"SOIL NAILING TECHNIQUE"

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Under the supervision of

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To

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CERTIFICATE

This is to certify that the work which is being presented in the project report titled **“SOIL NAILING TECHNIQUE”** 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 Punit Kumar Jain (131607), Komal Sharma (131662), Sahil Chauhan (131704) 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.

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ABSTRACT

The soil nailing is done to treat those natural soil slopes which are unstable in nature. The purpose of our project is to study the technique of soil nailing whether it is apt for soil stabilization or not. . The technique involves the insertion of relatively slender reinforcing elements into the slope – often general purpose reinforcing bars although solid or hollow-system bars are also available. Bars installed using drilling techniques are usually fully grouted and installed at a slight downward inclination. Typical soil nails **(Screw and Helical nails)** have been used in this project with its various **testing of slopes**. The comparative study has been performed by using these two types of nails in order to determine which nails give the more stabilised slope. This project serves the main focus in order to replicate the actual conditions of soil nailed structures while using the screw and helical nails.

We used prototype model tank with suitable dimensions in order to show our project work of soil nailing. The nails which were used during this project were fitted with foil strain gauge along with soldered copper connecting wires to show the required resistance value. The basic purpose of finding this resistance value was to convert it into the required strain value exhibited between soil and nail and it was done by using a suitable formula discussed later in this report.

The experimentation was performed by using soil slopes of 45˚, 60˚, 90˚ with nail inclination of 15˚ and 30˚. Our results and discussions shows it clearly that screw and helical nails give better load bearing capacity when being compared to drilling nails. This is because there is no such case of disturbance of normal strata of soil and its slope in screw and helical nails. The plotting of various graphs shows the behaviour of our model testing w.r.t different slope angle which depicts the actual scenario of soil nailed structures inclined at specific angle.

Keywords: Screw Nails, Helical Nails, Soil Nailing, Slope Stabilization.

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LIST OF SYMBOLS

FHWA – Federal Highway Administration

PMMA – Poly methyl 2 methyl propenoate

FOS – Factor of Safety

DMM – Digital Multimeter

UTM – Universal Testing Machine

R_1, R_2, R_3 – Known resistance arm of wheatstone bridge

Rg – Resistance of foil strain gauge

Vout – Output voltage of wheatstone bridge

Vin – Input voltage given to wheatstone bridge

β- Angle of nail with the horizontal

ε- Strain in nail

GF – Gauge Factor

$KAlSi_3O_8$ – $NaAlSi_3O_8$- $CaAl_2Si_2O_8$ - Feldspars

c – Cohesion

ϕ – Angle of Internal Friction

CHAPTER 1
INTRODUCTION

1.1 General

The method of soil nailing involves the penetration of steel bars or other similar materials. The process of soil nailing exhibits various situations at the spot such as flexibility, fast construction and finally it stabilizes both natural slopes and vertical or inclined excavations. Soil nailing consists of placing in the ground passive inclusions, closely spaced to restrain the resultant displacements. The general concept of soil nailing is to stabilize and strengthen the present ground by installing closely spaced steel bars, called nails into a slope or excavation as construction proceeds from the" top down". The working process makes a reinforced section that is stable enough and provides with a perfect ground mass. It is usually performed in earth retention structure that combines reinforcements and short crete to support excavation, hill sides, embankments steeping etc. The nails should have sufficient bending stress. Then the tension is developed in nails which provides resisting forces which is responsible for stabilizing the soil mass.

The main aim of soil nailing is to increase the tensile and shear strength of the soil and restrain its displacements. The procedure carried out is done by inserting the nails in a horizontal or sub horizontal manner. The nailing is in the form of drilled boreholes grouted along their total length to form 'grouted nails' or simply driven into the ground as 'driven nails'.

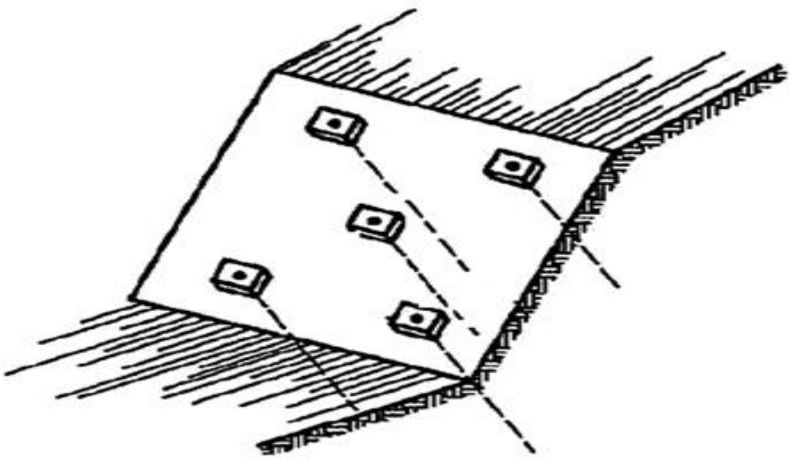


Fig 1.1: General concept of soil nailing (Geotechnicaldesign.info)

1.2 Development of the Soil Nailing Technique:

The technique which is called soil nailing was developed in the early 1960s from the basic techniques for bolting of rocks and multi-anchorage systems and partly from reinforced related technique **(Clouterre, 1991; FHWA, 1998)**. The New Austrian Tunnelling Method which was introduced in the early 1960s was assumed to be the basic prototype leading to the adoption of steel bars and shotcrete to reinforce or stabilize the ground. With the increased use of this technique, semi-empirical designs for soil nailing began to evolve in the early 1970s. The first systematic research on soil nailing, involving both model tests and full-scale field tests, was carried out in Germany in the mid-1970s. Further research and development work was initiated in France and the United States in the early 1990s. The result of this research and development work made the benchmark for the formulation of the design and construction approach for the soil nailing technique in the subsequent decades.

1.3 Various types of soil nailing:

Various types of soil nailing methods that are employed in the field is listed below:

1. Grouted Nail: After the basic excavation is done, the very first step is drilling of holes in the sloped face and then the nails are placed in the pre-drilled holes. Finally, the drill hole is then filled with cemented grout.

2. Driven Nail: In this type of soil nailing, nails are driven in a mechanical approach to the wall during excavation. The installing procedure of this type of soil nailing is very fast; but it does not give protection against corrosion. This method is basically used as temporary nailing.

3. Self-Drilling Soil Nail: Those bars which are hollow from inside are driven and the injection of grouting is done simultaneously during the drilling process. This type of nailing is much quicker than the grouted nailing and it shows more corrosion protection than the nails which are driven.

4. Jet-Grouted Soil Nail: Jet grouting follows the mechanism of eroding the ground and thereby steel nails are installed by creating the desired holes. In this type the grout again gives corrosion protection for different nails used.

5. Launched Soil Nail: As the name specify the bars are "launched" into the soil mass with very high or impactful speed using firing mechanism by passing compressed air. This method of installation is very rapid and reliable; however it is often doubtful to control the bar length which penetrates the ground.

1.4 Stability considerations:

External Stability: The nailed slope external or global stability includes sloped nail stability, overturning and slipping of soil-nail mass, failure of bearing capacity against basal heave due to excavation. Usually long-term stability problem come into account like rain which is seasonal. Therefore in such cases ground water table becomes low plus the seeping water restricts the stability of nailed slope without facing or adequate drainage system.

Internal Stability: It consists of numerous modes of failure of nailed structure e.g. pull-out failure of nailed soil, tensile failure of nail, and punching shear failure. Therefore these difficulties are overcomed by:-

Establishing proper ground investigation with geotechnical testing for identification of soil parameters and ground properties.

We do in-situ test for determining soil nail interaction and nail strength.

1.5 Basic Mechanism of a Soil-Nailed System:

The techniques of soil nailing enhance the slopes stability, supporting walls and excavations generally through the mobilized tensile forces of soil nails. These forces are generated in the soil nails basically by the interaction due to friction between the soil nails and the grounded earth as well as the supported reactions given by soil-nail heads or facing. The forces which are tensile in nature strengthen the ground by supporting major of the applied shear loadings and by making the normal stresses in the soil on the potential failure surface to be increased, thus it allows higher shearing resistance to get mobilised. Soil-nail heads and the facing gives a condensed effect by restricting the ground deflection near normal to the slope surface. Due to this, the average effective stress plus the shearing resistance of the soil left behind the soil-nail heads will rise. It also give prevention of local failures near the slope surface, and to promote favoured action of the stabilized soil mass through the redistribution of forces for soil nails. The resistance against pullout failure of the soil nails is given by the part of soil nail that is inserted into the ground behind the potential failure surface.

A two-zone model is used to determine the internal stability of a soil nailed mass, called as the active zone and the passive zone (or resistant zone), which are separated by dividing surface or a potential failure surface (Figure1.5). The active zone is defined as the region in which there is front of the potential failure surface, where it has a potential to depart from the soil-nailed mass. The passive zone is the region which is behind the potential failure surface, where it is there for more or less intact. The soil nails act as a medium which tie the active zone to the passive zone.

In real application, in case of a soil slopes for example, unless the slope failure is depicted by joint settings where the failure surface is different, there is generally a zone called shear zone subjected to shear distortion. The nail-soil interaction is far complex and the major forces developed in the soil nails are due to many factors. These factors are the mechanical characteristics of the soil nails i.e(tensile strength, shear strength and bending capacity), the inclination and orientation of the soil nails, the shear strength of the ground, the relative stiffness of the soil nails and the ground, the friction between the soil nails and the ground, the size of soil-nail heads and the nature of the slope facing.

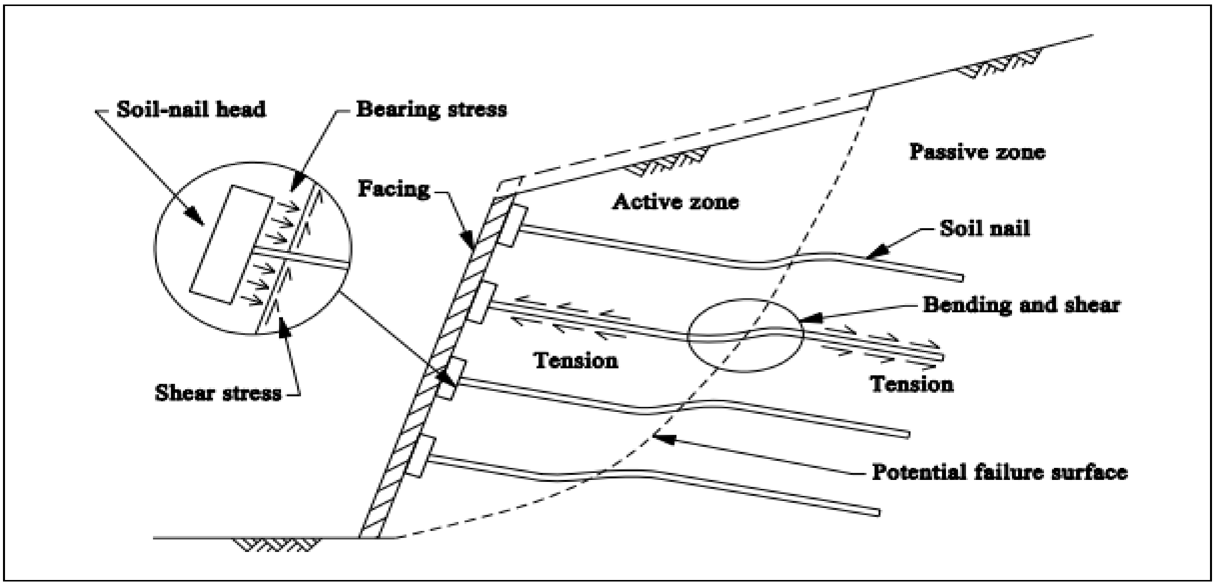


Fig 1.5: Basic Mechanism of Soil Nailed System

1.6 Practical Applications of Soil Nailing:

Soil nailing has been a popular technique to other conventional supporting systems and are applicable to following areas:

1. Nailed soil retaining structures to support excavations associated with basement construction of buildings, underground parking, cut and cover constructions, metro transportation systems, open mining etc.
2. Making the slopes stabilized.
3. Stabilization of tunnel portals and shafts.
4. Construction of abutments.

Soil nailing has also been used for remedial works **(Bruce and Jewell 1986)** including:

1. Repair of unstable old masonry gravity retaining walls.
2. Stabilization of failed soil slopes.
3. Repair of anchored walls that failed due to overloading or corrosion of tendon.
4. Repair of reinforced soil walls. In this case the soil nails took over the functions of the original reinforcing strips or fasteners that had been damaged or corroded.

1.7 Merits and Demerits of soil nailing:

1.7.1 **Merits (Juran and Elias 1992):**

1. **Economic advantage**: Past experience in France (Bruce and Jewel 1992) and USA (Shen et al., 1981b), indicate that soil nailing can result in 10% to 30% savings in cost when compared to an anchored diaphragm wall.
2. **Simple and light construction equipment :** The equipment required for executing soil nailing such as drilling rigs for nail installation , guns for short Crete application and grouting are relatively small scale, easily movable and produce little noise.
3. **Adaptability to site conditions:** Soil nailing operation is fast and systematic. In heterogeneous where boulders or hard rocks may be encountered, soil nailing is mainly more feasible than other techniques such as slurry walls and soldier piles because it involves only small diameter drilling for the installation of nails.
4. **Performance:** Experience and research indicated that the overall movements required to mobilize the reinforcement forces are surprisingly small **(Cartier and Gigan, 1983).**The maximum lateral displacements at the end of the excavations were generally not more than 0.3% of excavation depth **(Bruce and Jewell 1987).**

5. **Space:** Soil nailing provides an obstruction free working space which can result in considerable reduction in construction time for basement works and tunnel construction.

6. **Structure stability:** Soil nailing uses a large number of nails due to which failure of any one nail may not be detrimental to the structural stability.

7. **Suitability during earthquake:** Soil nailing generally performed well even in seismically active regions **(Gassler and Gudehus, 1981).**

1.7.2 Demerits:

1. This technique of soil nailing requires cuts which can stand unsupported for depths of about 1 to 2 m at least for few hours prior to shortcreting and nailing. This requires cohesion or some apparent cohesion in the natural soil, otherwise pre-treatment such as grouting may be necessary **(Gassler, 1990)** to stabilize the face.

2. Mobilization of tension in the nail require relative displacement of soil and reinforcement. Hence in urban sites where ground movement must be avoided, this technique may not be feasible.

3. In corrosive ground, durability considerations rule out the use of soil nails as permanent support.

4. The presence of utilities, underground structures or other buried obstructions poses restrictions to the length and layout of soil nails.

5. The zone taken by soil nails is sterilised and the site poses constraints to future development.

6. Permission has to be obtained from the owners of the adjacent land for the installation of soil nails beyond the lot boundary. This poses limitations on the basic layout of soil nails.

7. The presence of high groundwater levels may lead to construction difficulties in hole drilling and grouting, and instability problems of slope surface in the case of soil-nailed excavations.

1.8 Comparison of soil nailing with reinforced soil:

The similarity between soil nailing and reinforced soil lies in one aspect that friction is mobilized at the soil as a result of which the lateral deformations of soil are restrained. Also the difference lies in the following points **(Bruce and Jewell, 1986):**

1. Soil nailing is done through series of staged excavation from "Top down" while reinforced soil is constructed from "Bottom up" layer by layer. This difference in two approaches tells the difference in stress and strain pattern.

2. The nailed soil structure's reinforcement are usually grouted to effectively bond the reinforcement to the surrounding ground, therefore the reinforcement is much stiffer compared to reinforced soil.

3. Properties cannot be preselected since soil nailing is in-situ reinforcing technique whereas in case of reinforced soil, the soil is a new fill which can be selected and controlled.

1.9 Construction Sequence of soil nailing:

Standard construction sequence of soil nails can be divided into the following four stages:

1. Excavation of soil:

Soil is excavated in lifts to accommodate at least a single row of facing panels. Moreover each height of such lift should secure the overall stability of the uncovered soil until the nail is ready to transfer the load to the soil mass under the critical slip surface as shown in fig 1.9 (a).

2. Positioning of facing material:

Facing material like facing panels are positioned or laid down in rows as shown in fig 1.9 (b)

3. Drilling, Nailing & Grouting:

Nail holes are then drilled to the designed nail length and inclination. After that designed nails are inserted into the hole and grouted to develop a strong bond between the nail and the soil.

To confirm the perfect contact between back of the facing panel and the soil surface, the gap behind the facing material is filled by injecting a cement slurry or mortar as shown in fig 1.9 (c).

4. Reinforcement tightening:

Nails are tightened by nut bolted connection so that the tensile bar force near the facing can be mobilized to the design level. It is usually necessary to ensure the stability of soil slope close to the slope face especially in the case of sandy soil.

Once the tightening of the reinforcement for selected row is over, the above three steps are repeated for the successive rows of soil nails as shown in fig 1.9 (d).

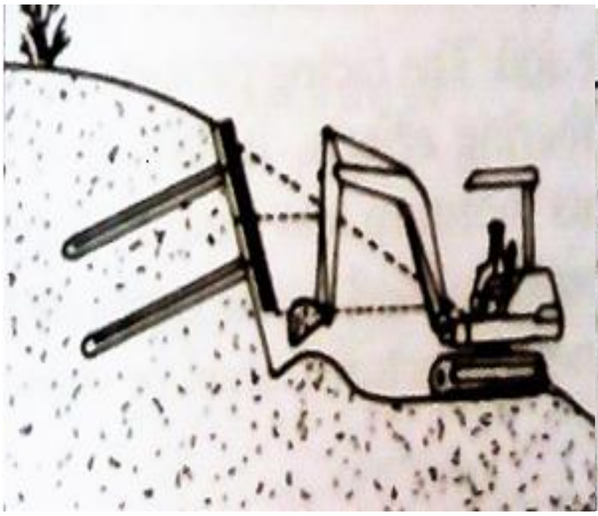


Fig 1.9 (a) Excavation

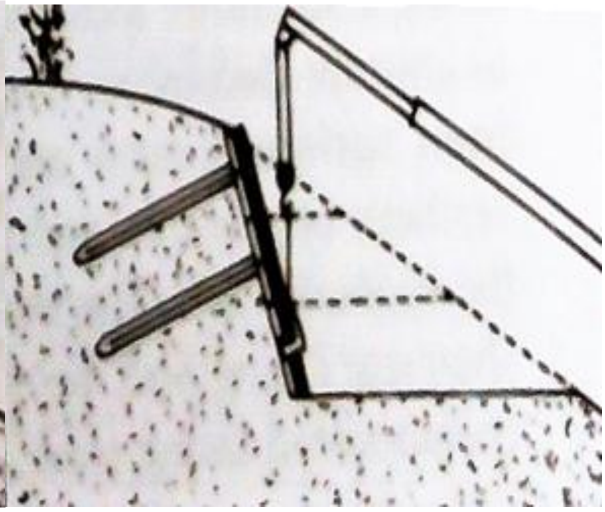


Fig 1.9 (b) Positioning of facing

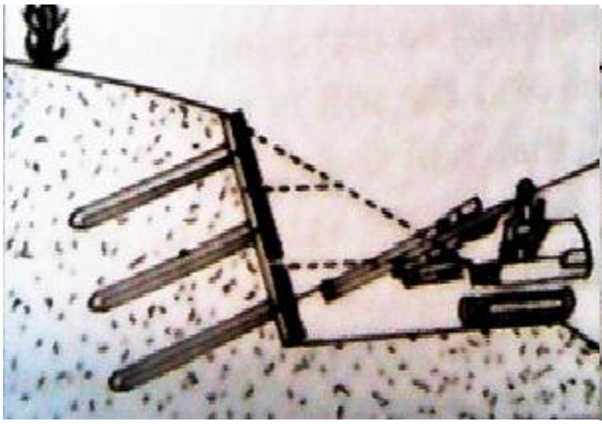


Fig 1.9 (c) Drilling, Nailing and Grouting

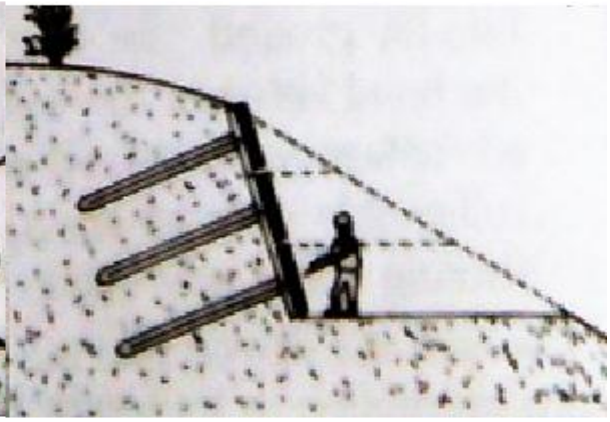


Fig 1.9 (d) Reinforcement action

Fig 1.9: Construction Sequence

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. This methodology can be adopted at embankment sites, natural slopes, highways, etc. including free board of riverbank area of natural rivers. However in soils with very less shear strength soil nailing becomes very uneconomical due to high density of nails.

2.2 Research work on soil nailing

In Soil nailing there is a very new area of research in civil engineering hence not much literature is available. But few of the in situ experiments in situ and model analysis were done to study the soil nailing which are as follows.

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** and concluded that the 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. Conclusions derived from the experiment were that the factor of safety increases with the length of pile effective length which gives maximum stability to the slope was the pile having length 1 to 2.5 times the height of the slope. Stiffness factor also plays a very significant role in increasing the factor of safety, maximum factor of safety was obtained when the stiffness factor was 0.002 irrespective of the slope material. They also studied the effect of nail spacing on factor of safety and saw that factor of safety decreases with increase in pile spacing and the optimum spacing is concluded was 4D for the sandy slope having the slope of 1:1, and in the case of clay spacing was not having any significant effect on factor of safety.

Further 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 they concluded that the nails oriented upwards having larger lengths embedded in the upper part of the slope generally leaded to more stability than that of nails placed at bottom of slope. The value of the upward inclination of the nails has very small range of values ranging from nearly zero to a maximum of 6º. When all other nail parameters of slope like slope angle, soil type, water content were kept constant then it was seen that unequal spacing of the nails, having higher lengths at top and lower lengths of soil nails at bottom of the slope resulted in the optimal design and it was seen that slope failure is more critical at the top hence larger length nails were required at top of the soil where as at bottom even nails with small lengths did not showed any significant amount of change in stability hence it was proved from their experiment that soil needs more reinforcement at top of the slope rather than bottom. The savings of pile material in the above mentioned method was estimated round about 8 to 27%.

Wan-Huan ZHOU (2008) did the pull out test in laboratory and on actual sight conditions and compared the result obtained in his both of studies. This study was done to prove the results produced theoretically by applying the FEM (Finite Element Method) practically. They computed stresses and strains in nails by using the strain gauges and also drew their bending moment diagrams and their studies showed that with increase in applied overburden pressure, the time needed for obtaining the stress equilibrium in the box increases.

Grouting pressure leads in increases of the earth pressure, but this earth pressure could not be maintained for a very long time and higher is the applied grouting pressure the longer period of time that grouting pressure will be maintained .Their studies also showed that saturation increases the vertical effective stresses around the soil nail and thickness of the soil which was adhered around the nail was also not uniform around the soil nail which showed that the effective stresses coming on different were different.

Experiment was done by FBG and strain gauges to detect the strain and it appeared that the FBG (Fibre Bragg Grating) sensors showed higher reliability than the strain gauges for the small strain monitoring.

B. R. Srinavasa Murthy, G. L. Sivakumar Babu and A. Srinavas(2002) wrote the paper and described the features of soil-nailed walls .They did experiment in actual site conditions on wall with nails and without nails. Their study was to check the stability of wall and find out the critical depths with and without soil nailing. The stability analysis of prototype of soil nailed walls showed that the critical depth of wall became twice when nails were inserted into the wall.

C.Y. Cheuk, K.K.S. Ho, and A.Y.T. Lam (2016) experimented soil on loose volcanic soil, for the experiment they considered two key mechanisms

- Static liquefaction
- Sliding.

Their experiment was to study the effect of different angles of nail and on different lengths of nail inserted into the soil. The length of nails were put in the increasing order from top to bottom. And that was as follow row 1=5m, row2=8m, row3=10m, row4=12m, row5=13m, row6=15m, row7=15m.

They made three experimental setups for these experiments which are as follows.

In first setup they kept nails at more inclination 56.3º with the horizontal as shown in fig (2.1).

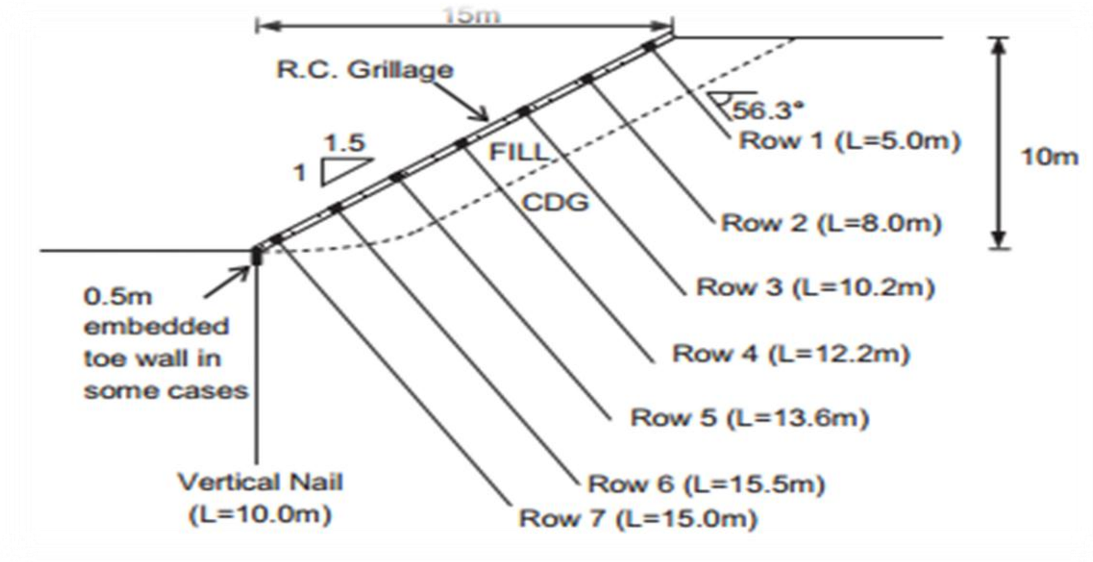


Fig 2.1 Steeper inclination of nails at 56.3 º

In second setup of experiment the nails were at lesser inclination of 20 º shown in fig(2.2).

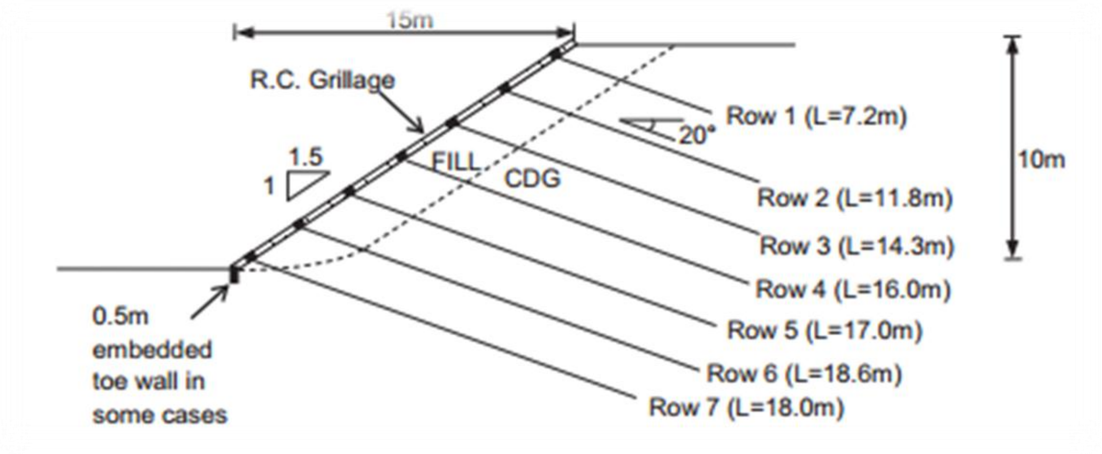
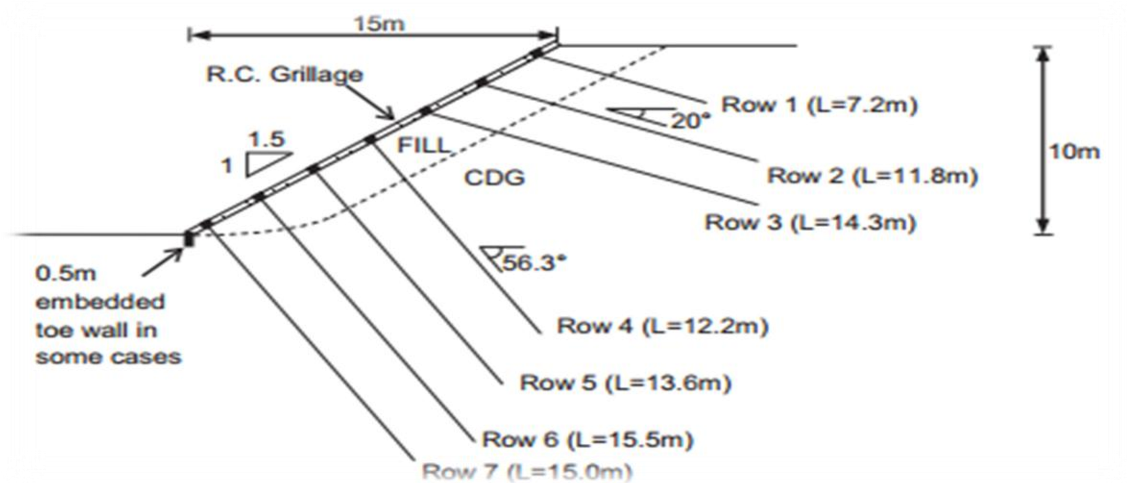


Fig 2.2 Soil slope with less steeper nail inclination at 20 º

Third setup they made hybrid arrangement by putting upper nails at 20º and lower nails at 56.3ºas in fig(2.3) .

Fig 2.3 Soil nails with hybrid inclination 20º inclination at top and 56.3 º at bottom.



