

Three tests are performed on slopes of different angles i.e 45°, 60° and 90°. The nails are inserted at an angle of 20° as shown in the figure below.

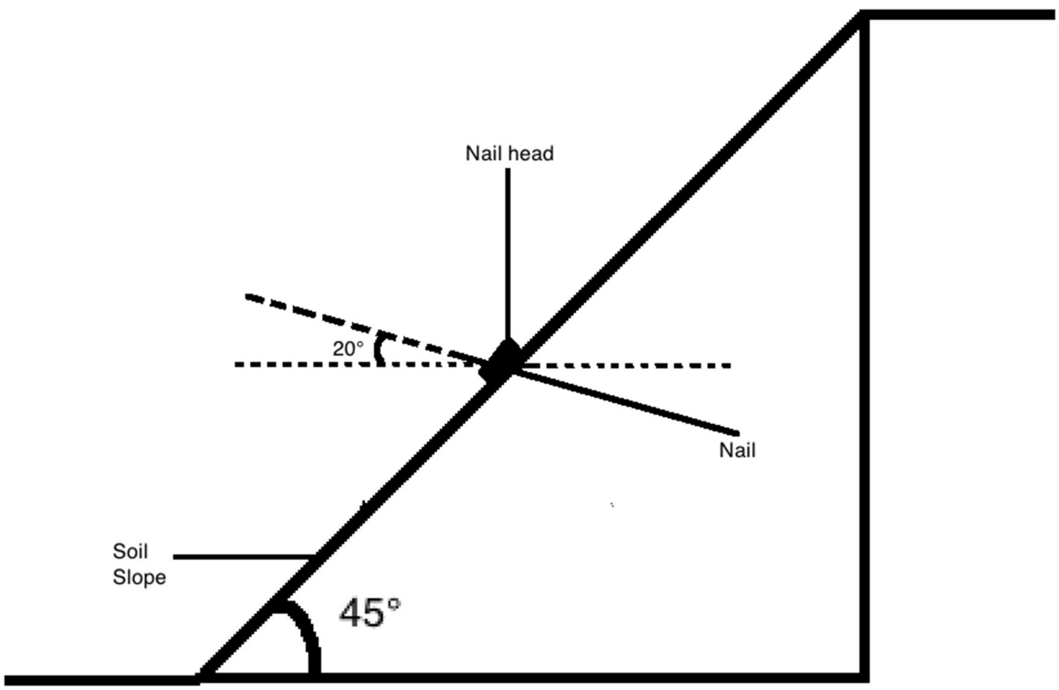


Fig.4.1 alignment of nail

4.2 EXPERIMENTAL RESULTS

4.2.1 Screwed Nails

Table 4.1 outcomes of screwed nails.

Slope Angle	Load Capacity without nails	Load Capacity with nails	Increase in Load Capacity
45°	28.9 kN	42.6 kN	13.7 kN
60°	22.7 kN	31.8 kN	9.1 kN
90°	15.7 kN	22.9 kN	7.2 kN

4.2.2 Helical Nails

Table 4.2 outcomes of helical nails.

Slope Angle	Load Capacity without nails	Load Capacity with nails	Increase in Load Capacity
45°	28.9 kN	35.6 kN	6.7 kN
60°	22.7 kN	27.4 kN	4.7 kN
90°	15.7 kN	19.7 kN	4.0 kN

4.3 Detailed outcome of experiments with different nails

4.3.1 Screwed Nails

4.3.1.1 Test 1: 45° Slope angle

Fig.4.2 Nail force vs Nail strain (nail 1)

Figure 4.2 shows the graph between nail force and nail strain for nail labeled as 1 as shown in fig. 3.10(wooden facing).
This graph shows that at a particular value of nail strain , no nail force(tensile force) is mobilized, but after some value of nail strain, a tensile force of nearly 9 kN is mobilized which remains constant for further values of nail strains.

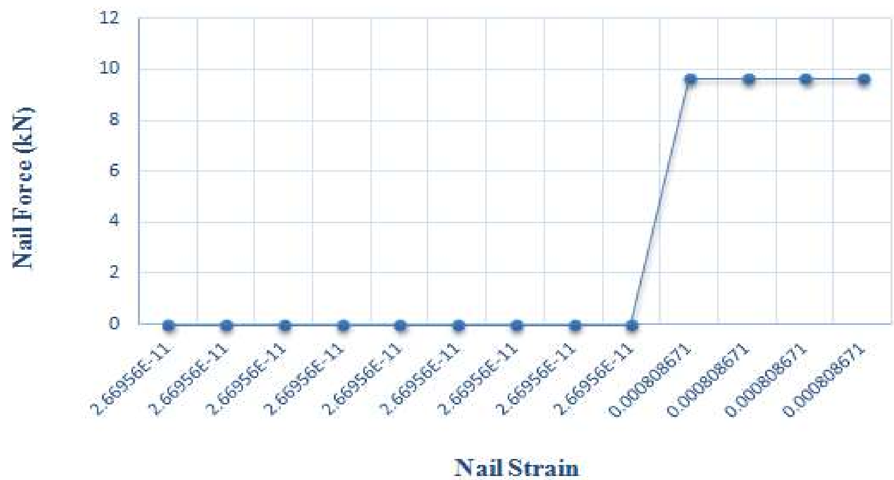


Fig.4.3 Nail force vs nail strain (nail 2)

Figure 4.3 also shows the graph between nail force and nail strain for nail labeled as 2 in fig. 3.10.This graph is similar to graph in fig.4.2.

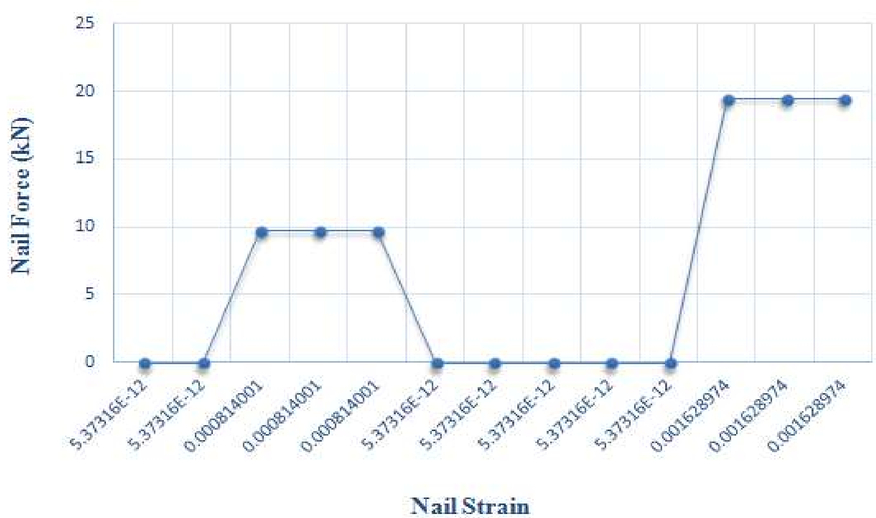


Fig. 4.4 Nail force vs nail strain (nail 3)

Figure 4.4 also shows the graph between nail force and nail strain for nail labeled as 3. Here the nail force is mobilized at some nail strain and again it becomes 0 and after greater value of nail strain , the nail force is again mobilized and then it becomes constant which shows the failure of slope.

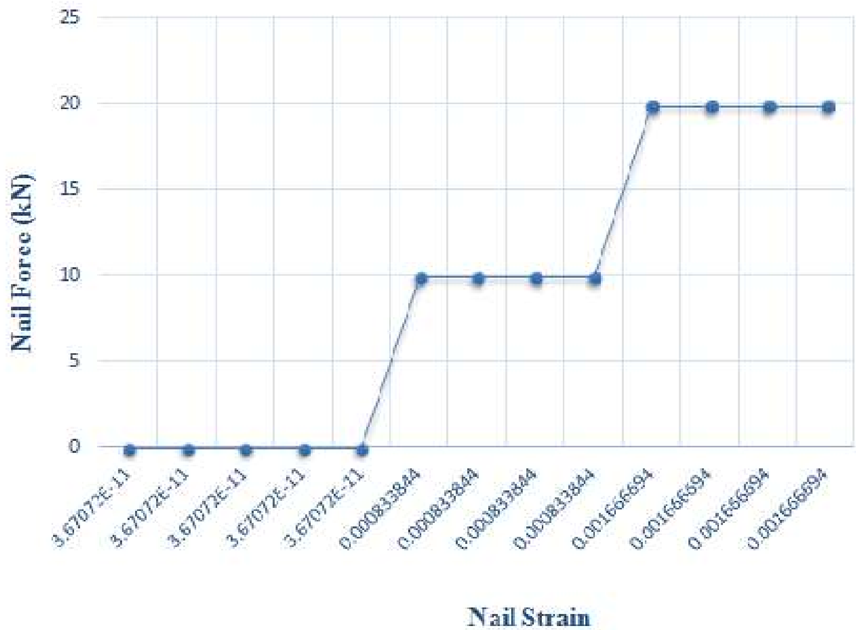


Fig. 4.5 Nail force vs nail strain (nail 4)

Figure 4.5 shows the graph between nail force and nail strain for nail labeled as nail 4 in fig. 3.10.

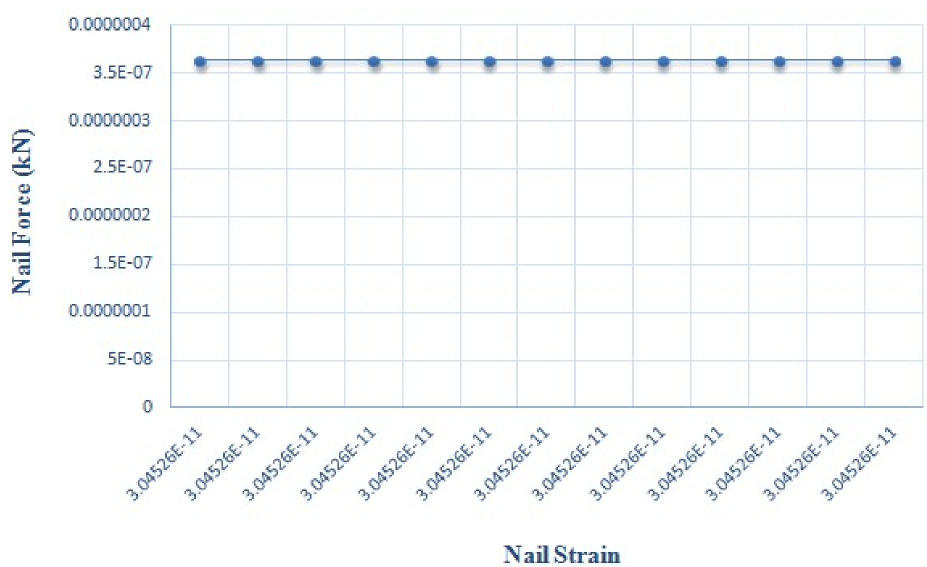


Fig.4.6 Nail force vs nail strain (nail 5)

Figure 4.6 shows the graph between nail force and nail strain for nail labeled as nail 5 in fig. 3.10.
Here the value of nail forces is negligible and also constant for all nail strains.

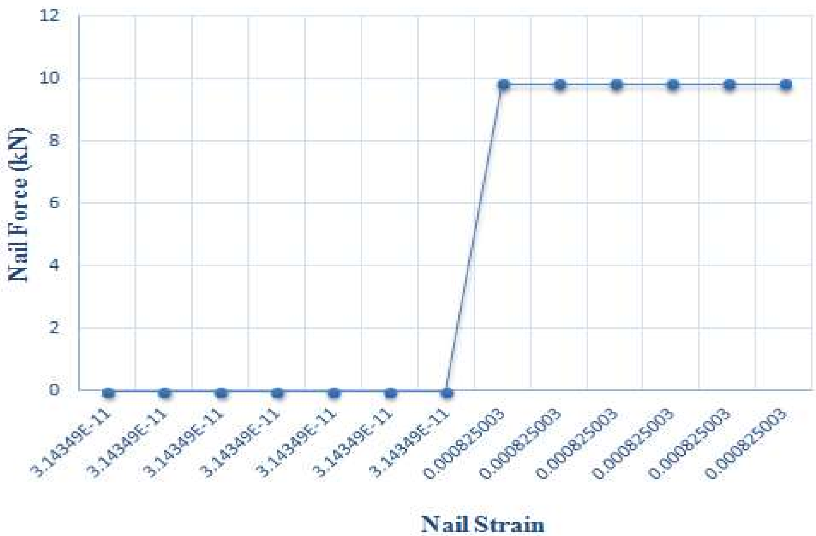


Fig. 4.7 Nail force vs nail strain (nail 6)

Figure 4.7 shows the graph between nail force and nail strain for nail labeled as nail 6 in fig. 3.10.
This graph is also similar to the graphs of other labeled nails.

Table 4.3 Calculations: Screwed Nails – 45° slope

Soil Stress Strain			
Time (Seconds)	**Load (KN)**	**Displacement (mm)**	**Stress (KN/m²**
0	0	0	0
10	0.3	0	3.75
20	0.9	0	11.25
30	1.9	0	23.75
40	2.3	0	28.75
50	2.4	0	30
60	16.3	0	203.75
70	19.9	9.3	248.75
80	21.6	25.2	270
90	24.9	45.5	311.25
100	31.5	57.3	393.75
110	34.5	80.5	431.25
120	42.6	109	532.5

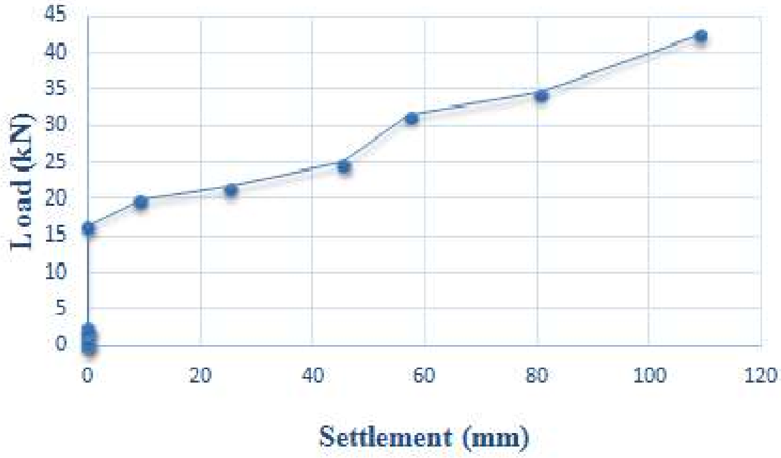


Fig. 4.8 load vs settlement curve (1st experiment)

Figure 4.8 shows load vs settlement curve for first experiment.

<u>Ultimate load at failure is=42.6KN</u>

Fig.4.9 normal layer condition

Fig. 4.10 layer condition after testing

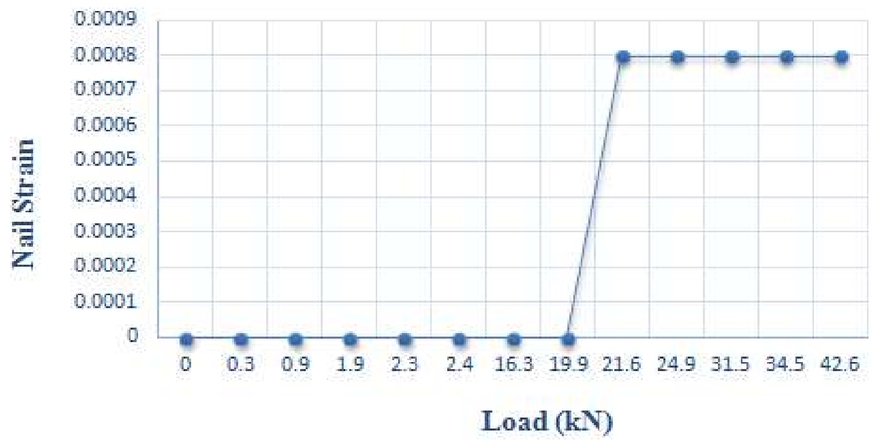


Fig. 4.11 Nail strain vs load (nail 1)

Figure 4.11, Figure 4.12, Figure 4.16 shows graph between nail strain and load applied It shows nail strain becomes constant at a particular value of load applied.

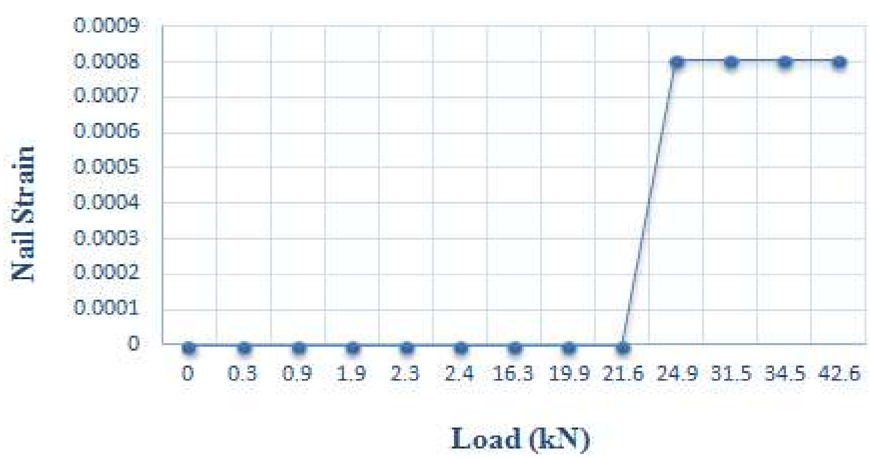


Fig. 4.12 nail strain vs load (nail 2)

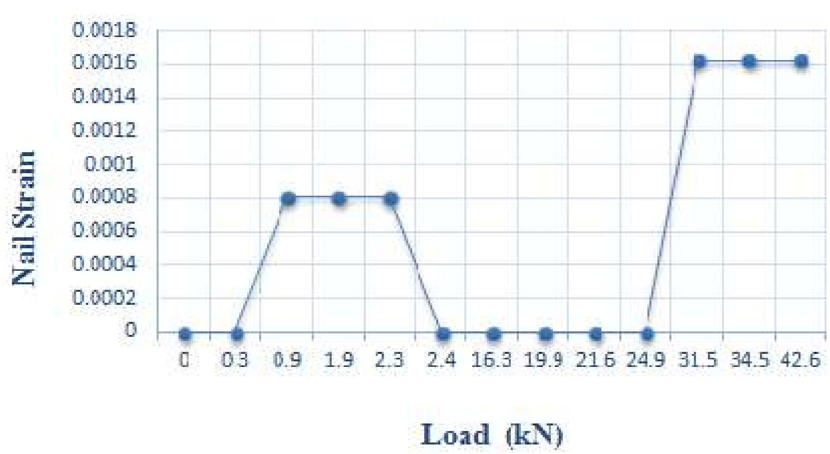


Fig. 4.13 nail strain vs load (nail 3)

Figure 4.13 shows graph between nail strain and load applied.
It shows nail strain slightly increases at very less load then remains constant for for load and then decreases to zero. This might be due to mobilization of the soil. After about 25 kN load, there is sudden increase in the strain.

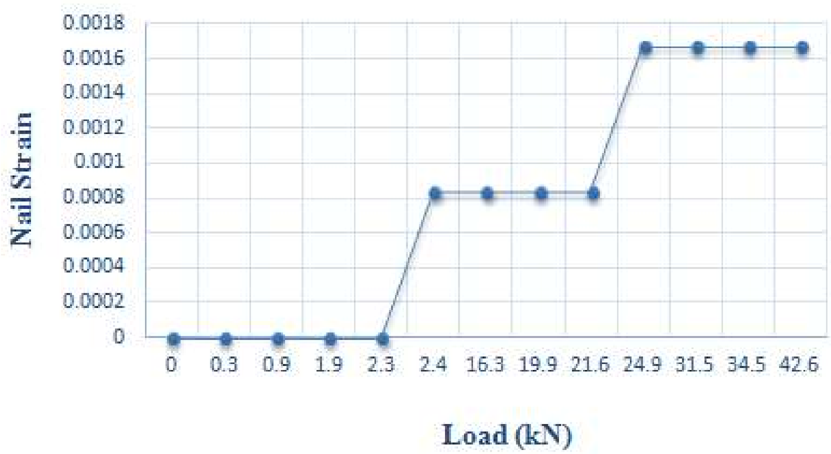


Fig. 4.14 nail strain vs load (nail 4)

Figure 4.14 shows graph between nail strain and load applied.
It shows nail strain increases slightly at a certain load and then remains constant for crtain increase in load then after increasing further load, the strain again increases and then remains constant.