After doing the experiment they concluded that by inserting steeper nails at top and less steeper nails at bottom of the slope gave higher stability to the slope

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.2.4

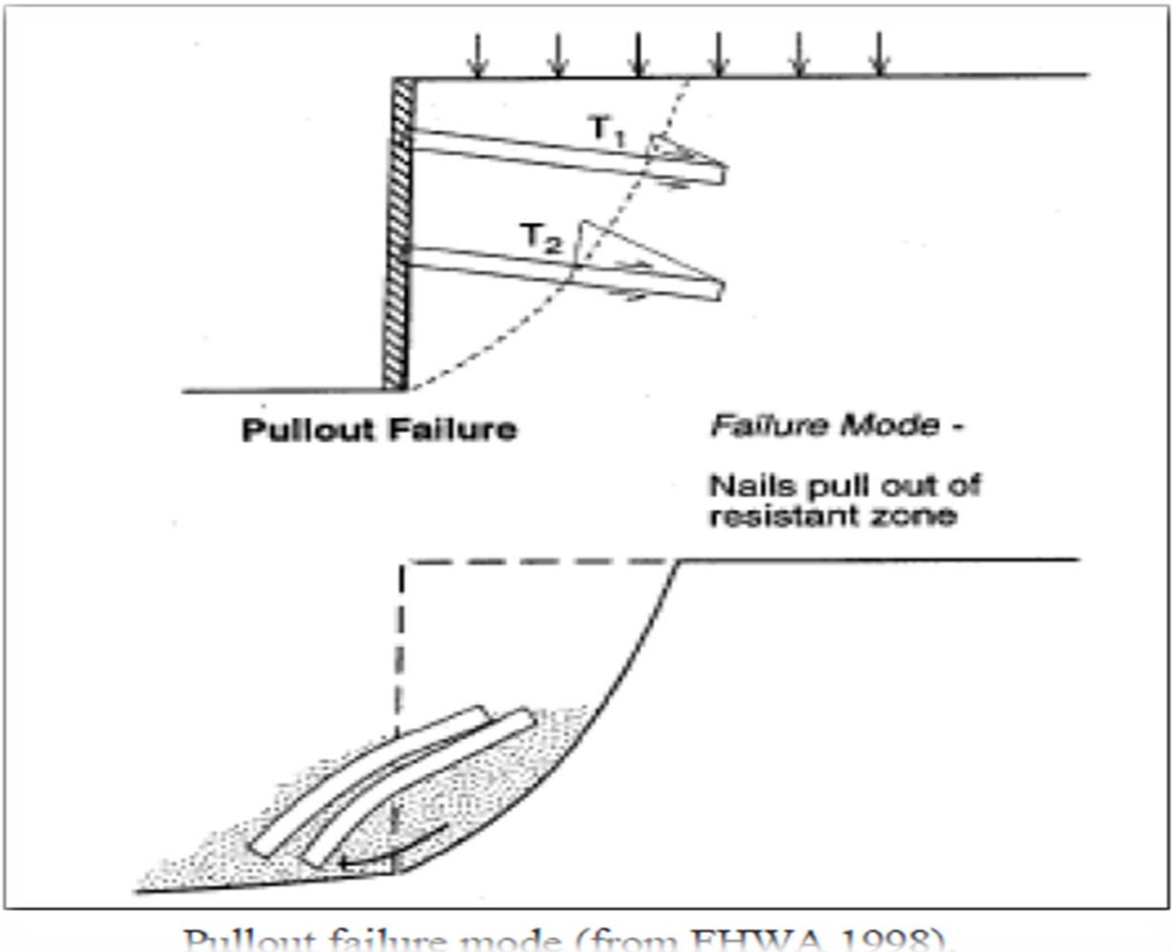


Fig 2.4 Pullout failure mode (from FHWA 1998)

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 shown in fig 2.5 .This could be protected by providing adequate cover to nails to prevent it from corrosion.

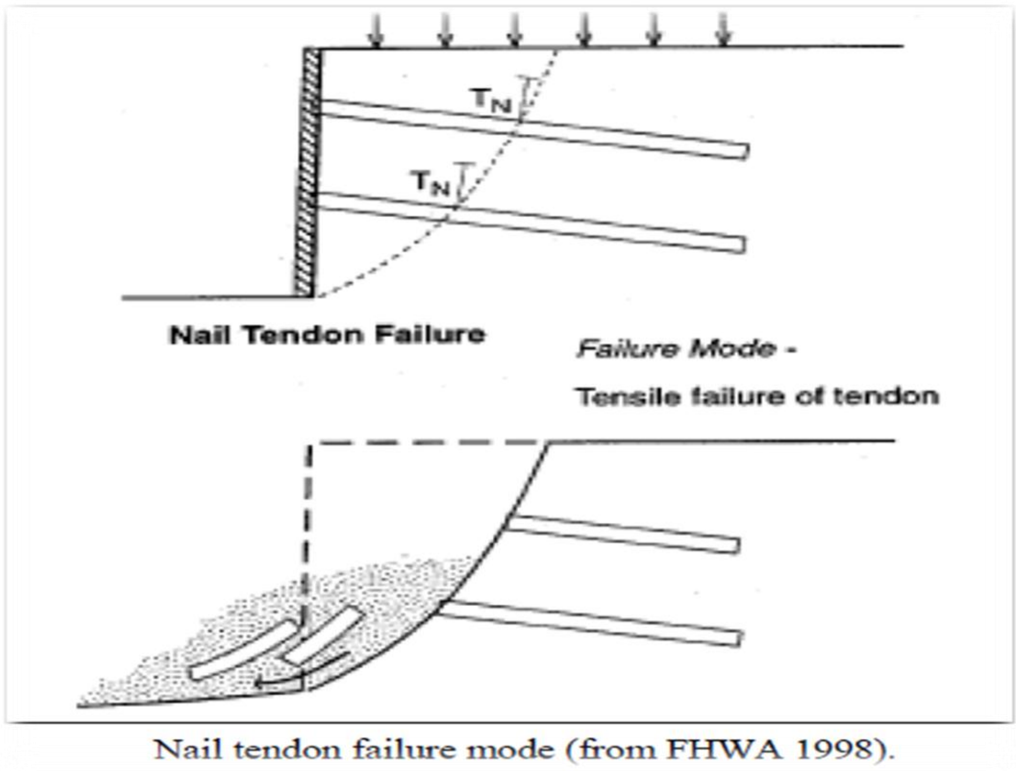


Fig 2.5 Nail tendon failure mode (from FHWA 1998)

Face failure mode for soil nail is generally neglected and due to inadequate thickness of shortcrete nail protrudes out from slope after failure shown in fig 2.6. This failure is prevented by putting steel plate with facing correctly as shown in figure.

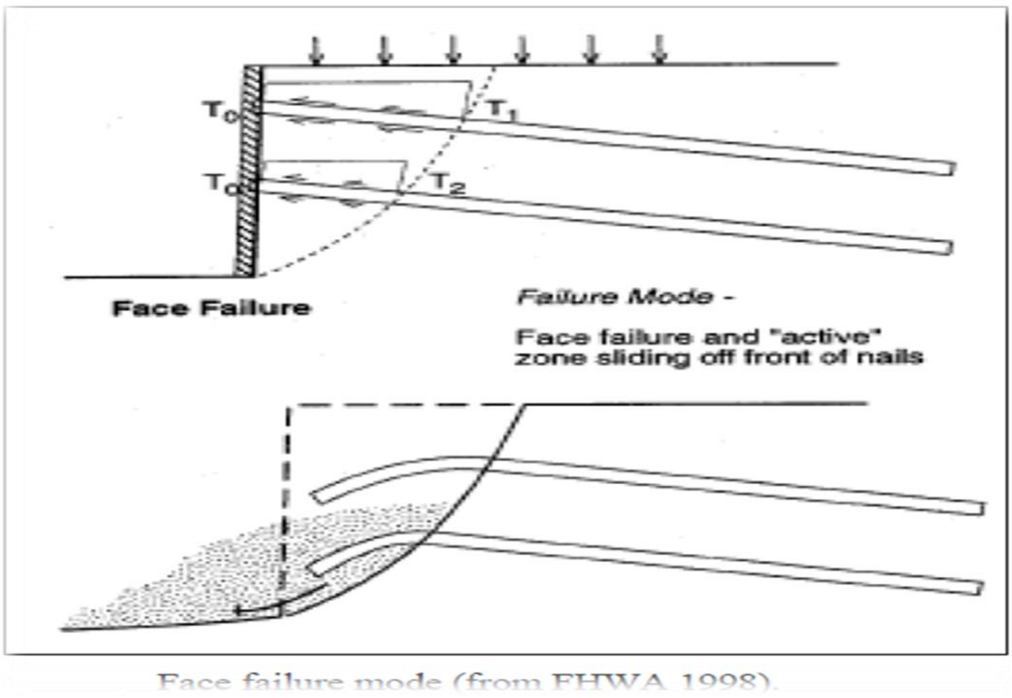


Fig 2.6 Face failure mode (From FHWA 1998)

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 shown in **fig 2.7** and **fig 2.8** 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.

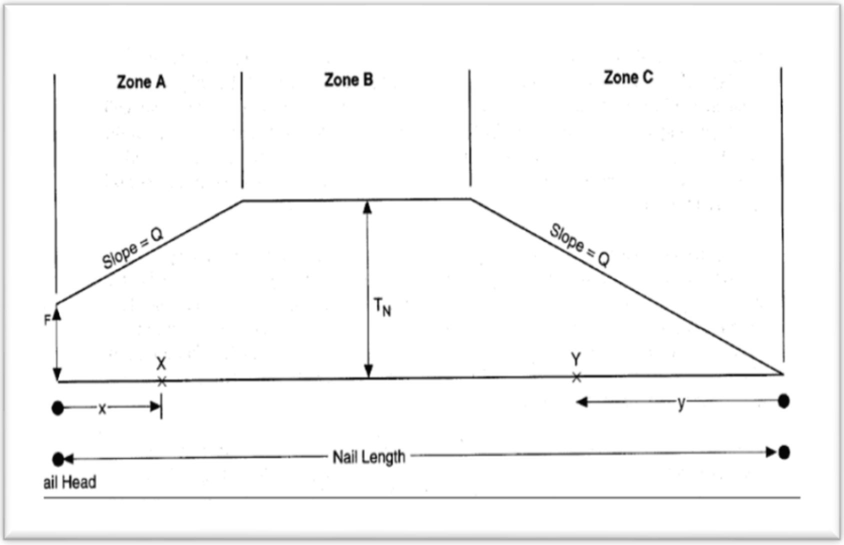


Fig 2.7 Nail load diagram

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.

Stability of slope is not dependent only on nails but also on the type of facing used in the nailing process **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 shown in fig 2.10 and fig 2.11

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 shown in fig2.12,fig2.13 and fig2.14.

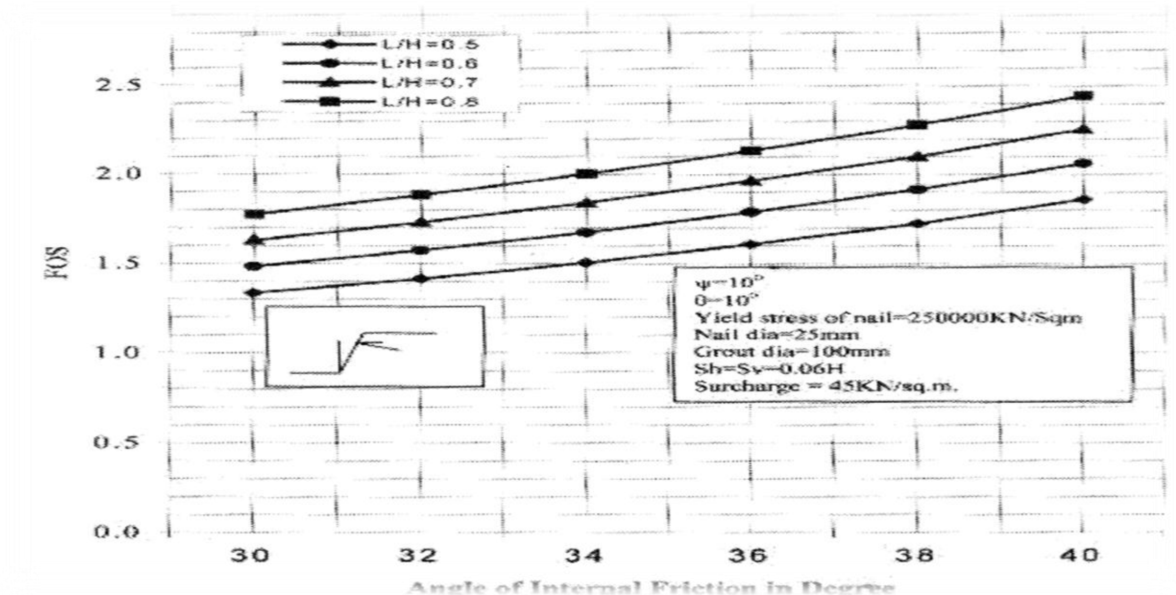


Fig 2.8 Variation of FOS with Angle of Internal friction

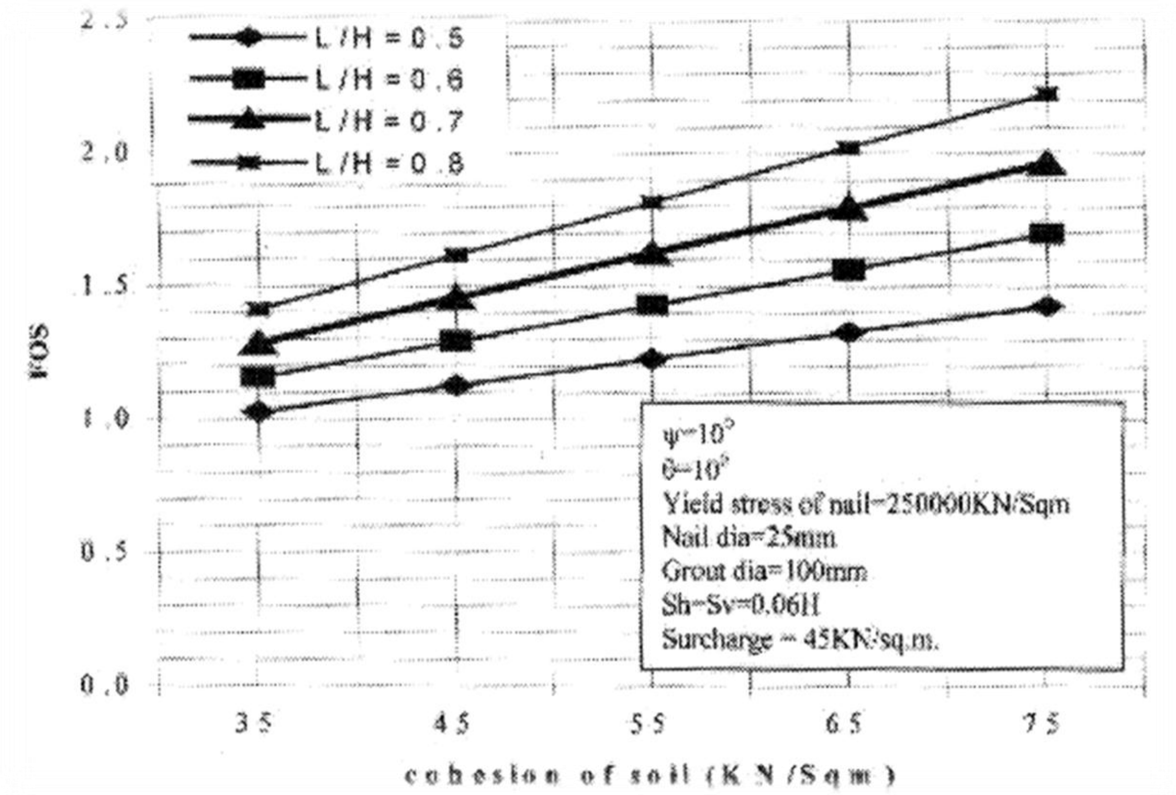


Fig 2.9 Variation of FOS with cohesion of soil

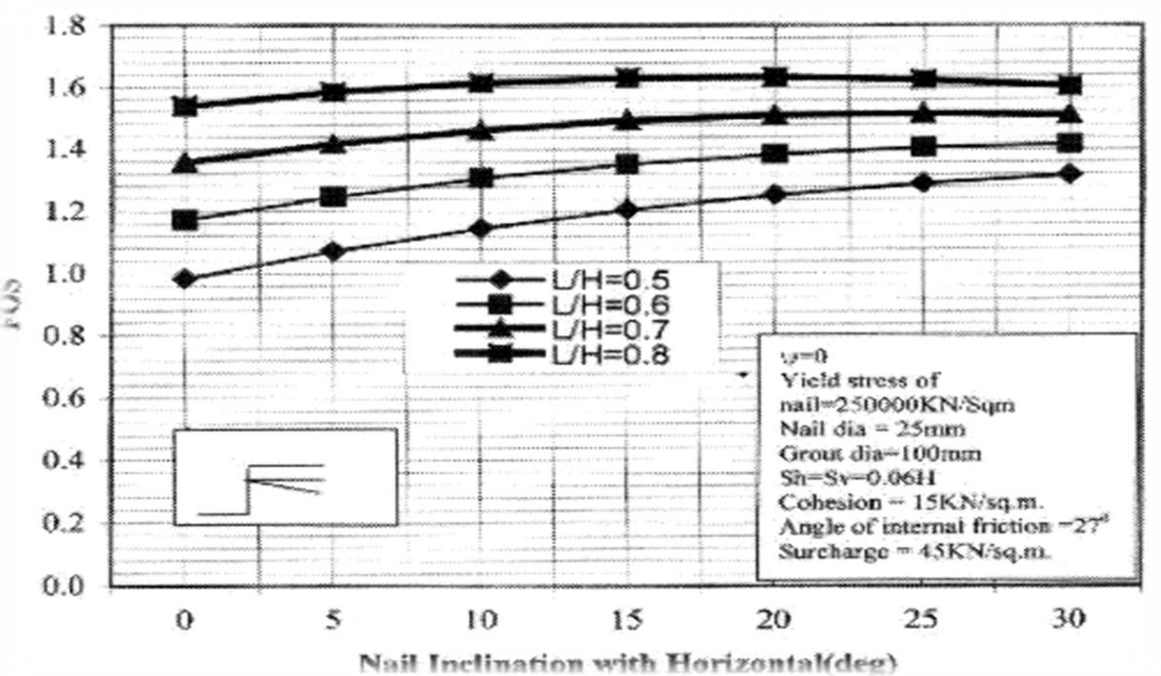


Fig 2.10 Variation of FOS with nail inclination with horizontal

Saytendra Mittal concluded that 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 which are grouted with cement slurry are more effective than the direct driven nails. Nails having length up to 0.8 times the height of cut is a reasonable length for providing a stable cut in soil and minimum nail length required to perform well in field is of 0.7 m. For designing the nailed open cuts the best method which is applicable is friction circle method. If there is no idea of spacing of nails then Horizontal and vertical spacing of nails could be kept the same for less calculation work. FOS is higher for inclined nailed wall than that for a vertical wall because in inclined slopes the vertical components of force are less than that of vertical slope cuts. FOS increases with nail inclination with horizontal up to 15 degrees, beyond which the FOS decreases hence to keep optimum inclination take between 0 to 15 degrees.

2.3 SUMMARY OF LITERATURE REVIEW

In brief what we can understand from the previous experiments is listed as follows.

N.Ramya Gandhi and K. Ilamparuthi

- Effective pile location for clay slope is 0.2 times the width of the slope from the toe.
- In sandy slope the favourable location having higher factor of safety, is at the mid width of slope.
- Factor of safety increases with the length of pile, effective length offering maximum stability to the slope was equal 1 to 2.5 times the slope height.
- Stiffness factor also increase the factor of safety, and maximum factor of safety was obtained when the stiffness factor was 0.002 irrespective of the slope material.
- Factor of safety decreases with increase in pile spacing and the optimum spacing is concluded was 4D for the sandy slope having the slope of 45^0.
- In case of clay spacing was not having any significant effect on soil stability.

C.R. Patra and P.K. Basudhar(2005)

- Nails having larger lengths embedded in the upper part of the slope are generally more stable rather than that of longer nails placed at bottom so embedding larger length nails at top and shorter at bottom of slope could save up to 8 to 27% of pile material.
- Nails inclined upward gives more stability but inclination of the nails has very small range of nearly zero to a maximum of 6^o.

Wan-Huan ZHOU (2008)

- She did pull out test to verify the results from finite element method and concluded following.
- Grouting pressure increases earth pressure, but this it could not be maintained for a very long time.
- Saturation increases the vertical effective stresses and thickness of the soil which was adhered around the nail .

B. R. Srinavasa Murthy, G. L. SivakumarBabu and A. Srinavas(2002)

- They checked the stability of wall and find out the critical depths with and without soil nailing. And their experiment showed that the critical depth of wall became twice when nails were inserted into the wall.

C.Y. Cheuk, K.K.S. Ho, and A.Y.T. Lam

- They inserted nails at different angles and at different locations concluded that inserting steeper nails at top and less steeper nails at bottom of the slope gave higher stability to the slope.

Saytendra Mittal

- Nails grouted with cement slurry are more effective than the direct driven nails.
- Nails having length up to 0.8 times the height of cut is a reasonable length for providing a stable cut in .
- For designing the nailed open cuts the best method which is applicable is friction circle method.
- If there is no idea of spacing of nails then Horizontal and vertical spacing of nails could be kept the same for less calculation work.

FOS is higher for inclined nailed wall than that for a vertical wall.

2.4 Objectives

Following are the objectives of our study

- Study of reinforcing effect of screw nails and helical nails on soil slopes at 45°, 60° and 90°.
- Study of failure mechanism, load displacement of nailed slope with nail inclination of 15° and 30°.

- Study that what will be the benefit of nailing if we insert it by screwing it rather than normal drilling
- Study of nail forces along screw nails and helical nails and check which nail is having highest mobility also to see its effect on slope's longitudinal displacement.
- To check the longitudinal displacement of slope when force is applied on the nailed slope prototype as main function of nails is to restrict the displacement.

CHAPTER 3

METHODOLOGY

3.1 General

In the project certain equipments were used. A model tank of dimension 60cm X 40cm X 60cm. 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 the experiment certain tests were performed on the soil like sieve analysis, pycnometer test, direct shear test.

3.2 Equipment Used

3.2.1 Model Tank

Model Tanks has been fabricated as in fig.3.2.1 (b). Materials used in fabrication are:

a) Pesrpex Sheet - Poly-methyl methacrylate (PMMA), also known as acrylic or acrylic glass as well as by the trade names Plexiglas, Acrylite, Lucite, and Perspex, 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 it's occasional historic designation as acrylic. Chemically, it is the synthetic polymer of methyl methacrylate. It's thickness 2mm.

b) Iron Angles

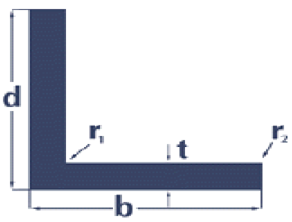


Fig. 3.2.1 (a) Iron angle used in fabrication of model tank

D	30	Depth d mm
B	30	Width b mm
T	3	Thickness t mm

c) Screws

Size of each Model Tank is 60cm X 40cm X 60cm.

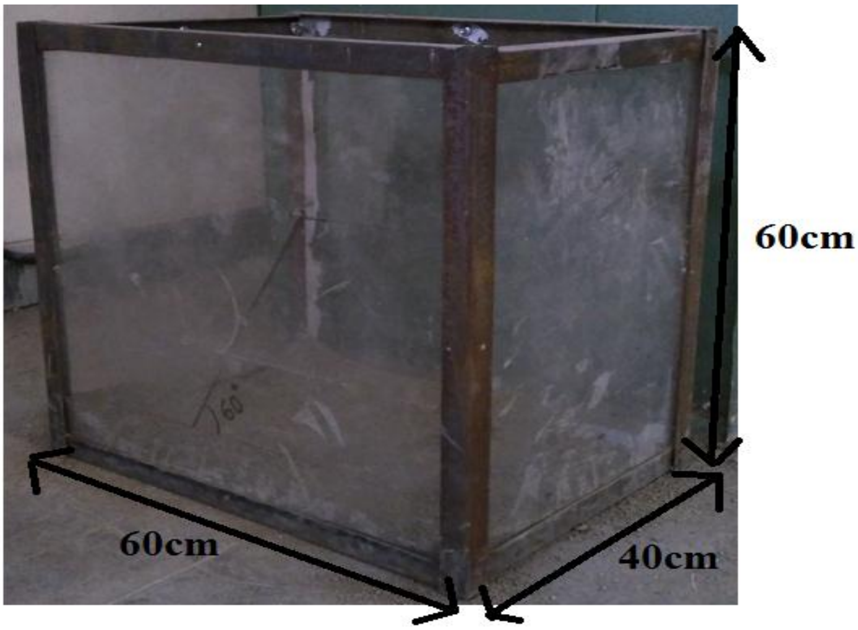


Fig. 3.2.1 (b) Model Tank

3.2.2 Nails

6 hollow screw nails of Stainless Steel are fabricated with threads on it as in fig.3.2.2.(a).

Length of a nail = 170mm

Inner Diameter of a nail = 8mm

Outer Diameter of a nail = 12mm

On each nail foil strain gauge was put and connecting wires were soldered.

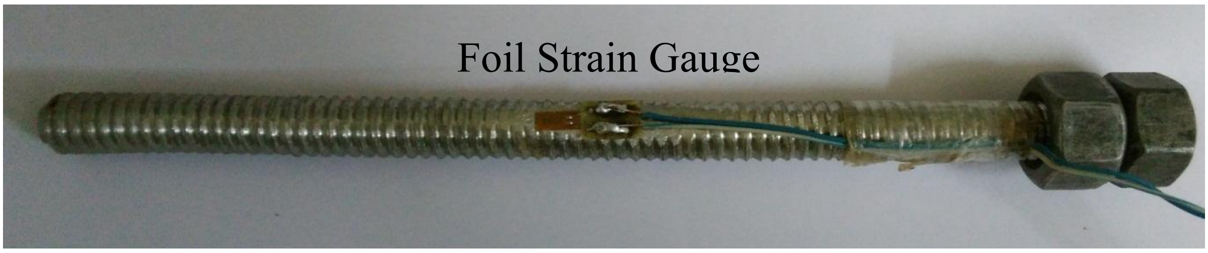


Fig. 3.2.2.(a) Screw nail Fitted with Foil Strain Gauge

6 hollow helical nails of Galvanised Iron pipe are fabricated with helical on it as in fig.3.2.2.(b).

Length of a nail = 175mm

Inner Diameter of a nail = 14mm

Outer Diameter of a nail = 18mm

Diameter of helical = 40mm

On each nail foil strain gauge was put and connecting wires were soldered.

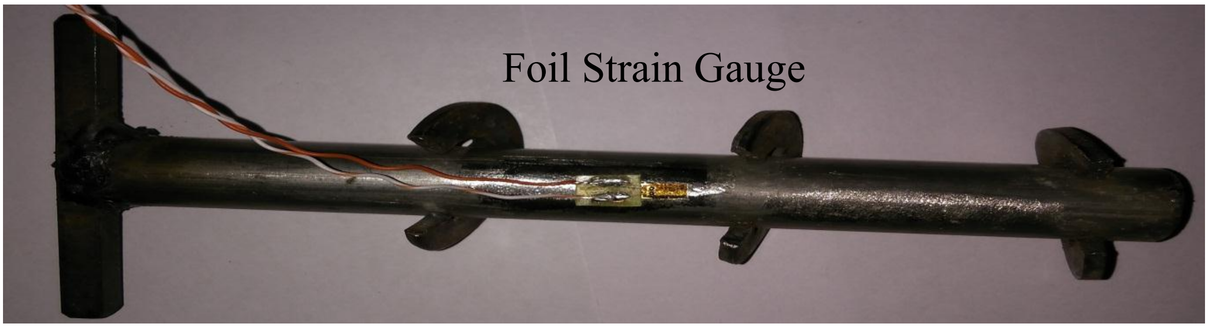


Fig. 3.2.2.(b) Helical nail Fitted with Foil Strain Gauge

3.2.3 Foil Strain Gauges

Foil Strain Gauges are pressure transmitters which are used to detect strain. Foil Strain Gauges used were of 120 Ω. A Foil Strain Gauge was mounted on each nail and was soldered with copper wires.

Basal Size = 6.6 X 3.2 mm

Wire Grid Size = 3.0 X 2.3 mm

The Basal Material – Phenolic-Epoxy-Acetal

The Nominal Tolerance - <3Ω

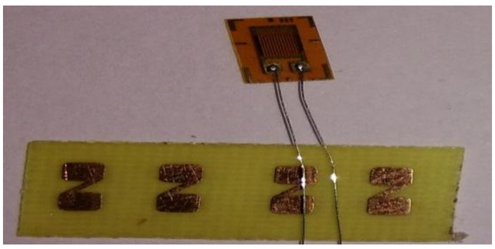


Fig. 3.2.3 Foil Strain Gauge

3.2.4 Digital Multimeter

A **digital multimeter (DMM)** is a test tool used to measure two or more electrical values—principally voltage (volts), current (amps) and resistance (ohms). It is a standard diagnostic tool for technicians in the electrical/electronic industries.

Digital multimeters long ago replaced needle-based analog meters due to their ability to measure with greater accuracy, reliability and increased impedance. Fluke introduced its first digital multimeter in 1977.

Digital multimeters combine the testing capabilities of single-task meters—the voltmeter (for measuring volts), ammeter (amps) and ohmmeter (ohms). Often they include a number of additional specialized features or advanced options. Technicians with specific needs, therefore, can seek out a model targeted for particular tasks.

The face of a digital multimeter typically includes four components:

- Display: Where measurement readouts can be viewed.
- Buttons: For selecting various functions; the options vary by model.
- Dial (or rotary switch): For selecting primary measurement values (volts, amps, ohms).
- Input jacks: Where test leads are inserted.

We used DT830D Digital Multimeter for measure of voltage in milli volts.

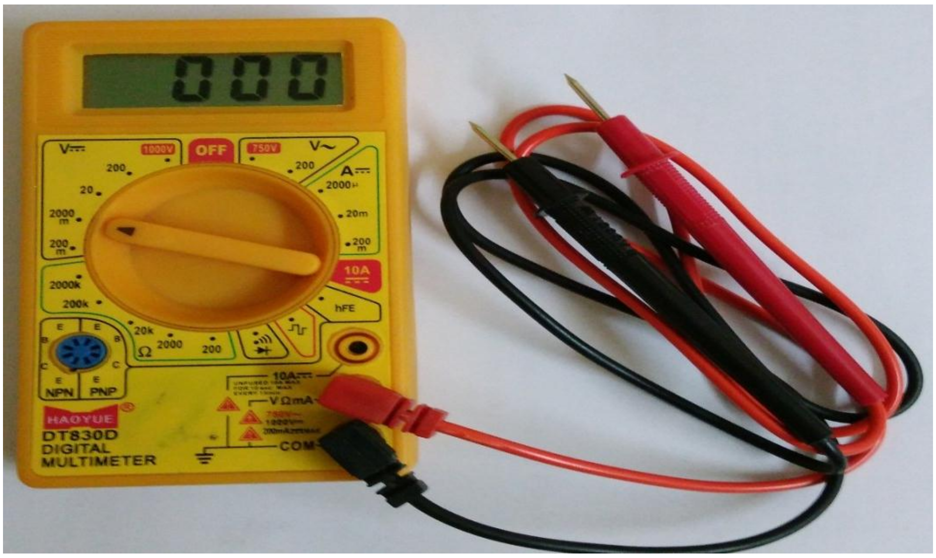


Fig. 3.2.4 Digital Multimeter

3.2.5 Wheatstone Bridge

A **Wheatstone bridge** is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. The primary benefit of a wheatstone bridge is its ability to provide extremely accurate measurements (in contrast with something like a simple voltage divider). Its operation is similar to the original potentiometer.

$$\frac{R1}{R2} = \frac{R3}{R4}$$

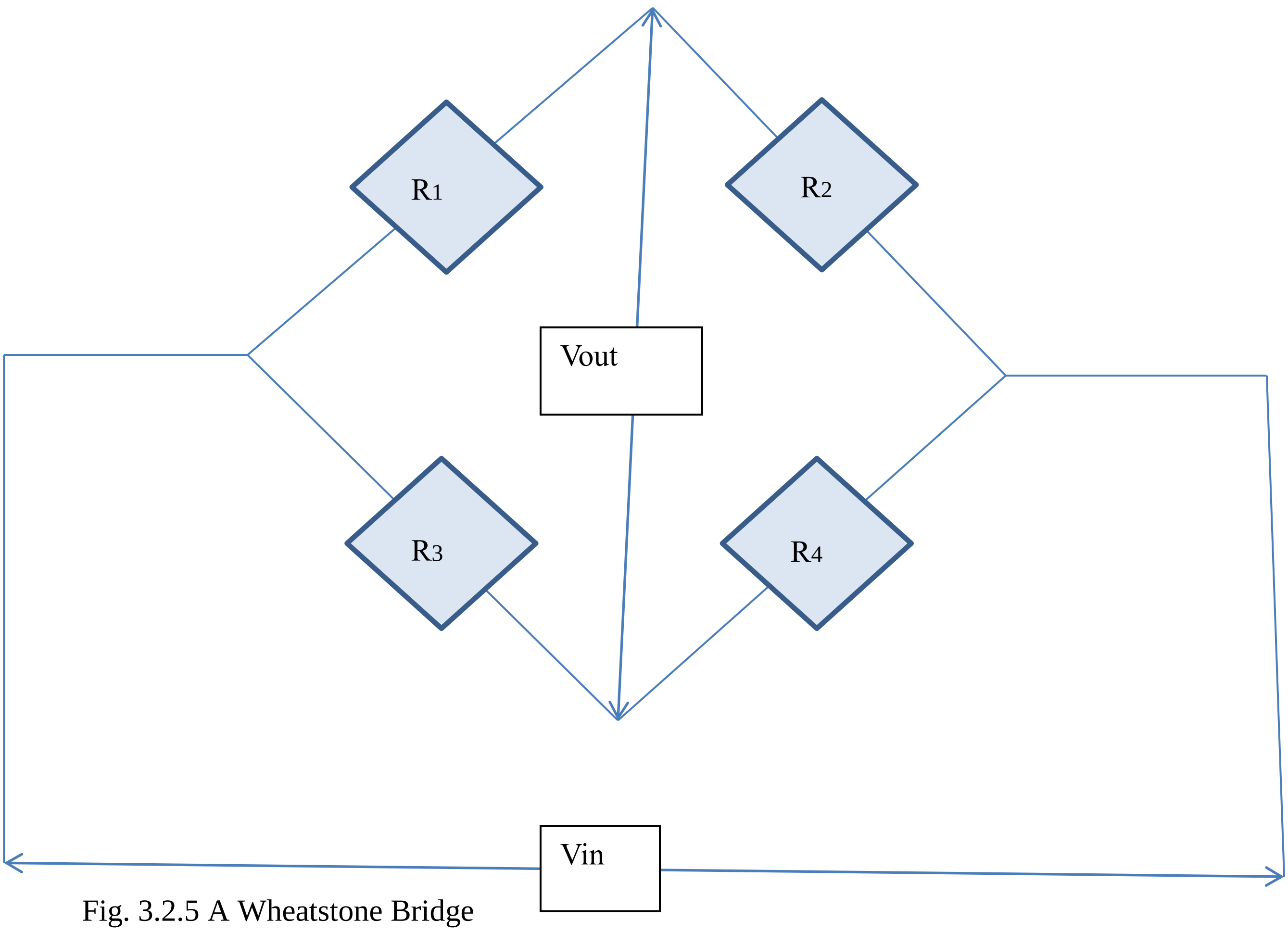


Fig. 3.2.5 A Wheatstone Bridge

3.2.6 Connecting Wires

Copper wires of diameter 1mm were used for connections.

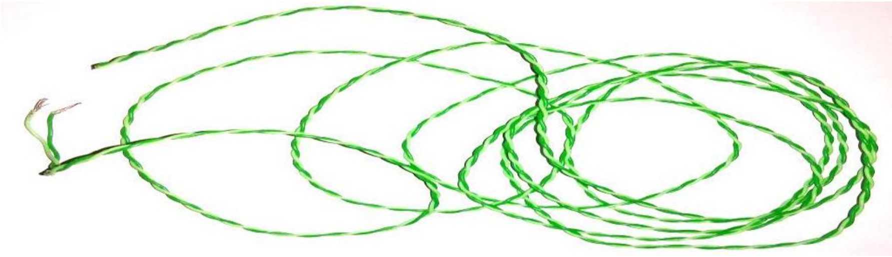


Fig. 3.2.6 Copper Connecting Wires

3.3 Soil Tests

3.3.1 Sieve Analysis

A **sieve analysis** (or **gradation test**) is a practice or procedure used (commonly used in civil engineering) to assess the particle size distribution (also called gradation) of a granular material.

The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, crushed rock, clays, granite, feldspars, coal, and soil, a wide range of

manufactured powders, grain and seeds, down to a minimum size depending on the exact method. Being such a simple technique of particle sizing, it is probably the most common.

Procedure:

Take oven dried sample of soil that weighs about 1000 g. If soil particles are lumped or conglomerated crush the lumped and not the particles. Determine the mass of the sample accurately. Prepare the stack of sieves, sieves having larger opening are placed above the sieves having smaller opening. A pan is placed under the last sieve to collect the soil passing throughh the last sieve. Here is the list of sieves used.

Table 3.3.1 Size sieves used

Sieve Size (μm)
10000
4750
2000
1000
600
425
300
212
150
75

Make sure sieves are clean, if many soil particles are stuck in the openings try to poke them out using brush. Pour the soil from step 3 into the stack of sieves from the top and place the cover, put the stack in the sieve shaker and fix the clamps, adjust the time on 10 to 15 minutes and get the shaker going. Stop the sieve shaker and measure the mass of each soil retained.

3.3.2 Pycnometer Test

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:

$$\boldsymbol{G = \frac{M2-M1}{(M2-M1)-(M3-M4)}} \text{.....................................} \textbf{eq (a)}$$

Where,

M_1=mass of empty Pycnometer,

M_2= mass of the Pycnometer with dry soil

M_3= mass of the Pycnometer and soil and water,

M_4 = mass of Pycnometer filled with water only.

G= Specific gravity of soil.

Procedure:

Clean and dry the Pycnometer. Tightly screw its cap. Take its mass (M_1) to the nearest of 0.1 g as in fig. 3.3.2 (a). Unscrew the cap and place about 200 g of oven dried soil in the Pycnometer. Screw the cap. Determine the mass (M_2) as in fig 3.3.2 (b). Unscrew the cap and add sufficient amount of de-aired water to the Pycnometer so as to cover the soil. Screw on the cap. Shake well the contents. Leave the Pycnometer to a still to remove the entrapped air, for about 20 minutes for fine-grained soils and about 10 minutes for coarse-grained soils. Fill the Pycnometer with water, about three-fourths full. Reapply the vacuum for about 5min till air bubbles stop appearing on the surface of the water. Fill the Pycnometer with water completely upto the mark. Dry it from outside. Take its mass (M_3) as in fig 3.3.2 (c). Empty the Pycnometer. Clean it and wipe it dry. Fill the Pycnometer with water only. Screw on the cap upto the mark. Wipe it dry. Take its mass (M_4) as in fig 3.3.2 (d).

Fig 3.3.2 (a) M_1 Mass of empty pycnometer bottle

Fig 3.3.2 (b) M_2 Mass of pycnometer with soil

Fig 3.3.2 (b) M_2 Mass of pycnometer with soil and water

Fig. 3.3.2 (d) M_4 Mass of pycnometer with water

3.3.3 Direct Shear Test

A **direct shear test** is a laboratory or field test used by geotechnical engineers to measure the shear strength properties of soil or rock material, or of discontinuities in soil or rock masses.

The test is performed on three or four specimens from a relatively undisturbed soil sample. A specimen is placed in a shear box which has two stacked rings to hold the sample; the contact between the two rings is at approximately the mid-height of the sample. A confining stress is applied vertically to the specimen, and the upper ring is pulled laterally until the sample fails, or through a specified strain. The load applied and the strain induced is recorded at frequent intervals to determine a stress–strain curve for each confining stress. Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion (c) and the angle of internal friction, commonly known as friction angle (ϕ). The results of the tests on each specimen are plotted on a graph with the peak (or residual) stress on the y-axis and the confining stress on the x-axis. The y-intercept of the curve which fits the test results is the cohesion, and the slope of the line or curve is the friction angle.

A number of samples of the soil are tested each under different vertical loads and the value of shear stress at failure is plotted against the normal stress for each test. Provided there is no excess pore water pressure in the soil, the total and effective stresses will be identical. From the stresses at failure, the failure envelope can be obtained.

The test has several **advantages:**

• It is easy to test sands and gravels.

• Large samples can be tested in large shear boxes, as small samples can give misleading results due to imperfections such as fractures and fissures, or may not be truly representative.

• Samples can be sheared along predetermined planes, when the shear strength along fissures or other selected planes are needed.

The **disadvantages** of the test include:

• The failure plane is always horizontal in the test, and this may not be the weakest plane in the sample. Failure of the soil occurs progressively from the edges towards the centre of the sample.

• There is no provision for measuring pore water pressure in the shear box and so it is not possible to determine effective stresses from undrained tests.

• The shear box apparatus cannot give reliable undrained strengths because it is impossible to prevent localised drainage away from the shear plane.

Direct Shear Test without Nail

Procedure:

Check the inner dimension of the soil container. Put the parts of the soil container together. Place the soil in smooth layers (approximately 10 mm thick) and tamp the soil. Make the surface of the soil plane. Put the upper grating and loading block on top of soil. Apply the desired normal load. Remove the shear pin. Attach the dial gauge which measures the change. Start the motor. Take the reading of the shear force and record the reading.

Fig. 3.3.3 (a) Direct Shear Test Machine

Fig. 3.3.3 (b) Soil Sample Preparation

Direct Shear Test with Nail

Procedure:

Check the inner dimension of the soil container. Put the parts of the soil container together. Place the soil in smooth layers (approximately 10 mm thick) and tamp the soil. Make the surface of the soil plane. At the middle height place the nail horizontally as in fig 3.3.3 (c). Put the upper grating and loading block on top of soil. Apply the desired normal load. Remove the shear pin. Attach the dial gauge which measures the change. Start the motor. Take the reading of the shear force and record the reading.

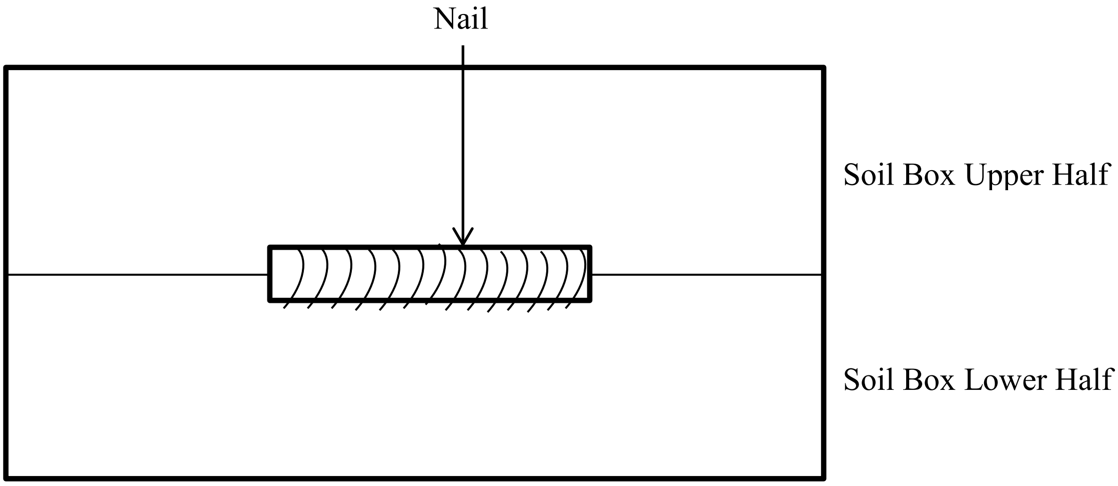


Fig. 3.3.3 (c) Soil Box with nail

Fig. 3.3.3 (d) Placing of nail.

3.4 Slope Preparation

3 slopes were to be tested- 45°, 60° and 90°.

3.4.1 Preparation of 45° Slope

Procedure:

The slope is divided in layers of 5cm and markings 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 90kg. Base is made in layers of 5cm weighing 22.5kg each. After pouring 22.5kg of soil, tamping is done to get the desired density. After base of 20cm is prepared, the facing of dimension 42.4cmX40cm of wooden ply as in fig 3.4.1 (b) is fixed at the marking of 45°. The wooden ply has hole for the nails. Vertical spacing of hole on ply=10.6cm. Horizontal spacing of hole on ply=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 = 15° or 30° from horizontal as in fig 3.4.1 (a). The weight of soil for slope is calculated according to the density, 18.393KN/m^3.

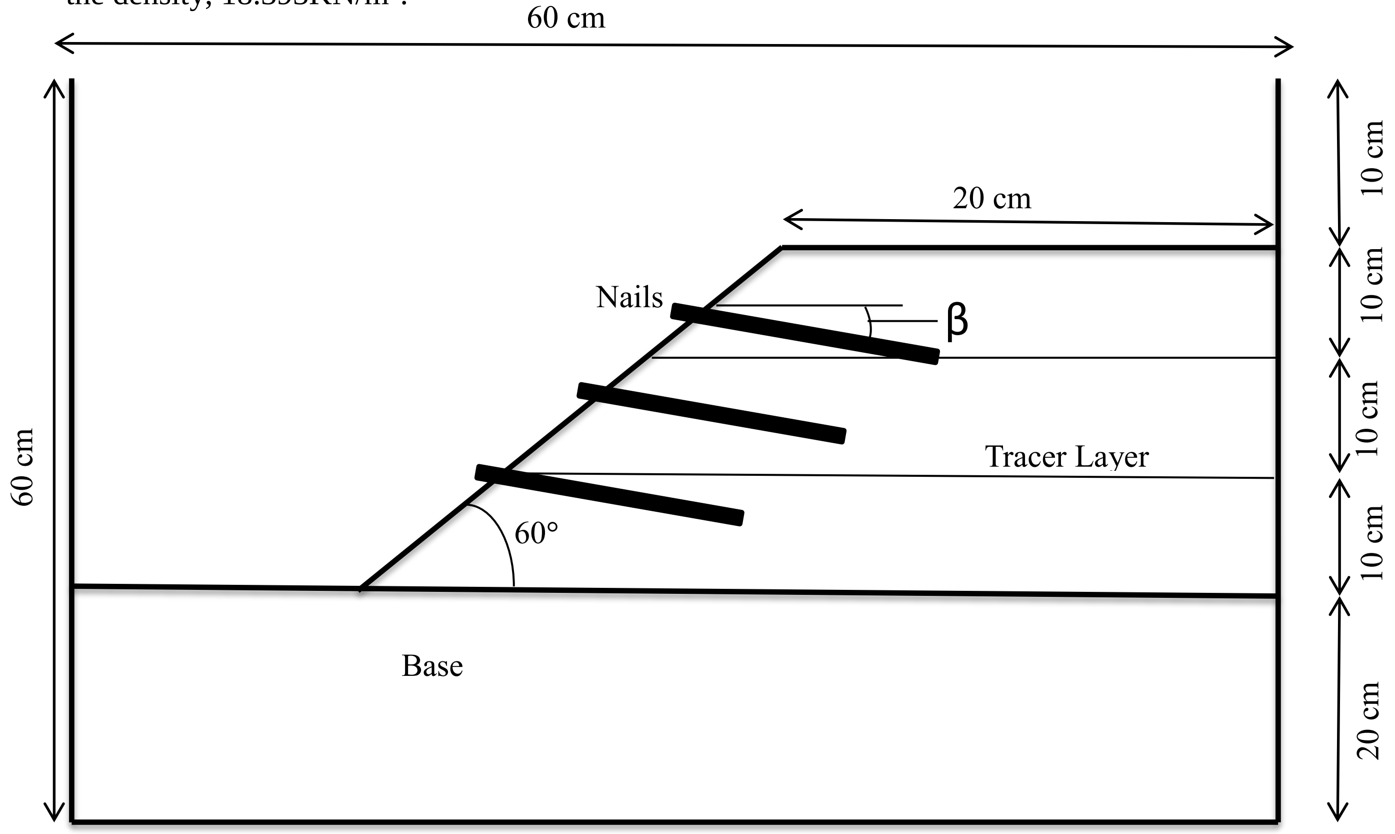


Fig. 3.4.1 (a) Cross-section of a 45° slope.

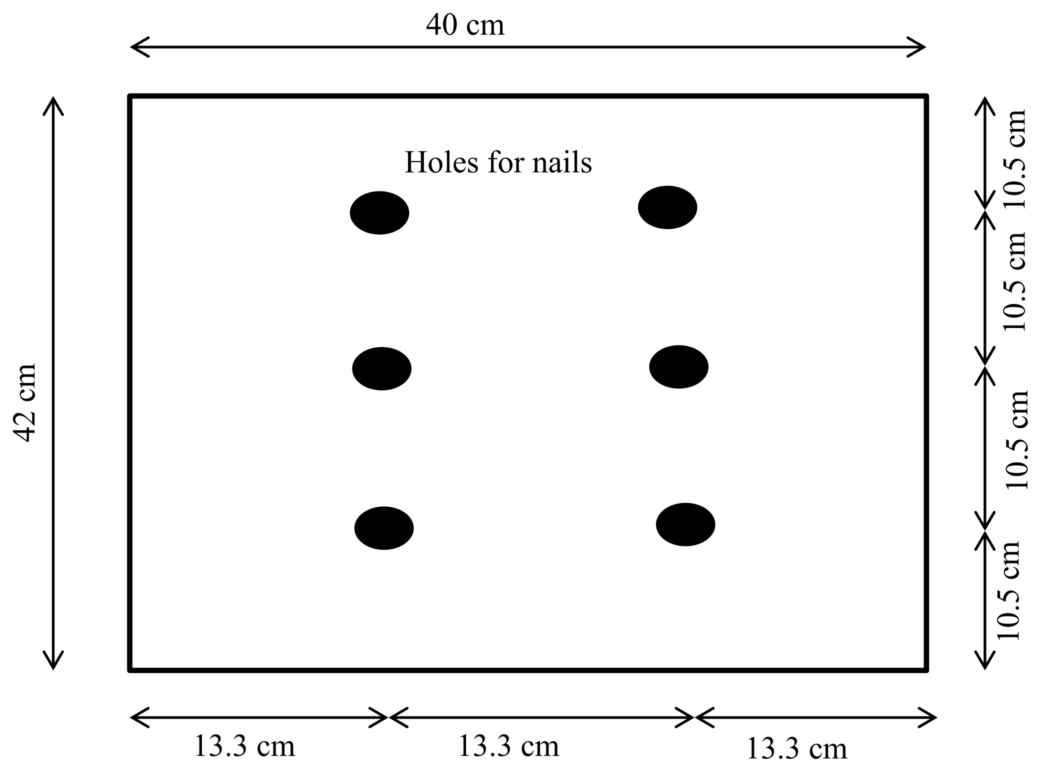


Fig 3.4.1 (b) Cross-section of facing of wooden ply.

3.4.2 Preparation of 60° Slope

Procedure:

The slope is divided in layers of 5cm and markings 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 90kg. Base is made in layers of 5cm weighing 22.5kg each. After pouring 22.5kg of soil, tamping is done to get the desired density. After base of 20cm is prepared, the facing of dimension 34.6cmX40cm of wooden ply as in fig 3.4.2 (b) is fixed at the marking of 60°. The wooden ply has hole for the nails. Vertical spacing of hole on ply = 8.6cm. Horizontal spacing of hole on ply=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. Nails are at 15° or 30° from horizontal as in fig 3.4.2 (a). Tamping is done to get the desired density. The weight of soil for slope is calculated according to the density, 18.5KN/m^3.

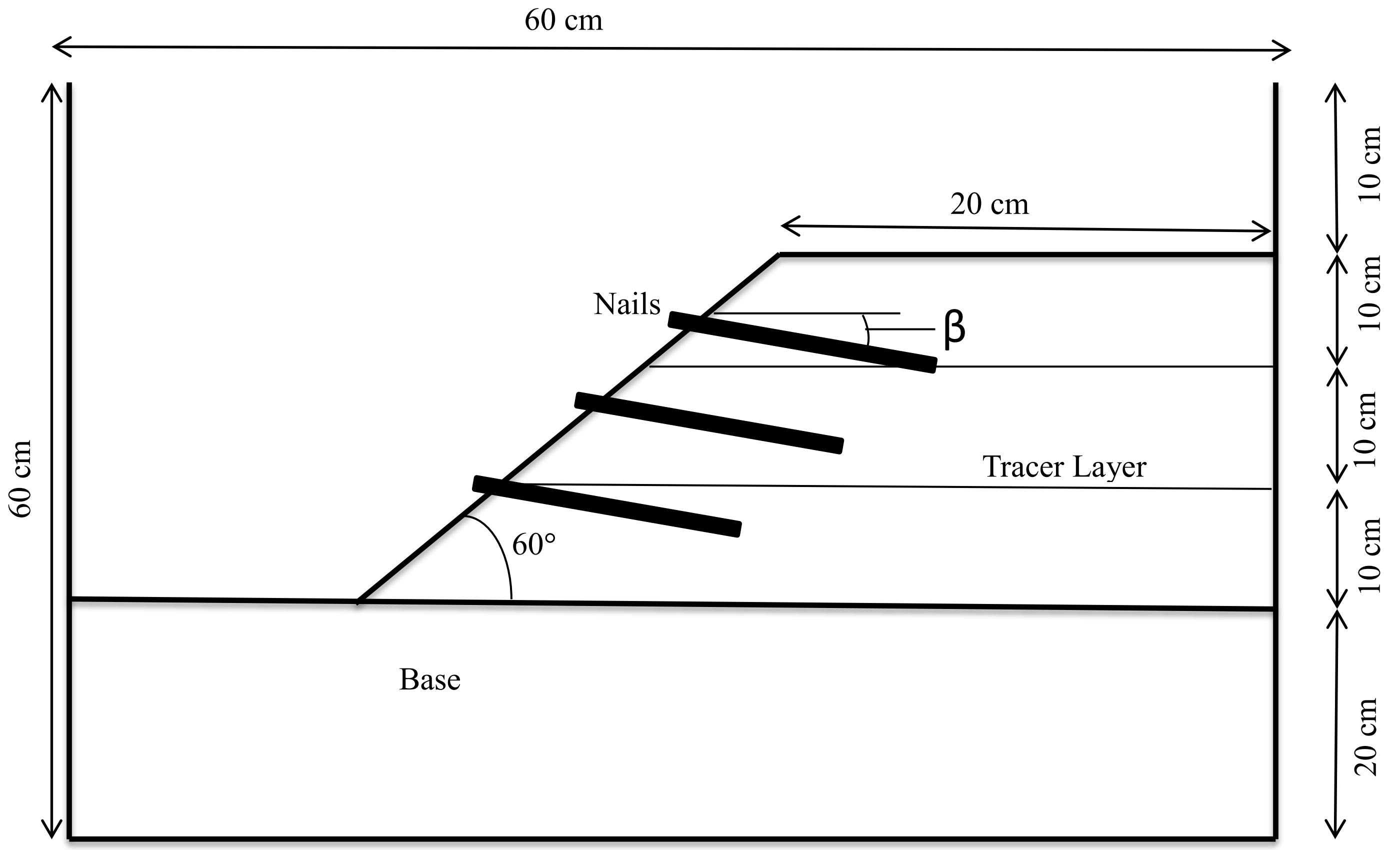


Fig. 3.4.2 (a) Cross-section of 60° slope

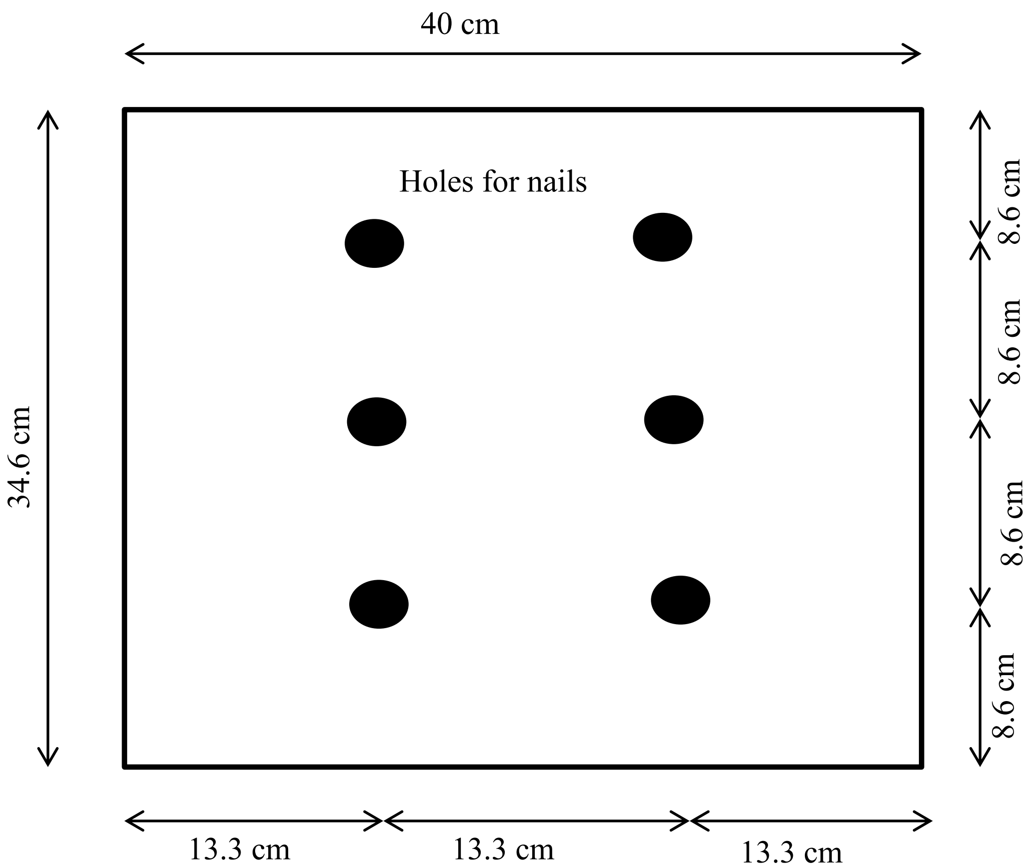


Fig. 3.4.2 (b) Cross-section of facing of wooden ply.

3.4.3 Preparation of 90° Slope

Procedure:

The slope is divided in layers of 5cm and markings 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 90kg. Base is made in layers of 5cm weighing 22.5kg each. After pouring 22.5kg of soil, tamping is done to get the desired density. After base of 20cm is prepared, the facing of dimension 30cmX40cm of wooden ply as in fig . 3.4.3 (b) is fixed at the marking of 90°. The wooden ply has hole for the nails. Vertical spacing of hole on ply=7.5cm. Horizontal spacing of hole on ply=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. Nails are at 15° or 30° from horizontal as in fig 3.4.3 (a). Tamping is done to get the desired density. The weight of soil for slope is calculated according to the density, 18.393KN/m^3.

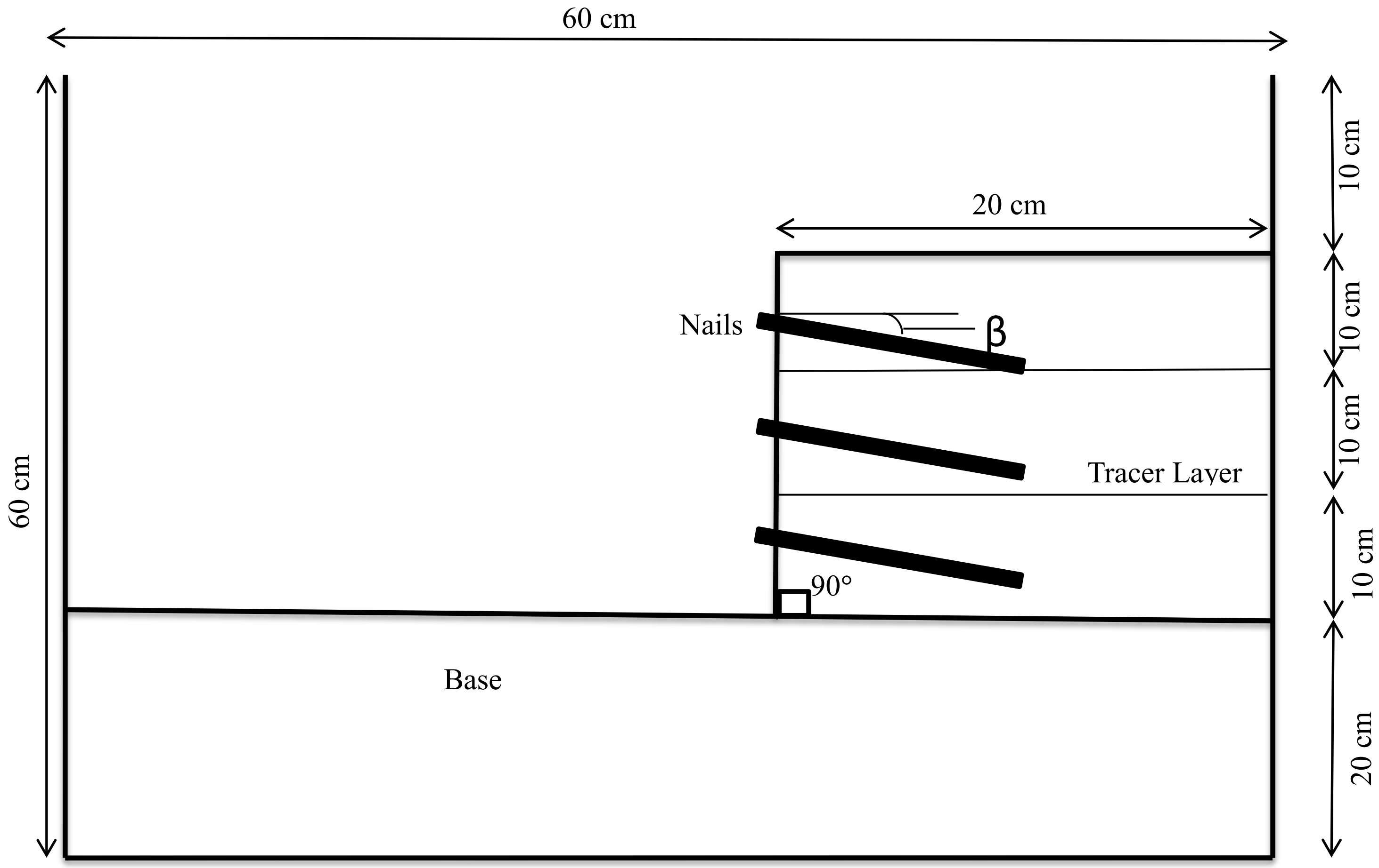


Fig. 3.4.3 (a) Cross-section of 90° slope.

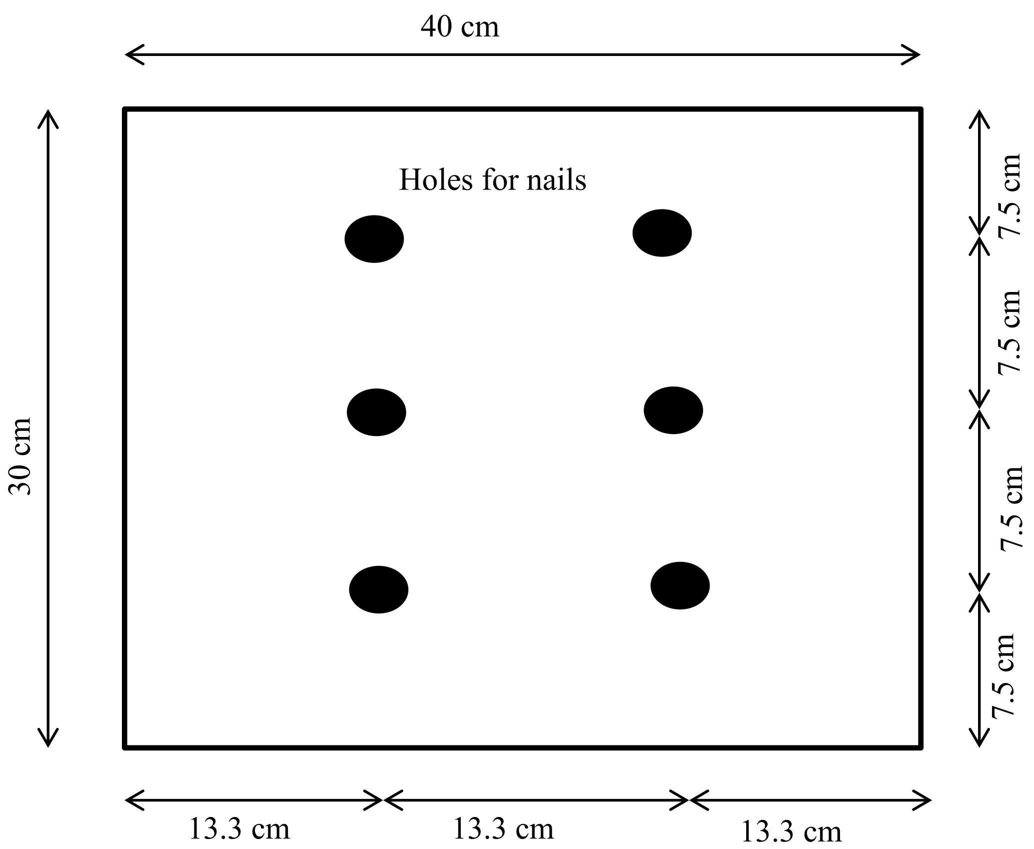


Fig. 3.4.3 (b) Cross-section of facing of wooden ply.