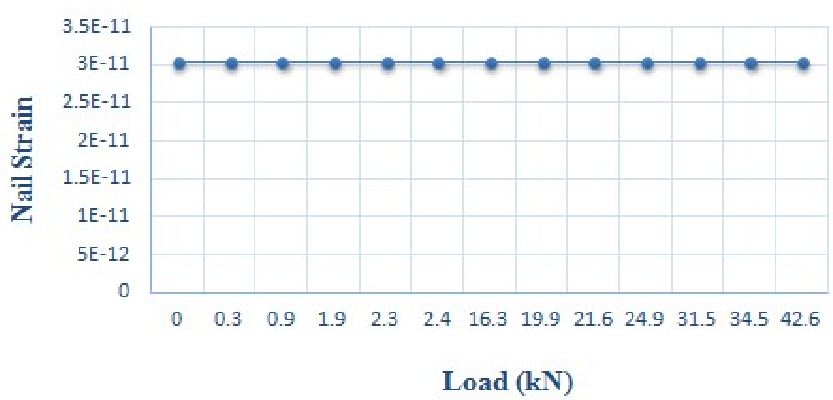


Fig. 4.15 nail strain vs load (nail 5)

Figure 4.15 show a constant value of strain over the entire application of load. This is because there was no effect of load applied on the bottom most layer of soil. This small value of strain is because of the weight of the soil.

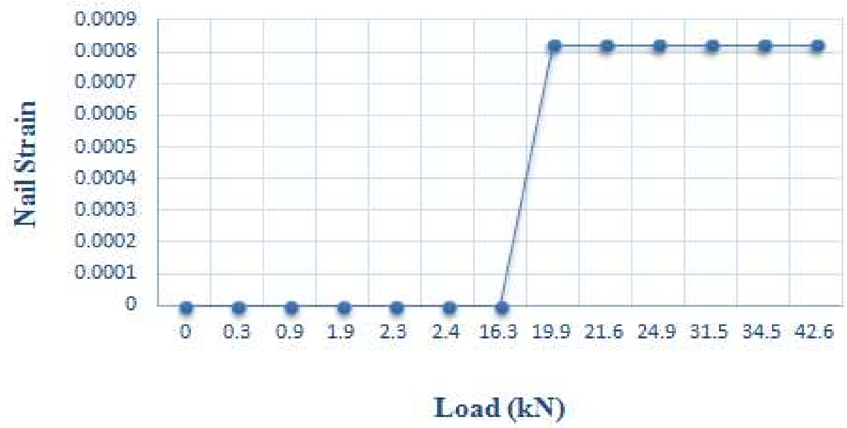


Fig. 4.16 nail strain vs load (nail 6)

4.3.1.2 Test 2: 60° Slope angle

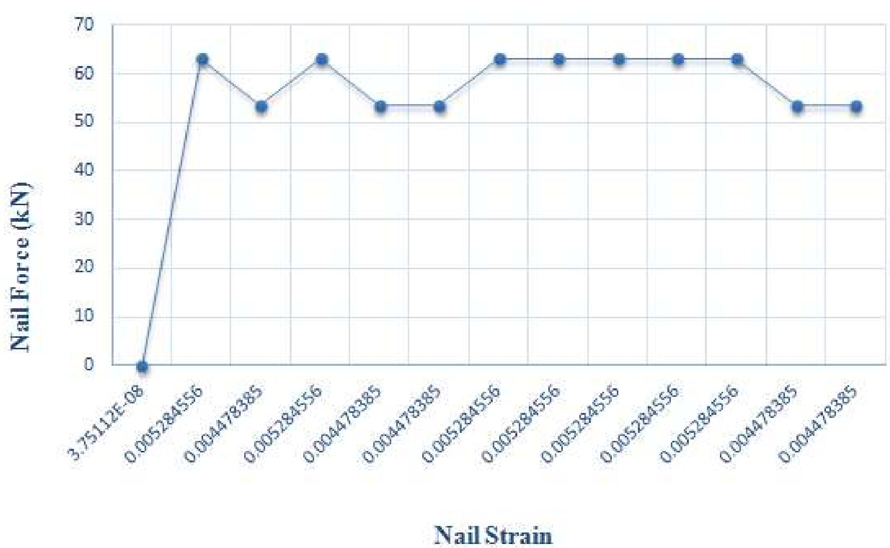


Fig. 4.17 nail force vs nail strain (nail 1)

Figure 4.17 shows graph between nail force and nail strain. The value of nail forces changes with nail strain as it is shown in graph and becomes constant at last showing failure condition.

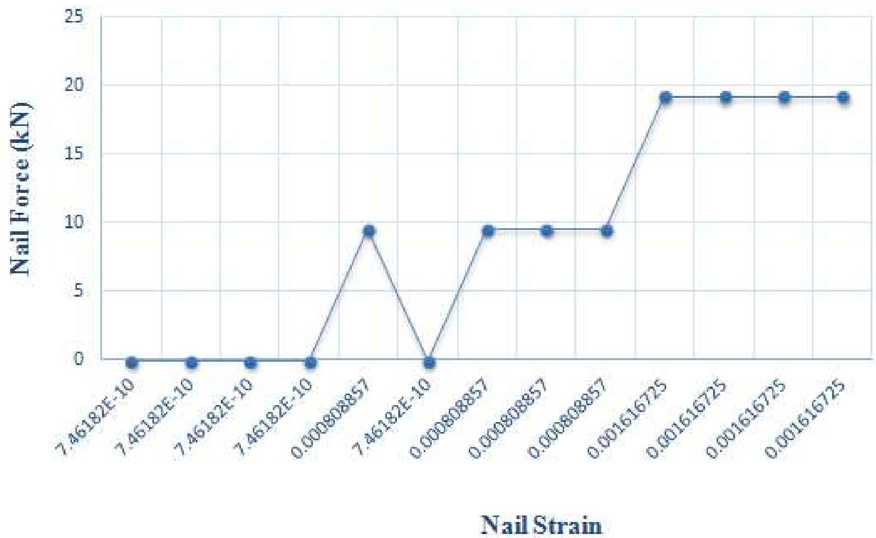


Fig. 4.18 nail force vs nail strain (nail 2)

In this graph nail forces are changing continuously with nail strains and at last becomes constant at a value nearing 19 kN,which shows the failure condition.

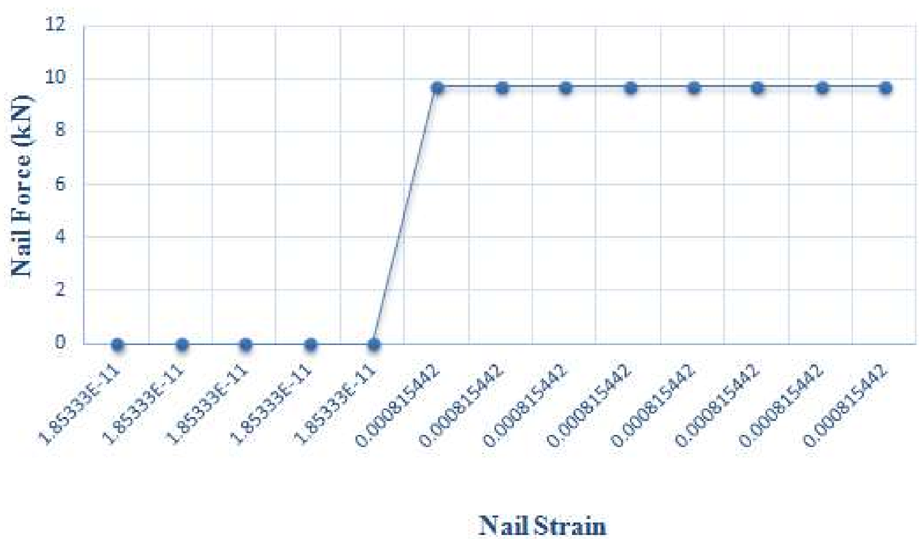


Fig. 4.19 nail force vs nail strain (nail 3)

Figure 4.19 also shows the graph which is same as earlier cases.

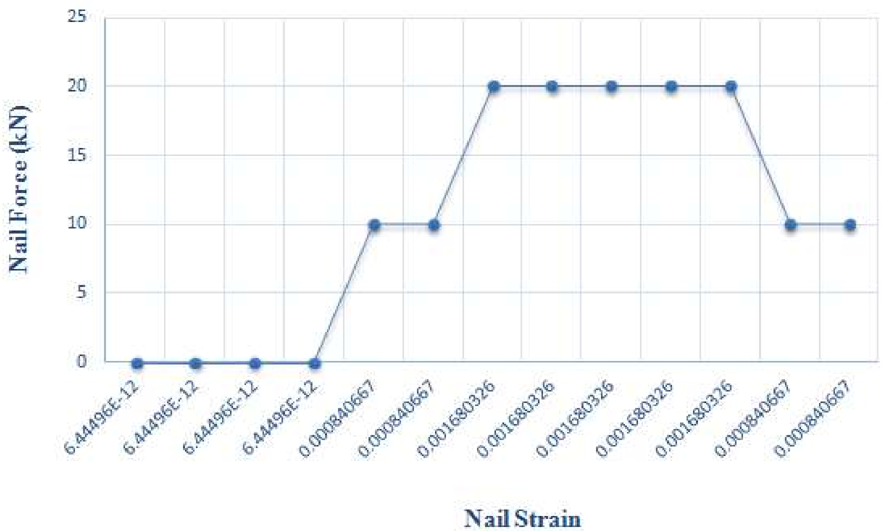


Fig. 4.20 nail force vs nail strain (nail 4)

Fig. 4.21 nail force vs nail strain (nail 5)

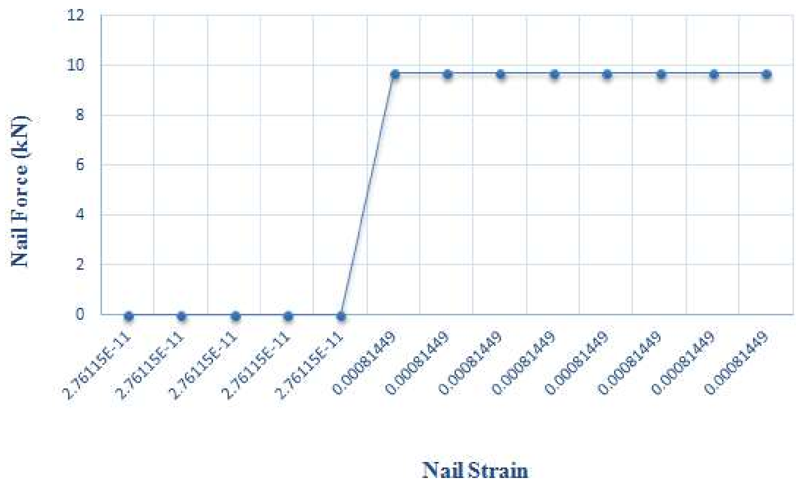


Fig. 4.22 nail force vs nail strain (nail 6)

All the above graphs are similar in their trend. All the graph shows that initially there is no force generated in the nail with the strain. As the strain increases further, there is increase in the nial force and after certain strain the nail force becomes contant.

Table. 4.4 Calculations: Screwed Nails – 60° slope

Soil Stress Strain			
Time (Seconds)	Load (KN)	Displacement (mm)	Stress (KN/m^2
0	0	0	0
10	2.5	0	31.25
20	13.3	0	166.25
30	14	0	175
40	14.1	0	176.25
50	14.5	0	181.25
60	15	0	187.5
70	16.2	0	202.5
80	18.1	0	226.25
90	19.2	0	240
100	22.2	0	277.5
110	25.3	0	316.25
120	31.8	0	397.5

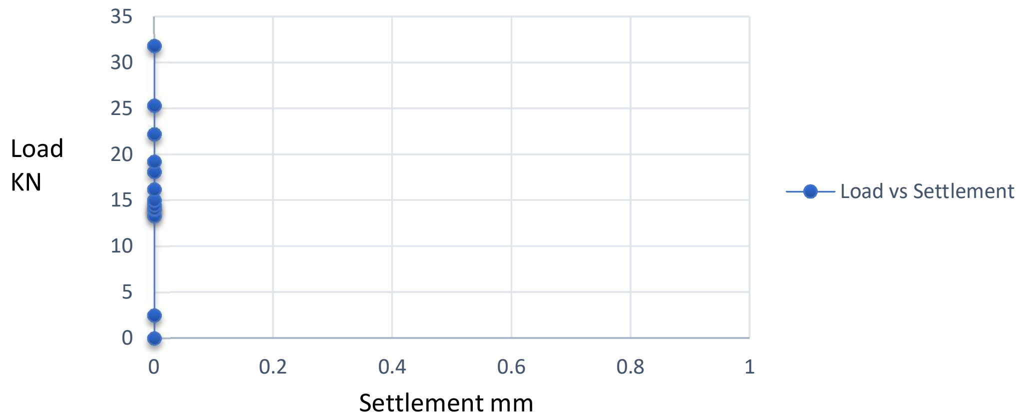


Fig. 4.23 load vs settlement curve (2nd experiment)

Figure 4.23 shows the load vs settlement curve for second experiment and it shows error in multimeter showing settlement and the ultimate load at failure comes out to be 30.8 kN.

Ultimate load at failure=31.8kN

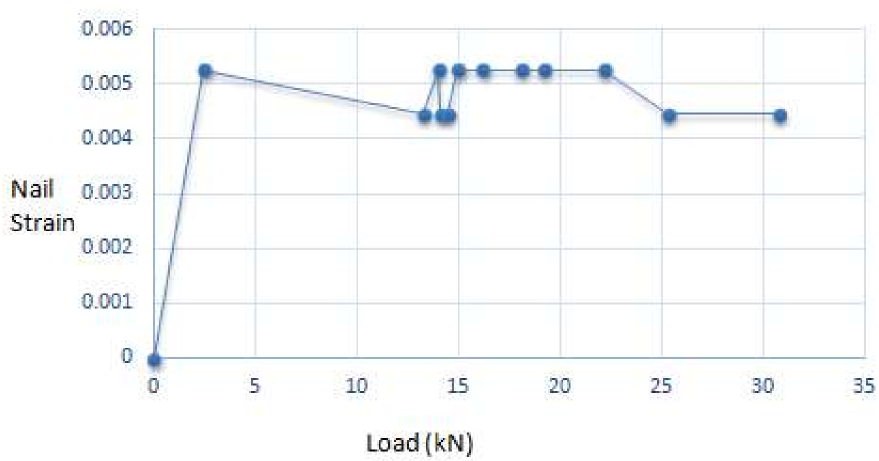


Fig.4.24 Nail strain vs load (nail 1)

Figure 4.24 shows graph between nail strain recorded in strain gauges and load applied by UTM (Universal Testing Machine).
Following are the graphs of other nails.

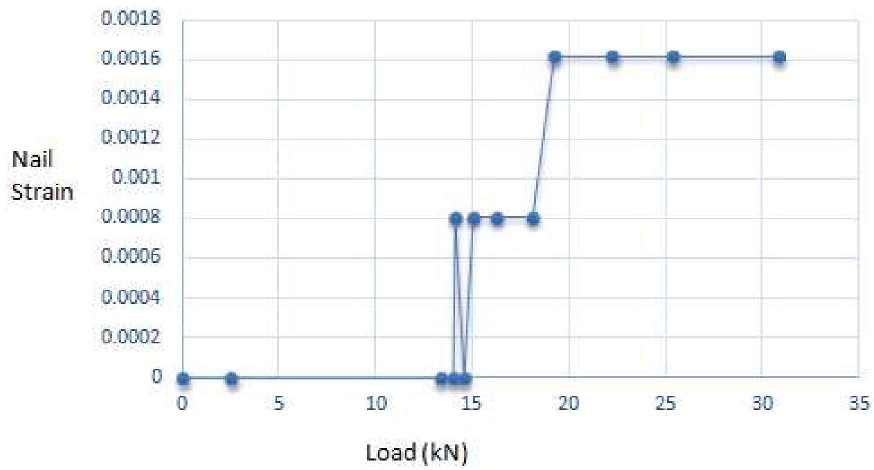


Fig.4.25 Nail strain vs load (nail 2)

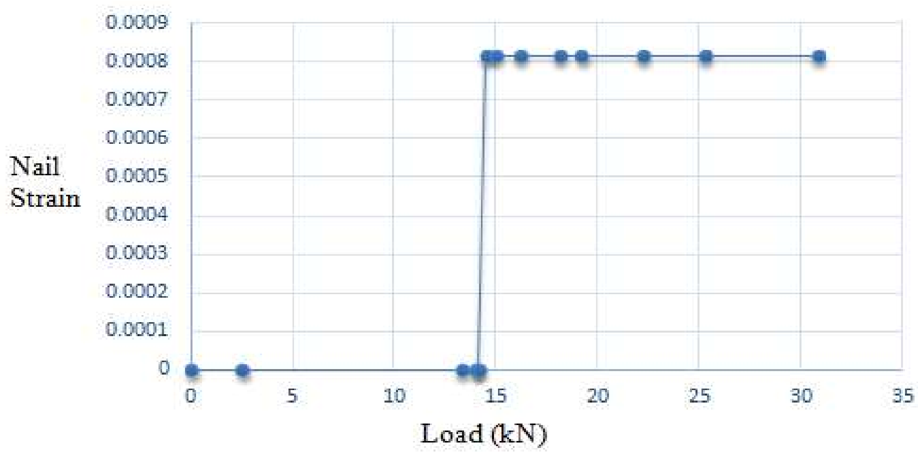


Fig.4.26 Nail strain vs load (nail 3)

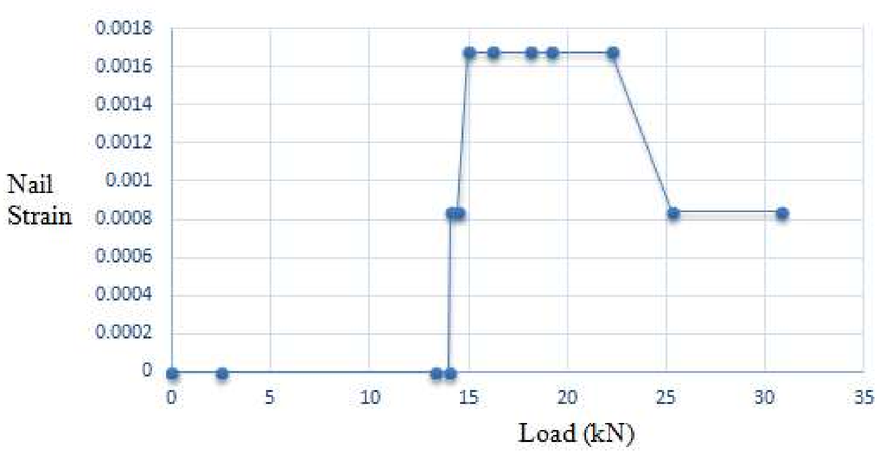


Fig.4.27 Nail strain vs load (nail 4)

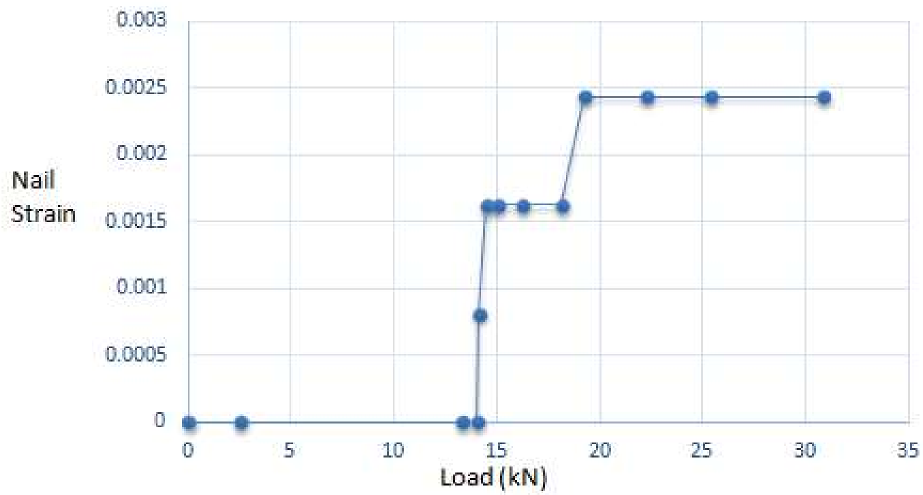


Fig.4.28 Nail strain vs load (nail 5)

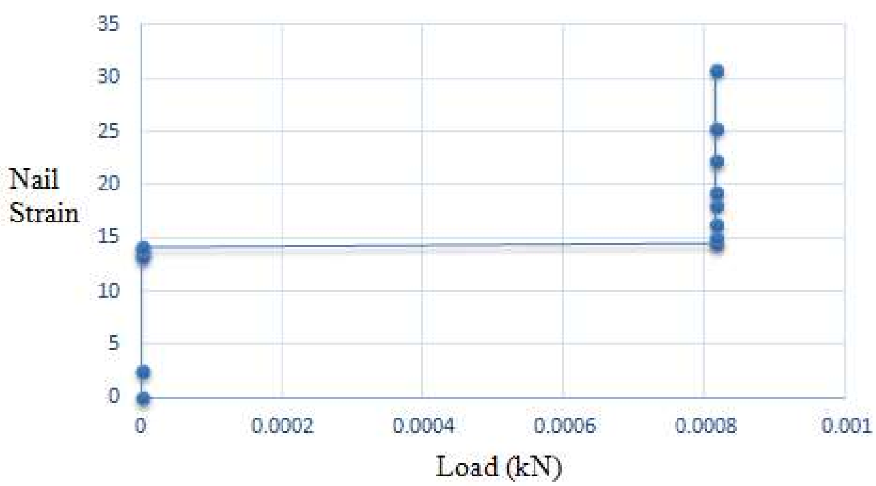


Fig.4.29 Nail strain vs load (nail 6)

All the graphs have similar trend. Initially there is no strain in the top and middle layer nails. As the load increases, there is increase in the strain and at certain points there is decrease in the strain. This is because of the mobilization of the soil.