3.5 Testing Procedure

Testing of slope was done by applying load from UTM and measuring the change in resistance of strain gauge in each nail.

Procedure:

Six nail are installed in each slope fitted with strain gauges at the middle of each nail. These strain gauges are soldered with wires. Each strain gauge is connected to a separate wheatstone bridge. Each wheatstone bridge is supplied with input voltage of about 5V as given in table 3.5.2. The load is applied from UTM on the slope with a bearing plate of iron on top of size 40cm X 20cm to give uniform loading as in fig 3.5 (d). As the load increases, the resistance in strain gauge changes which is measured by measuring the output voltage of wheatstone bridge which is recorded as in fig 3.5 (b) and 3.5 (c). Connection is shown in fig 3.5 (a). The relation between voltage and resistance of wheatstone bridge is:

$$\frac{\text{Vout}}{\text{Vin}} = \left(\left(\frac{\text{R3}}{\text{R3+Rg}}\right) - \left(\frac{\text{R2}}{\text{R2+R1}}\right)\right) \text{……………..…….eq.1}$$

Vin – Input voltage provided to the wheatstone bridge as given in table 3.5.2 and table 3.5.4

R_1, R_2, R_3 – Arms of wheatstone bridge as given in table 3.5.1 and table 3.5.3

Rg – Resistance of foil strain gauge

Now this resistance value is used to calculate the strain value of the nail by the formula:

$$\varepsilon = \frac{\frac{\Delta R}{R}}{GF} \quad \text{...eq.2}$$

ΔR – Change in resistance

R – Initial resistance of foil strain gauge

GF – Gauge Factor

Ɛ-Strain in nail

Frome recorded output voltage and provided input voltage and known resistors R_1, R_2 and R_3 gauge resistance Rg is calculated by the formula given in eq.1. From this recorded values of Rg, change in resistance if calculated ΔR and from this ΔR, strain in the nail is calculated by the formula given in eq.2.

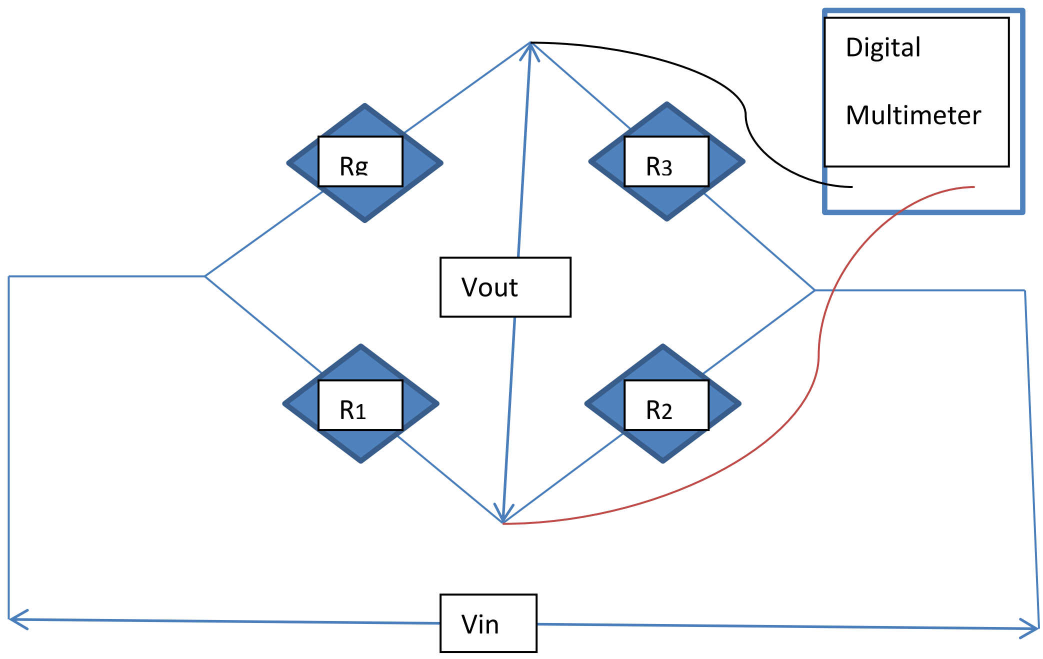


Fig. 3.5 (a) Setup a wheatstone bridge circuit used.

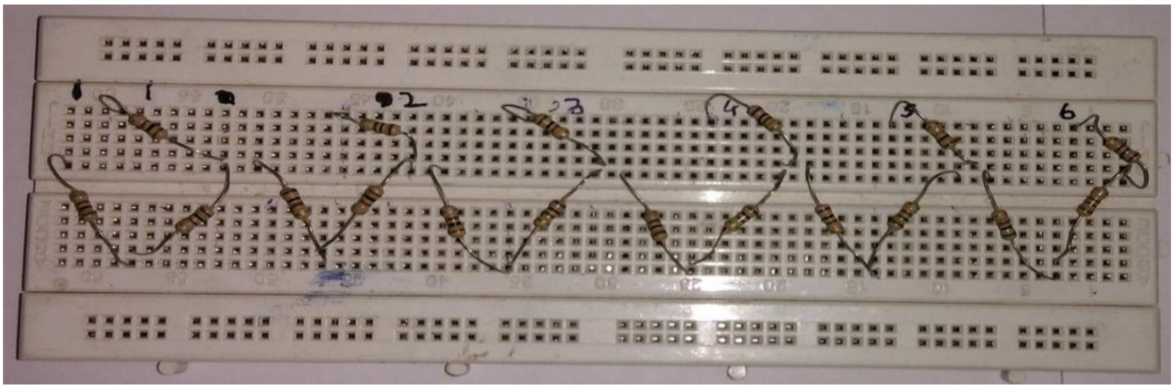


Fig 3.5 (b) Breadboard with 6 separate wheatstone bridges.

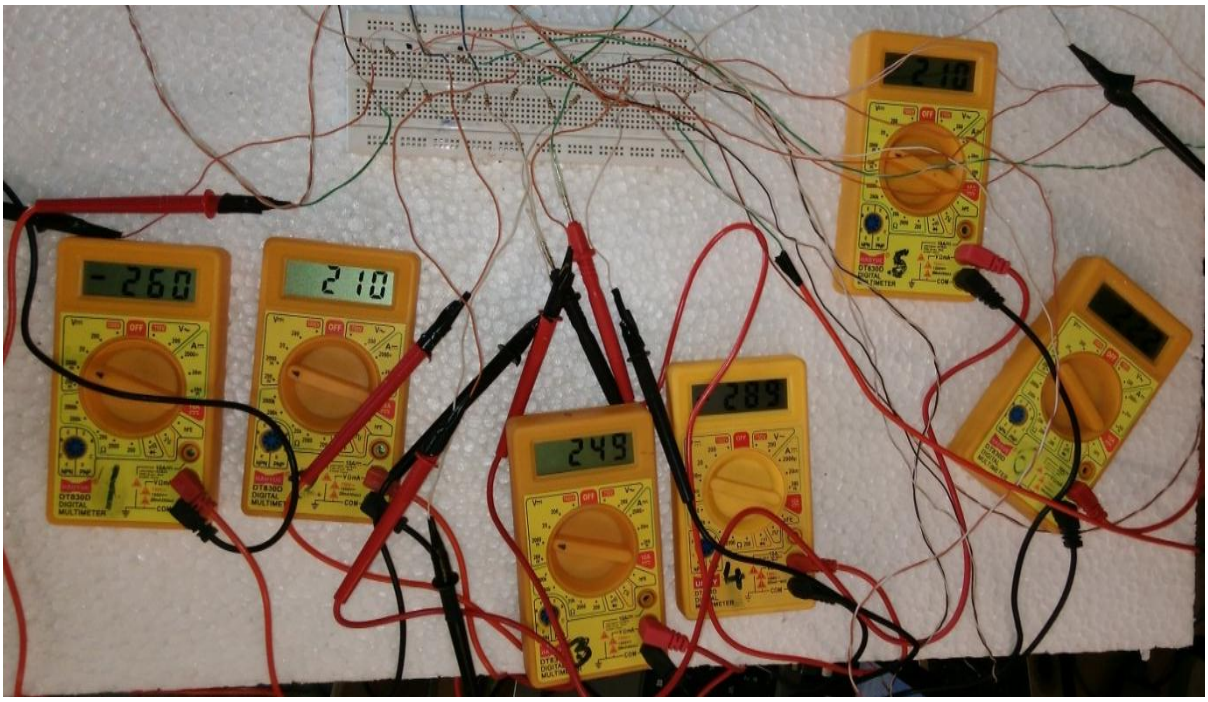


Fig. 3.5 (c) Digital Multimeters connected to wheatstone bridges to measure V_{out}

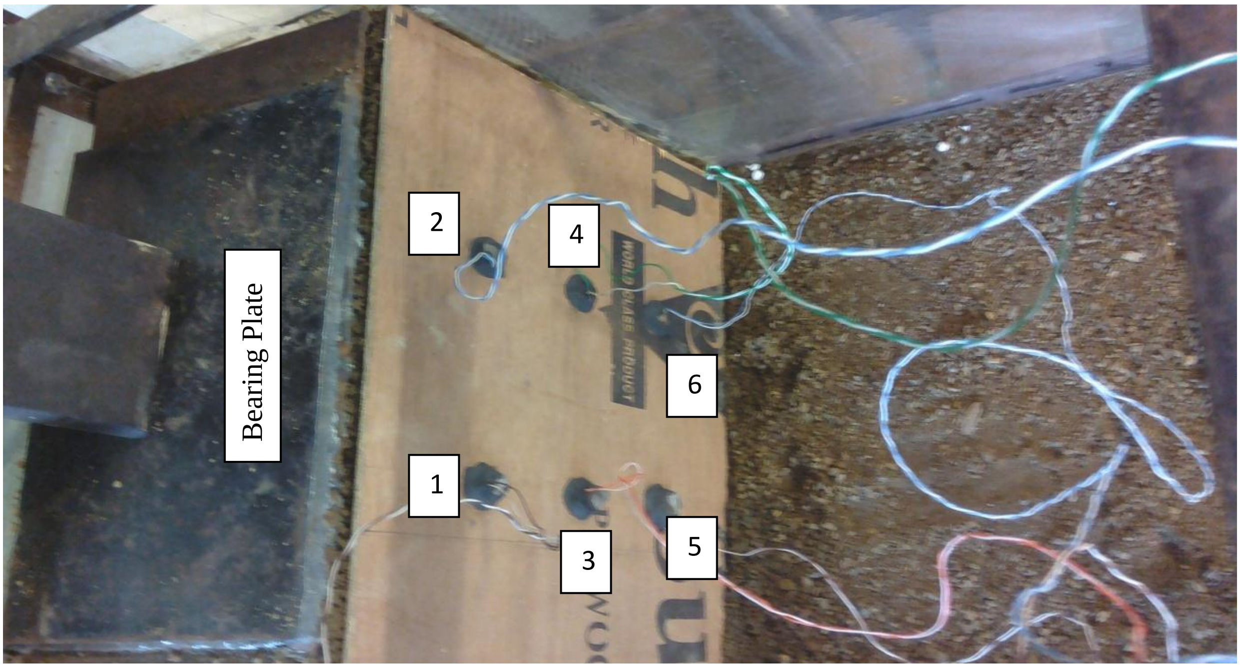


Fig. 3.5 (d) Nails installed in slope and their connecting wires going to their Separate wheatstone bridge.

Table 3.5.1 The list of resistance of arms are of six wheatstone bridge for screw nails.

	1st	2nd	3rd	4th	5th	6th
R_1	101.2 Ω	100.6 Ω	101.4 Ω	99.8 Ω	101.8 Ω	101.2 Ω
R_2	101.6 Ω	101.7 Ω	103.4 Ω	100.9 Ω	99.7 Ω	99.5 Ω
R_3	100.2 Ω	104.7 Ω	102.5 Ω	98.5 Ω	101.8 Ω	100.6 Ω

Table 3.5.2 Input voltages for different slopes in screw nails.

Slope	45°		60°		90°	
Nail Inclination	15°	30°	15°	30°	15°	30°
V_{in1}	5.12 V	5.12 V	5.07 V	4.95 V	5.11 V	5.13 V
V_{in2}	5.12 V	5.12 V	5.07 V	4.95 V	5.15 V	5.17 V
V_{in3}	5.12 V	5.14 V	5.13 V	5.05 V	5.14 V	5.17 V
V_{in4}	5.03 V	4.99 V	5.10 V	5.09 V	3.86 V	5.13V
V_{in5}	5.05 V	4.99 V	5.10 V	5.09 V	2.63 V	5.09 V
V_{in6}	5.15 V	5.12 V	5.19 V	5.14 V	2.44 V	5.09 V

Table 3.5.3 The list of resistance of arms are of six wheatstone bridge for helical nails.

	1st	2nd	3rd	4th	5th	6th
R_1	100.6 Ω	99.9 Ω	100.8 Ω	99.1 Ω	101.2 Ω	100.6 Ω
R_2	101 Ω	101 Ω	102.6 Ω	102.6 Ω	99.1 Ω	98.8 Ω
R_3	99.5 Ω	104 Ω	101.9 Ω	97.8 Ω	101.1 Ω	100 Ω

Table 3.5.4 Input voltages for different slopes in helical nail.

Slope	45°		60°		90°	
Nail Inclination	15°	30°	15°	30°	15°	30°
V_{in1}	5.12 V	5.14 V	5.08 V	5.15 V	5.14 V	5.14 V
V_{in2}	5.12 V	5.14 V	5.08 V	5.15 V	5.14 V	5.14 V
V_{in3}	5.13 V	5.09 V	5.15 V	5.14 V	5.01 V	5.12 V
V_{in4}	5.10 V	5.10 V	5.10 V	5.11 V	5.09 V	5.10 V
V_{in5}	5.02 V	5.03 V	5.03 V	5.02 V	5.03 V	5.03 V
V_{in6}	5.02 V	5.03 V	5.03 V	5.01 V	5.03 V	5.03 V

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

Experimentations on soil nailing techniques to enhance the stability of soil slope, and to find out the optimum technique for obtaining the maximum stability by varying the soil nail parameters like nail length, nail diameter, nail material, angle of inclination, facing material etc were done from past few decades by different researchers. Few of the studies were conducted theoretically by using Finite Element Method, few were done by model testing and some of them were experimentations directly on the slope prototype in natural existing conditions and the concluded various results as listed in chapter 2 of this report.

We continued this experimentation on soil nailing techniques with an aim of checking out the stability of the slopes at 45º, 60º and 90º angels from horizontal as shown in chapter 3 (in figure 3.4.1**;**3.4.2**;**3.4.3 respectively). The nails were driven at different angels of 15º and 30º in each of the above mentioned angles of slope. The method which is chosen in our experiment is model testing whose details are given in chapter 3 of this report. After doing the experiment following things could be discussed.

4.2 Results and discussions

For this experiment the model tank was made up of perspex sheet having the thickness of 2mm and the modulus of rigidity of this sheet was not considered which could differ our results from in situ soil conditions. Few tests which were conducted on soil to get its properties and results concluded from them are as follows.

4.2.1 Sieve analysis Sieve analysis was done to get the particle size distribution of soil by which we can classify our soil on the basis of grain size. Readings obtained from sieve analysis are displayed in the table no 4.1 and its graphical representation is shown in fig 4.1. Particles with grain size less than 0.002 mm are clays, from 0.002mm to 0.05mm are silt,0.05mm to 0.10mm fine sand,0.25mm to0.50mm medium sand and from 0.5mm to 2 mm are coarse sand. (Refer to ANNEXURE A Table 4.1)

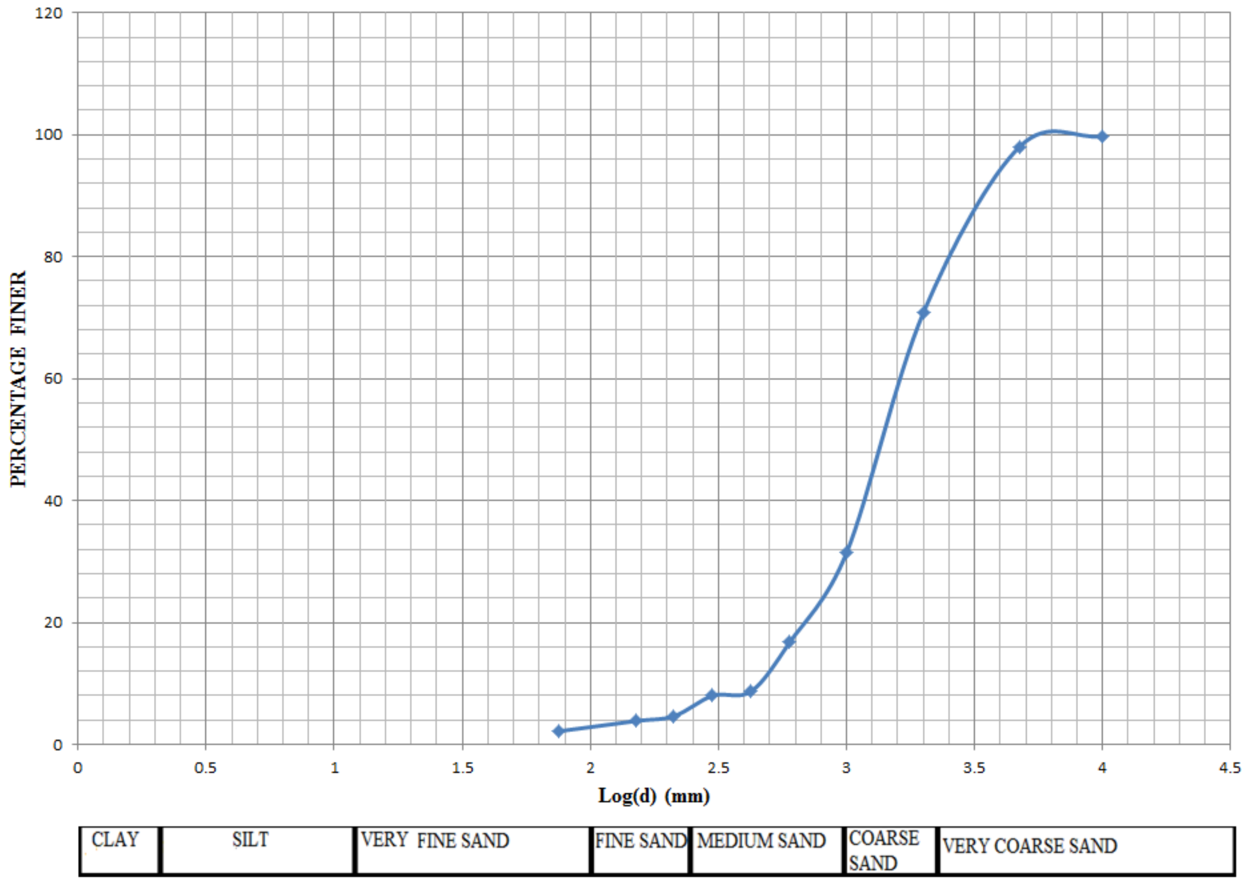


Fig 4.1 Particlesize distribution curve

Result From above graph we concluded that our soil **is sand (poorly graded)**.

4.2.2 Moisture content Moisture content was calculated by oven drying method at the temperature of 105º C and the moisture content of soil was 5% by which we can say that our soil will have apparent cohesion due to the presence of water.

4.2.3 Direct Shear Test: Now after sieve analysis we know that our soil is poorly graded sand with the moisture content of 5% .In sandy soil the strength governing factor is angle of friction (ϕ) but in natural state our soil already contained moisture content of 5% thus apparent cohesion will also be there in soil. To obtain these strength parameters direct shear test was done on the soil sample, and for this three different soil samples were made one was with dry soil, second with 5% moisture content and third one was soil sample with nail inserted in it to get the effect of soil nail on c and ϕ and the results are shown in the following tables.

4.2.3.1 Dry soil sample

Direct shear test was done on the soil sample (Refer to ANNEXEURE B table 4.2, 4.3, 4.4).

Table 4.1 Normal stress and Shear Stress

	Normal Stress (kg/cm^2)	Shear Stress (kg/cm^2)
Sample 1	0.2	0.12665
Sample 2	0.4	0.18754
Sample3	0.8	0.21467

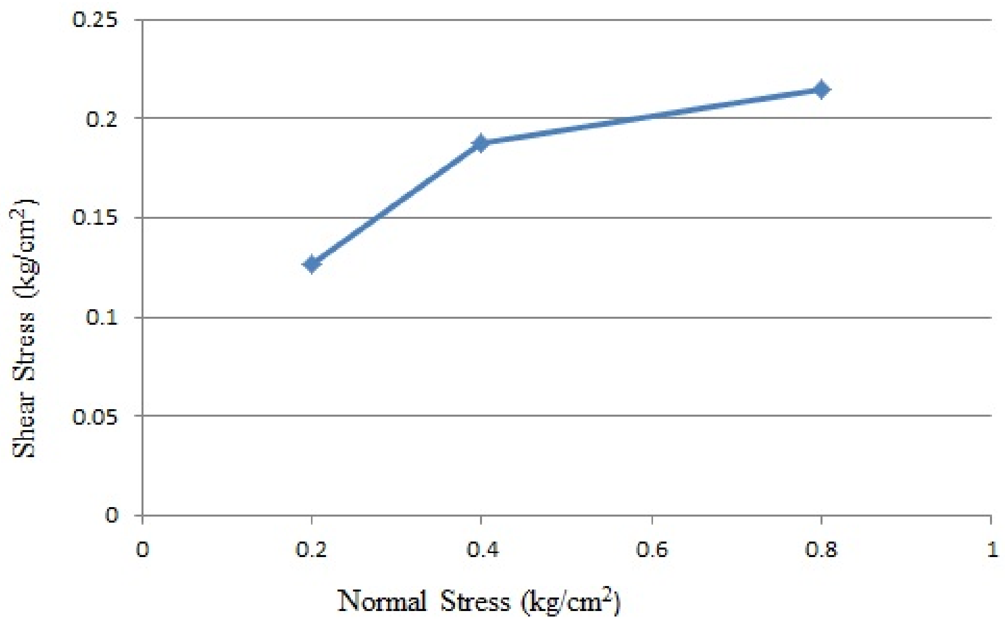


Fig 4.2 Variation of Shear Stress and Normal Stress

Result: - After doing the experiment we found out the c and ϕ values as follows:-

- c value = 0.01 kg/cm^2
- ϕ value = 30º

These values of c and Φ shows that our soil is mostly sand as c value is very-very less hence some moisture content will be required to get apparent cohesion for making steeper slopes of 60º and 90º. The moisture content selected for slope building was 5

.

4.2.3.2 Direct shear test with moisture content of 5%

Moisture content of a soil can alter the strength parameters of soil so it becomes important to study the effect of water content in the soil which is to be used for model testing.

The soil used for testing was sand thus having a very low value of cohesion. Hence 5%water content was kept to get apparent cohesion in soil particles so that steeper slopes of 60º and 90º could be made as stated before.

But excessive water content could also be not kept as it leads to the generation of excessive pore water pressure in soil while compaction. On application load soil first gets consolidated and during the process of consolidation slope may rupture due to excessive pore water pressure giving failure before reaching its true bearing capacity.

One more reason to keep water content limited is that when water content is beyond saturation point the load is taken by water initially until it seeps out and hence stress strain readings of the nails will not be accurate ,but will be lesser than actual ones.

Table 4.2 Normal stress and Shear Stress

	Normal Stress (kg/cm^2)	Shear Stress (kg/cm^2)
Sample 1	0.2	0.05855
Sample 2	0.4	0.07215
Sample 3	0.6	0.07897

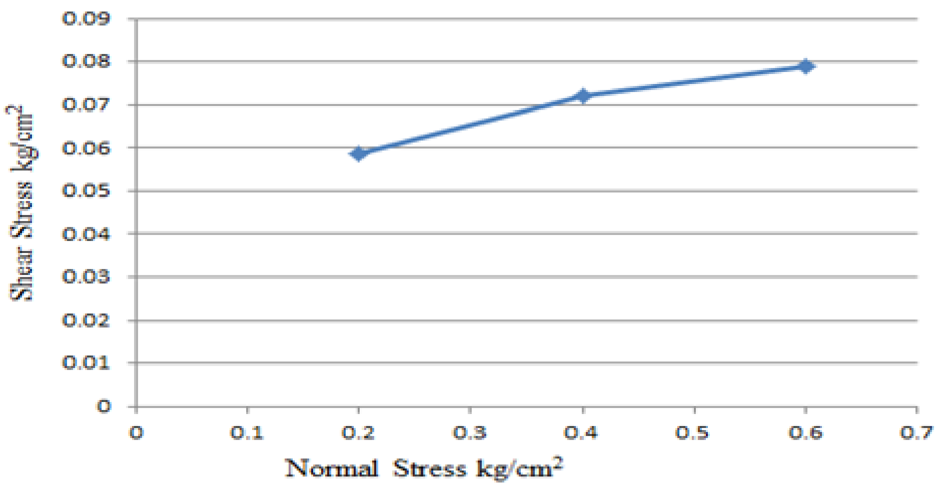


Fig 4.3 Variation of Shear Stress and Normal Stress

Result: - After drawing normal stress v/s shear stress curve of soil with 5% moisture content following values of c and ϕ were computed. (Refer to ANNEXURE B Table 4.5, 4.6, 4.7)

- c value = 0.05kg/cm^2
- ϕ value= 37º

From these values we could say that apparent cohesion came in the soil due to water in it which is also described in the theory by various researchers.

4.2.3.3 Direct shear test with nail embedded in sample

Direct shear test on the sample with the nail inscribed in it was important to check that how much is the change in soil strength parameters C and ϕ after inserting the nail. Theoretically we can assume that the grooves of the nail will have high friction between soil and nail's surface which may increase the c or ϕ value, but due to nail insertion the compaction of soil may decrease which in turn may decrease ϕ. As ϕ do not only depends upon the resistance between the soil particles but also on compaction of soil. Similarly c can also change due to change in cohesion properties of nail surface and soil.

Normally we assume that soil nail increases the stability of slope by holding the soil mass in active and passive zones but stability increase may also be due to increase in shear strength parameters of soil itself by densification of soil around nail.

Table 4.3 Normal stress and Shear Stress

	Normal Stress (kg/cm^2)	Shear Stress (kg/cm^2)
Sample 1	0.2	0.16797
Sample 2	0.4	0.17303
Sample 3	0.8	0.22519
Sample 4	1	0.24073

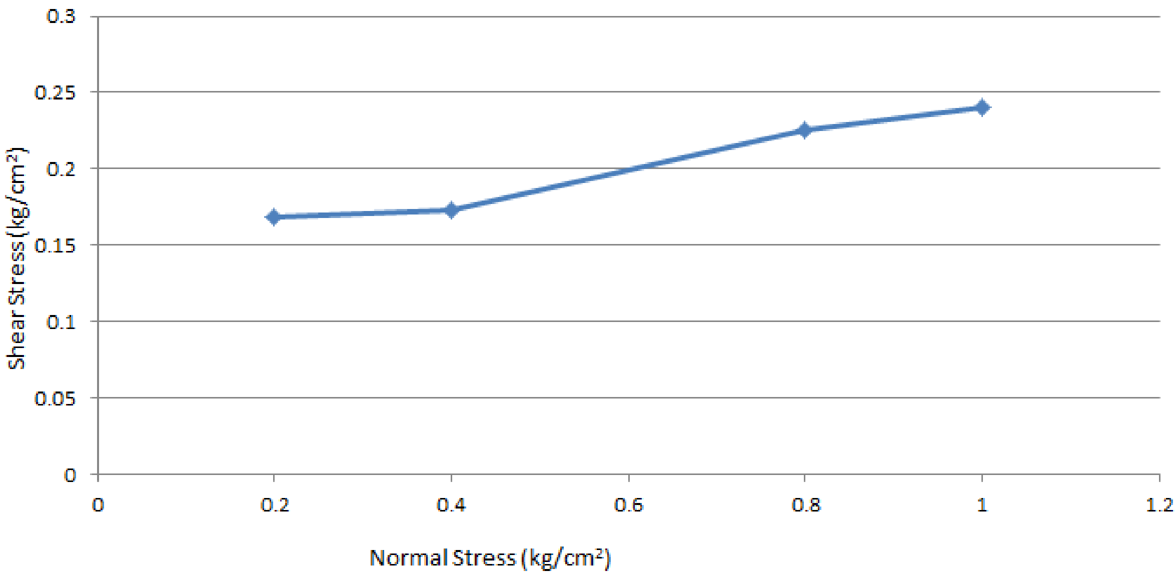


Fig 4.4 Variation of Shear Stress and Normal Stress

. **Result: -**After doing DST with sand with nail inscribed in it we found that the c value increased to 0.15kg/cm^2 and ϕ value decreased to 26º and this could be due to larger adherence between nail surface and soil but decrease in ϕ may be due to loosening of soil after driving nail to it. (Refer to ANNEXURE B Table 4.8, 4.9, 4.10, 4.11)

4.2.4 Determination of specific gravity

Specific gravity of the soil could be calculated by pycnometer test or by specific gravity bottle. Specific gravity bottle is mainly used for the calculation of specific gravity of fine particles having size less than 75ɥ like clay and cement because finer are the particles greater is the accuracy required. Fine particles get easily suspended in the liquid and do not settle down easily thus specific gravity bottle having lesser volume is used. Our soil lied in the category of poorly graded sand when we saw the graph of particle size distribution as shown fig 3.1 hence method used to calculate the specific gravity was pycnometer method.

Formulation for calculating the specific gravity by pycnometer is shown in (Eq.4.1)

$$G = \frac{M2 - M1}{(M2 - M1) - (M3 - M4)} \text{ ....(Eq. 4.1)}$$

Where,

M_1=mass of empty Pycnometer,

M_2= mass of the Pycnometer with dry soil

M_3= mass of the Pycnometer and soil and water,

M_4 = mass of Pycnometer filled with water only.

G= Specific gravity of soil.

Table 4.4 Data of pycnometer test

	Description	Mass (in gm)
M1	Mass of empty pycnometer	460.5
M2	Mass of pycnometer with soil	540.9
M3	Mass of pycnometer with soil and water	1307.7
M4	Mass of pycnometer with water only	1257.3

By putting all the values in the (Eq4.1) we got the specific gravity of soil 2.68. Literature also confirms that specific gravity of sand varies from (2.60 to 2.70) .Sands with higher values of specific gravity contains heavy elements. Specific gravity of our sand is 6.8 which confirm the presence of heavy elements.

The sand which we used is crushed stone sand, mainly containing siltstone having main composition of elements like feldspars ($KAlSi_3O_8$ – $NaAlSi_3O_8$ – $CaAl_2Si_2O_8$), quartz and mica responsible for the higher value of specific gravity.

Specific gravity as such does not influence the slope stability directly but higher is the specific gravity more earth pressure will act on nails which in turn could increase frictional force between soil and nail as friction force is dependent on normal reaction force and heavy weight have higher normal reaction but on the other hand with increase in specific gravity the destabilising component w(sinɵ) will also increase which could lead to soil failure. Thus direct relations between specific gravity and slope stability are difficult to establish.

4.3 Slope Testing with Screw Nails

4.3.1 Test on 45° slope with nail inclination of 15°.

Our first model testing was done on the slope of 45° with nail inclination of 15° and the results which were obtained.

Following graphs are plotted which shows the strain in different nails at different load applied. For load and strain values refer to ANNEXURE Table 4.12, 4.13.

Fig 4.3.1(a) Slope before failure **Fig 4.3.1(b) Slope after failure**

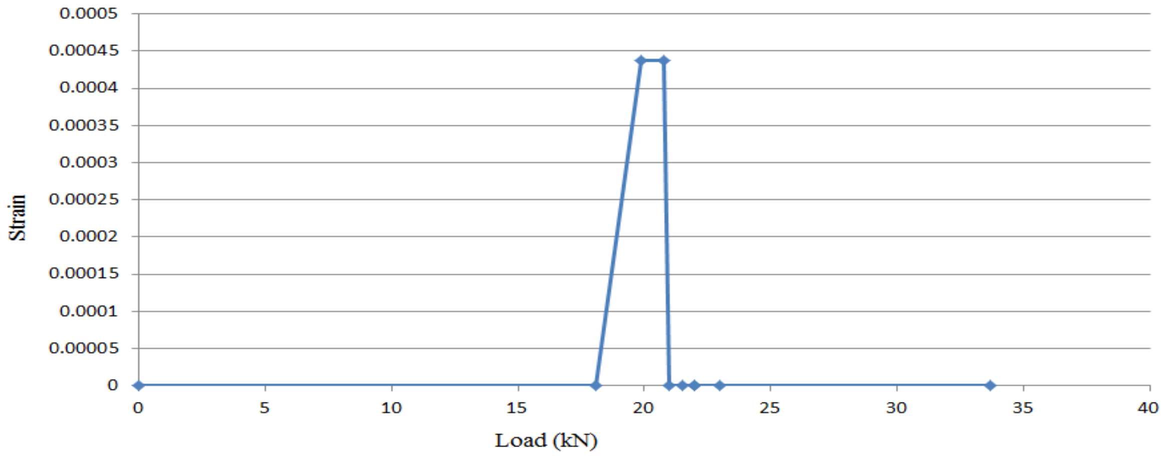


Fig4.5 Graph of Nail Strain vs Load in nail 1.

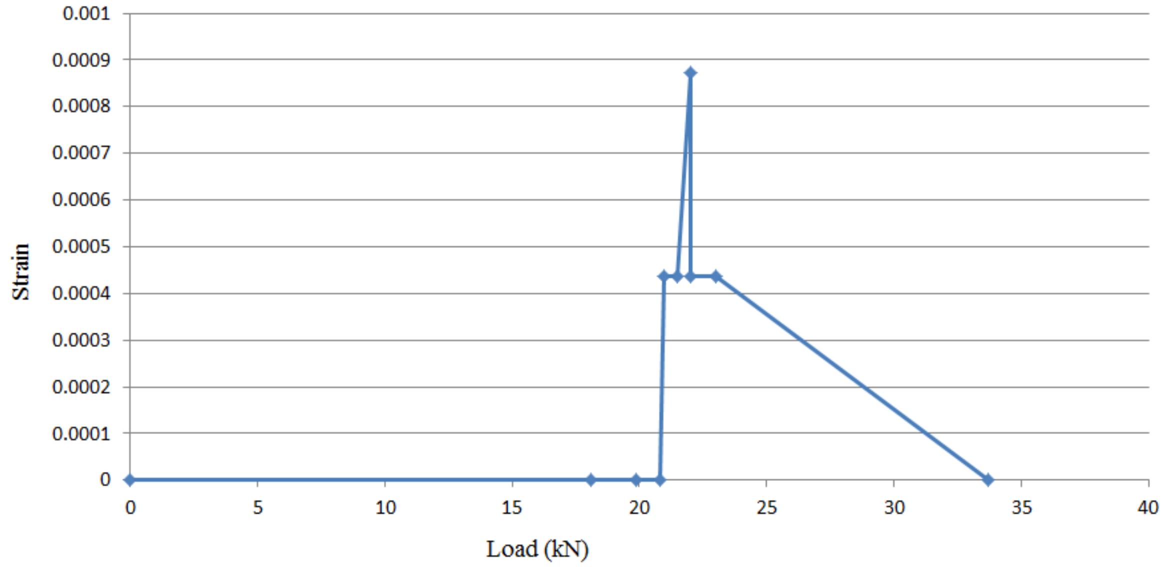


Fig 4.6 Graph of Nail Strain vs Load in nail 2.

Strain does not come immediately after applying the load. Firstly load is taken by the soil, afterwards it is transferred to the nails. This load causes strain in the nails. The nail 1 and 2 being at same level shows the same type of behaviour.

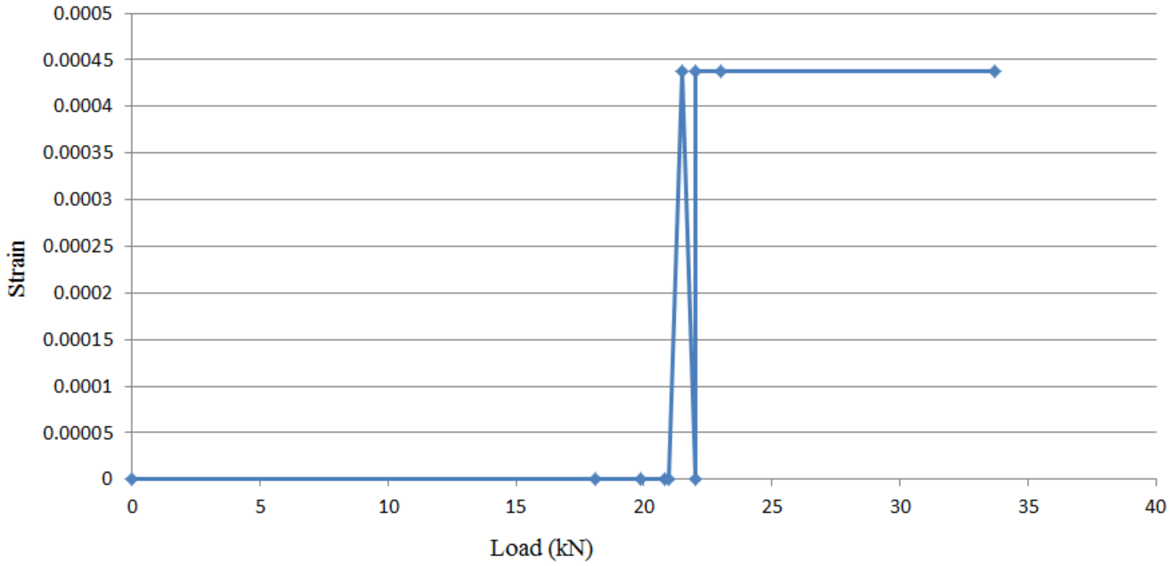


Fig 4.7 Graph of Nail Strain vs Load in nail 3.

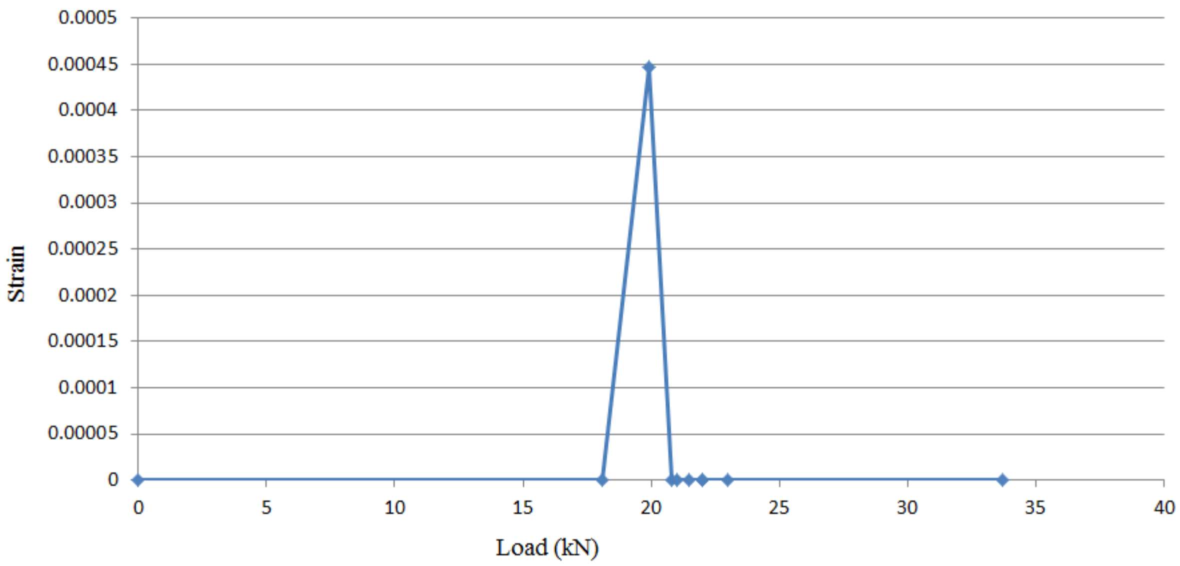


Fig. 4.8 Graph of Nail Strain vs Load in nail 4.

The nail 3 and 4 shows somewhat same behaviour. With the increase the load, strain develops around same time. The strain in nails becomes zero at the end due to failure of slope and loosening of soil. 45° slope is the most stable slope so it is able to with stand high amount of force.

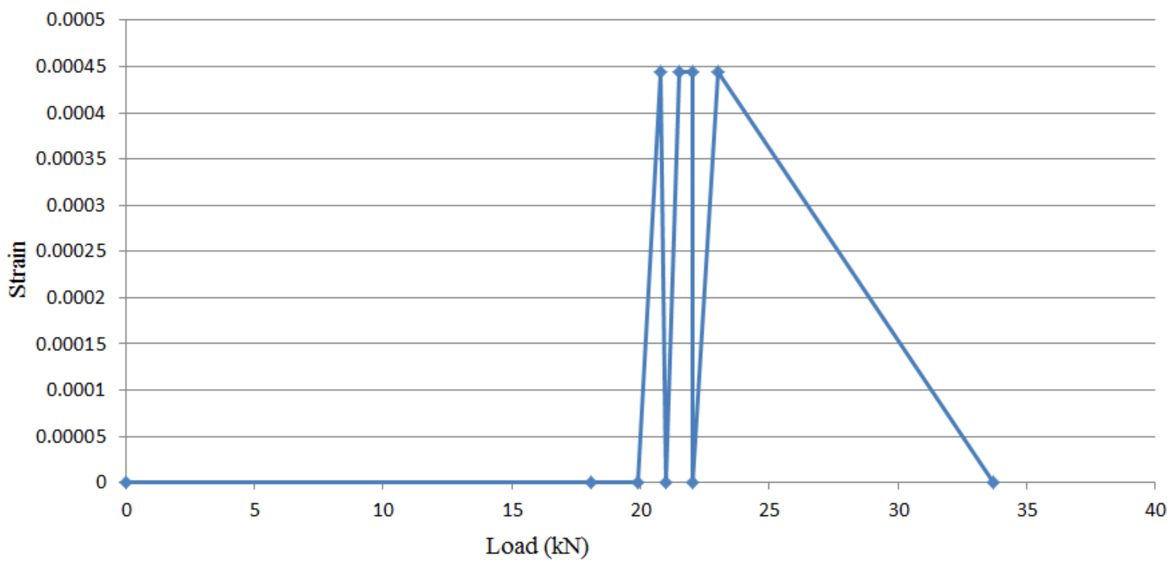


Fig 4.9 Graph of Nail Strain vs Load in nail 5.

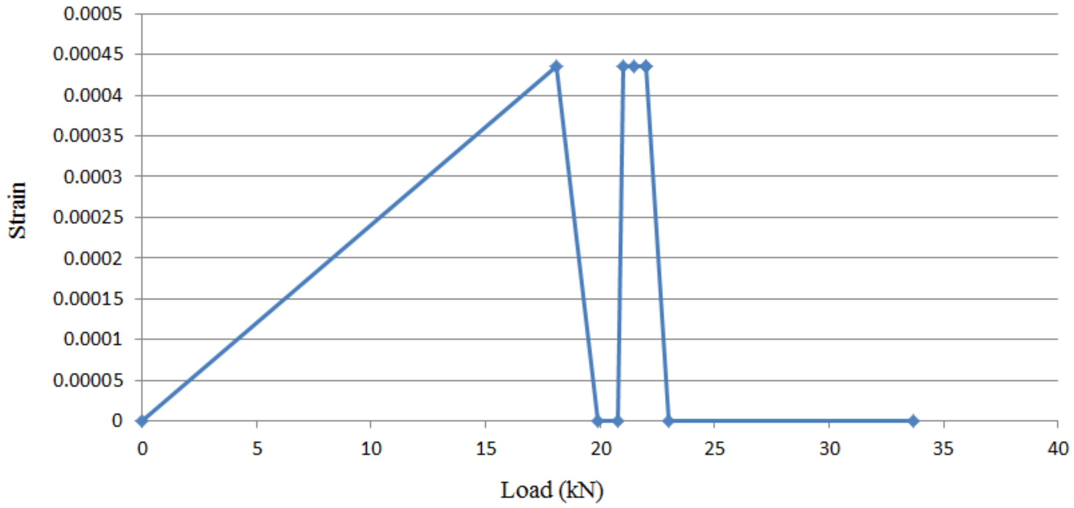


Fig 4.10 Graph of Nail Strain vs Load in nail 6.

Discussion of results: - After doing the experiment the following results came as shown in table 4.15 and table 4.16. After analysing these results we can interpret that strains do not come immediately after applying load and even strains do not come on same time on all the nails few of the nails starts taking load early like nail 6 started getting strain 10 seconds after applying the load but nail 2 and 3 took 30 to 40 seconds to take load. It shows that every nail do not get the load on same time the bottom nails gives strain first and upper nails gives strain after an interval of time it could be because of excess overburden pressure of soil mass on lower nails. It could also be seen that even though strain on upper nails comes late but strain values are maximum at top within first few seconds after that strains at the bottom of the slope are higher it may be because of formation of failure crack on upper side of slope and now stress could not be transferred to the nail from soil.

Table 4.16 shows the force taken by individual nails in the slope when the load is applied as stress (nail force) is directly proportional to the strains calculated thus same conclusions about forces could be made that upper nails bears most of the forces and lower nails have lesser forces.

4.3.2 Test on 45° slope with nail inclination of 30°

Second model testing was done on the slope of 45° with nail inclination of 30° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.14, 4.15.

Fig 4.3.2(a) Slope before failure

Fig 4.3.2(b) Slope after failure

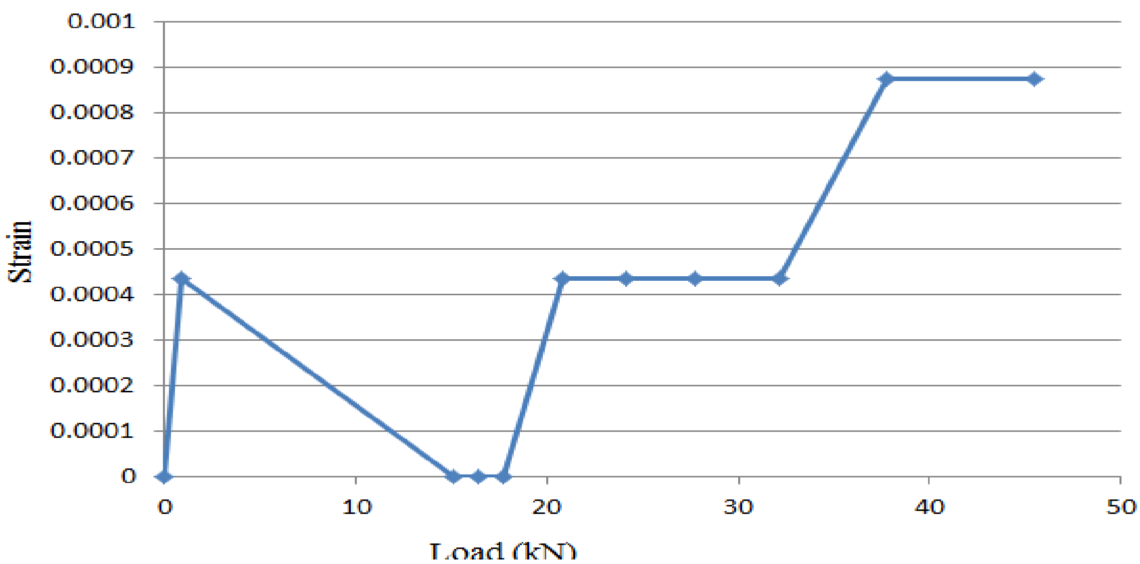


Fig 4.11 Graph of Nail Strain vs Load in nail 1.

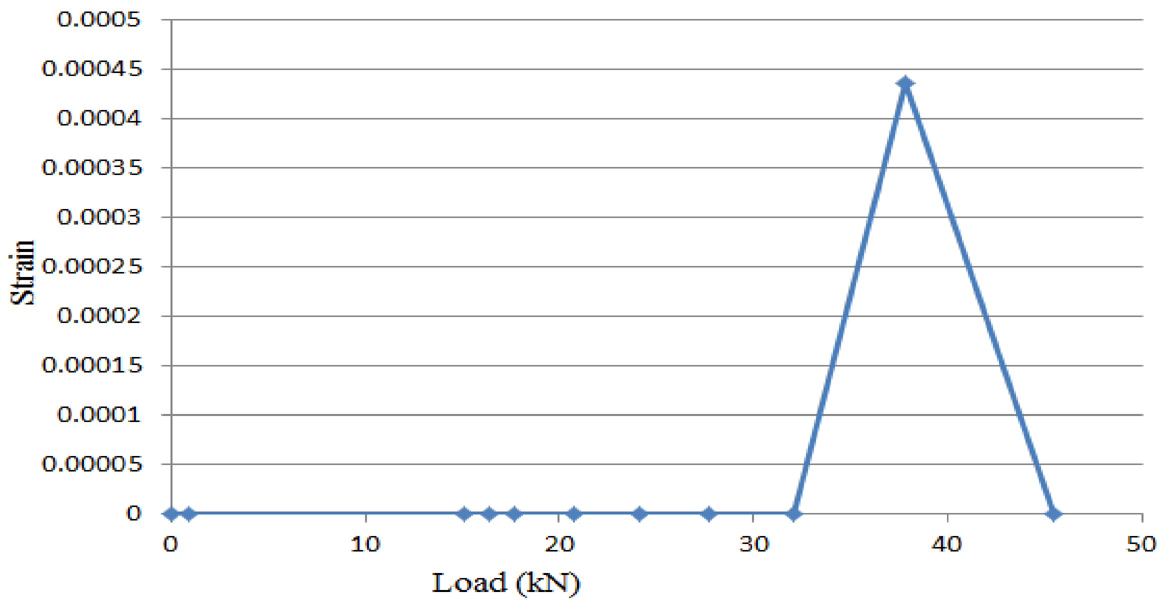


Fig 4.12 Graph of Nail Strain vs Load in nail 2.

In test at 30° nail inclination with horizontal the effective angle between nail and slope is near 90° so it is able to withstand even more force than the previous slope. Though the strain is generated in nail at near the end, the nails do take the load.

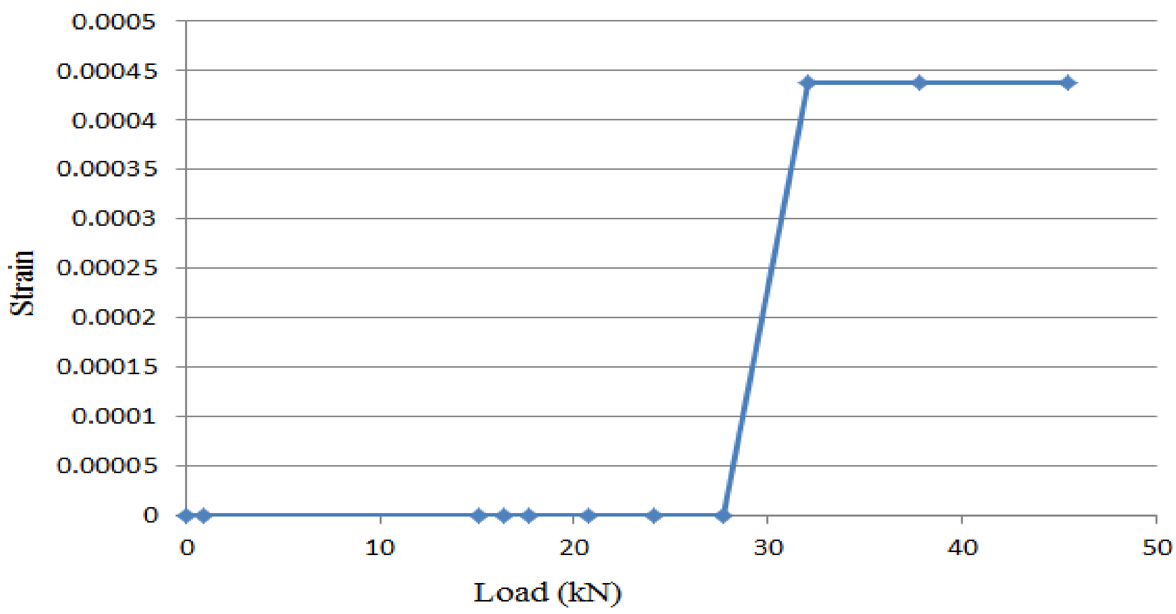


Fig 4.13 Graph of Nail Strain vs Load in nail 3.

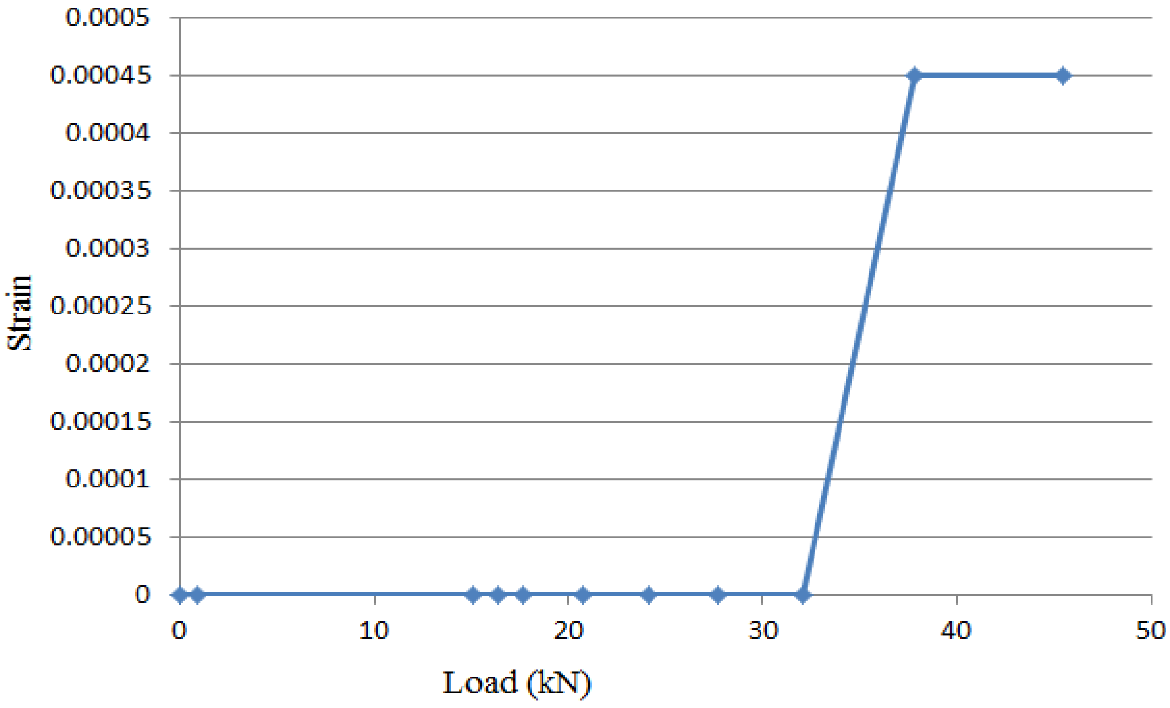


Fig 4.14 Graph of Nail Strain vs Load in nail 4.

The nail 3 and 4 are at same level so they shows the nearly the same behaviour. Nails are stained till the failure of slope.

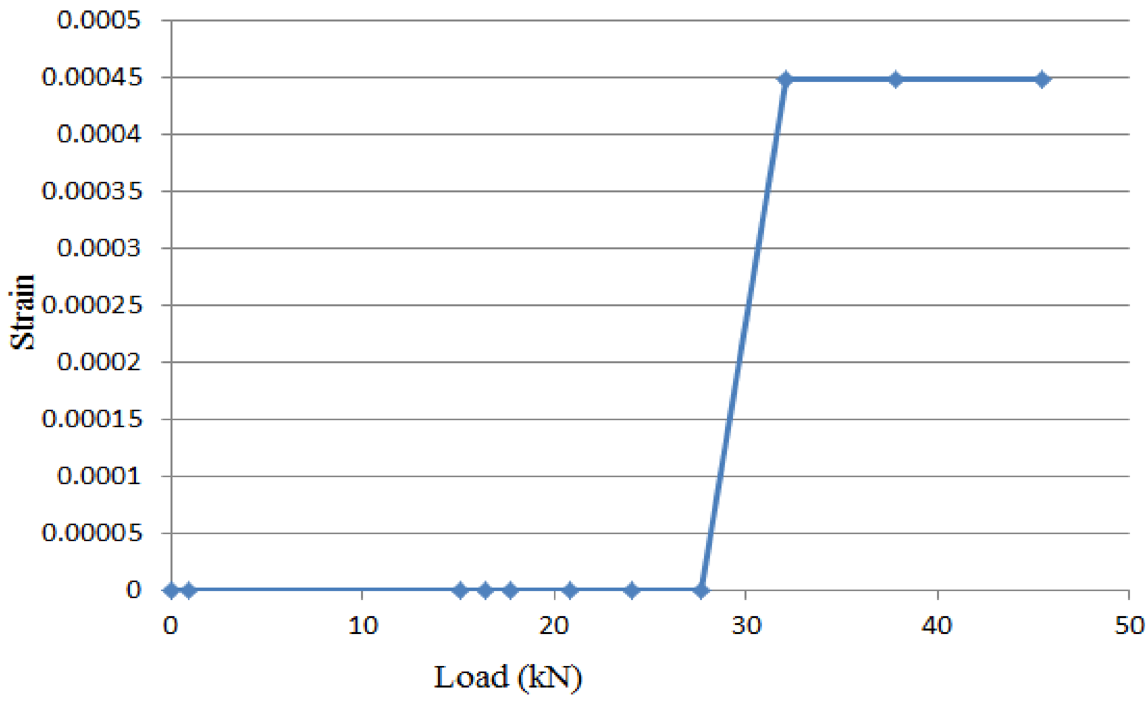


Fig 4.15 Graph of Nail Strain vs Load in nail 5.

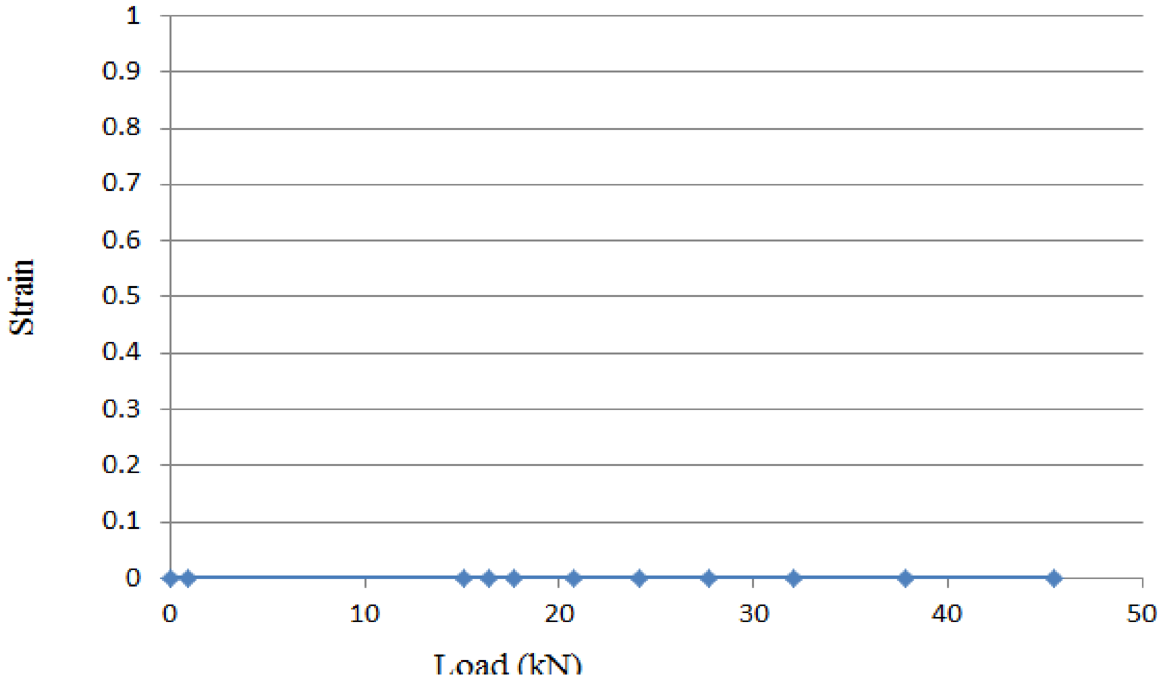


Fig 4.16 Graph of Nail Strain vs Load in nail 6.

Discussion of results: - Again almost same experiment was done on the slope of 45º but this time the nail inclination was kept 30º with respect to horizontal and similar results were obtained as in previous experimental setup of 15º nail inclination. Strain values of upper nails were higher as compared to the strain values of lower nails and same result could be derived that upper nails have more deflections then lower nails initially until failure crack did not passed through it, but this time strains were generated in first on upper nail (Nail 1) at 10 seconds after applied load this could be because of impact loading but this strain is remained for very less time and became zero from 20 to 50 seconds after that continuous strain is observed in nail from 50 seconds until sample is failed .Strain in nail one remained constant for small instant and after that it increased but in nail 2 strain was almost zero throughout the experiment and just increased a bit at the end of 80th second which shows that sometimes load could be taken by the adjacent nail inserted parallel to it and nail 1 and 2 were inserted in parallel this phenomenon is also written by **N.Ramya Gandhi and K. Ilamparuthi** (2012) in their paper (discussed in chapter 2) and they told that a nail can influence the space about four times the diameter of nail around it, thus to avoid the interference of one nail on other the distance between the nail should be at least eight times the diameter that is approximately 16cm but our distance was only 13.33cm apart hence it makes the possibility of sharing the load of one nail by other and this could be reason we got more strains on nail 1 and nail 2 could barely have only one strain value. Some of the strains were seen in the nail 3,4,5 but the values of strain were very less as compared to the nail number 1.

Comparing the results of 15º nail inclination and 30º nail inclination at the soil slope of 45º: - After comparison we can say that in 15º slope the strain value of upper nail was lower than the strain values obtained from 30º slope but it was just opposite in lower nails. It shows that it is more beneficial to have lower angle slope on upper end and higher value slope on lower. This same result was also derived by **C.Y. Cheuk, K.K.S. Ho, and A.Y.T. Lam (**refer chapter 2**)** when they did this experiment.

4.3.3 Test on 60° slope with nail inclination of 15°

Third model testing was done on the slope of 60° with nail inclination of 15° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.16, 4.17.