As shown in Fig 4.29, there is a certain value of strain when no load is applied. This is because of the weight of the soil.

4.3.1.3 Test3: 90° slope angle

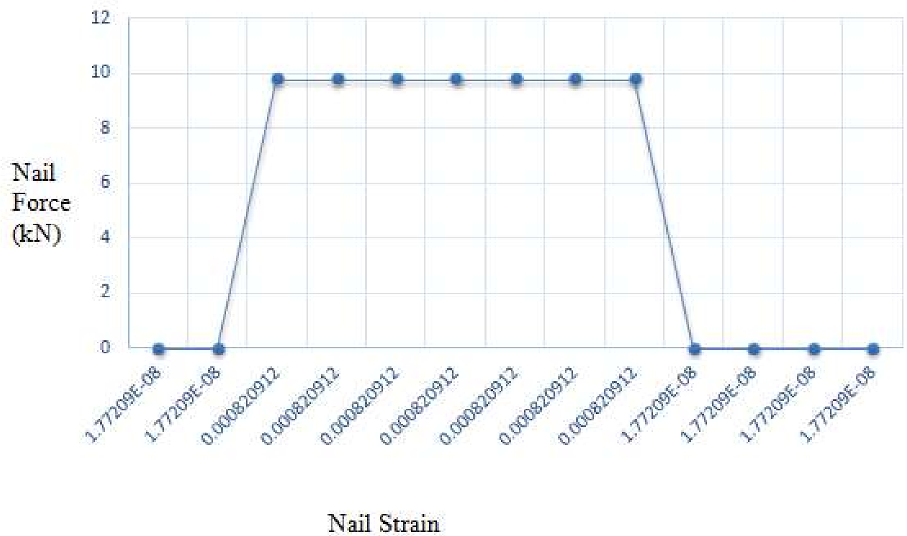


Fig. 4.30 Nail force vs nail strain(nail 1)

Figure 4.30 shows graph between nail force and nail strain, here firstly the nail force increases rapidly and then becomes constant and then again decreases to 0.

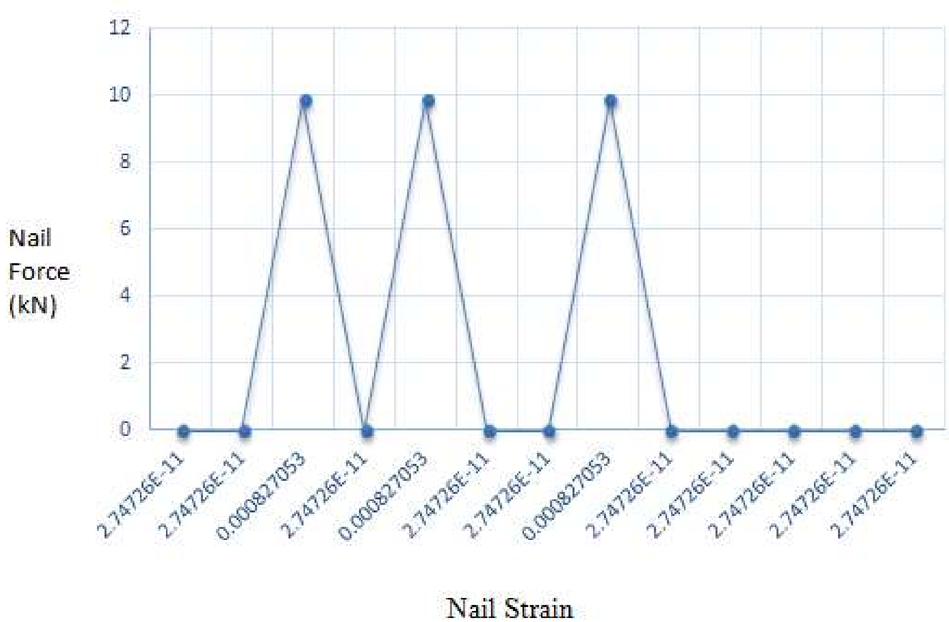


Fig. 4.31 Nail force vs nail strain(nail 2)

Figure 4.31 shows graph for second nail , here the pattern is zig zag where the nail forces are changing rapidly with change in nail strain as depicted from figure.

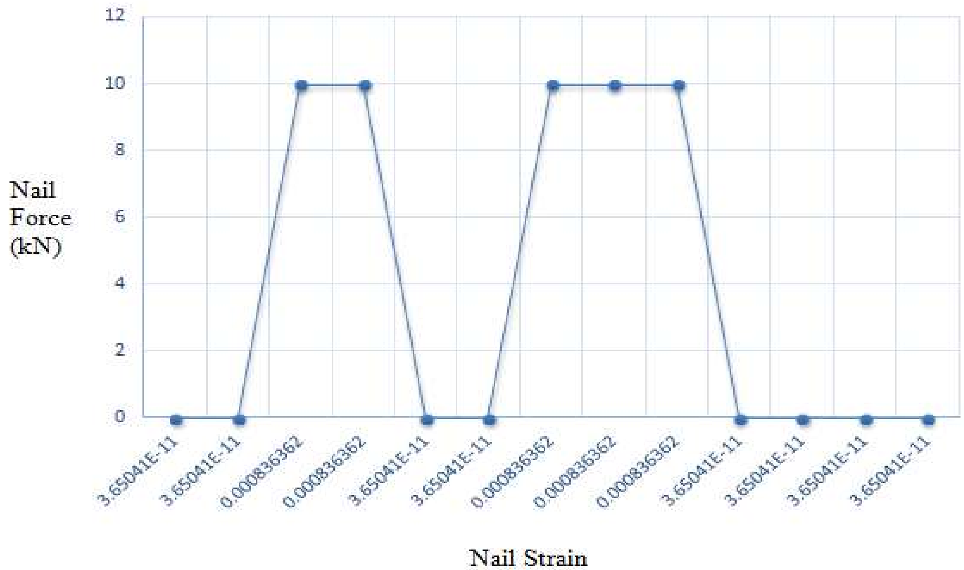


Fig. 4.32 Nail force vs nail strain(nail 3)

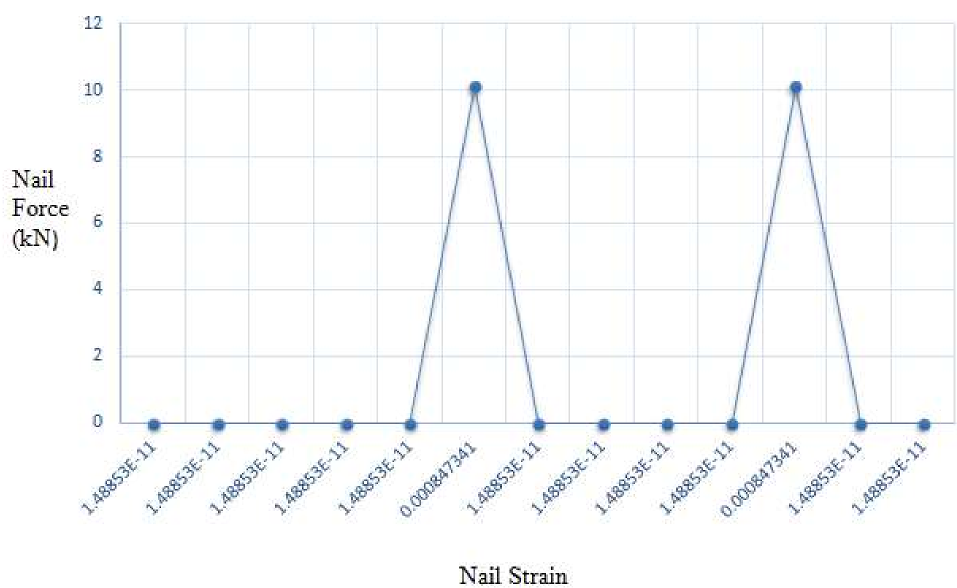


Fig. 4.33 Nail force vs nail strain(nail 4)

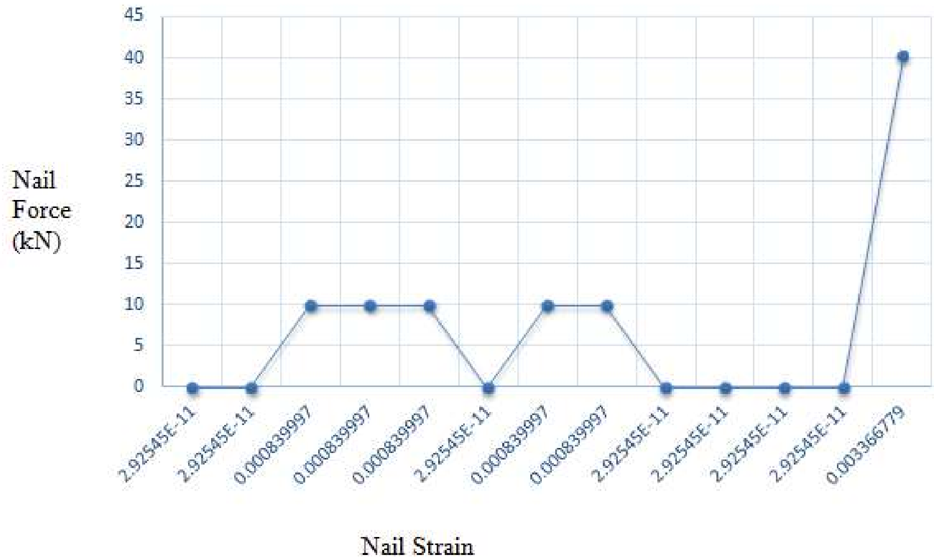


Fig. 4.34 Nail force vs nail strain(nail 5)

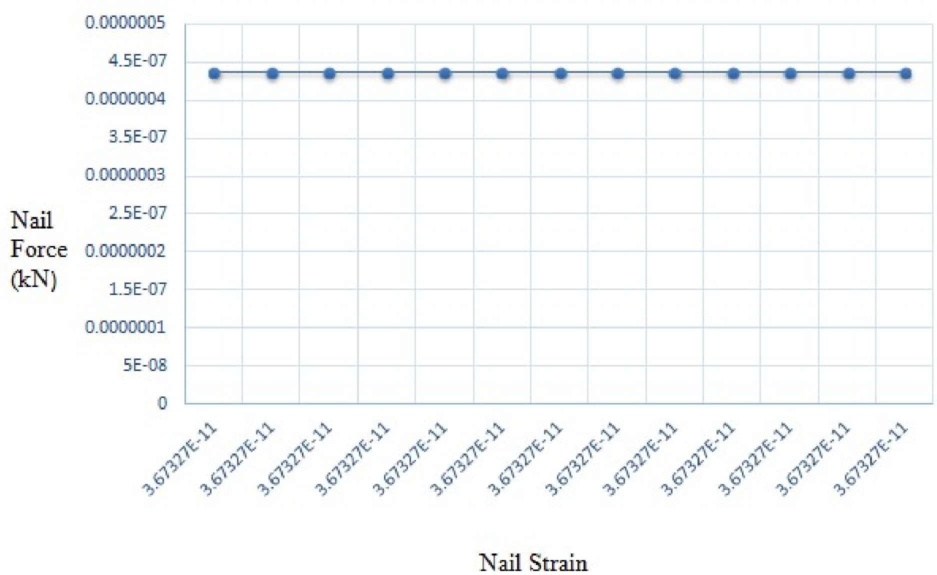


Fig. 4.35 Nail force vs nail strain(nail 6)

Figure 4.35 shows very negligible development of nail force (tensile force). This is because of the constant weight of the soil above the nail.

Table.4.5 Stress Calculations: Screwed Nails – 90° slope

Soil Stress Strain			
Time (Seconds)	Load (KN)	Displacement (mm)	Stress (KN/m^2
0	0	0	0
10	0.1	0	1.25
20	0.2	0	2.5
30	2.2	0	27.5
40	4	0	50
50	4.7	0	58.75
60	5.7	0	71.25
70	8.6	8.3	107.5
80	13.2	29.3	165
90	16.1	47.3	201.25
100	18.4	60.2	230
110	21.2	82.6	265
120	22.9	110	286.25

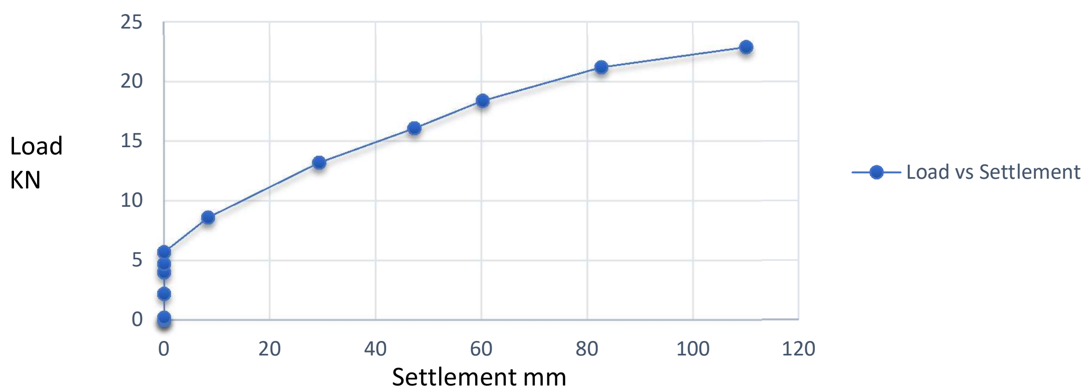


Fig. 4.36 load vs settlement curve (3rd experiment)

This figure shows the load vs settlement curve which gives the ultimate load at failure as 24.9 kN.

<u>Ultimate load at failure=22.9kN</u>

Fig. 4.37 normal layer condition

Fig 4.38 layers condition after testing

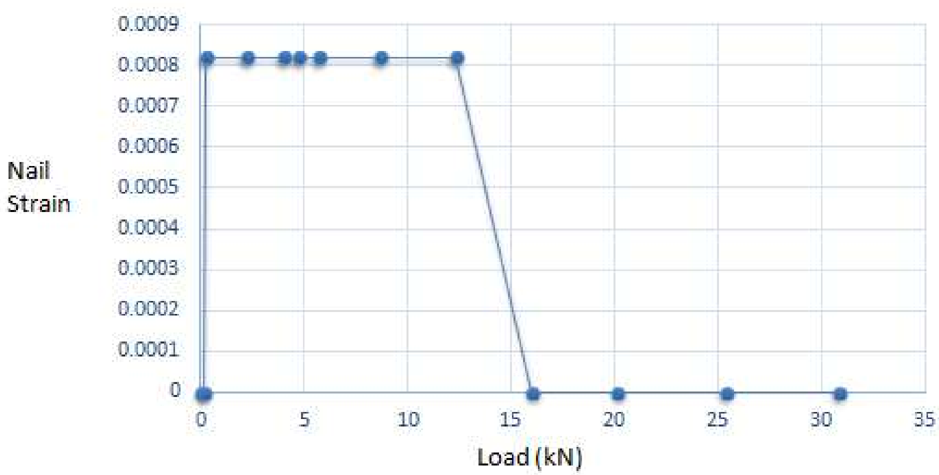


Fig. 4.39 Nail strain vs load (nail 1)

Figure 4.39 shows the graph between nail strain and load applied via UTM (Universal Testing Machine).
The following are the graphs of other nails.

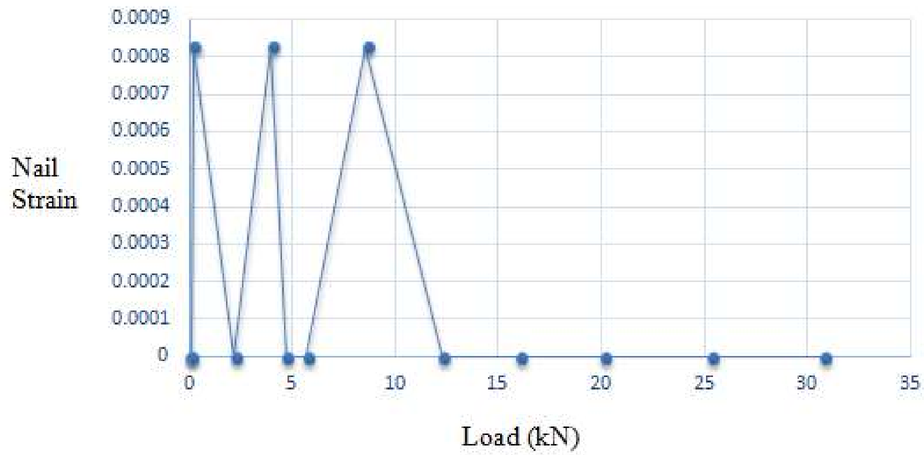


Fig. 4.40 Nail strain vs load (nail 2)

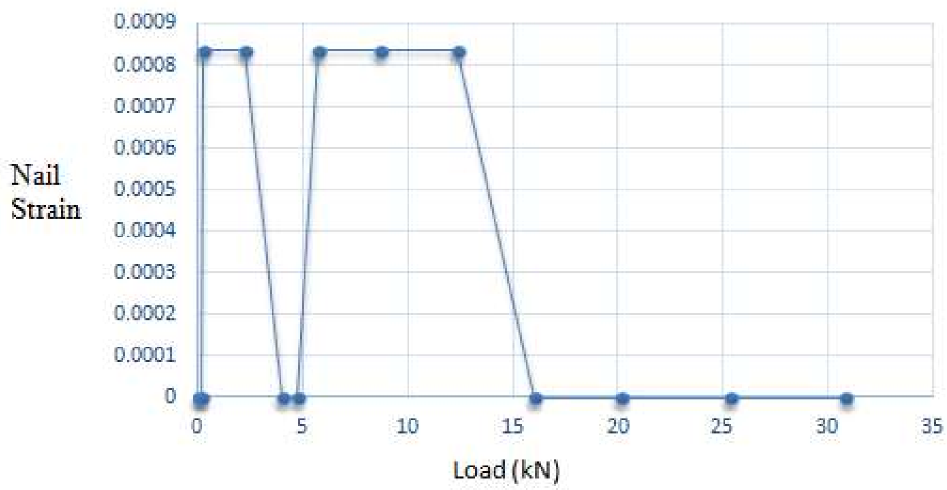


Fig. 4.41 Nail strain vs load (nail 3)