Fig 4.3.3(a) Slope before failure

Fig 4.3.3(b) Slope after failure

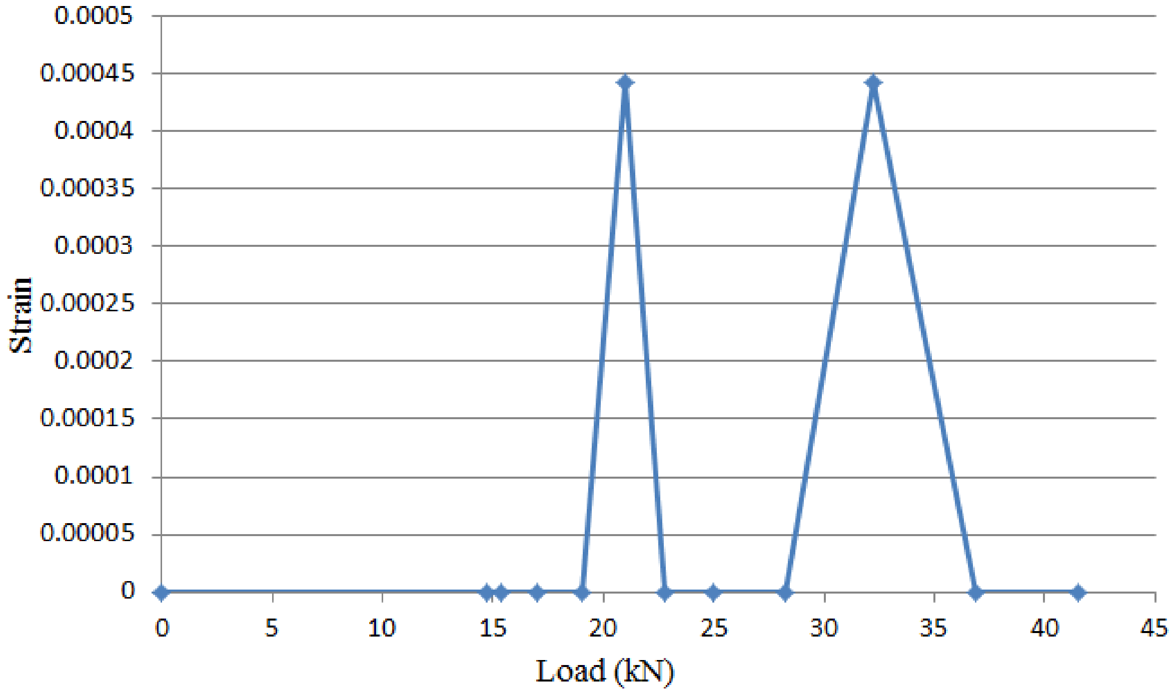


Fig 4.17 Graph of Nail Strain vs Load in nail 1.

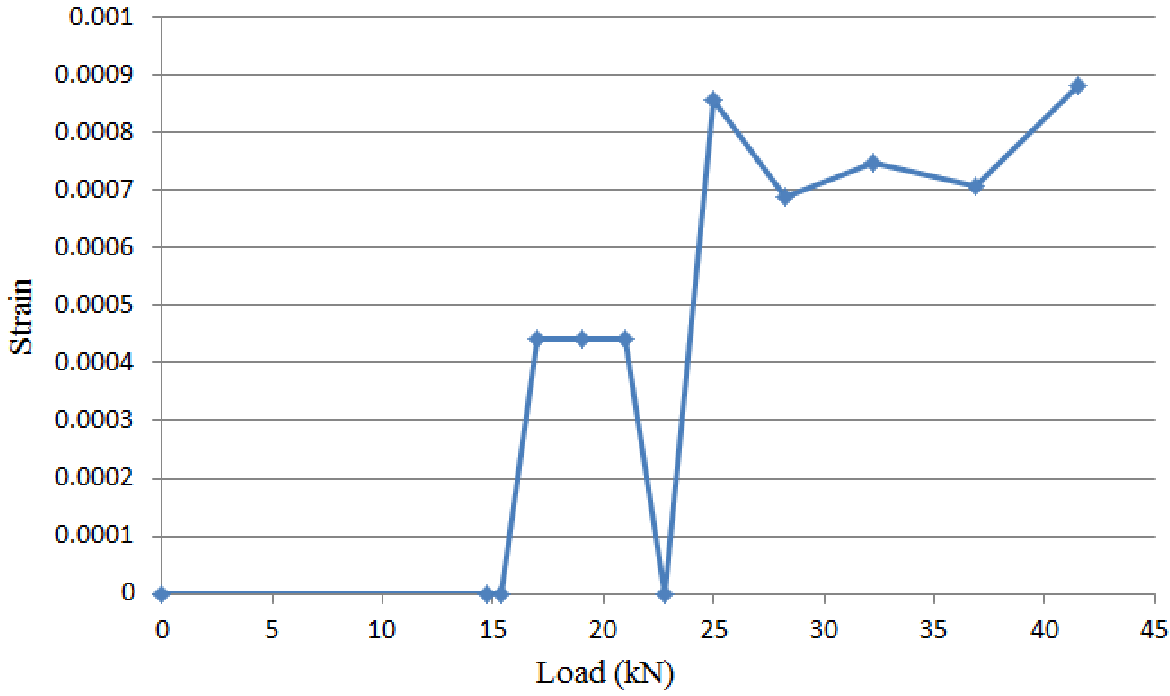


Fig 4.18 Graph of Nail Strain vs Load in nail 2.

The effective angle between the slope surface and the nail is 75° equal to previous experiment but the slope angle for this experiment is 60° which is less stable than 45°, so it takes little less load than the previous slope.

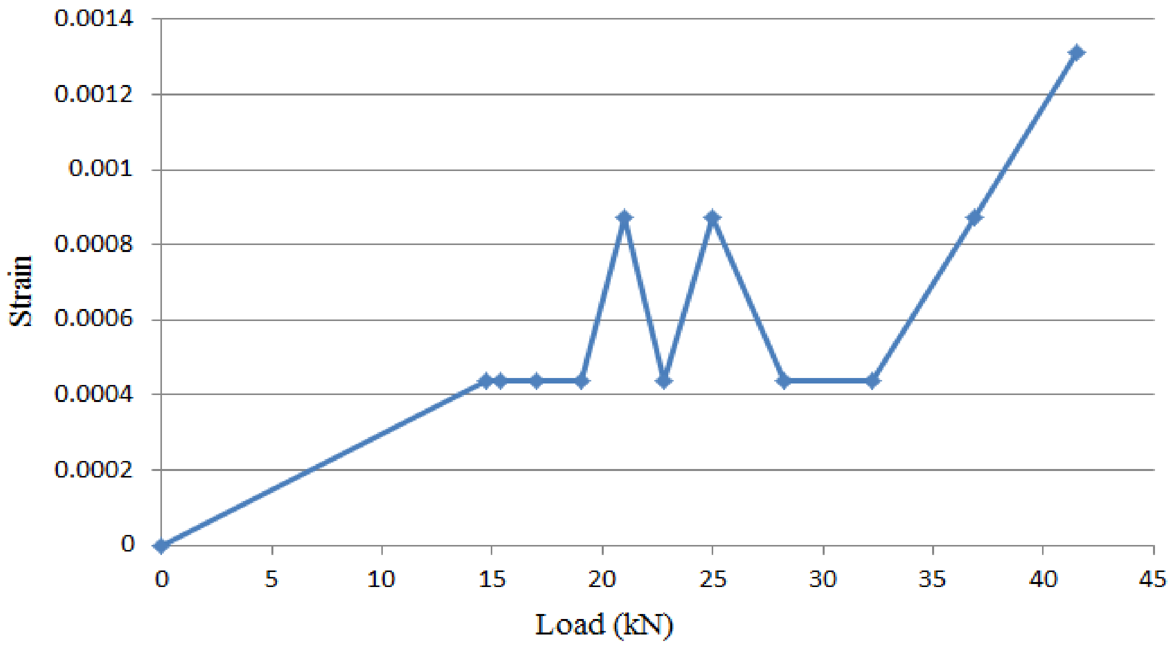


Fig 4.19 Graph of Nail Strain vs Load in nail 3.

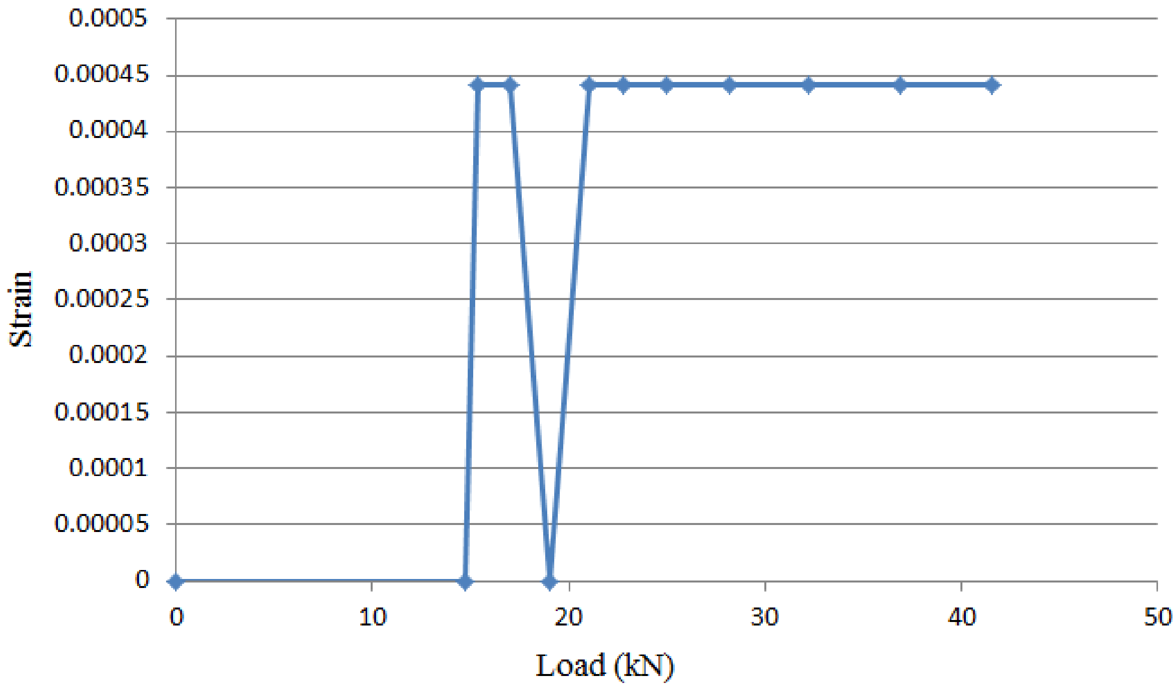


Fig 4.20 Graph of Nail Strain vs Load in nail 4.

At the middle level both the nails 3 and 4 keeps on taking the strain till the failure of slope. In 60º slope the strain values of lower nails were more than the upper nails and least strain variance is observed in the nails which are at centre of the slope but in nail 3 strain values were increasing slowly with the increase in load.

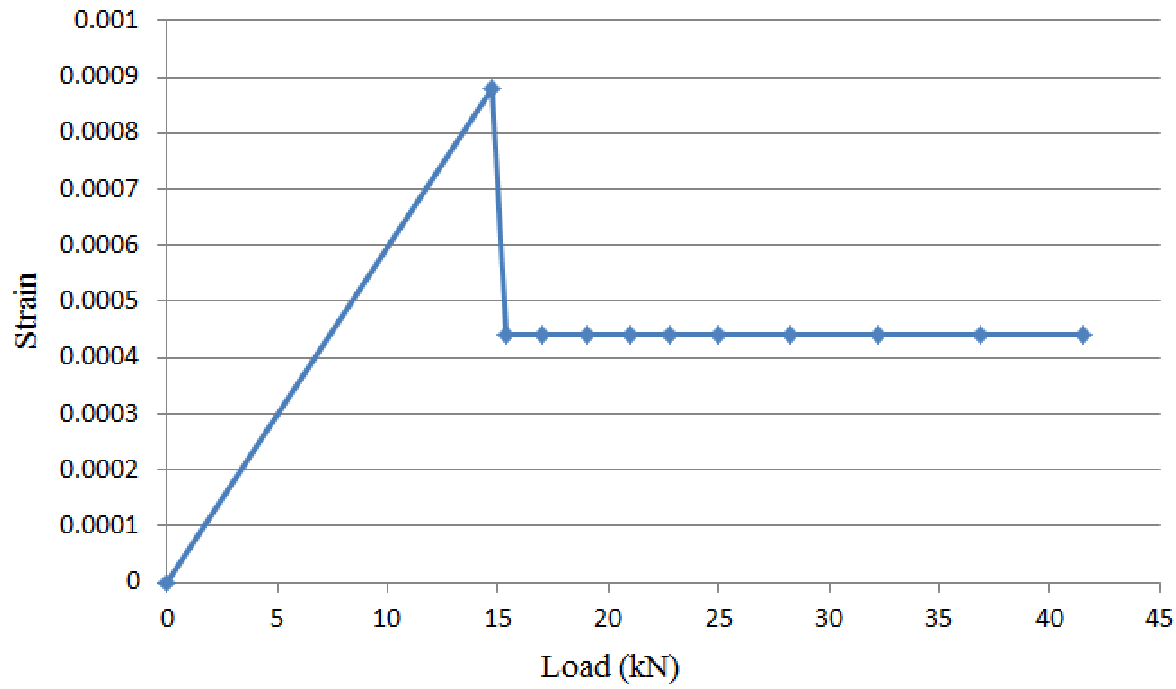


Fig 4.21 Graph of Nail Strain vs Load in nail 5.

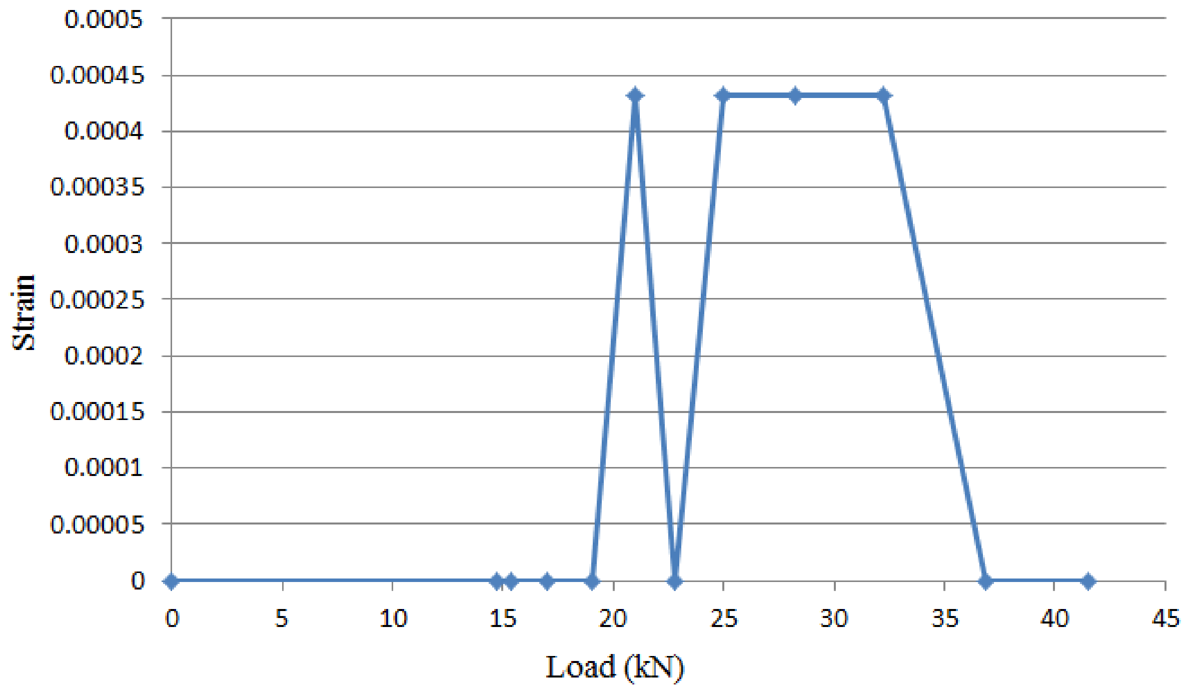


Fig 4.22 Graph of Nail Strain vs Load in nail 6.

Discussion of results: -A bit different results were seen from above experiment like in above experiments with 45º slope upper nails were having more strain, but in 60º slope the strain values of lower nails were more than the upper nails and least strain variance is observed in the nails which are at centre of the slope but in nail 3 strain values were increasing slowly with the increase in load. Strains in each nail were having very less variation as compared to 45º slope. It showed that higher will be the angle of slope more closer will be the strain values of the nails inserted vertically it could be due to the reason that in 45º slope stress is distributed over the large area leading to lesser value of stress at base of slope where as in 60º slope the area available for the distribution of stress is lesser than 45º slope.

4.3.4 Test on 60° slope with nail inclination of 30°

Forth model testing was done on the slope of 60° with nail inclination of 30° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.18, 4.19.

Fig 4.3.4(a) Slope before failure

Fig 4.3.4(b) Slope after failure

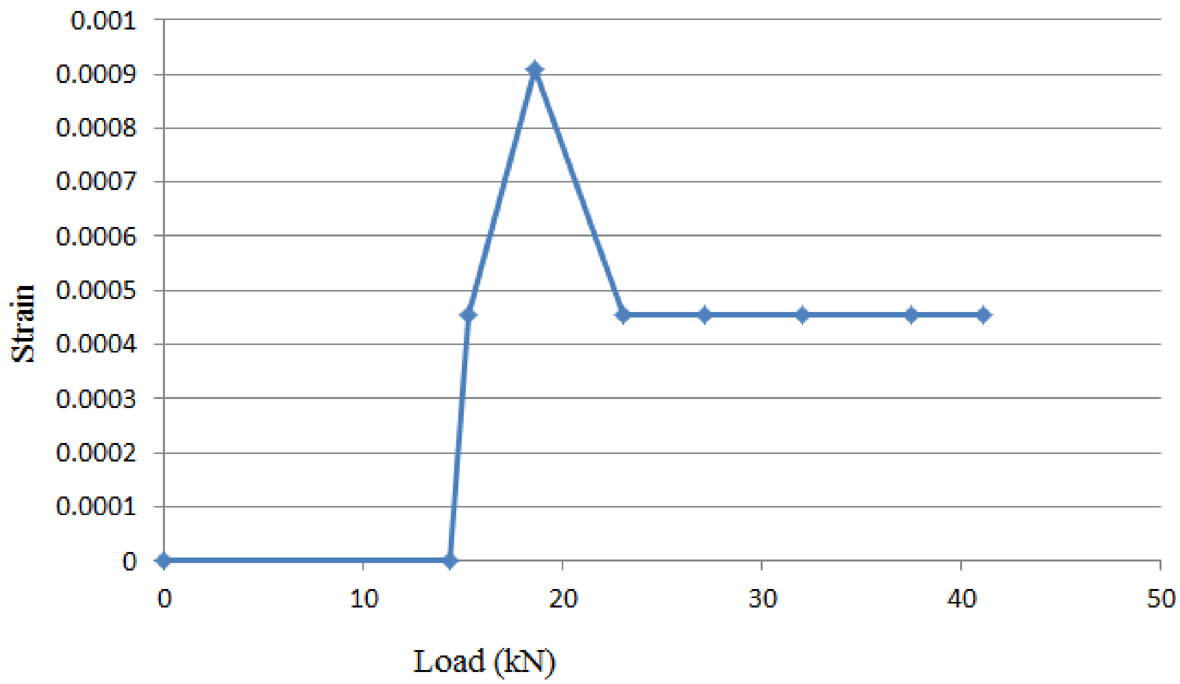


Fig 4.23 Graph of Nail Strain vs Load in nail 1.

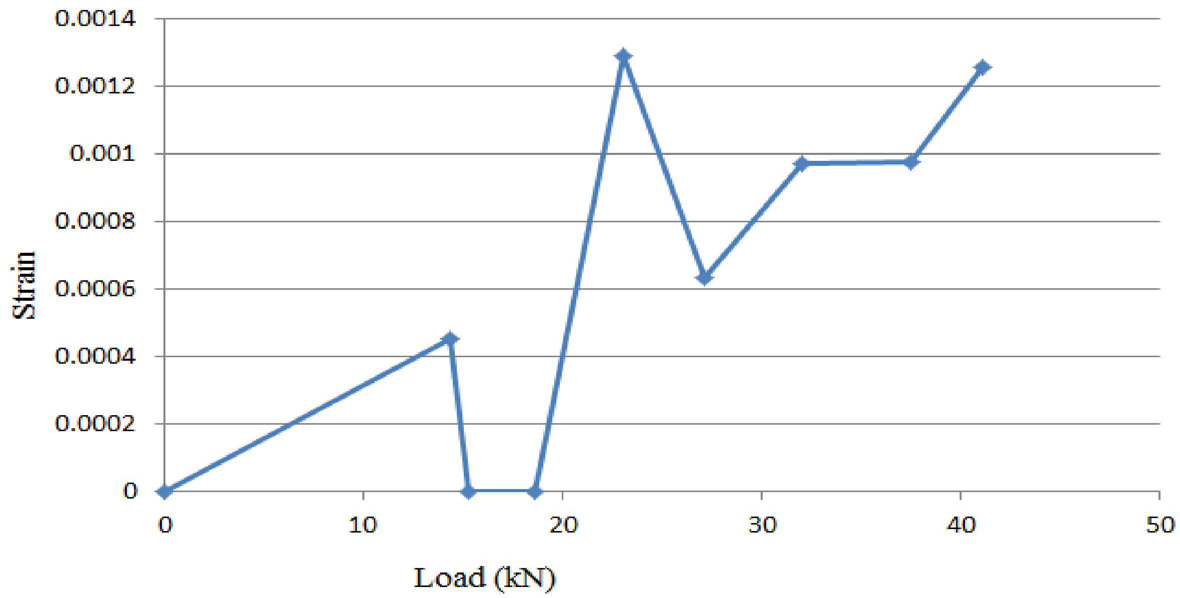


Fig 4.24 Graph of Nail Strain vs Load in nail 2.

In this experiment the effective angle between slope surface and nail is 90°. The nails shows the higher values of strain as compared to previous experiment. This shows that when effective angle between the slope surface and nail is 90°, the slope can take higher load and nails take higher load and thus stabilizing the slope. The slope angle being 60° but still it is able to take load near to the load taken by 45° slope is because of this reason only.

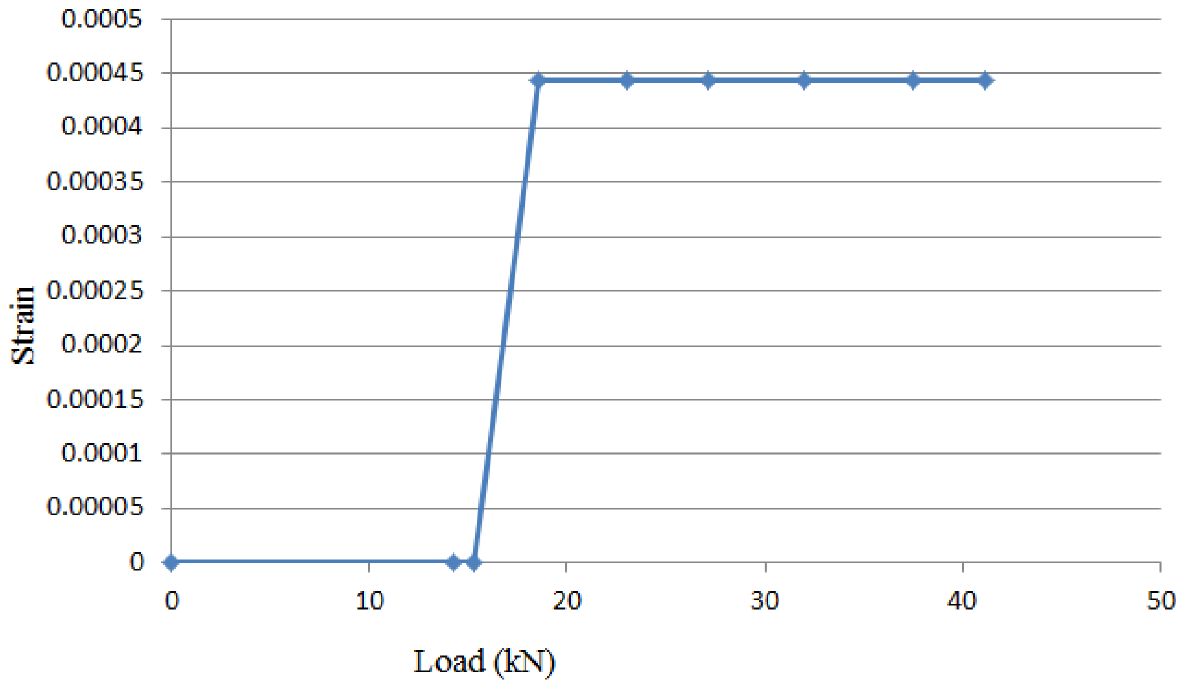


Fig 4.25 Graph of Nail Strain vs Load in nail 3.

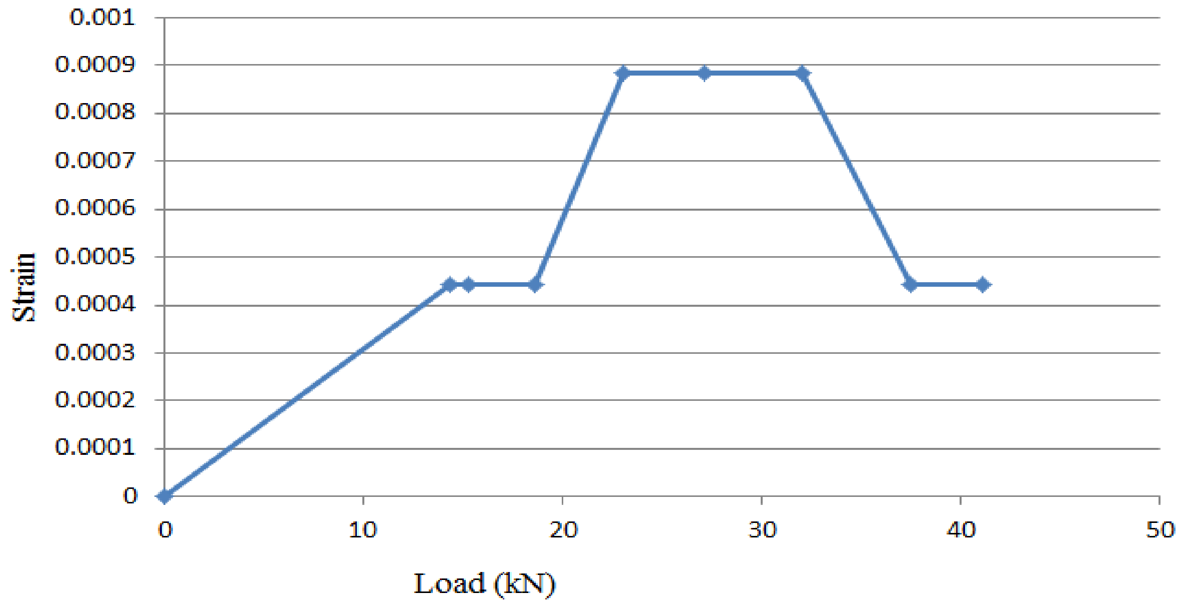


Fig 4.26 Graph of Nail Strain vs Load in nail 4.

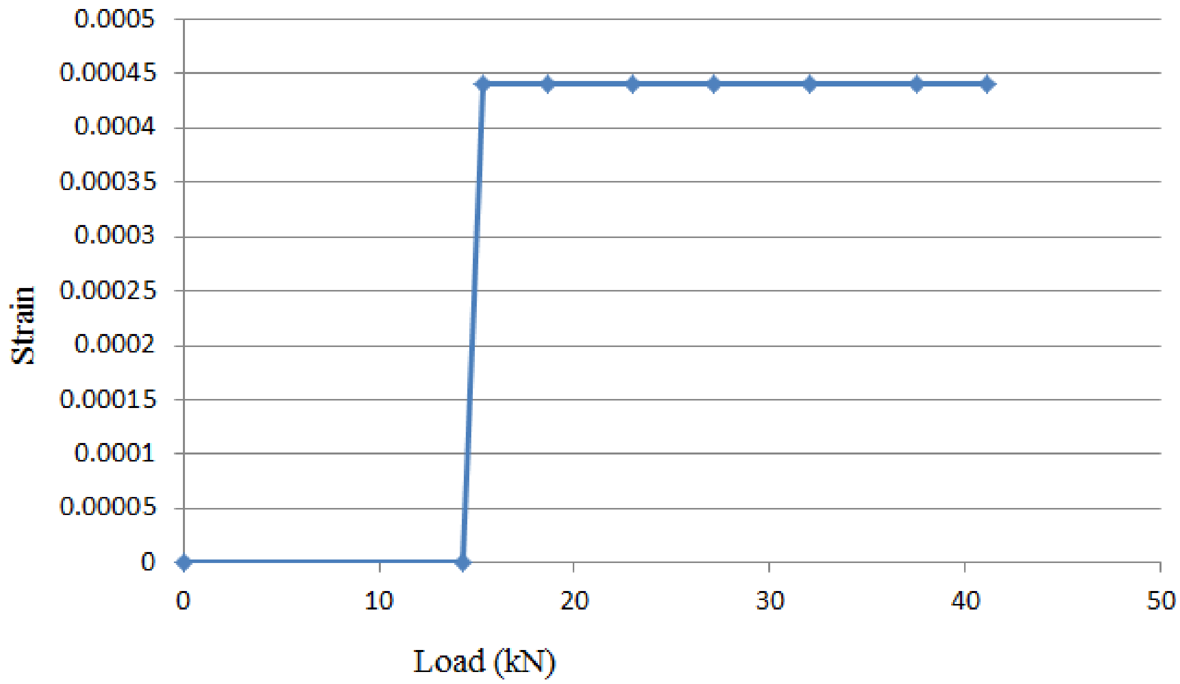


Fig 4.27 Graph of Nail Strain vs Load in nail 5.

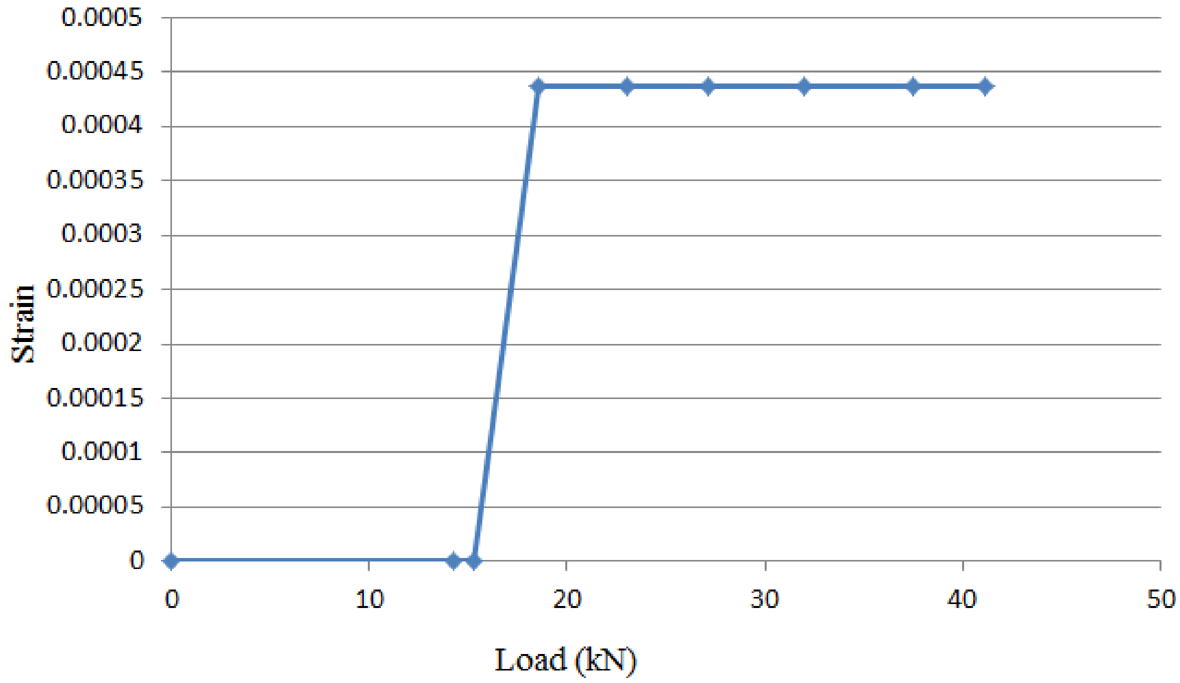


Fig 4.28 Graph of Nail Strain vs Load in nail 6.

Discussion of results: - The results of 60º slope with an nail inclination of 30º are tabulated in table 4.11 and table 4.12 and results showed that initially no strains were taken by any of the nails after 10 seconds nail 2 and nail 4 got strains simultaneously after then strain of nail 2 increased rapidly whereas of other nails there is not a such rapid increase of strain values this could be the tilting of bearing plate to one side due to some eccentricity or fault in compaction of soil. In between the experiment almost after 20 seconds the strain of nail 2 became 0 and there was immediate strain recorded in nail one it may be stress is transferred to nail 1 from nail 2 for an instant and after that due to tilting of bearing plate nail 2 showed very high value of strain where as in nail 1 strain remained constant till failure .Exactly similar thing happened with nail 3 and nail 4 where strain in nail 3 was constant but of nail 4 increased rapidly .By studying the result we got to know that settlement of soil is not constant horizontally hence bearing plate may tilt due to differential settlement but its effect remained only for first two rows of nails as last layer was sufficiently compacted where the third row of nails was there. It shows effect of load decreases along the depth of soil sample.

4.3.5 Test on 90° slope with nail inclination of 15°

Fifth model testing was done on the slope of 90° with nail inclination of 15° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.20, 4.21.

Fig 4.3.5(a) Slope before failure **Fig 4.3.5(b) Slope after failure**

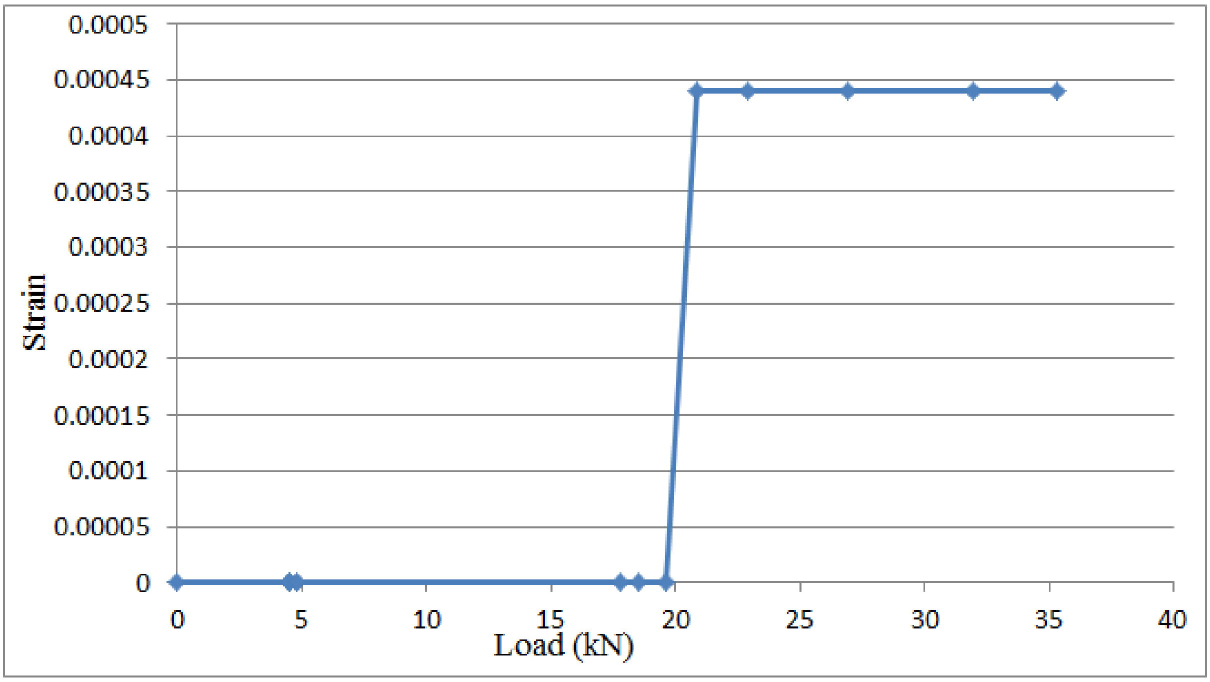


Fig 4.29 Graph of Nail Strain vs Load in nail 1.

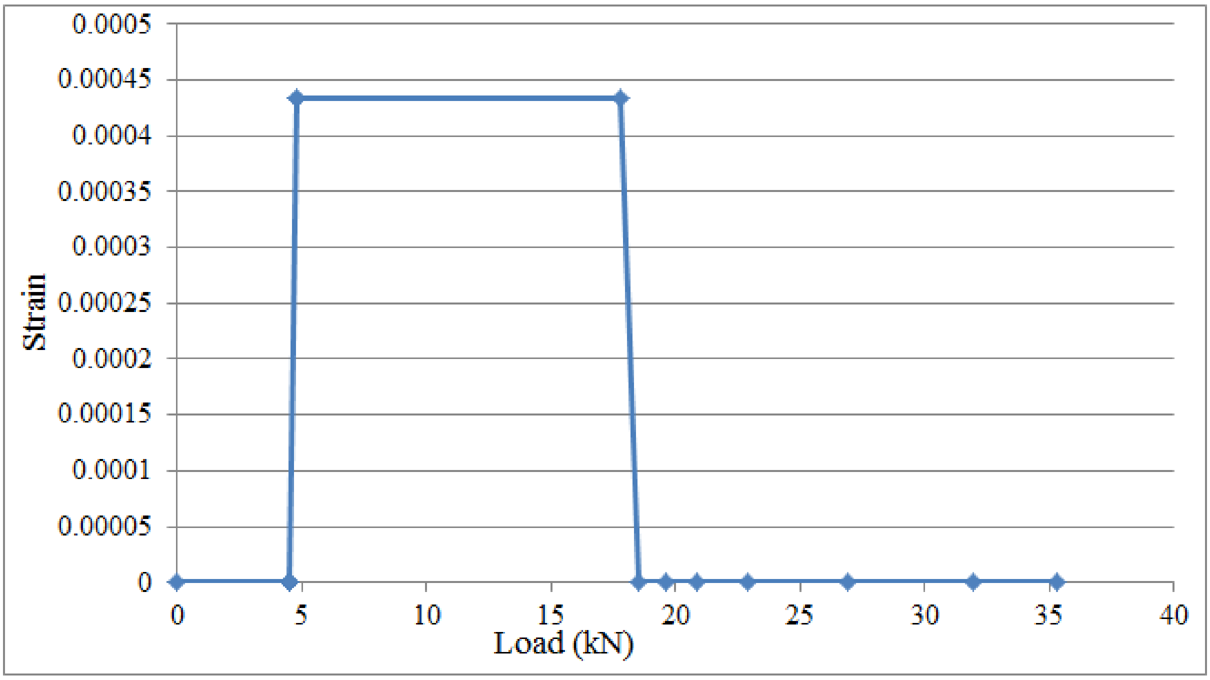


Fig 4.30 Graph of Nail Strain vs Load in nail 2.

90° being the least stable slope it take least load. Strain generated in nails is also less because the effective angle between slope surface and nail is greater than 90°. With increase in load the strain in nails 1 and 2 increases but goes to zero after some time even when the load is increasing. This is because the most of the load now is taken by the lower level nails.

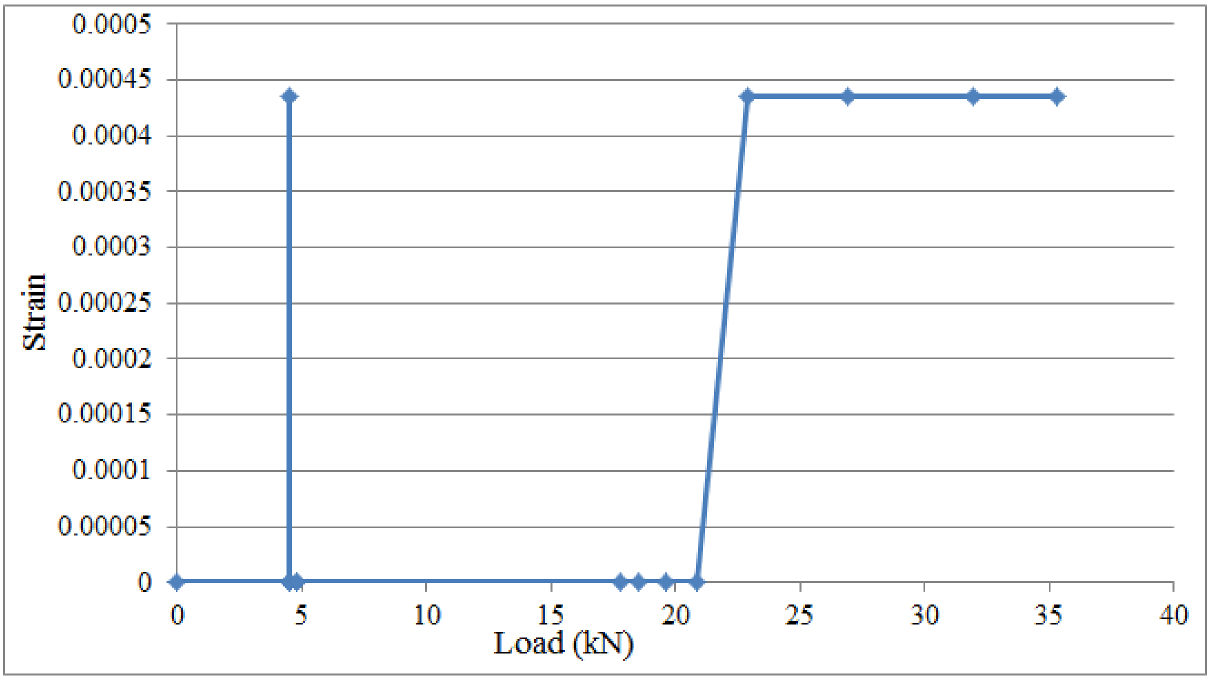


Fig 4.31 Graph of Nail Strain vs Load in nail 3.

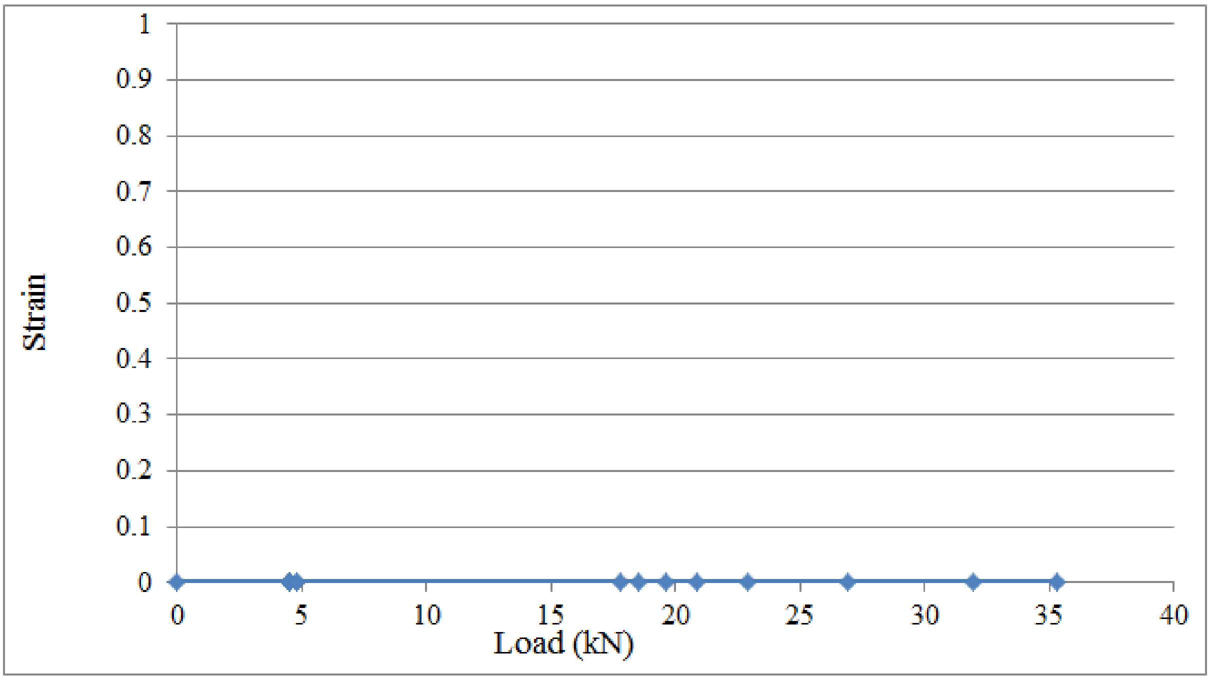


Fig 4.32 Graph of Nail Strain vs Load in nail 4

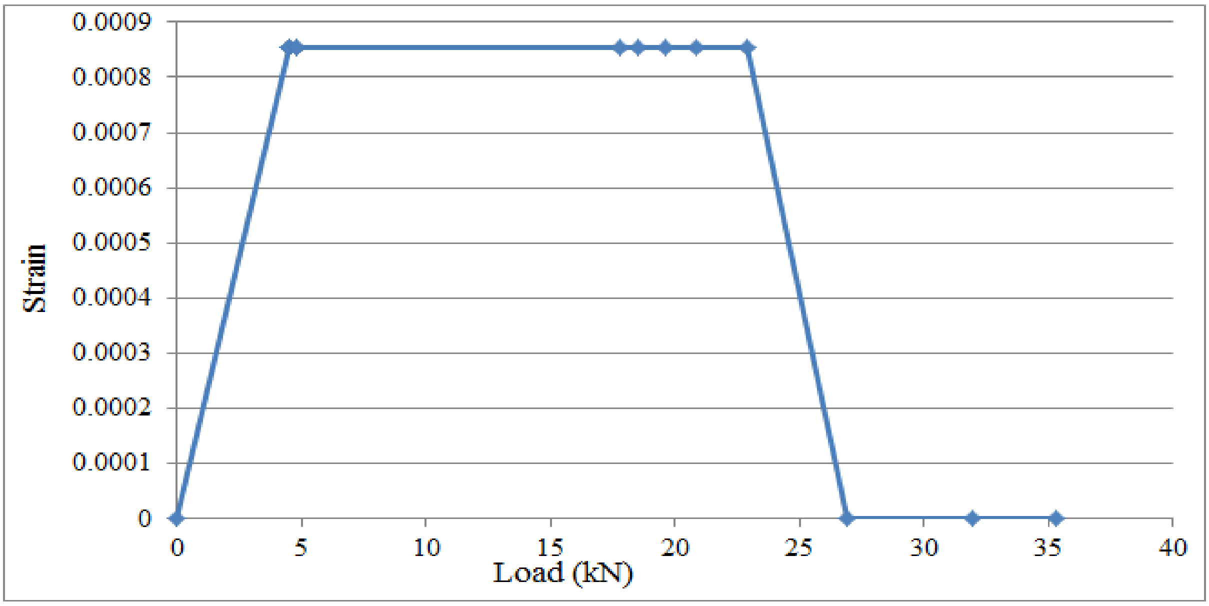


Fig 4.33 Graph of Load vs Nail Strain in nail 5.

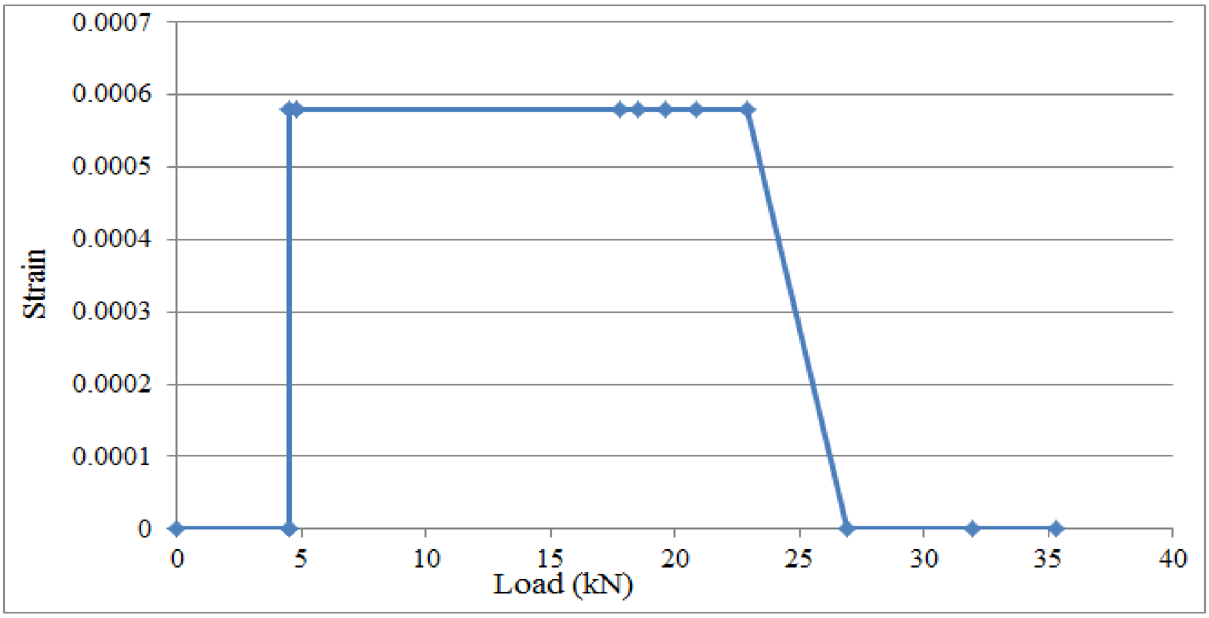


Fig 4.34 Graph of Load vs Nail Strain in nail 6.

Discussion of result: - After 60º we moved to steeper slope of 90º with nail inclination of 15º and results of this experiment showed that nails at the bottom most part were having maximum strain due to the reason that stress did not spread over larger area in 90º slope and hence lower most part is having maximum strain and strain remained almost constant for every nail which means that this slope failed very early until we could get increase in the value of strain hence even after soil nailing it is most unstable slope. Strain value is increasing from top to bottom. Zero strain values could be seen in the table

4.3.6 Test on 90° slope with nail inclination of 30°

Sixth model testing was done on the slope of 90° with nail inclination of 30° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.22, 4.23.

Fig 4.3.6(a) Slope before failure **Fig 4.3.6(b) Slope after failure**

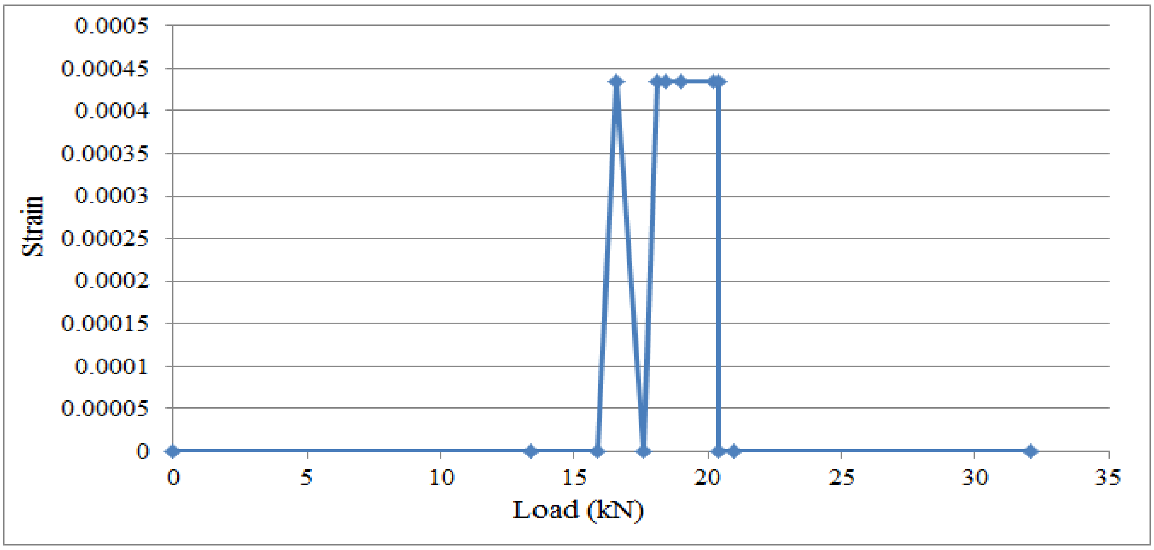


Fig 4.35 Graph of Nail Strain vs Load in nail 1.

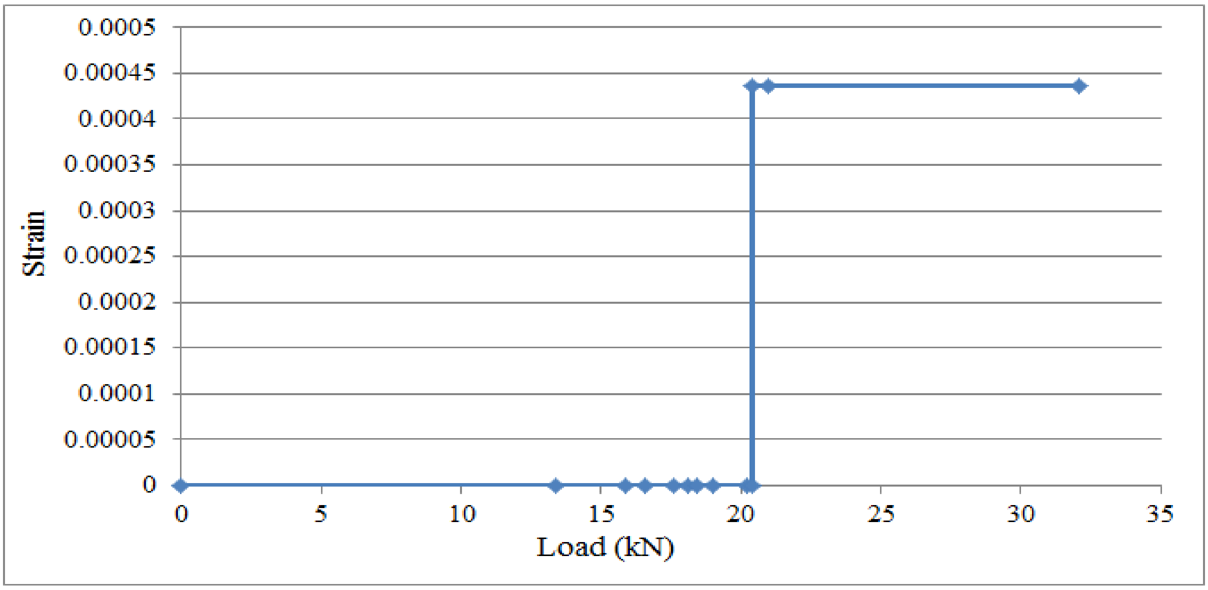


Fig 4.36 Graph of Nail Strain vs Load in nail 2.

In this experiment the effective angle between the slope surface and nail is 120°. So it takes even less load than the previous one. The variation of strain is less because the slope failed very early before we could get the higher variation of strain in nails. In 90° slope the load is spread over less area so they tend to fail early and take less load.

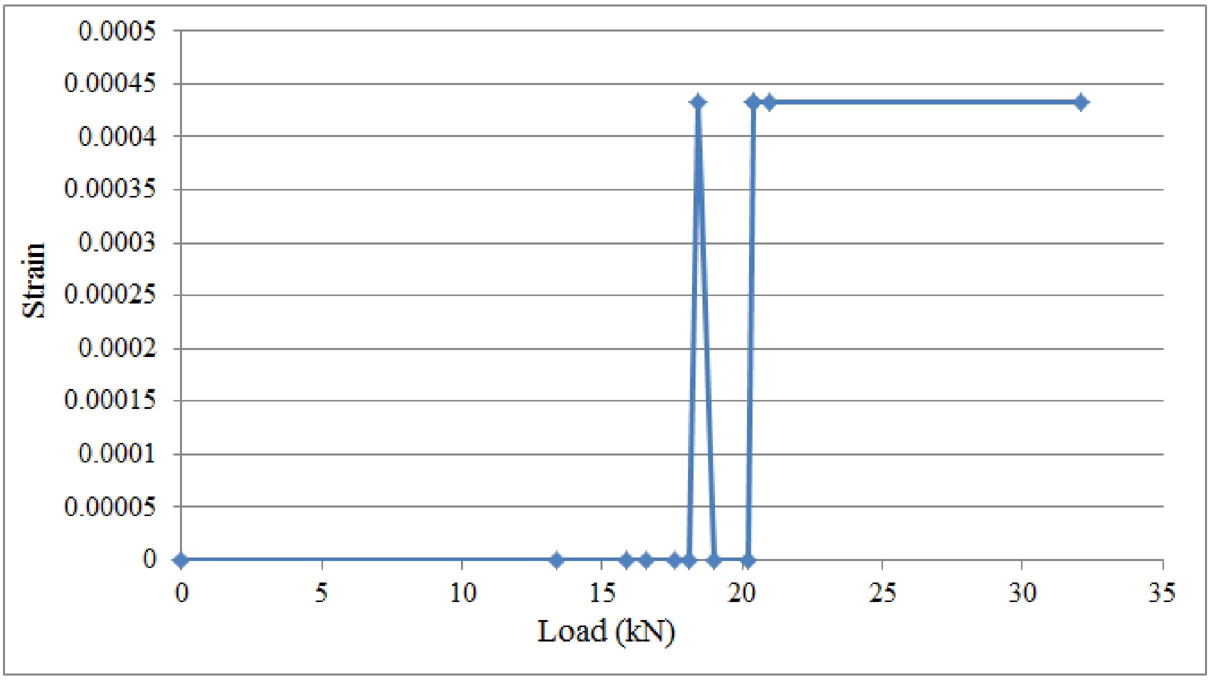


Fig 4.37 Graph of Nail Strain vs Load in nail 3.

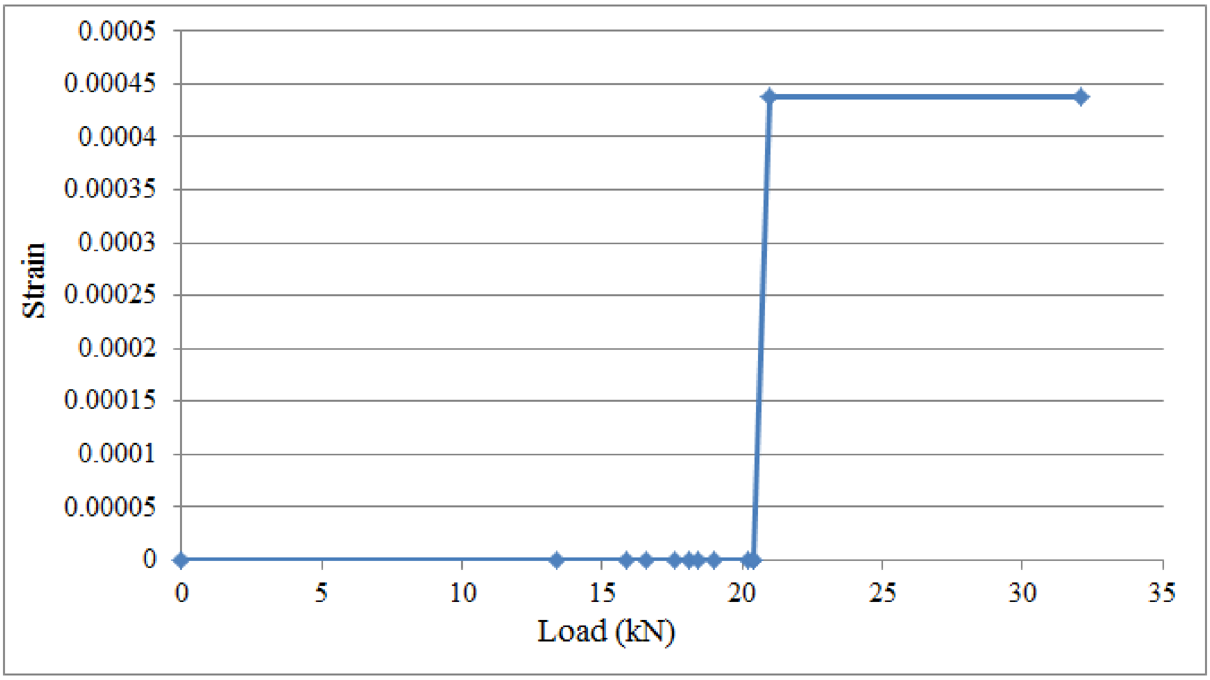


Fig 4.38 Graph of Nail Strain vs Load in nail 4.

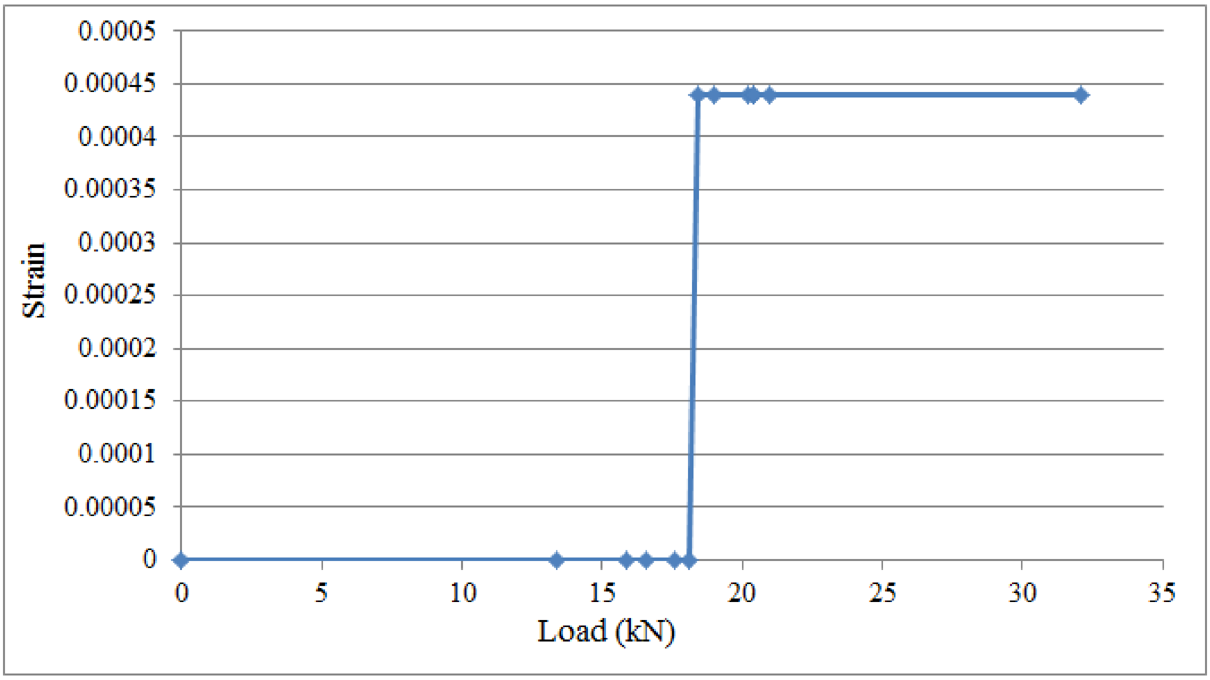


Fig 4.39 Graph of Nail Strain vs Load in nail 5.