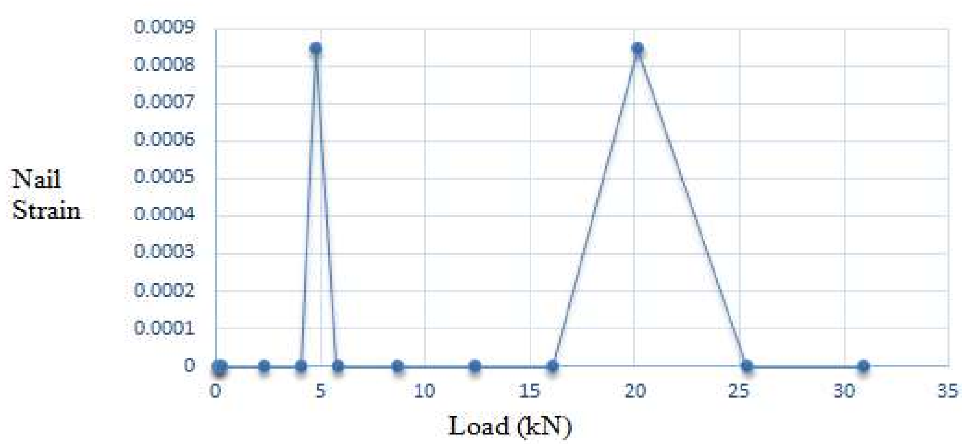


Fig. 4.42 Nail strain vs load (nail 4)

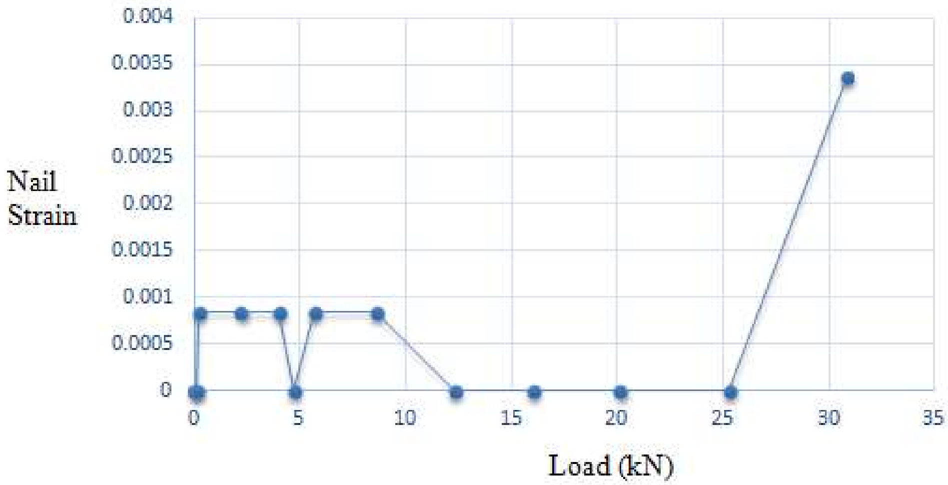


Fig. 4.43 Nail strain vs load (nail 5)

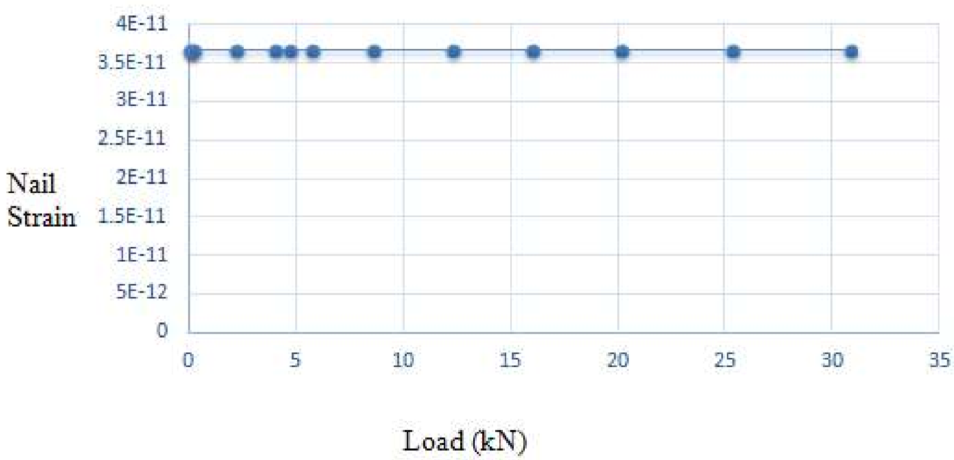


Fig. 4.44 Nail strain vs load (nail 6)

All the graphs have similar trend. Initially there is no strain in the top and middle layer nails. As the load increases, there is increase in the strain and at certain points there is decrease in the strain. This is because of the mobilization of the soil.

4.3.2 Helical Nails

4.3.2.1 Test 1: 45° Slope angle

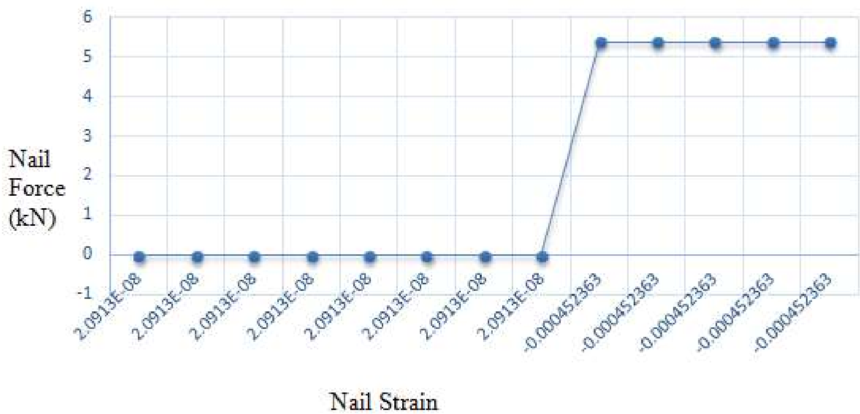


Fig.4.45 nail force vs nail strain(nail1)

The max tensile force mobilised is 5.2 kN.

Fig.4.46 nail force vs nail strain(nail 2)

The max tensile force mobilised is 5.2 kN.

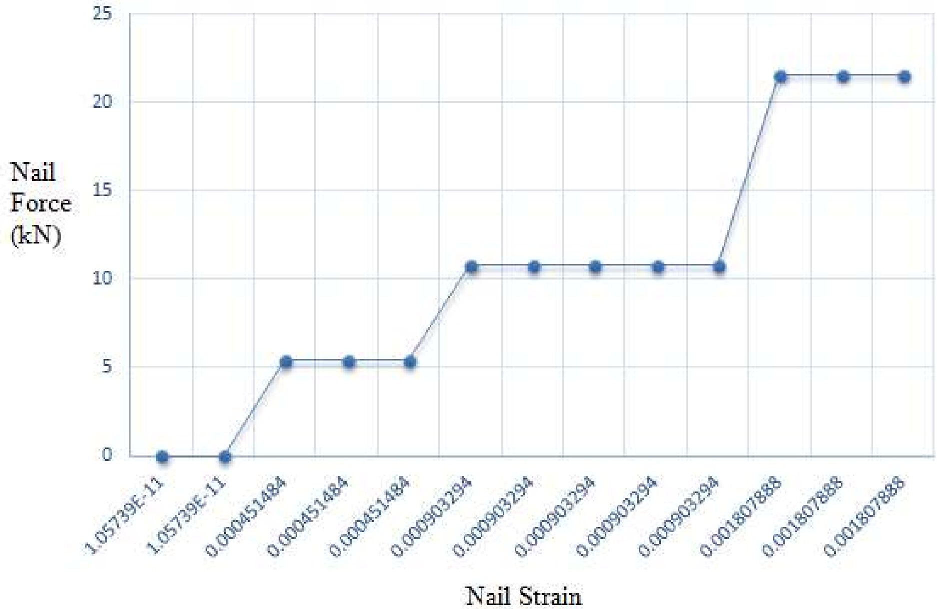


Fig.4.47 nail force vs nail strain(nail 3)

The max tensile force mobilised is 22 kN.

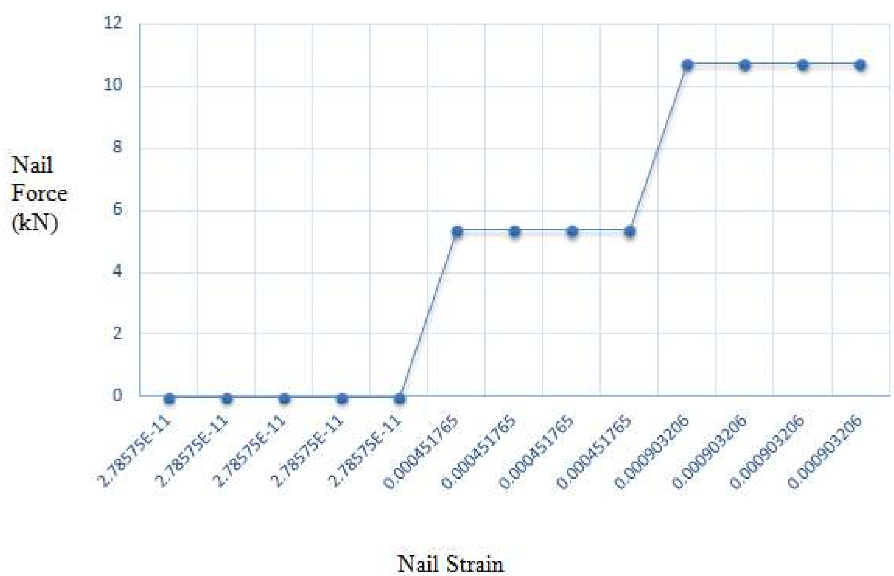


Fig.4.48 nail force vs nail strain(nail 4)

The max tensile force mobilised is 10.5 kN.

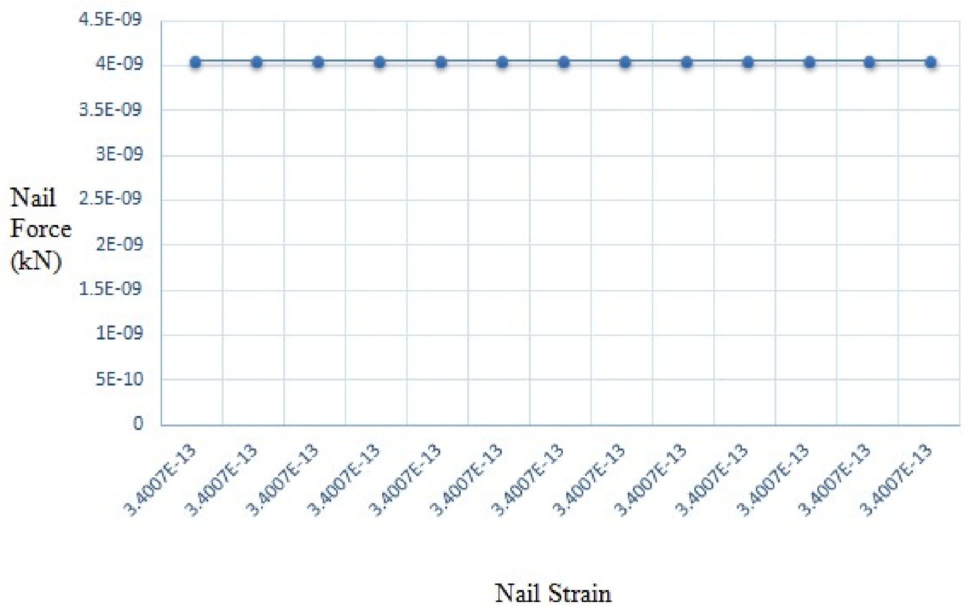


Fig.4.49 nail force vs nail strain(nail 5)

Here tensile force mobilized is quite negligible and constant as seen from graph (fig.4.49)

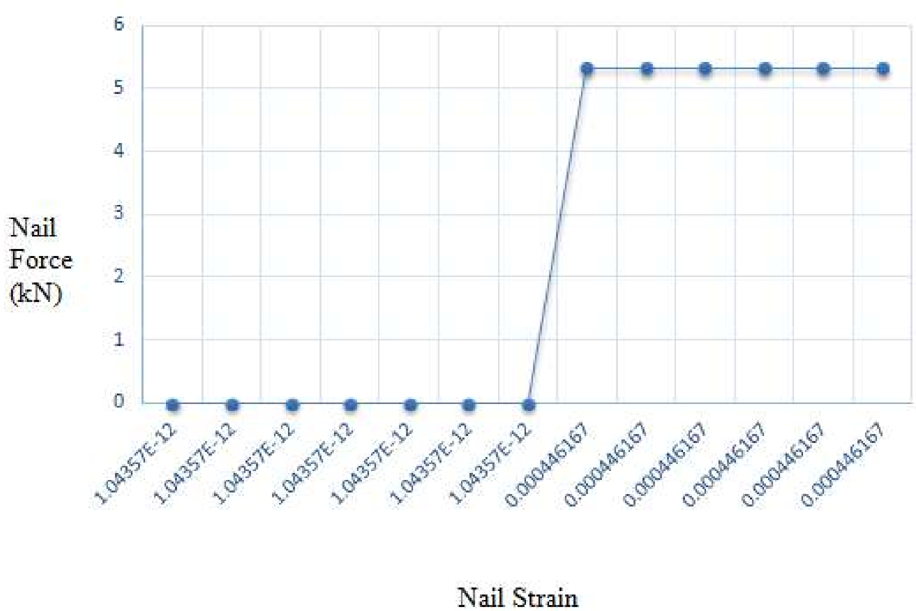


Fig.4.50 nail force vs nail strain(nail 6)

The max tensile force mobilised is 5.2 kN.

Table.4.6 Stress Calculations: helical Nails – 45° slope

Soil Stress Strain			
Time (Seconds)	Load (KN)	Displacement (mm)	Stress (KN/m^2
0	0	0	0
10	0.3	0	3.75
20	0.9	0	11.25
30	1.9	0	23.75
40	2.3	0	28.75
50	2.4	0	30
60	16.3	5.6	203.75
70	18.2	9.3	227.5
80	19.6	15.3	245
90	25.3	35.6	316.25
100	28.9	50.2	361.25
110	33.3	89.5	416.25
120	35.6	109	445

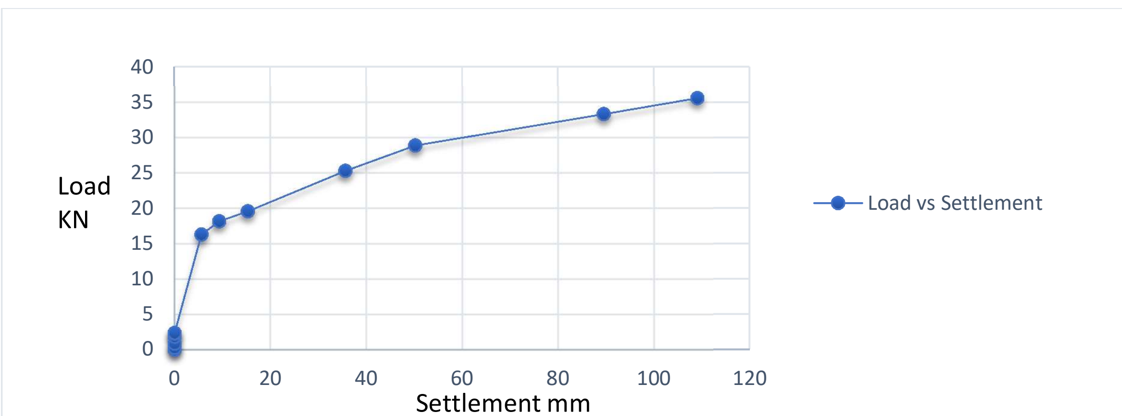


Fig.4.51 load vs settlement curve (4th experiment)

Figure 4.51 shows graph between load and settlement for helical nails inserted in 45° slope.

<u>The ultimate load at failure is 35.6 kN</u>

Fig 4.52 normal layer conditions

Fig. 4.53 layer condition after test

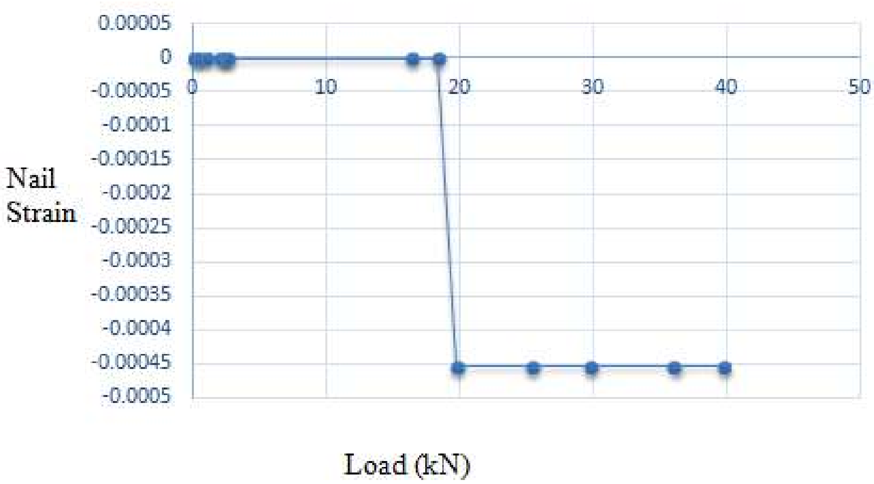


Fig. 4.54 Nail strain vs load (nail 1)

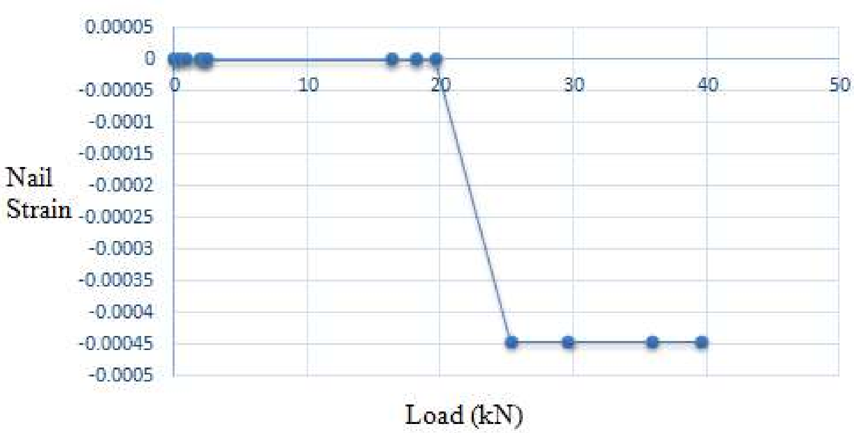


Fig. 4.55 Nail strain vs load (nail 2)

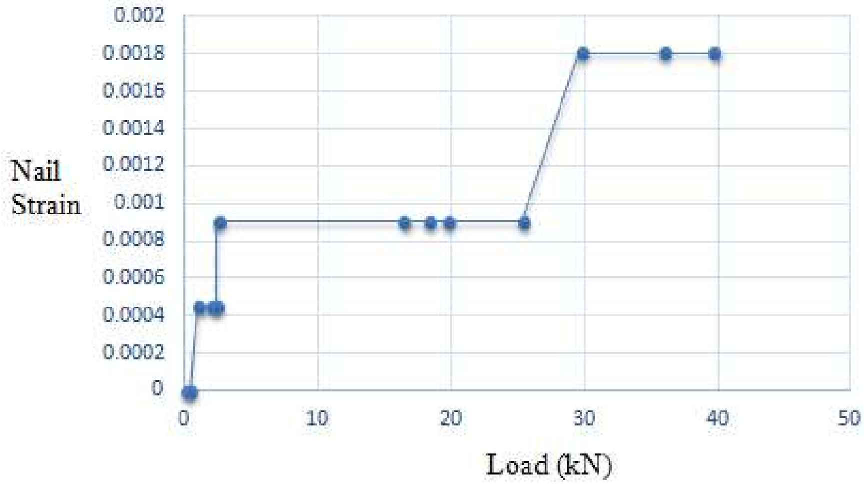


Fig. 4.56 Nail strain vs load (nail 3)

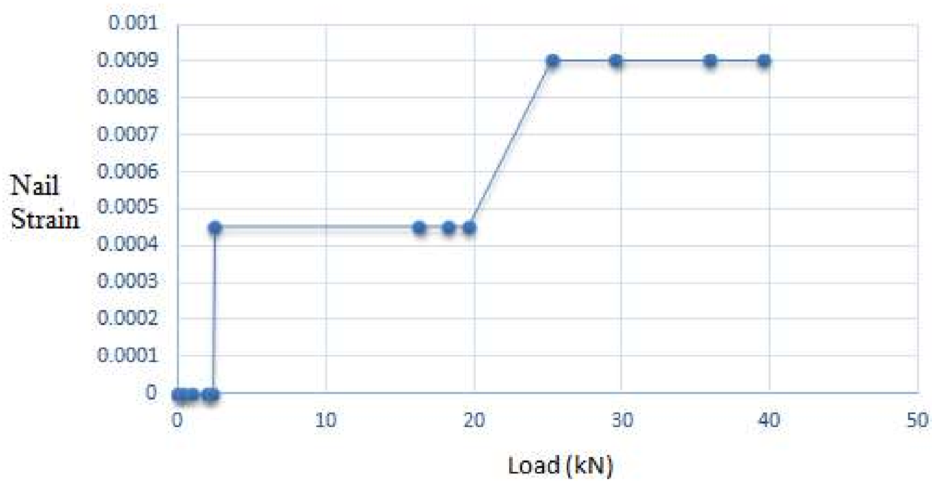


Fig. 4.57 Nail strain vs load (nail 4)

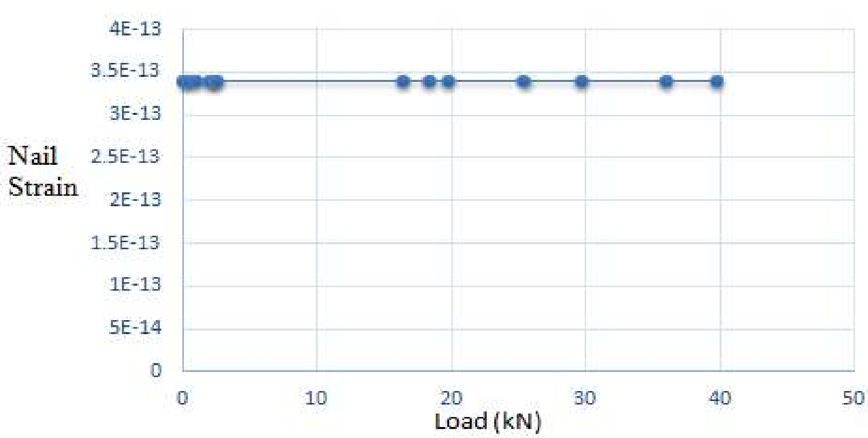


Fig. 4.58 Nail strain vs load (nail 5)

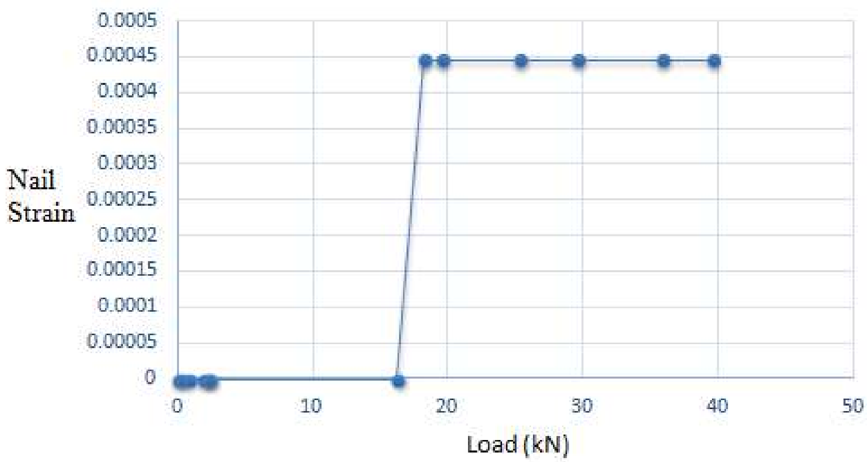


Fig. 4.59 Nail strain vs load (nail 6)

All the graphs have similar trend. Initially there is no strain in the top and middle layer nails. As the load increases, there is increase in the strain and at certain points there is decrease in the strain. This is because of the mobilization of the soil.

<u>4.3.2.2 Test 1: 60° Slope angle</u>

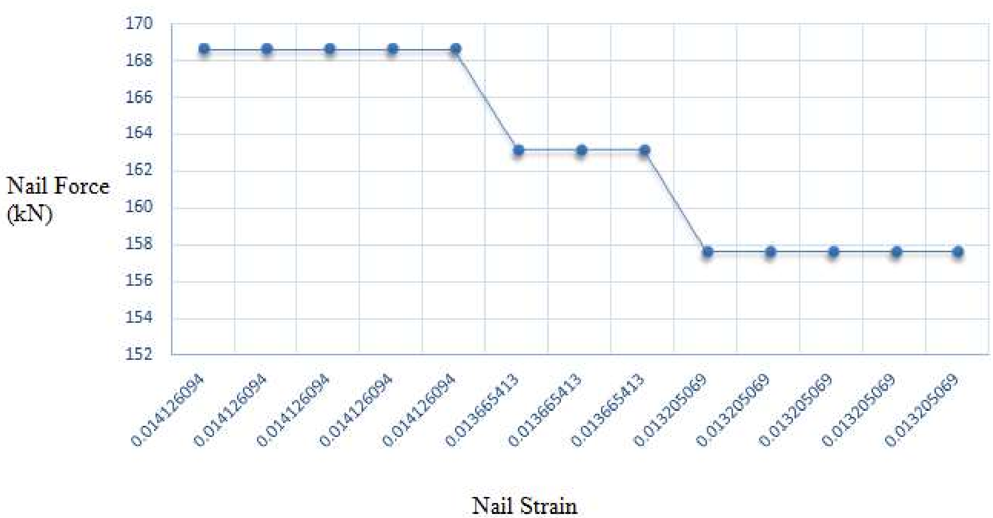


Fig. 4.60 Nail force vs nail strain (nail 1)

Figure 4.60 shows value of nail forces decreasing with increasing nail strains.

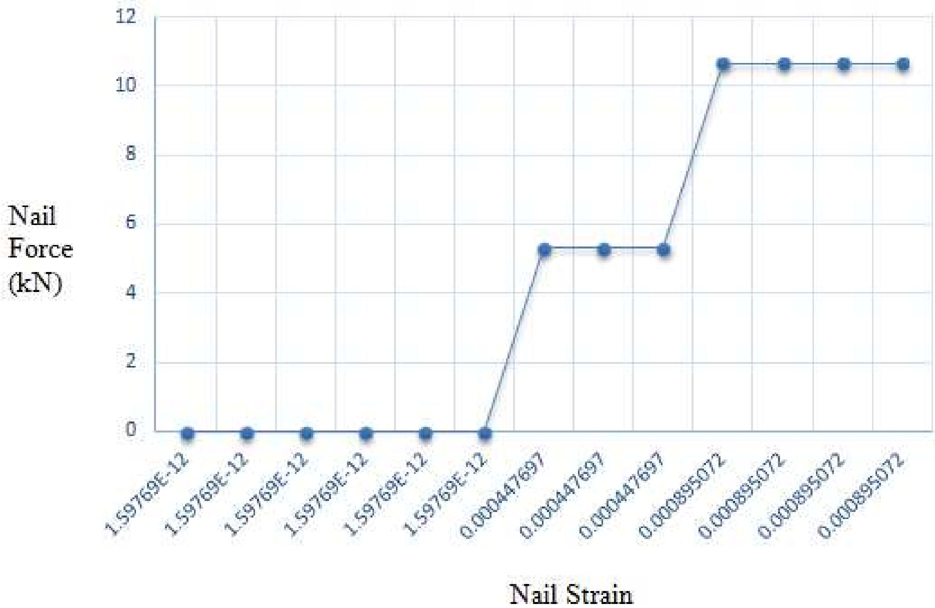


Fig. 4.61 Nail force vs nail strain (nail 2)

This graph shows increasing nail force values with increasing nail strains and becoming constant at a value of 10.5 kN.

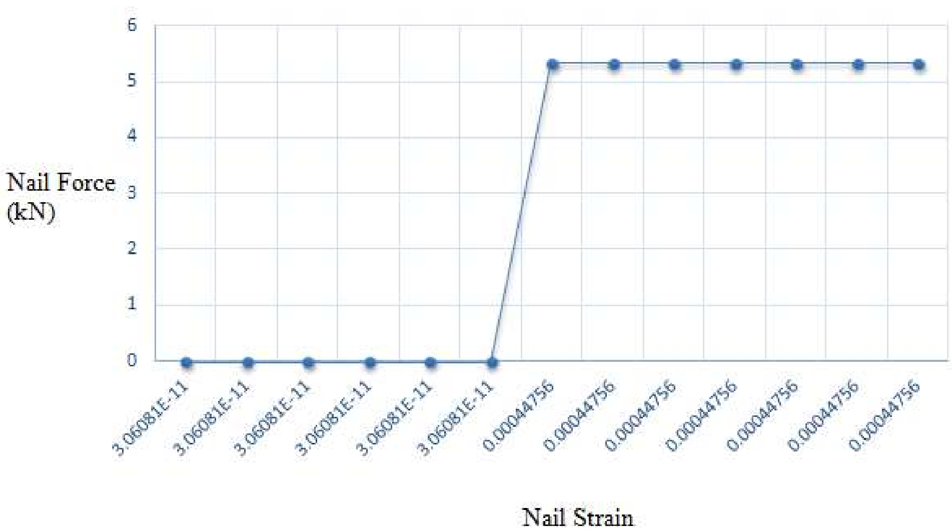


Fig. 4.62 Nail force vs nail strain (nail 3)

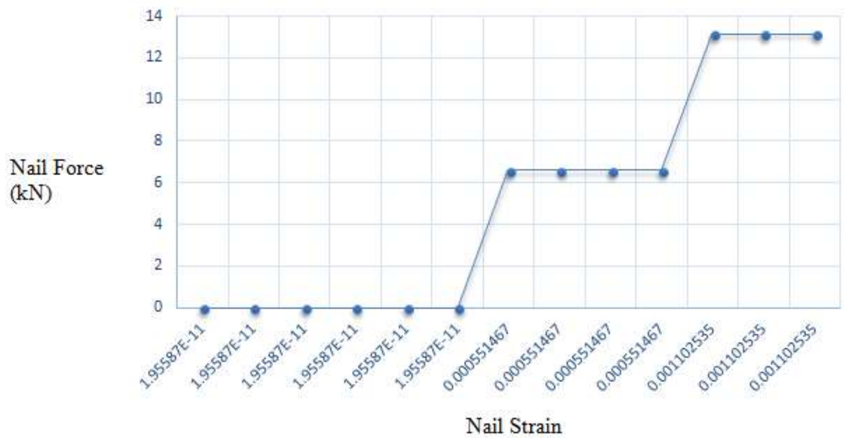


Fig. 4.63 Nail force vs nail strain (nail 4)

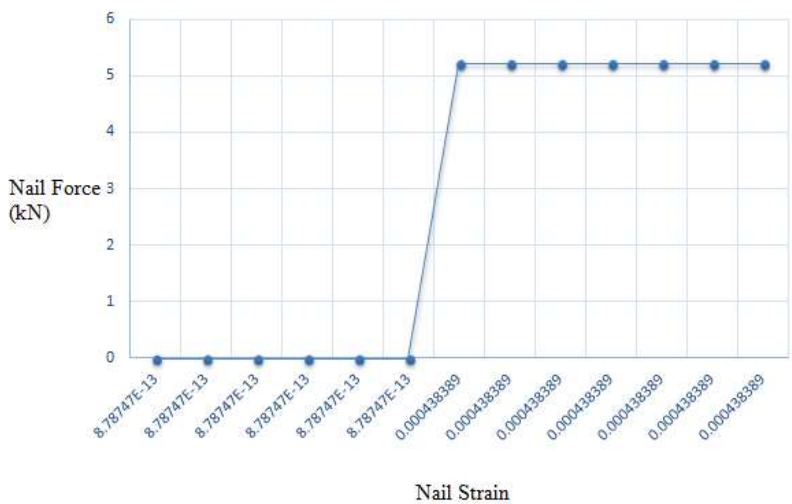


Fig. 4.64 Nail force vs nail strain (nail 5)

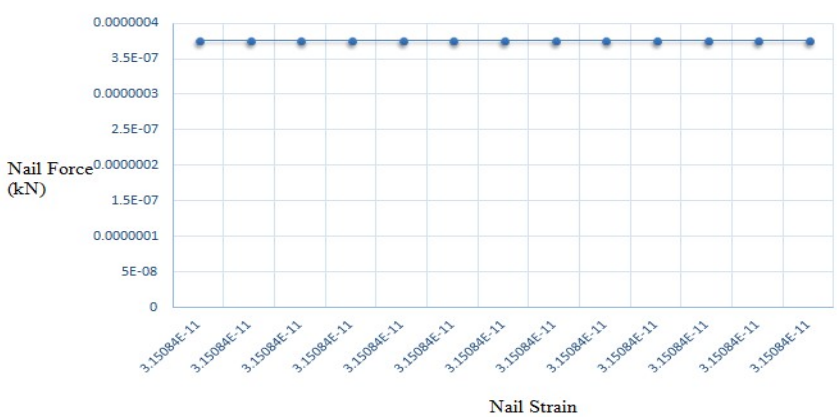


Fig. 4.65 Nail force vs nail strain (nail 6)

Table 4.7 Stress Calculations: Helical Nails –60° slope

Soil Stress Strain			
Time (Seconds)	Load (KN)	Displacement (mm)	Stress (KN/m^2
0	0	0	0
10	2.5	7	31.25
20	5.5	15	68.75
30	8.1	30	101.25
40	14.1	55	176.25
50	14.5	59	181.25
60	15	61	187.5
70	16.2	66	202.5
80	18.1	79	226.25
90	19.2	88	240
100	22.2	98	277.5
110	25.3	110	316.25
120	27.4	118	342.5

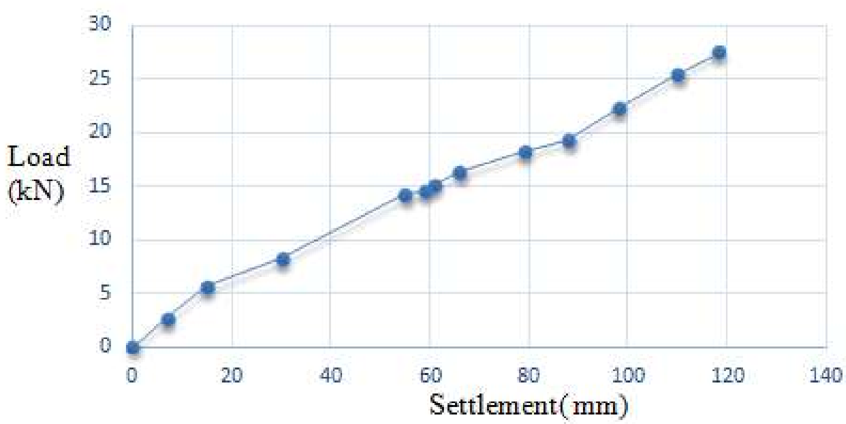


Fig. 4.66 load vs settlement curve(5th experiment)

<u>The ultimate load at failure is 27.4 kN</u>

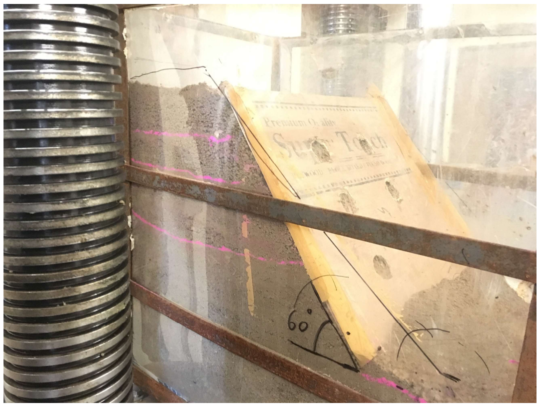


fig. 4.67 normal layer condition

Fig. 4.68 layer condition after test

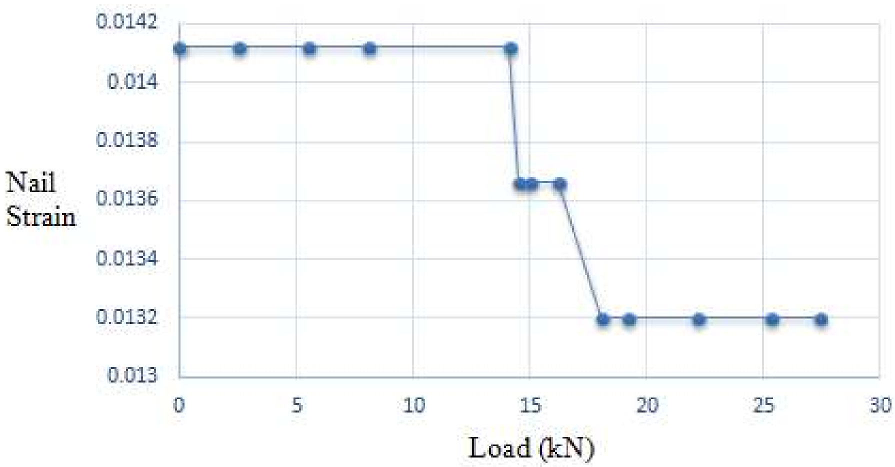


Fig. 4.69 nail strain vs load (nail 1)

This graph shows as the load increases , the nail strain decreases.

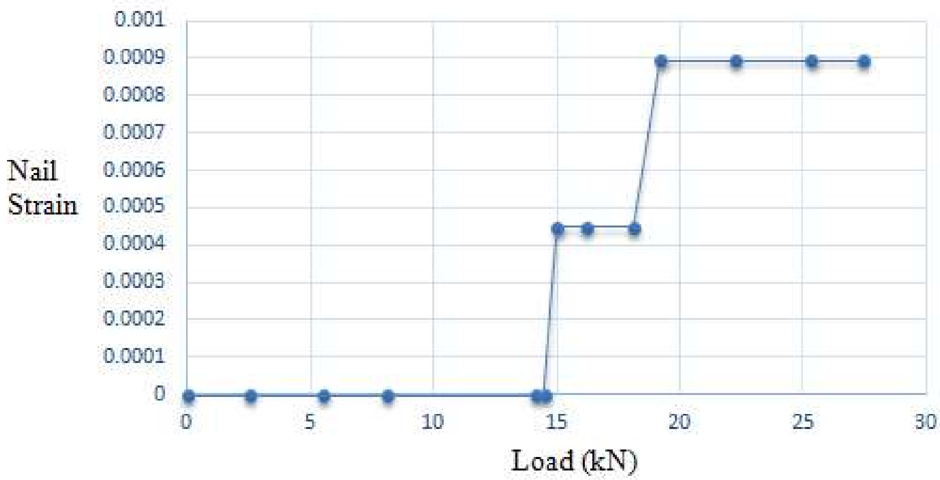


Fig. 4.70 nail strain vs load (nail 2)

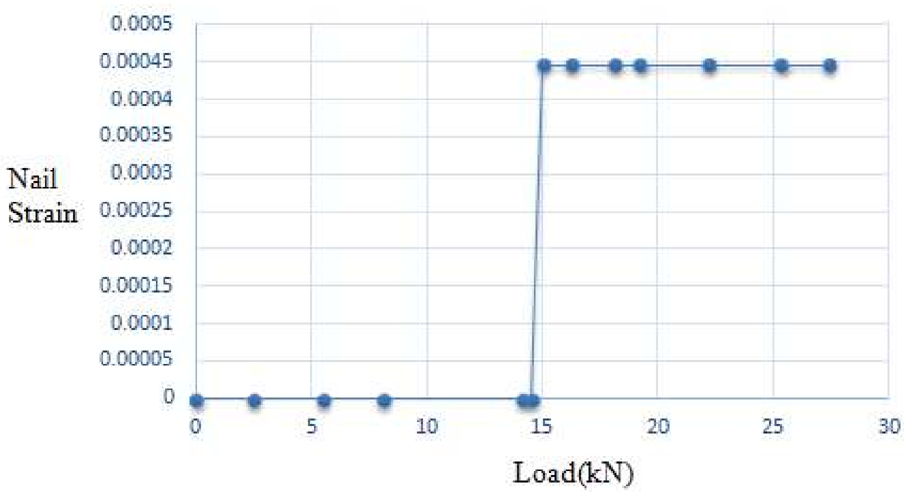


Fig. 4.71 nail strain vs load (nail 3)

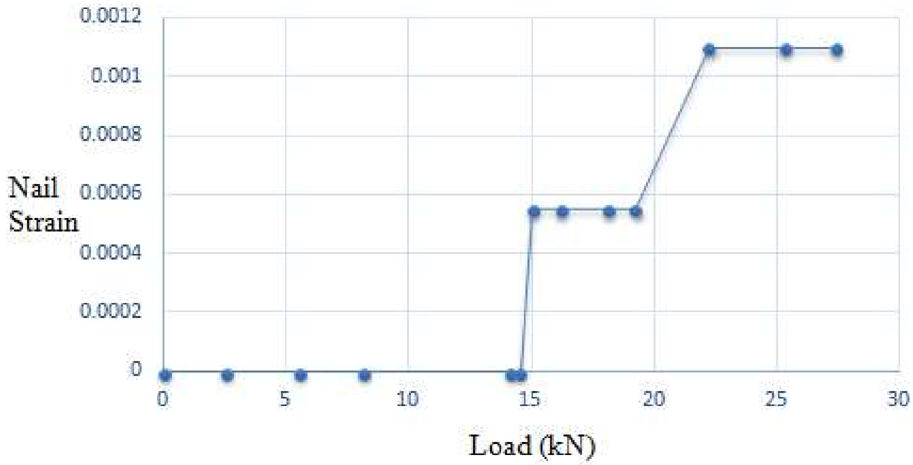


Fig. 4.72 nail strain vs load (nail 4)

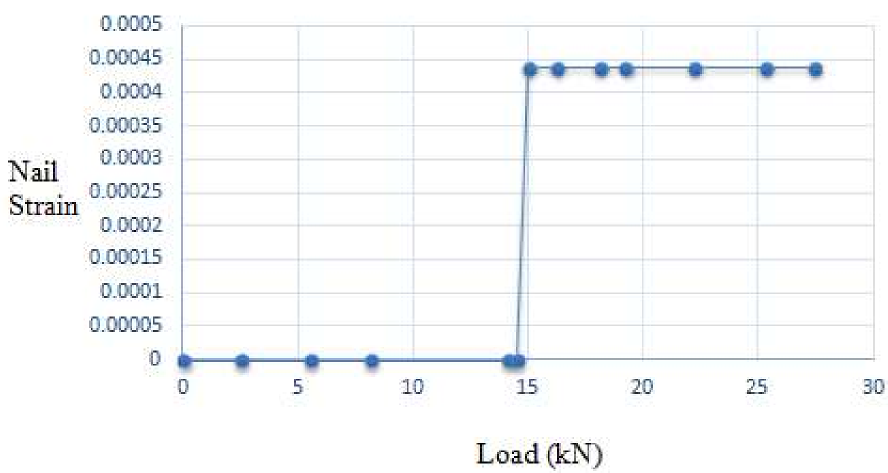


Fig. 4.73 nail strain vs load (nail 5)

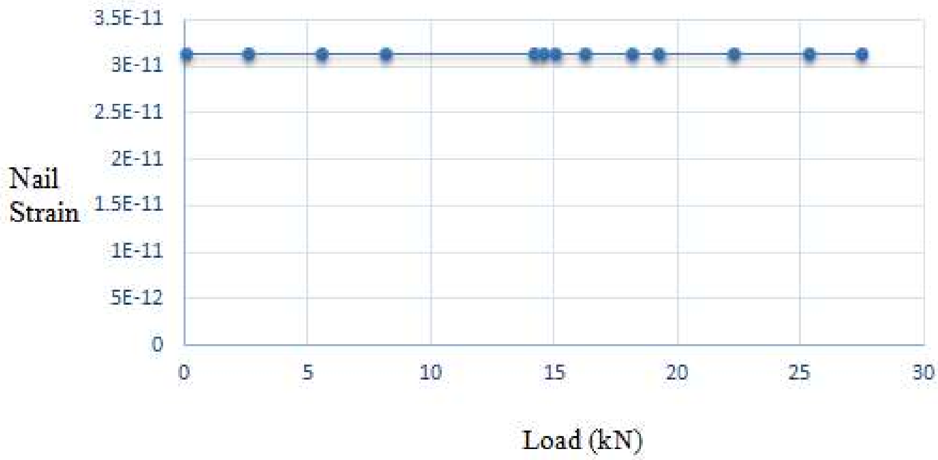


Fig. 4.74 nail strain vs load (nail 6)

All the graphs have similar trend. Initially there is no strain in the top and middle layer nails. As the load increases, there is increase in the strain and at certain points there is decrease in the strain. This is because of the mobilization of the soil.

4.3.2.3 Test 1: 90° Slope angle

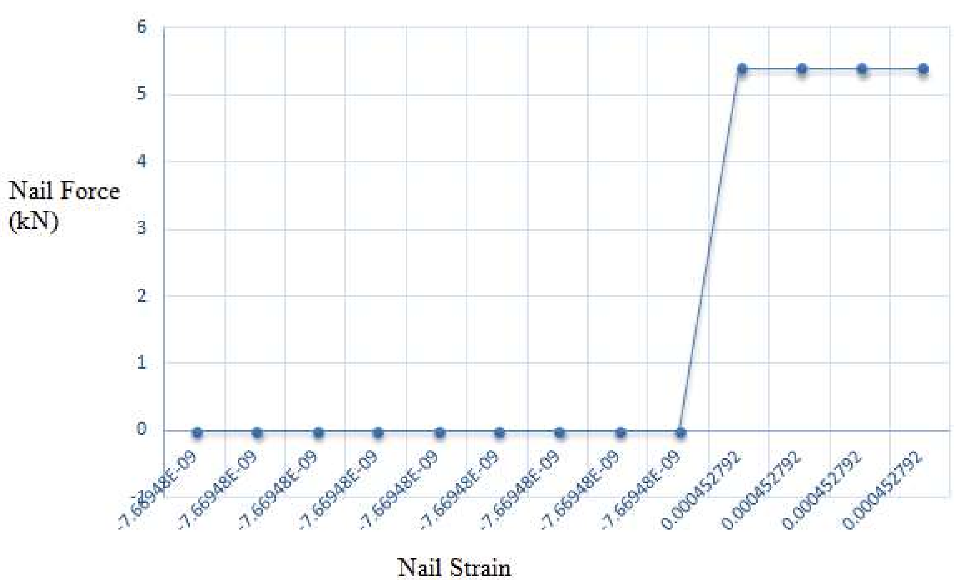


Fig. 4.75 nail force vs nail strain (nail 1)

The trend of this graph is same as the earlier graphs.
The following are the graphs of other nails.

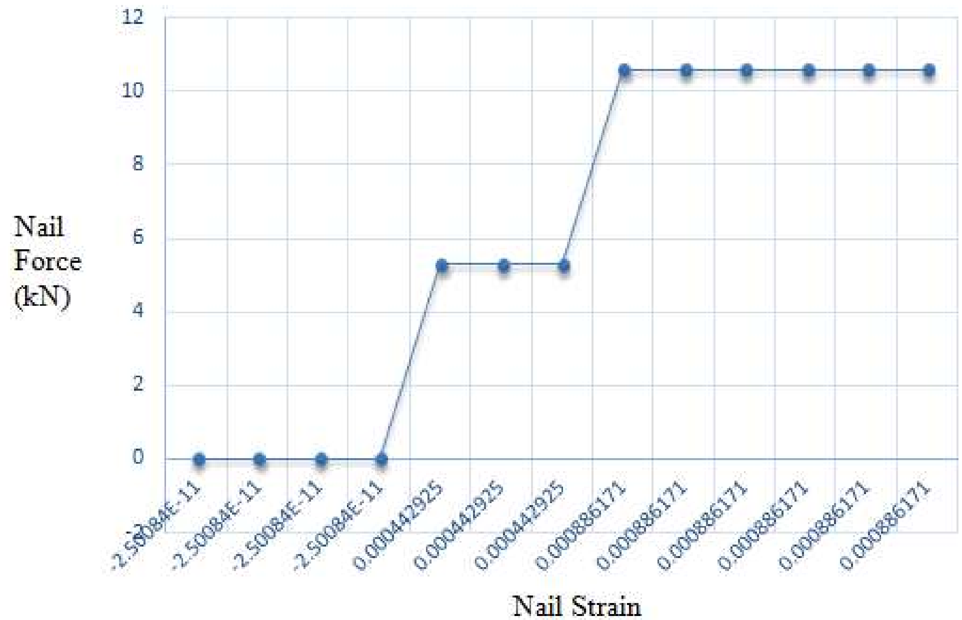


Fig. 4.76 nail force vs nail strain (nail 2)

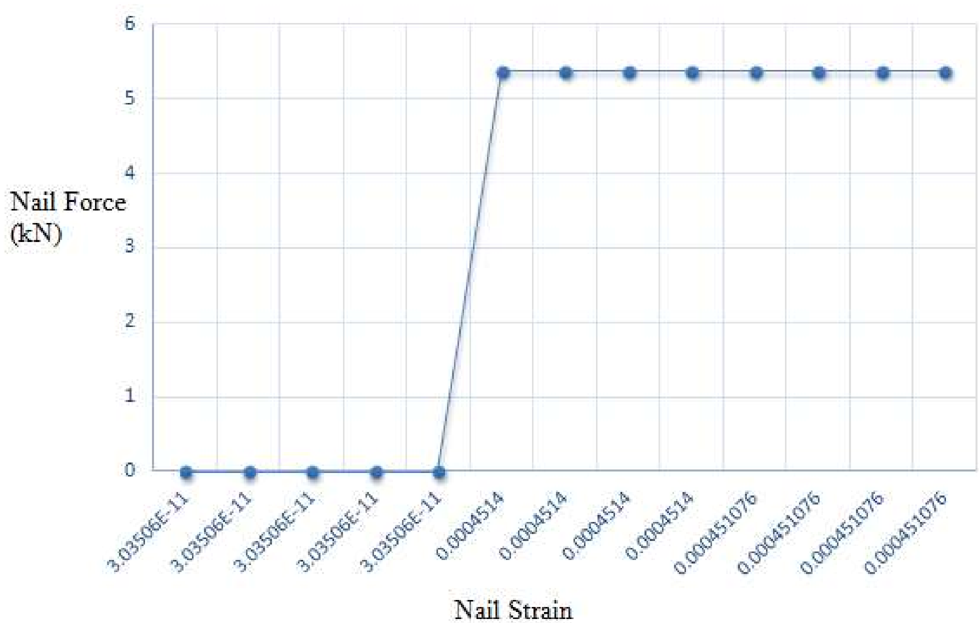


Fig. 4.77 nail force vs nail strain (nail 3)

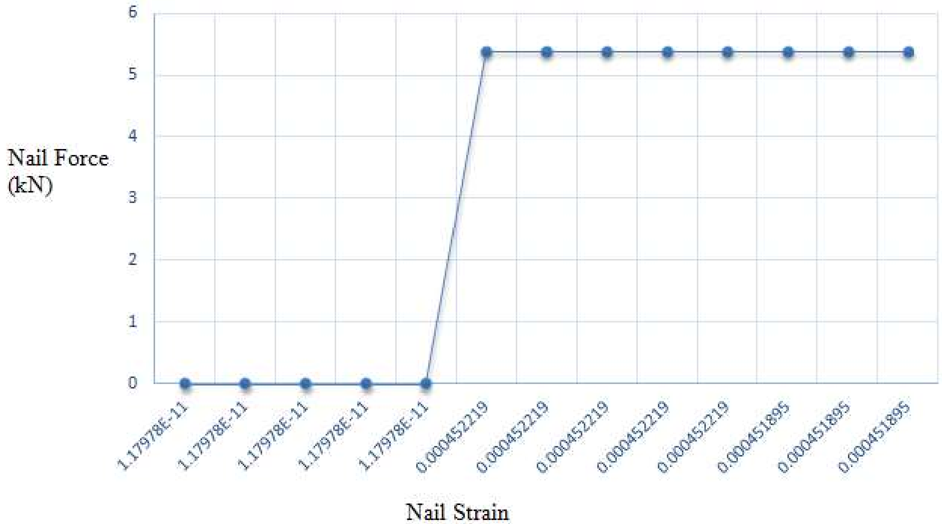


Fig. 4.78 nail force vs nail strain (nail 4)

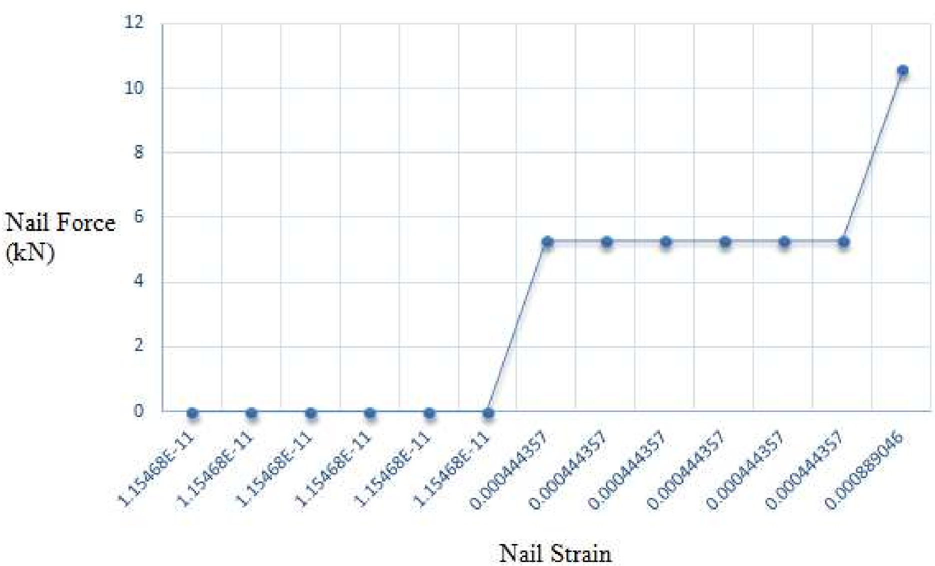


Fig. 4.79 nail force vs nail strain (nail 5)

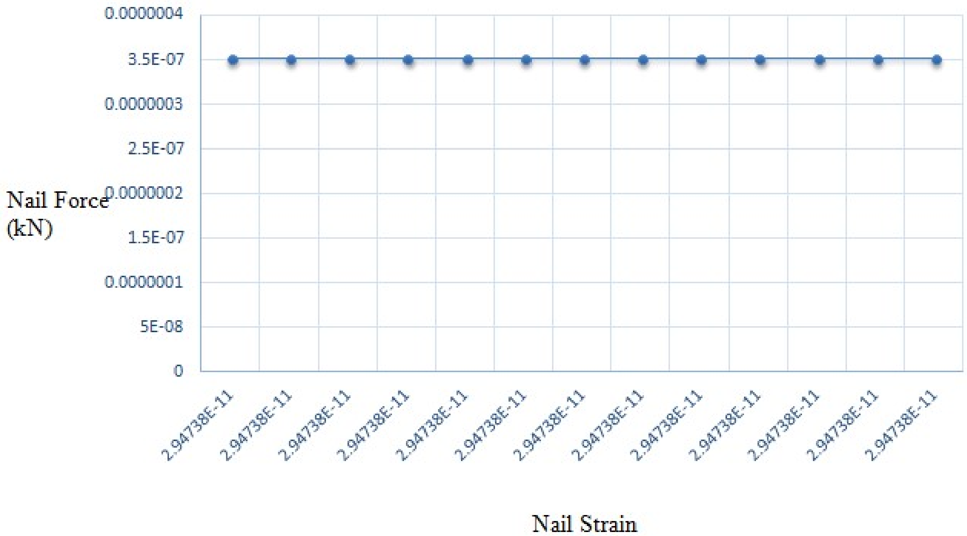


Fig. 4.80 nail force vs nail strain (nail 6)

All the graphs have similar trends as in the previous experiments.

Table. 4.8 Stress Calculations: Helical Nails – 90° slope

Soil Stress Strain			
Time (Seconds)	Load (KN)	Displacement (mm)	Stress (KN/m^2
0	0	0	0
10	0.1	7.6	1.25
20	0.2	8.5	2.5
30	2.2	9.6	27.5
40	3.6	12.6	45
50	4.5	17.6	56.25
60	5.2	29.6	65
70	7.9	35.4	98.75
80	11.2	42.6	140
90	13.9	50.3	173.75
100	15.4	79.6	192.5
110	17.5	89.6	218.75
120	19.7	110	246.25

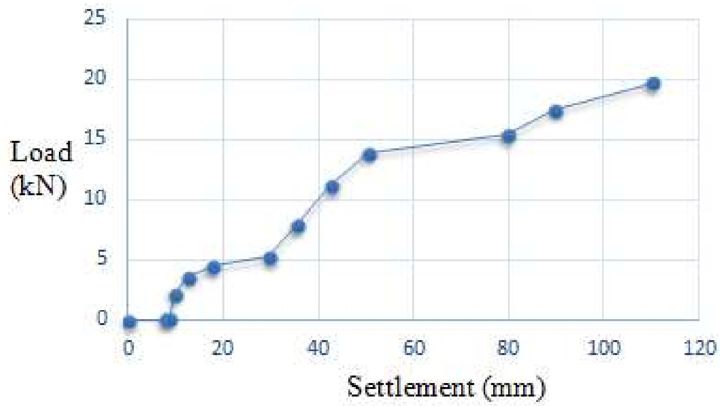


Fig. 4.81 load vs settlement curve (6th experiment)

Figure 4.81 shows the load vs settlement curve for sixth experiment and the ultimate load at failure comes out to be 19.7 kN.

<u>The ultimate load at failure is 19.7 kN</u>

Fig.4.82 normal layer condition

Fig. 4.83 layer condition after test

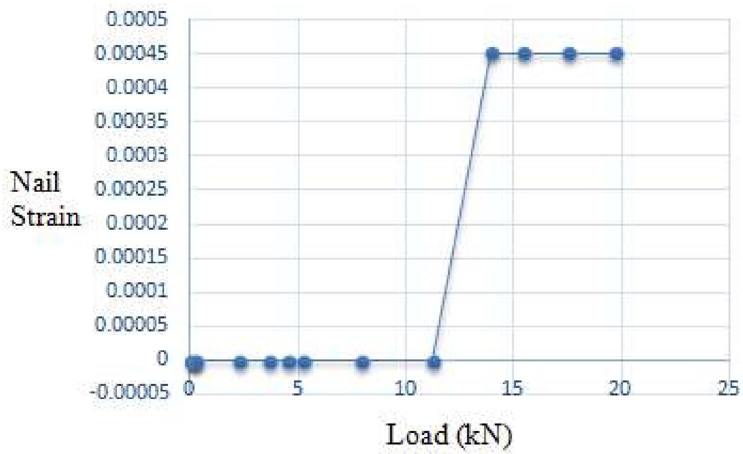


Fig. 4.84 nail strain vs load (nail 1)

This graph shows as the load increases the nail strain also increases and become constant at a value of 0.00045.
When the nail strain becomes contant it shows the value of load where there is no deflection in nails.
The following are the graphs of other nails.

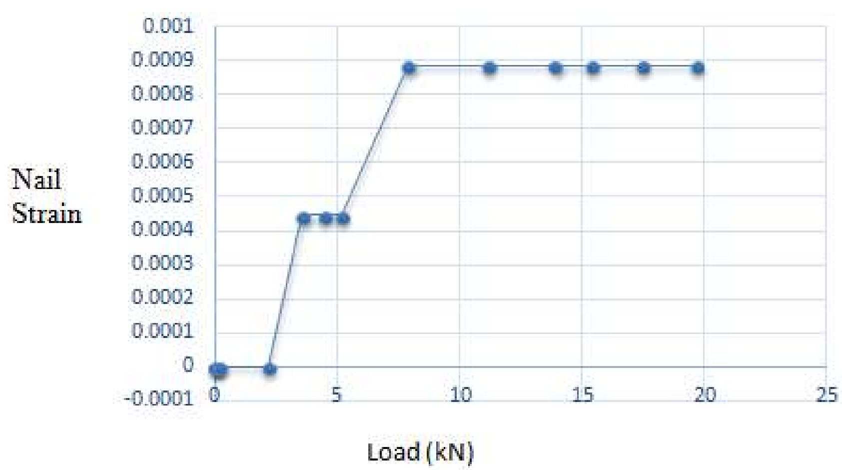


Fig. 4.85 nail strain vs load (nail 2)

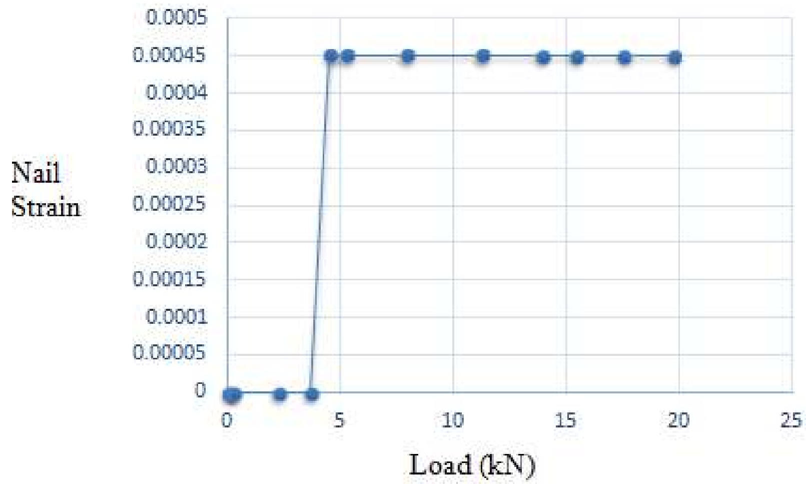


Fig. 4.86 nail strain vs load (nail 3)

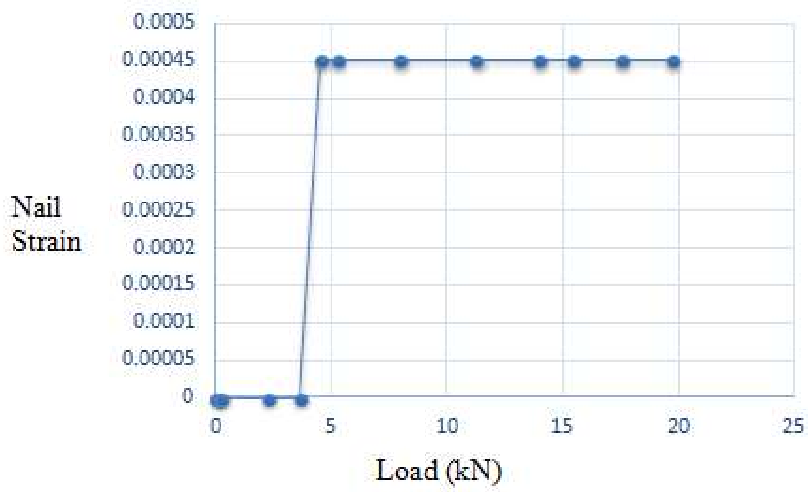


Fig. 4.87 nail strain vs load (nail 4)

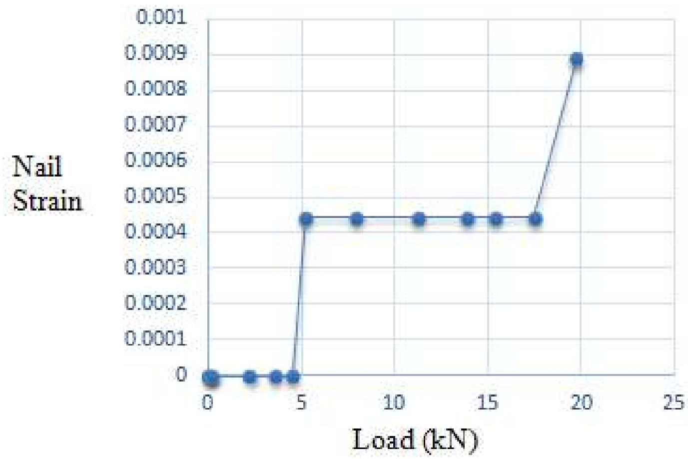


Fig. 4.88 nail strain vs load (nail 5)

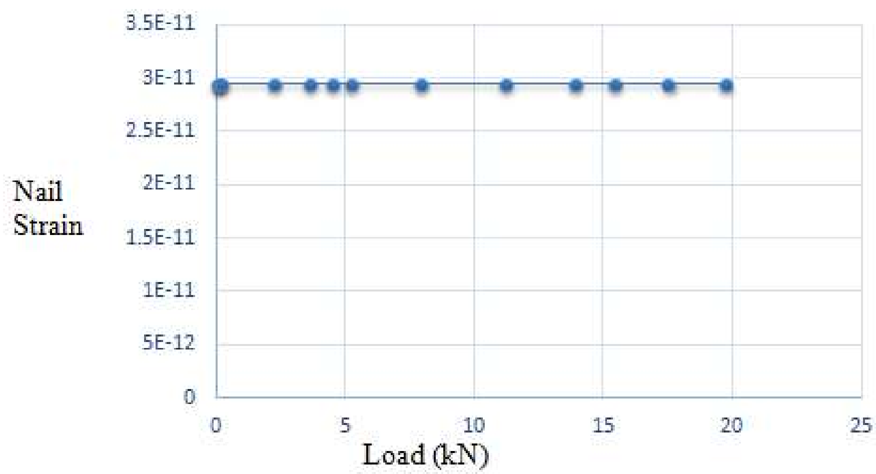


Fig. 4.89 nail strain vs load (nail 6)

All the graphs have similar trend. Initially there is no strain in the top and middle layer nails. As the load increases, there is increase in the strain and at certain points there is decrease in the strain. This is because of the mobilization of the soil.

CHAPTER 5

CONCLUSION

5.1 General

In this section, we will conclude the experiment results.

5.2 Conclusions

- The ultimate load carrying capacity of the soil increases with the insertion of nails.

- The most stable soil slope without nails is 45° as load carrying capacity is maximum of 3 slopes i.e 28.9 kN.

- The increase in the load carrying capacity of the soil is due to the friction between soil and the nail and tendency of nails to combat tensile force.

- The ultimate load carrying capacity increased more in case of screwed nails due to large increase in surface area (because of large number of screws), whereas in circular rings, although the diameter was more but the effective surface area was quite less.

- In circular ring nails, the surface was smooth (which was not the case with screwed nails), here the ultimate load carrying capacity increased because of generation of axial forces developed between soil and the rings.

- Nail failure was recognized as a bend deformation.

- The increase in the load carrying capacity of the soil is due to the friction between soil and the nail.

- The DST (Direct Shear Test) gives small value of ‘c’ of the soil. This can be due to the water added to the soil when compacted in layers.

- Nail failure was recognized as a bend deformation.

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ANNEXURE A
Lab Experiments

A.1 Experiments performed in laboratory

A.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.

Table. A.1 Observations of particle size distribution

		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			

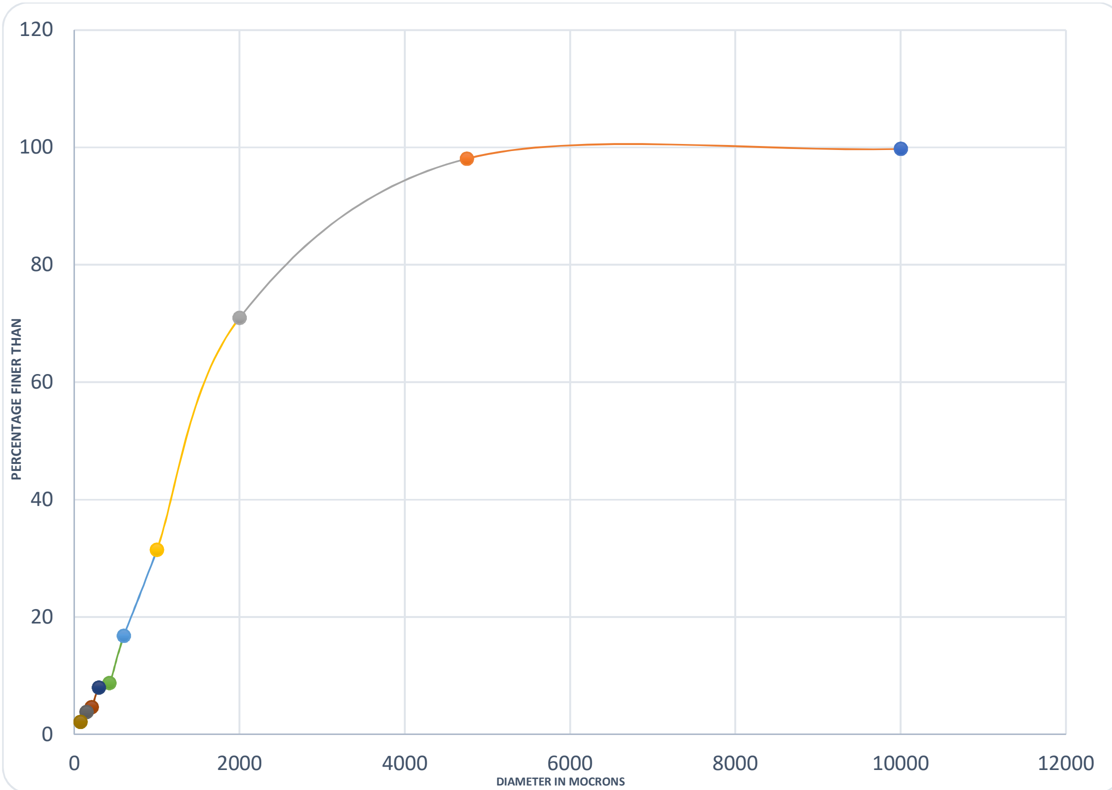

Fig. A.1 graph of percentage finer

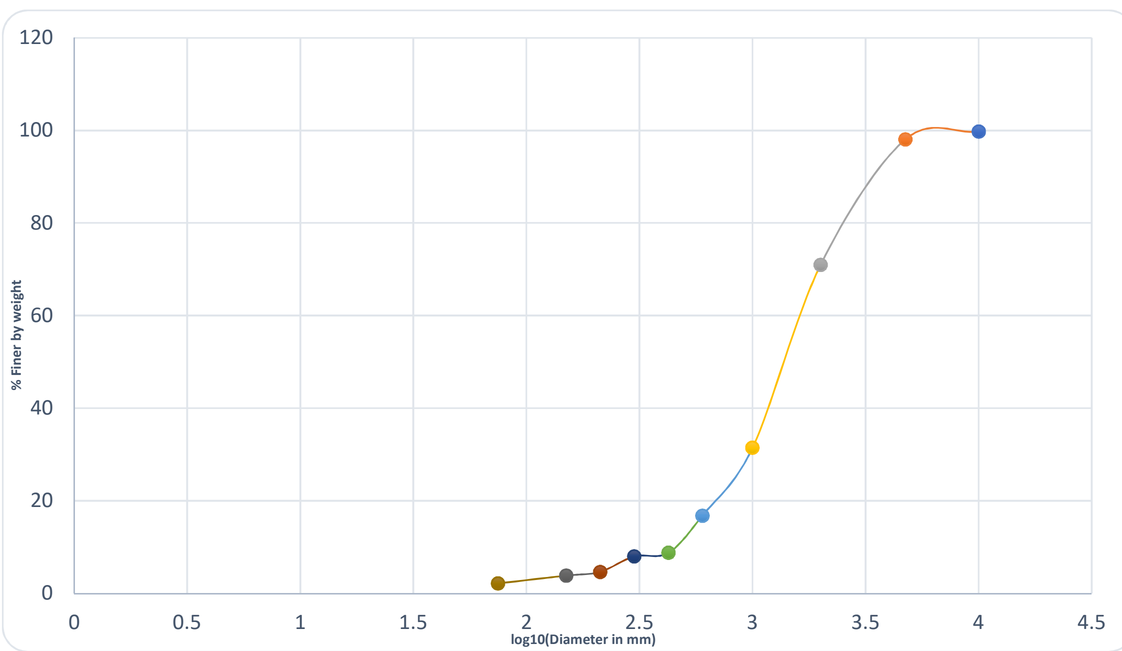

Fig.A.2 particle size distribution curve

Approximately 95% of soil particle size lies in between the range 4750 micron to 75 micron i.e the range of sand. Therefore, the soil is sandy soil. There are negligible traces of silt in the soil. Therefore ‘c’ of the soil can be taken as 0.

A.1.2 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

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

Table A.2 readings of 1st test

			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.3 readings of 2nd 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.4 readings of 3rd test.

Dial Gauge	proving ring	hor disp(mm)	strain	corrected area	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	

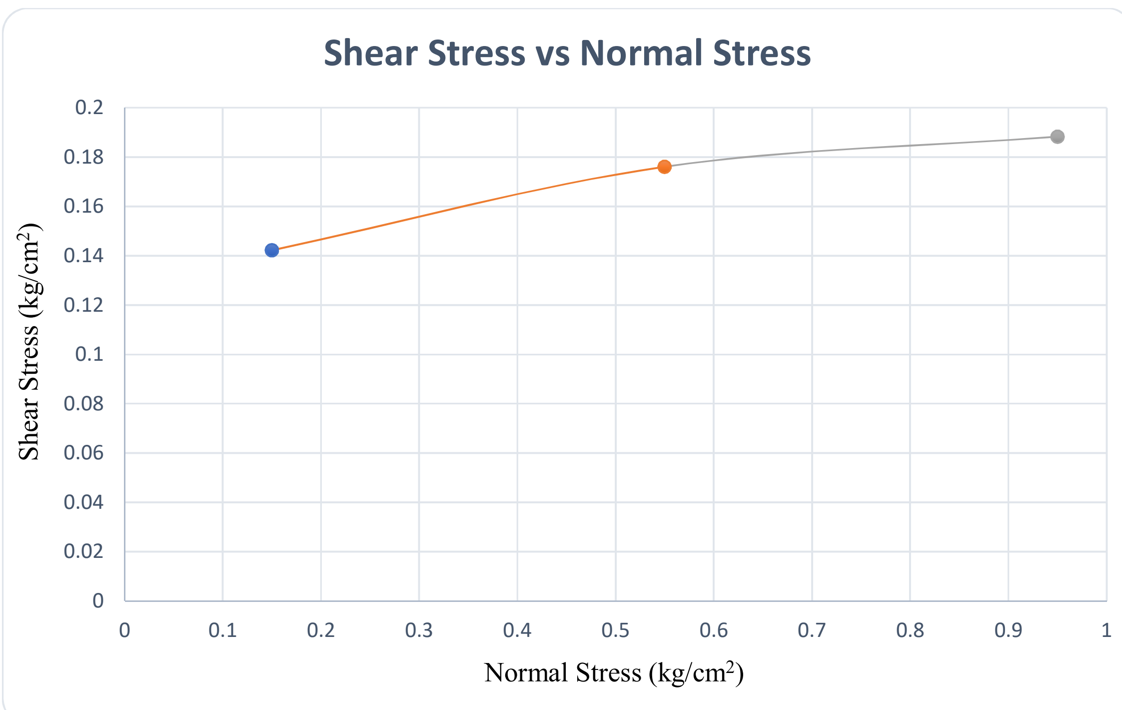

Fig.A.3 Shear Stress vs Normal Stress: With Nail

From experiment value of cohesion (c)=**0.13kg/cm^2.**

A.1.3.2 Values of experiment carried on soil without nails

Table A.5 readings of 1st test

		SOIL WITHOUT NAILS				
Dial Gauge	proving ring	hor disp(mm)	strain	corrected area	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.6 readings of 2nd test

Dial Gauge	proving ring	hor disp(mm)	strain	corrected area	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.7 readings of 3rd test

Dial Gauge	proving ring	hor disp(mm)	strain	corrected area	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	

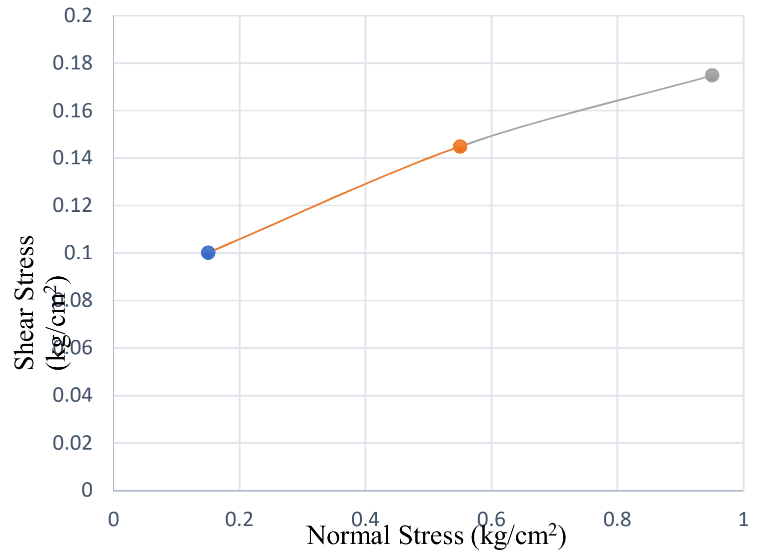

Fig. A.4 Shear Stress vs Normal Stress: Without Nail

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

ANNEXURE B
Experiments performed on model

B.1 Screwed Nails

B.1.1 45° slope

Table B.1 Calculations: Screwed Nails – 45° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2	V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4	V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
0	262	69.069	3E-08	212	76.4399	2.7E-11	250	70.3	5E-12	277	65	4E-11	261	70.83	3E-11	223	73.9	3E-11
10	262	69.069	3E-08	212	76.4399	2.7E-11	250	70.3	5E-12	277	65	4E-11	261	70.83	3E-11	223	73.9	3E-11
20	262	69.069	3E-08	212	76.4399	2.7E-11	249	70.4	0.0008	277	65	4E-11	261	70.83	3E-11	223	73.9	3E-11
30	262	69.069	3E-08	212	76.4399	2.7E-11	249	70.4	0.0008	277	65	4E-11	261	70.83	3E-11	223	73.9	3E-11
40	262	69.069	3E-08	212	76.4399	2.7E-11	249	70.4	0.0008	277	65	4E-11	261	70.83	3E-11	223	73.9	3E-11
50	262	69.069	3E-08	212	76.4399	2.7E-11	250	70.3	5E-12	278	64.9	8E-04	261	70.83	3E-11	223	73.9	3E-11
60	262	69.069	3E-08	212	76.4399	2.7E-11	250	70.3	5E-12	278	64.9	8E-04	261	70.83	3E-11	223	73.9	3E-11
70	262	69.069	3E-08	212	76.4399	2.7E-11	250	70.3	5E-12	278	64.9	8E-04	261	70.83	3E-11	222	74	0.0008
80	263	68.969	0.0008	212	76.4399	2.7E-11	250	70.3	5E-12	278	64.9	8E-04	261	70.83	3E-11	222	74	0.0008
90	263	68.969	0.0008	213	76.3287	0.00081	250	70.3	5E-12	279	64.8	0.002	261	70.83	3E-11	222	74	0.0008
100	263	68.969	0.0008	213	76.3287	0.00081	248	70.5	0.0016	279	64.8	0.002	261	70.83	3E-11	222	74	0.0008
110	263	68.969	0.0008	213	76.3287	0.00081	248	70.5	0.0016	279	64.8	0.002	261	70.83	3E-11	222	74	0.0008
120	263	68.969	0.0008	213	76.3287	0.00081	248	70.5	0.0016	279	64.8	0.002	261	70.83	3E-11	222	74	0.0008

Nail Forces (KN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0.0003	3.2E-07	6E-08	4E-07	4E-07	4E-07
10	0.0003	3.2E-07	6E-08	4E-07	4E-07	4E-07
20	0.0003	3.2E-07	9.7176	4E-07	4E-07	4E-07
30	0.0003	3.2E-07	9.7176	4E-07	4E-07	4E-07
40	0.0003	3.2E-07	9.7176	4E-07	4E-07	4E-07
50	0.0003	3.2E-07	6E-08	9.954	4E-07	4E-07
60	0.0003	3.2E-07	6E-08	9.954	4E-07	4E-07
70	0.0003	3.2E-07	6E-08	9.954	4E-07	9.8489
80	9.5287	3.2E-07	6E-08	9.954	4E-07	9.8489
90	9.5287	9.65395	6E-08	19.9	4E-07	9.8489
100	9.5287	9.65395	19.447	19.9	4E-07	9.8489
110	9.5287	9.65395	19.447	19.9	4E-07	9.8489
120	9.5287	9.65395	19.447	19.9	4E-07	9.8489

B.1.2 60° slope

Table B.2 Calculations: Screwed Nails – 60° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2	V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4	V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
0	264	68.9	4E-08	213	76.329	7E-10	247	70.504	2E-11	278	64.72	6E-12	192	78.743	3E-11	222	74.255	3E-11
10	264	68.9	0.005	213	76.329	7E-10	247	70.504	2E-11	278	64.72	6E-12	192	78.743	3E-11	222	74.255	3E-11
20	265	68.8	0.004	213	76.329	7E-10	247	70.504	2E-11	278	64.72	6E-12	192	78.743	3E-11	222	74.255	3E-11
30	264	68.9	0.005	213	76.329	7E-10	247	70.504	2E-11	278	64.72	6E-12	192	78.743	3E-11	222	74.255	3E-11
40	265	68.8	0.004	214	76.218	0.0008	247	70.504	2E-11	279	64.63	0.0008	193	78.628	0.0008	222	74.255	3E-11
50	265	68.8	0.004	213	76.329	7E-10	248	70.401	8E-04	279	64.63	0.0008	194	78.513	0.0016	223	74.146	0.0008
60	264	68.9	0.005	214	76.218	0.0008	248	70.401	8E-04	280	64.53	0.0017	194	78.513	0.0016	223	74.146	0.0008
70	264	68.9	0.005	214	76.218	0.0008	248	70.401	8E-04	280	64.53	0.0017	194	78.513	0.0016	223	74.146	0.0008
80	264	68.9	0.005	214	76.218	0.0008	248	70.401	8E-04	280	64.53	0.0017	194	78.513	0.0016	223	74.146	0.0008
90	264	68.9	0.005	215	76.107	0.0016	248	70.401	8E-04	280	64.53	0.0017	195	78.398	0.0024	223	74.146	0.0008
100	264	68.9	0.005	215	76.107	0.0016	248	70.401	8E-04	280	64.53	0.0017	195	78.398	0.0024	223	74.146	0.0008
110	265	68.8	0.004	215	76.107	0.0016	248	70.401	8E-04	279	64.63	0.0008	195	78.398	0.0024	223	74.146	0.0008
120	265	68.8	0.004	215	76.107	0.0016	248	70.401	8E-04	279	64.63	0.0008	195	78.398	0.0024	223	74.146	0.0008

Nail Forces (KN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	4E-04	9E-06	2E-07	8E-08	3E-07	3E-07
10	63.09	9E-06	2E-07	8E-08	3E-07	3E-07
20	53.46	9E-06	2E-07	8E-08	3E-07	3E-07
30	63.09	9E-06	2E-07	8E-08	3E-07	3E-07
40	53.46	9.6562	2E-07	10.036	9.6948	3E-07
50	53.46	9E-06	9.735	10.036	19.377	9.7234
60	63.09	9.6562	9.735	20.06	19.377	9.7234
70	63.09	9.6562	9.735	20.06	19.377	9.7234
80	63.09	9.6562	9.735	20.06	19.377	9.7234
90	63.09	19.301	9.735	20.06	29.047	9.7234
100	63.09	19.301	9.735	20.06	29.047	9.7234
110	53.46	19.301	9.735	10.036	29.047	9.7234
120	53.46	19.301	9.735	10.036	29.047	9.7234

B.1.3 90° slope

Table B.3 Calculations: Screwed Nails – 90° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2	V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4	V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
0	264	68.22	1.77E-08	206	76.60769	2.75E-11	251	69.53042	3.7E-11	278	64.52542	1.5E-11	162	81.54518	2.9E-11	224	73.41299	3.7E-11
10	264	68.22	1.77E-08	206	76.60769	2.75E-11	251	69.53042	3.7E-11	278	64.52542	1.5E-11	162	81.54518	2.9E-11	224	73.41299	3.7E-11
20	263	68.32	0.000821	205	76.72174	0.000827	250	69.6351	0.00084	278	64.52542	1.5E-11	161	81.66848	0.00084	224	73.41299	3.7E-11
30	263	68.32	0.000821	206	76.60769	2.75E-11	250	69.6351	0.00084	278	64.52542	1.5E-11	161	81.66848	0.00084	224	73.41299	3.7E-11
40	263	68.32	0.000821	205	76.72174	0.000827	251	69.53042	3.7E-11	278	64.52542	1.5E-11	161	81.66848	0.00084	224	73.41299	3.7E-11
50	263	68.32	0.000821	206	76.60769	2.75E-11	251	69.53042	3.7E-11	279	64.427	0.00085	162	81.54518	2.9E-11	224	73.41299	3.7E-11
60	263	68.32	0.000821	206	76.60769	2.75E-11	250	69.6351	0.00084	278	64.52542	1.5E-11	161	81.66848	0.00084	224	73.41299	3.7E-11
70	263	68.32	0.000821	205	76.72174	0.000827	250	69.6351	0.00084	278	64.52542	1.5E-11	161	81.66848	0.00084	224	73.41299	3.7E-11
80	263	68.32	0.000821	206	76.60769	2.75E-11	250	69.6351	0.00084	278	64.52542	1.5E-11	162	81.54518	2.9E-11	224	73.41299	3.7E-11
90	264	68.22	1.77E-08	206	76.60769	2.75E-11	251	69.53042	3.7E-11	278	64.52542	1.5E-11	162	81.54518	2.9E-11	224	73.41299	3.7E-11
100	264	68.22	1.77E-08	206	76.60769	2.75E-11	251	69.53042	3.7E-11	279	64.427	0.00085	162	81.54518	2.9E-11	224	73.41299	3.7E-11
110	264	68.22	1.77E-08	206	76.60769	2.75E-11	251	69.53042	3.7E-11	278	64.52542	1.5E-11	162	81.54518	2.9E-11	224	73.41299	3.7E-11
120	264	68.22	1.77E-08	206	76.60769	2.75E-11	251	69.53042	3.7E-11	278	64.52542	1.5E-11	158	82.03936	0.00337	224	73.41299	3.7E-11
130	264	68.22	1.77E-08	206	76.60769	2.75E-11	251	69.53042	3.7E-11	278	64.52542	1.5E-11	160	81.79194	0.00168	224	73.41299	3.7E-11
140	264	68.22	1.77E-08	207	76.49379	0.000826	251	69.53042	3.7E-11	278	64.52542	1.5E-11	160	81.79194	0.00168	224	73.41299	3.7E-11

Nail Forces (KN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0.000212	3.28E-07	4.4E-07	1.8E-07	3.5E-07	4.4E-07
10	0.000212	3.28E-07	4.4E-07	1.8E-07	3.5E-07	4.4E-07
20	9.800091	9.873402	9.98454	1.8E-07	10.0279	4.4E-07
30	9.800091	3.28E-07	9.98454	1.8E-07	10.0279	4.4E-07
40	9.800091	9.873402	4.4E-07	1.8E-07	10.0279	4.4E-07
50	9.800091	3.28E-07	4.4E-07	10.1156	3.5E-07	4.4E-07
60	9.800091	3.28E-07	9.98454	1.8E-07	10.0279	4.4E-07
70	9.800091	9.873402	9.98454	1.8E-07	10.0279	4.4E-07
80	9.800091	3.28E-07	9.98454	1.8E-07	3.5E-07	4.4E-07
90	0.000212	3.28E-07	4.4E-07	1.8E-07	3.5E-07	4.4E-07
100	0.000212	3.28E-07	4.4E-07	10.1156	3.5E-07	4.4E-07
110	0.000212	3.28E-07	4.4E-07	1.8E-07	3.5E-07	4.4E-07
120	0.000212	3.28E-07	4.4E-07	1.8E-07	40.1928	4.4E-07

B.2 Helical Nails

B.2.1 45° slope

Table B.4 Calculations: Circular Rings Nails – 45° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2	V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4	V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
0	243	81.98906	2.0913E-08	248	85.07057781	2.07352E-11	263	81.3274119	1.05739E-11	277	77.92619711	2.78575E-11	261	84.3981515	3.4007E-13	223	85.61649104	1.04357E-12
10	243	81.98906	2.0913E-08	248	85.07057781	2.07352E-11	263	81.3274119	1.05739E-11	277	77.92619711	2.78575E-11	261	84.3981515	3.4007E-13	223	85.61649104	1.04357E-12
20	243	81.98906	2.0913E-08	248	85.07057781	2.07352E-11	262	81.39350441	0.000451484	277	77.92619711	2.78575E-11	261	84.3981515	3.4007E-13	223	85.61649104	1.04357E-12
30	243	81.98906	2.0913E-08	248	85.07057781	2.07352E-11	262	81.39350441	0.000451484	277	77.92619711	2.78575E-11	261	84.3981515	3.4007E-13	223	85.61649104	1.04357E-12
40	243	81.98906	2.0913E-08	248	85.07057781	2.07352E-11	262	81.39350441	0.000451484	277	77.92619711	2.78575E-11	261	84.3981515	3.4007E-13	223	85.61649104	1.04357E-12
50	243	81.98906	2.0913E-08	248	85.07057781	2.07352E-11	261	81.45964447	0.000903294	278	77.86282929	0.000451765	261	84.3981515	3.4007E-13	223	85.61649104	1.04357E-12
60	243	81.98906	2.0913E-08	248	85.07057781	2.07352E-11	261	81.45964447	0.000903294	278	77.86282929	0.000451765	261	84.3981515	3.4007E-13	223	85.61649104	1.04357E-12
70	243	81.98906	2.0913E-08	248	85.07057781	2.07352E-11	261	81.45964447	0.000903294	278	77.86282929	0.000451765	261	84.3981515	3.4007E-13	222	85.68524975	0.000446167
80	244	81.9223	-0.000452363	248	85.07057781	2.07352E-11	261	81.45964447	0.000903294	278	77.86282929	0.000451765	261	84.3981515	3.4007E-13	222	85.68524975	0.000446167
90	244	81.9223	-0.000452363	249	85.00262513	-0.000443767	261	81.45964447	0.000903294	279	77.79950698	0.000903206	261	84.3981515	3.4007E-13	222	85.68524975	0.000446167
100	244	81.9223	-0.000452363	249	85.00262513	-0.000443767	259	81.5920674	0.001807888	279	77.79950698	0.000903206	261	84.3981515	3.4007E-13	222	85.68524975	0.000446167
110	244	81.9223	-0.000452363	249	85.00262513	-0.000443767	259	81.5920674	0.001807888	279	77.79950698	0.000903206	261	84.3981515	3.4007E-13	222	85.68524975	0.000446167
120	244	81.9223	-0.000452363	249	85.00262513	-0.000443767	259	81.5920674	0.001807888	279	77.79950698	0.000903206	261	84.3981515	3.4007E-13	222	85.68524975	0.000446167

Nail Forces (KN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0.00024966	2.47538E-07	1.26232E-07	3.32564E-07	4.05977E-09	1.24582E-08
10	0.00024966	2.47538E-07	1.26232E-07	3.32564E-07	4.05977E-09	1.24582E-08
20	0.00024966	2.47538E-07	5.389844968	3.32564E-07	4.05977E-09	1.24582E-08
30	0.00024966	2.47538E-07	5.389844968	3.32564E-07	4.05977E-09	1.24582E-08
40	0.00024966	2.47538E-07	5.389844968	3.32564E-07	4.05977E-09	1.24582E-08
50	0.00024966	2.47538E-07	10.78356689	5.393196518	4.05977E-09	1.24582E-08
60	0.00024966	2.47538E-07	10.78356689	5.393196518	4.05977E-09	1.24582E-08
70	0.00024966	2.47538E-07	10.78356689	5.393196518	4.05977E-09	5.326368751
80	-5.400338846	2.47538E-07	10.78356689	5.393196518	4.05977E-09	5.326368751
90	-5.400338846	-5.297709689	10.78356689	10.7825199	4.05977E-09	5.326368751
100	-5.400338846	-5.297709689	21.5826587	10.7825199	4.05977E-09	5.326368751
110	-5.400338846	-5.297709689	21.5826587	10.7825199	4.05977E-09	5.326368751
120	-5.400338846	-5.297709689	21.5826587	10.7825199	4.05977E-09	5.326368751

B.2.2 60° slope

Table B.5 Calculations: helical Nails – 60° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2	V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4	V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
0	233	82.7536898	0.014126094	256	84.39026418	1.59769E-12	242	82.82246651	3.06081E-11	259	79.0579574	1.95587E-11	231	86.68947734	8.78747E-13	249	83.66041119	3.15084E-11
10	233	82.7536898	0.014126094	256	84.39026418	1.59769E-12	242	82.82246651	3.06081E-11	259	79.0579574	1.95587E-11	231	86.68947734	8.78747E-13	249	83.66041119	3.15084E-11
20	233	82.7536898	0.014126094	256	84.39026418	1.59769E-12	242	82.82246651	3.06081E-11	259	79.0579574	1.95587E-11	231	86.68947734	8.78747E-13	249	83.66041119	3.15084E-11
30	233	82.7536898	0.014126094	256	84.39026418	1.59769E-12	242	82.82246651	3.06081E-11	259	79.0579574	1.95587E-11	231	86.68947734	8.78747E-13	249	83.66041119	3.15084E-11
40	233	82.7536898	0.014126094	256	84.39026418	1.59769E-12	242	82.82246651	3.06081E-11	259	79.0579574	1.95587E-11	231	86.68947734	8.78747E-13	249	83.66041119	3.15084E-11
50	234	82.68676991	0.013665413	256	84.39026418	1.59769E-12	242	82.82246651	3.06081E-11	259	79.0579574	1.95587E-11	231	86.68947734	8.78747E-13	249	83.66041119	3.15084E-11
60	234	82.68676991	0.013665413	257	84.32225795	0.000447697	243	82.75574403	0.00044756	260	78.99370971	0.000551467	232	86.62107064	0.000438389	249	83.66041119	3.15084E-11
70	234	82.68676991	0.013665413	257	84.32225795	0.000447697	243	82.75574403	0.00044756	260	78.99370971	0.000551467	232	86.62107064	0.000438389	249	83.66041119	3.15084E-11
80	235	82.61989896	0.013205069	257	84.32225795	0.000447697	243	82.75574403	0.00044756	260	78.99370971	0.000551467	232	86.62107064	0.000438389	249	83.66041119	3.15084E-11
90	235	82.61989896	0.013205069	258	84.25430049	0.000895072	243	82.75574403	0.00044756	260	78.99370971	0.000551467	232	86.62107064	0.000438389	249	83.66041119	3.15084E-11
100	235	82.61989896	0.013205069	258	84.25430049	0.000895072	243	82.75574403	0.00044756	261	78.92950849	0.001102535	232	86.62107064	0.000438389	249	83.66041119	3.15084E-11
110	235	82.61989896	0.013205069	258	84.25430049	0.000895072	243	82.75574403	0.00044756	261	78.92950849	0.001102535	232	86.62107064	0.000438389	249	83.66041119	3.15084E-11
120	235	82.61989896	0.013205069	258	84.25430049	0.000895072	243	82.75574403	0.00044756	261	78.92950849	0.001102535	232	86.62107064	0.000438389	249	83.66041119	3.15084E-11

Nail Forces (KN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	168.6380443	1.90733E-08	3.65401E-07	2.33493E-07	1.04905E-08	3.76149E-07
10	168.6380443	1.90733E-08	3.65401E-07	2.33493E-07	1.04905E-08	3.76149E-07
20	168.6380443	1.90733E-08	3.65401E-07	2.33493E-07	1.04905E-08	3.76149E-07
30	168.6380443	1.90733E-08	3.65401E-07	2.33493E-07	1.04905E-08	3.76149E-07
40	168.6380443	1.90733E-08	3.65401E-07	2.33493E-07	1.04905E-08	3.76149E-07
50	163.1384136	1.90733E-08	3.65401E-07	2.33493E-07	1.04905E-08	3.76149E-07
60	163.1384136	5.34462582	5.342997927	6.583440687	5.233511753	3.76149E-07
70	163.1384136	5.34462582	5.342997927	6.583440687	5.233511753	3.76149E-07
80	157.6428047	5.34462582	5.342997927	6.583440687	5.233511753	3.76149E-07
90	157.6428047	10.68541916	5.342997927	6.583440687	5.233511753	3.76149E-07
100	157.6428047	10.68541916	5.342997927	13.16211855	5.233511753	3.76149E-07
110	157.6428047	10.68541916	5.342997927	13.16211855	5.233511753	3.76149E-07
120	157.6428047	10.68541916	5.342997927	13.16211855	5.233511753	3.76149E-07

B.2.3 90° slope

Table. B.6 Stress Calculations: helical Nails – 90° slope

Time (Seconds)	V(out)1	Nail 1	Strain 1	V(out)2	Nail 2	Strain 2	V(out)3	Nail 3	Strain 3	V(out)4	Nail 4	Strain 4	V(out)5	Nail 5	Strain 5	V(out)6	Nail 6	Strain 6
0	254	81.25735	7.66948E-09	215	87.3405772	-2.50084E-11	261	81.45964447	3.03506E-11	280	77.73623012	1.17978E-11	193	89.12378983	1.15468E-11	232	84.99993925	2.94738E-11
10	254	81.25735	7.66948E-09	215	87.3405772	-2.50084E-11	261	81.45964447	3.03506E-11	280	77.73623012	1.17978E-11	193	89.12378983	1.15468E-11	232	84.99993925	2.94738E-11
20	254	81.25735	7.66948E-09	215	87.3405772	-2.50084E-11	261	81.45964447	3.03506E-11	280	77.73623012	1.17978E-11	193	89.12378983	1.15468E-11	232	84.99993925	2.94738E-11
30	254	81.25735	7.66948E-09	215	87.3405772	-2.50084E-11	261	81.45964447	3.03506E-11	280	77.73623012	1.17978E-11	193	89.12378983	1.15468E-11	232	84.99993925	2.94738E-11
40	254	81.25735	7.66948E-09	214	87.41021081	0.000442925	261	81.45964447	3.03506E-11	280	77.73623012	1.17978E-11	193	89.12378983	1.15468E-11	232	84.99993925	2.94738E-11
50	254	81.25735	7.66948E-09	214	87.41021081	0.000442925	260	81.52583211	0.0004514	279	77.79950698	0.000452219	193	89.12378983	1.15468E-11	232	84.99993925	2.94738E-11
60	254	81.25735	7.66948E-09	214	87.41021081	0.000442925	260	81.52583211	0.0004514	279	77.79950698	0.000452219	192	89.19507486	0.000444357	232	84.99993925	2.94738E-11
70	254	81.25735	7.66948E-09	213	87.4798948	0.000886171	260	81.52583211	0.0004514	279	77.79950698	0.000452219	192	89.19507486	0.000444357	232	84.99993925	2.94738E-11
80	254	81.25735	7.66948E-09	213	87.4798948	0.000886171	260	81.52583211	0.0004514	279	77.79950698	0.000452219	192	89.19507486	0.000444357	232	84.99993925	2.94738E-11
90	255	81.19112	-0.000452792	213	87.4798948	0.000886171	262	81.39350441	0.000451076	279	77.79950698	0.000452219	192	89.19507486	0.000444357	232	84.99993925	2.94738E-11
100	255	81.19112	-0.000452792	213	87.4798948	0.000886171	262	81.39350441	0.000451076	281	77.67299867	0.000451895	192	89.19507486	0.000444357	232	84.99993925	2.94738E-11
110	255	81.19112	-0.000452792	213	87.4798948	0.000886171	262	81.39350441	0.000451076	281	77.67299867	0.000451895	192	89.19507486	0.000444357	232	84.99993925	2.94738E-11
120	255	81.19112	-0.000452792	213	87.4798948	0.000886171	262	81.39350441	0.000451076	281	77.67299867	0.000451895	191	89.26641315	0.000889046	232	84.99993925	2.94738E-11
130	255	81.19112	-0.000452792	213	87.4798948	0.000886171	262	81.39350441	0.000451076	281	77.67299867	0.000451895	191	89.26641315	0.000889046	232	84.99993925	2.94738E-11
140	255	81.19112	-0.000452792	213	87.4798948	0.000886171	262	81.39350441	0.000451076	281	77.67299867	0.000451895	191	89.26641315	0.000889046	232	84.99993925	2.94738E-11

Nail Forces (KN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	9.15586E-05	-2.98552E-07	3.62327E-07	1.40842E-07	1.37846E-07	3.5186E-07
10	9.15586E-05	-2.98552E-07	3.62327E-07	1.40842E-07	1.37846E-07	3.5186E-07
20	9.15586E-05	-2.98552E-07	3.62327E-07	1.40842E-07	1.37846E-07	3.5186E-07
30	9.15586E-05	-2.98552E-07	3.62327E-07	1.40842E-07	1.37846E-07	3.5186E-07
40	9.15586E-05	5.2876633	3.62327E-07	1.40842E-07	1.37846E-07	3.5186E-07
50	9.15586E-05	5.2876633	5.388840946	5.398615522	1.37846E-07	3.5186E-07
60	9.15586E-05	5.2876633	5.388840946	5.398615522	5.304759239	3.5186E-07
70	9.15586E-05	10.57915252	5.388840946	5.398615522	5.304759239	3.5186E-07
80	9.15586E-05	10.57915252	5.388840946	5.398615522	5.304759239	3.5186E-07
90	-5.405453704	10.57915252	5.38496671	5.398615522	5.304759239	3.5186E-07
100	-5.405453704	10.57915252	5.38496671	5.394741323	5.304759239	3.5186E-07
110	-5.405453704	10.57915252	5.38496671	5.394741323	5.304759239	3.5186E-07
120	-5.405453704	10.57915252	5.38496671	5.394741323	10.61348136	3.5186E-07