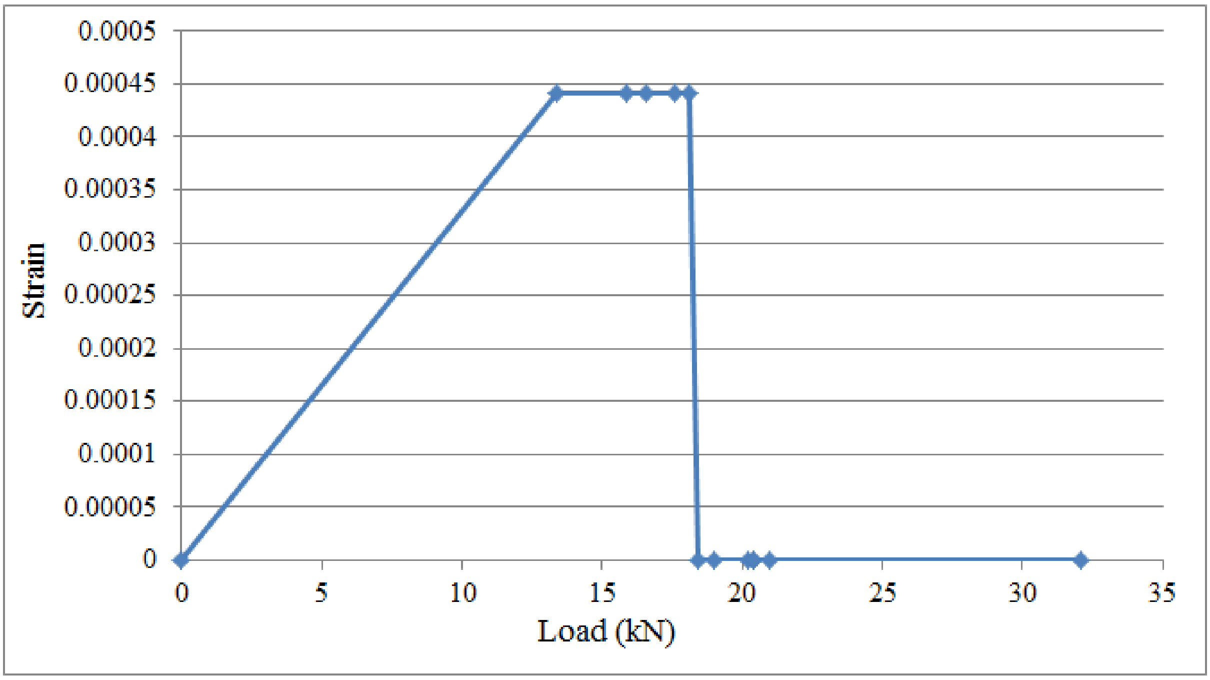


Fig 4.40 Graph of Nail Strain vs Load in nail 6.

Discussion of results: - From the results of this experiment of slope of 90º and nail angle of 30º we can see that strain value increases as we go down the slope whose reason stated above that in 90º slope stress do not spread in horizontal direction thus the whole load is just concentrated on that initial area giving higher values of strains on lower nails than upper nails. Similar to the nail inclination of 15º with 90º slope the strain values came after a while and remained constant also strain values were lesser than 15º slope hence 15º nail inclination gave much higher stability than 30º inclined slope.

One more thing can be concluded that unlike 60º and 45º slopes there is not any significant amount of change in slope stability if nails are put at different angels at different levels.

4.4 Slope Testing with Helical Nails

Similar experiment was done with helical nails and the strain value and forces developed in nails were observed at each 10 seconds interval and are tabulated as follows.

But this time we also measured the lateral displacement of the slope plot get the graph of slope after failure. The graph showed us the maximum displacement of soil mass after the failure of slope.

4.4.1 45° slope with 15° nail inclination

First model testing was done on the slope of 45° with nail inclination of 15° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.24, 4.25.

Fig 4.4.1(a) Slope before failure **Fig 4.4.1(b) Slope after failure**

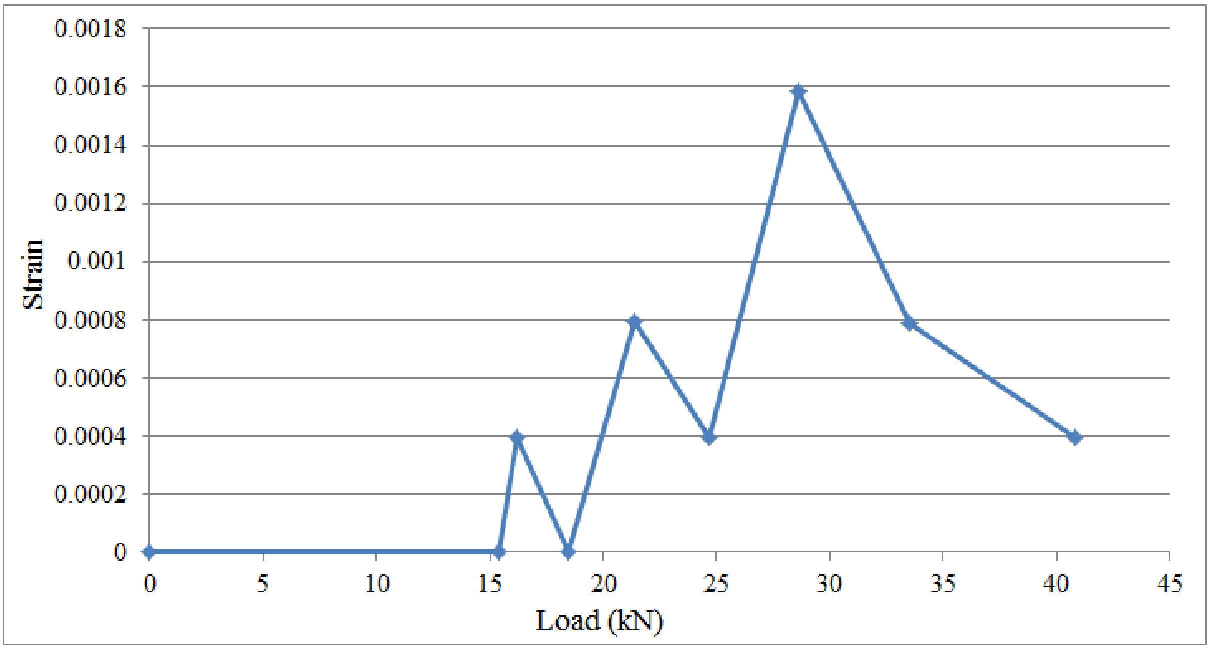


Fig 4.41 Graph of Nail Strain vs Load in nail 1.

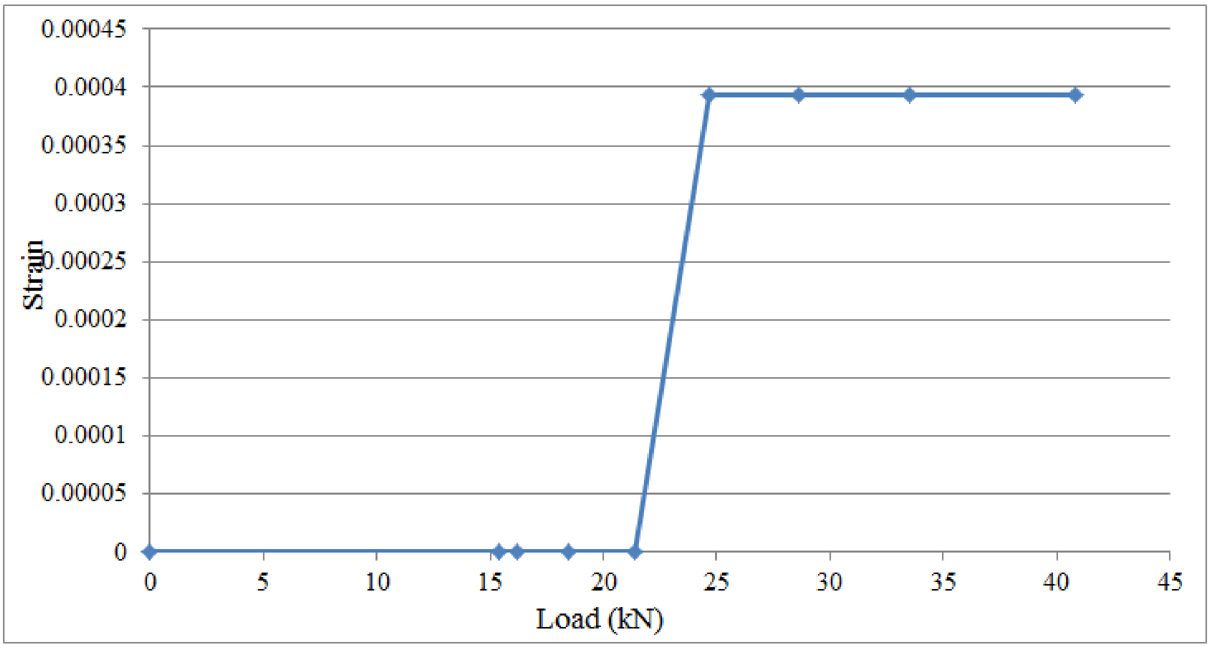


Fig 4.42 Graph of Nail Strain vs Load in nail 2.

Strain does not come immediately after applying the load. Firstly load is taken by the soil, afterwards it is transferred to the nails. This load causes strain in the nails.

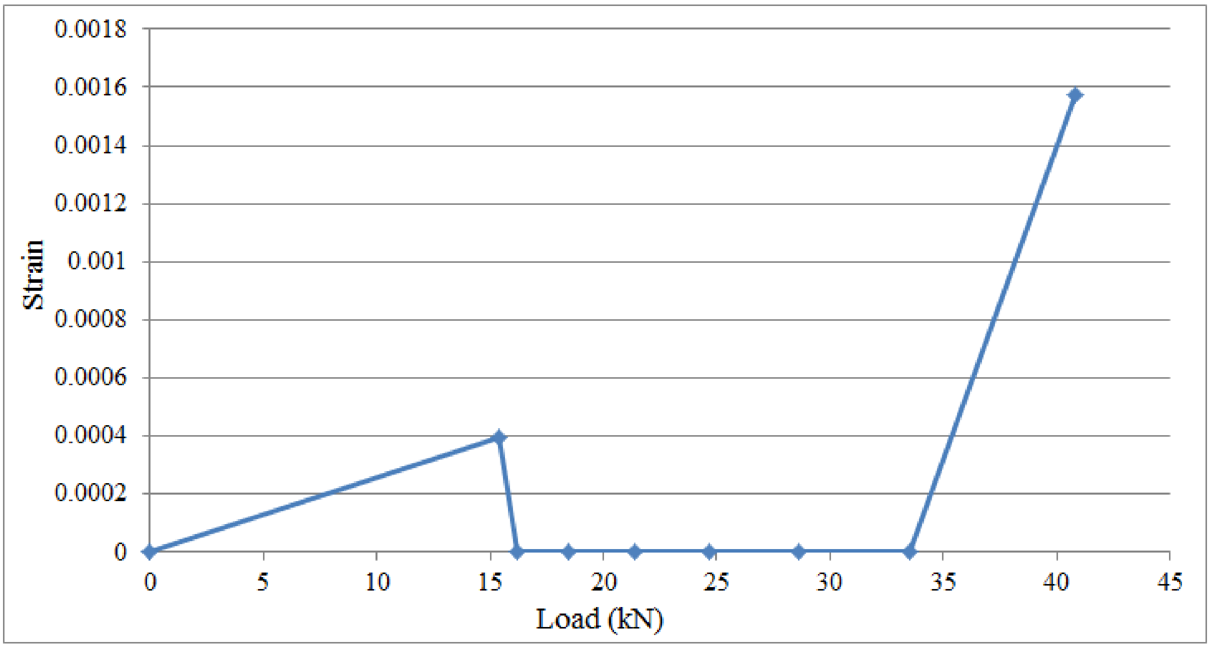


Fig 4.43 Graph of Nail Strain vs Load in nail 3.

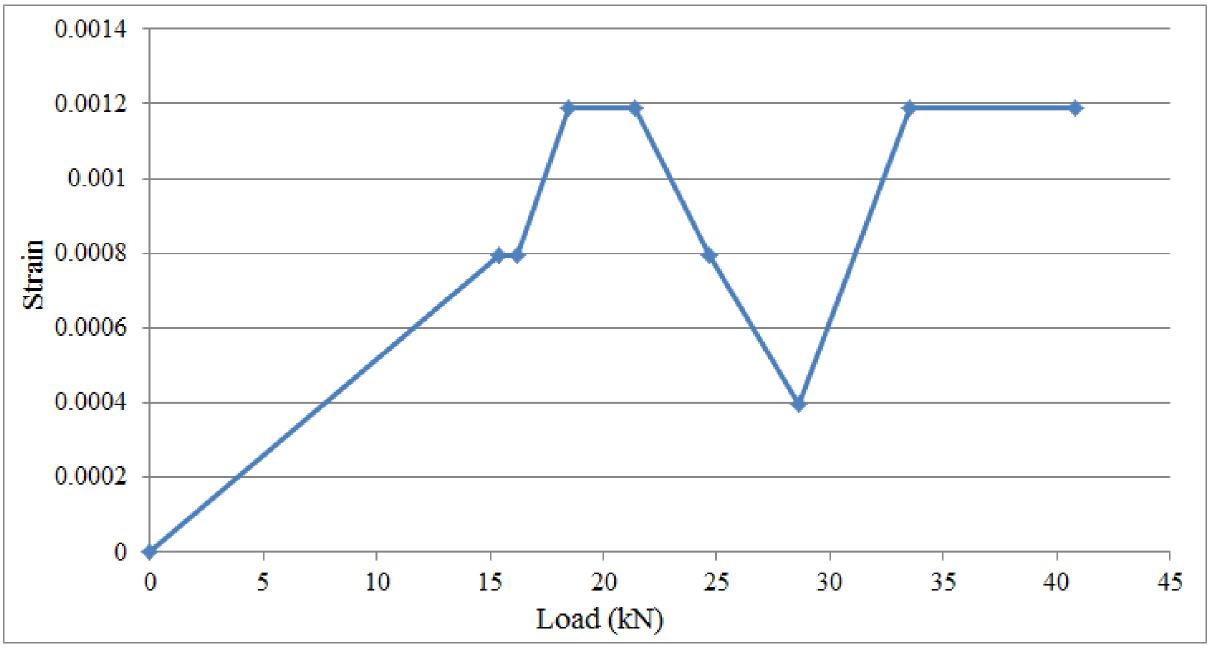


Fig 4.44 Graph of Nail Strain vs Load in nail 4.

The maximum force of 31.668 KN and strain is taken by nail 3 and interesting thing is that before acquiring this load the nail was having zero force for 50 seconds duration and after that slope failed. After seeing this it could be said that nail 3 got shock loading. After nail 3, nail 4 is having highest load of 23.90 KN and also nail 4 is inserted parallel to the nail 3 hence it means the plane joining nail 3 and 4 is having maximum mobilisation in slope.

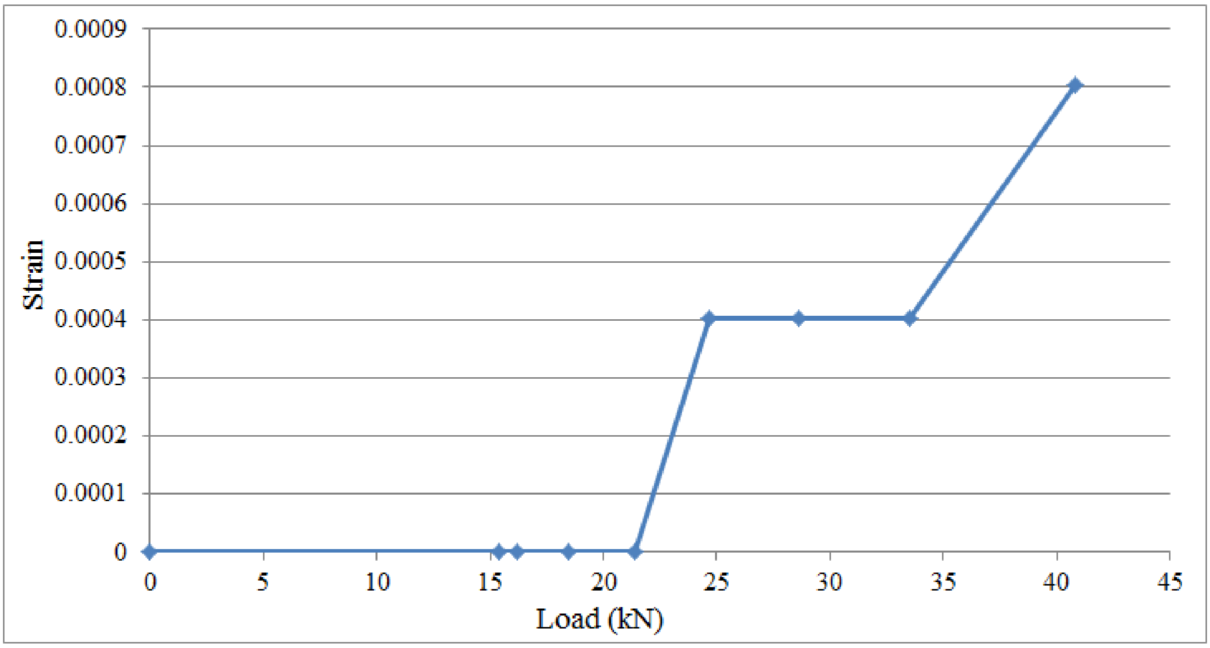


Fig 4.45 Graph of Nail Strain vs Load in nail 5.

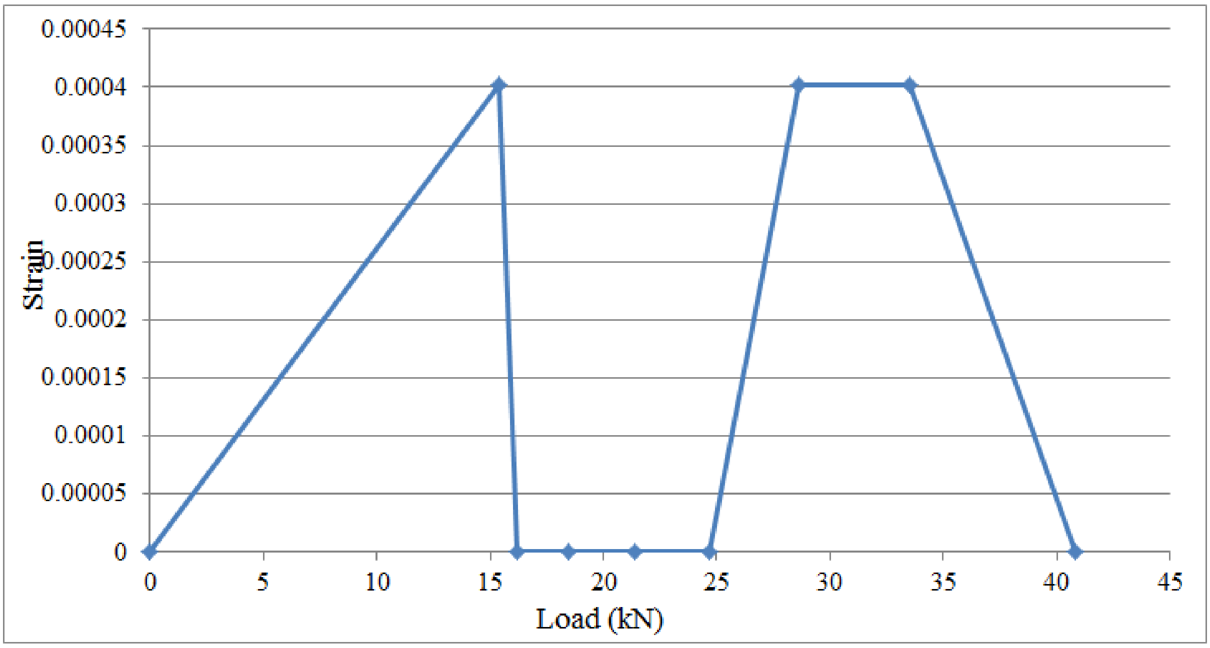


Fig 4.46 Graph of Nail Strain vs Load in nail 6.

Nail 5 is having greater force than nail 6 hence nail 5 held soil more firmly giving lesser lateral displacement at left face towards which nail 5 is inserted.

Table 4.5 Stress in soil at equal interval of time

Time (Seconds)	Load (kN)
0	0
10	15.4
20	16.2
30	18.5
40	21.4
50	24.7
60	28.6
70	33.5
80	40.8

Table 4.6 Lateral displacement at left face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	8.5
5	8.5
10	6
15	3.5
20	1

Table 4.7 Lateral displacement at right face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	10
5	5.8
10	4.7
15	2.4
20	0.8

Results and discussions:-

After doing the experiment the strain and nail forces values are tabulated in table (4.27) and table (4.28) .Strains do not came immediately after applying load few of the nails starts taking load early like nail 3, 4 and 6 started getting strain 10 seconds after applying the load but nail 1, 2 and 5 took load after 20, 50, 50 seconds respectively.. The maximum force of 31.668 KN and strain is taken by nail 3 and interesting thing is that before acquiring this load the nail was having zero force for 50 seconds duration and after that slope failed. After seeing this it could be said that nail 3 got shock loading. After nail 3, nail 4 is having highest load of 23.90 KN and also nail 4 is inserted parallel to the nail 3 hence it means the plane joining nail 3 and 4 is having maximum mobilisation in slope.

Nail 5 is having greater force than nail 6 hence nail 5 held soil more firmly giving lesser lateral displacement at left face towards which nail 5 is inserted.

4.4.2 45° slope with 30° nail inclination

When similar experiment was repeated with the nail inclination of 30° following results were observed. For load and strain values refer to ANNEXURE Table 4.26, 4.27.

Fig 4.4.2(a) Slope before failure

Fig 4.4.2(b) Slope after failure

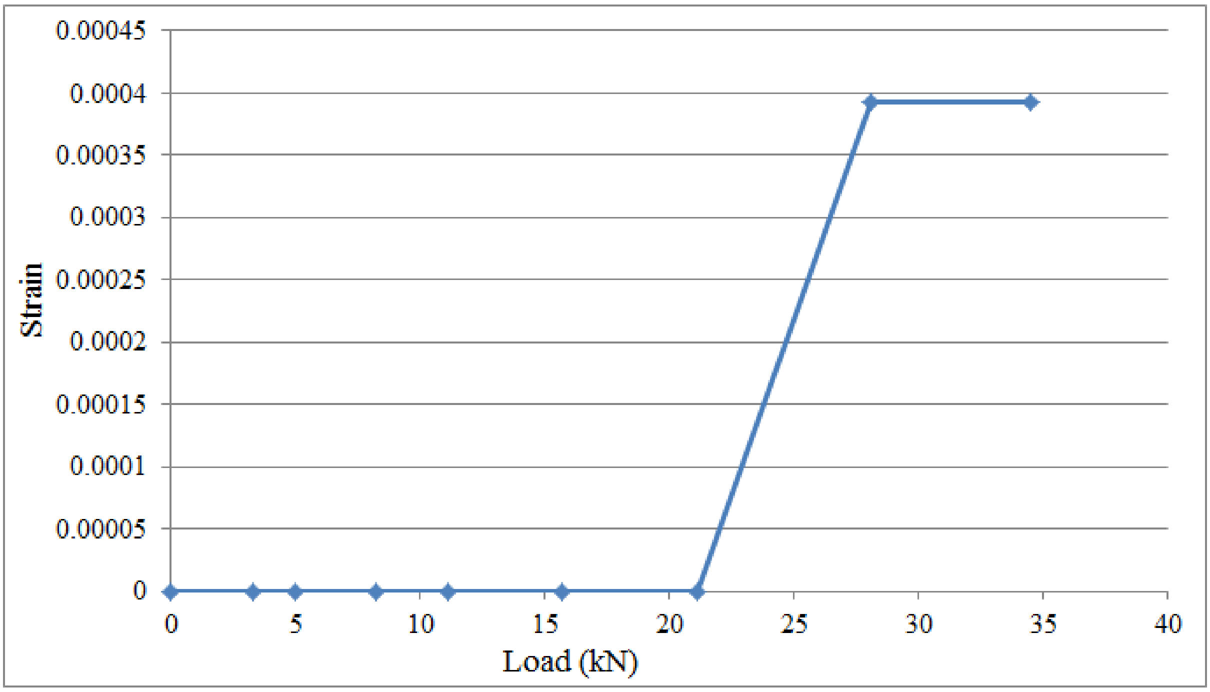


Fig 4.47 Graph of Nail Strain vs Load in nail 1.

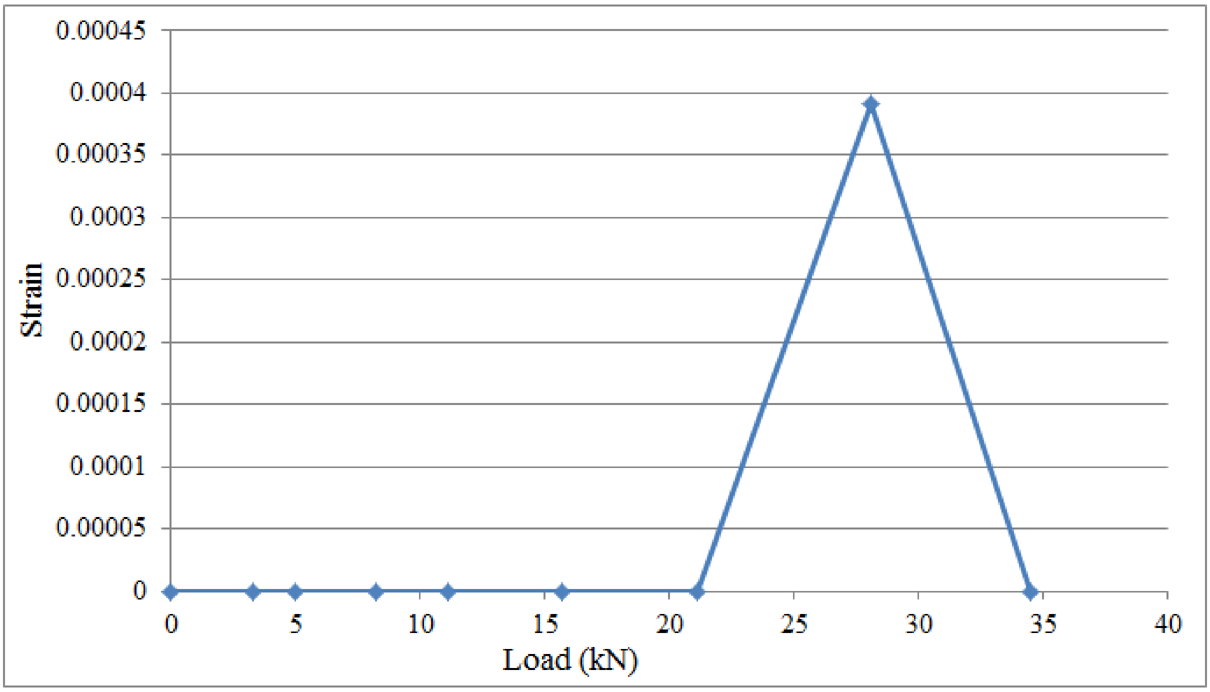


Fig 4.48 Graph of Nail Strain vs Load in nail 2.

The strain in nail 1 and 2 comes at the same and of the same amount. These nails are parallel and at the same height, so the shows nearly the same behaviour.

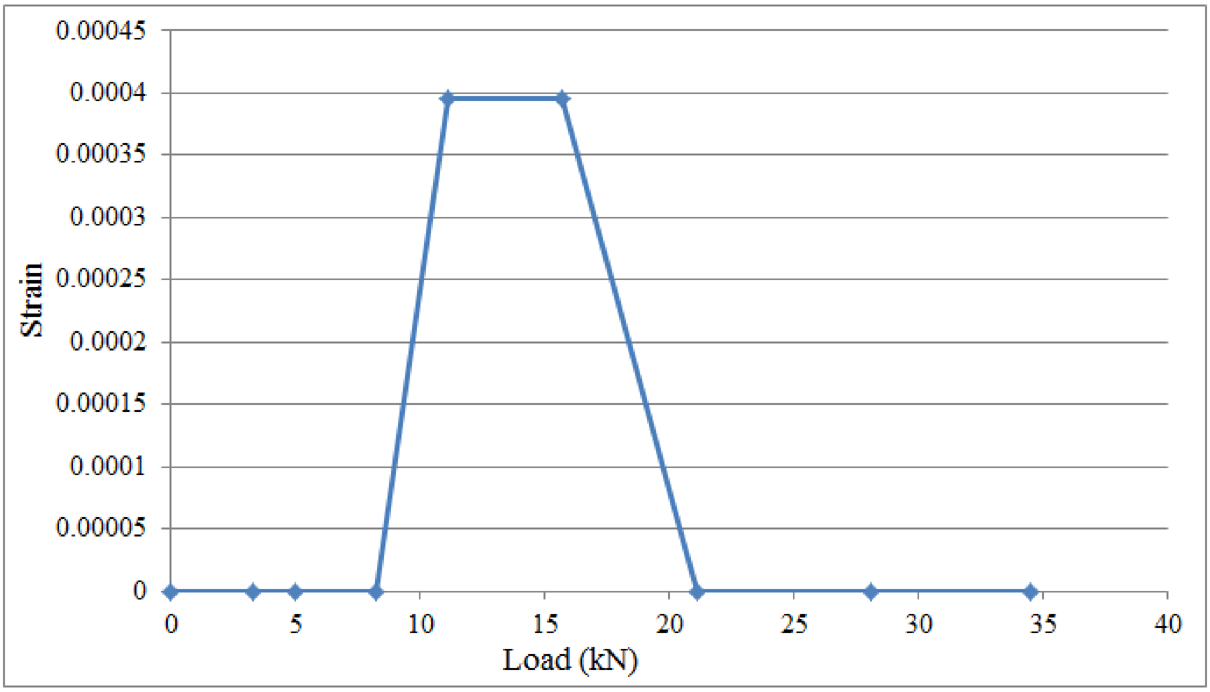


Fig 4.49 Graph of Nail Strain vs Load in nail 3.

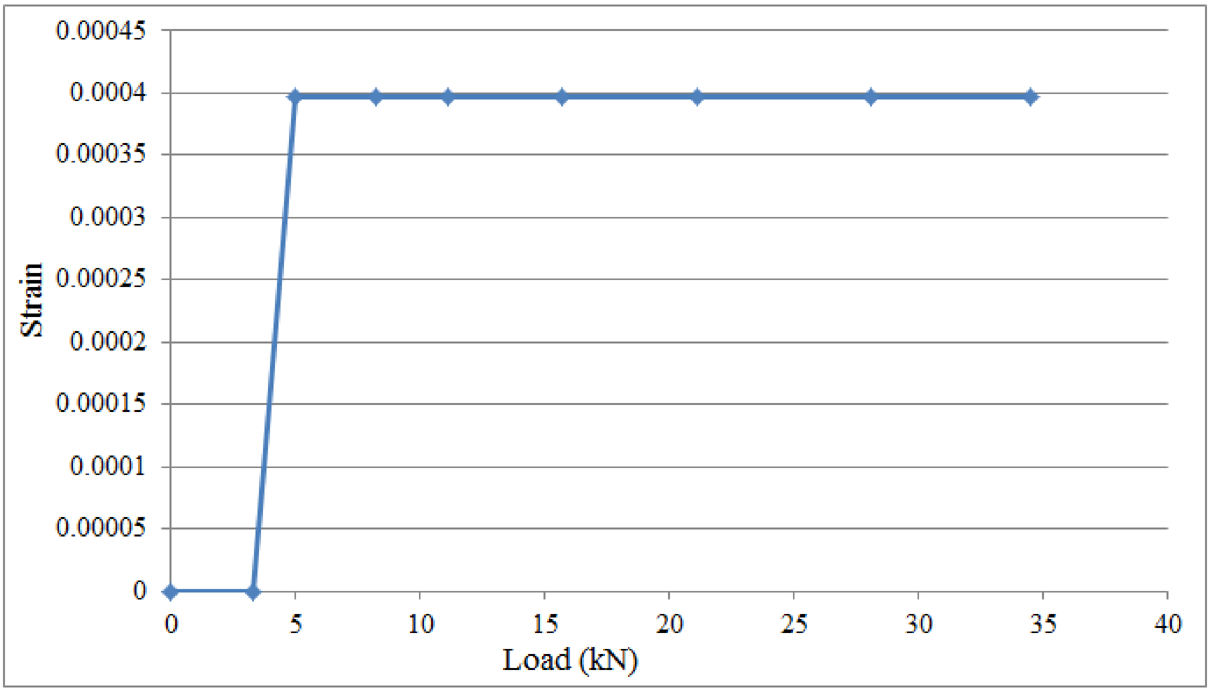


Fig 4.50 Graph of Nail Strain vs Load in nail 4.

Similar to 15° nail inclination experiment strains came at different time at different nails this time nail 4, 5, 6 got strain first and this could be due to overburden pressure on these nails force on nail 4 remained constant from 20 seconds to failure which came after 80 seconds of load application.

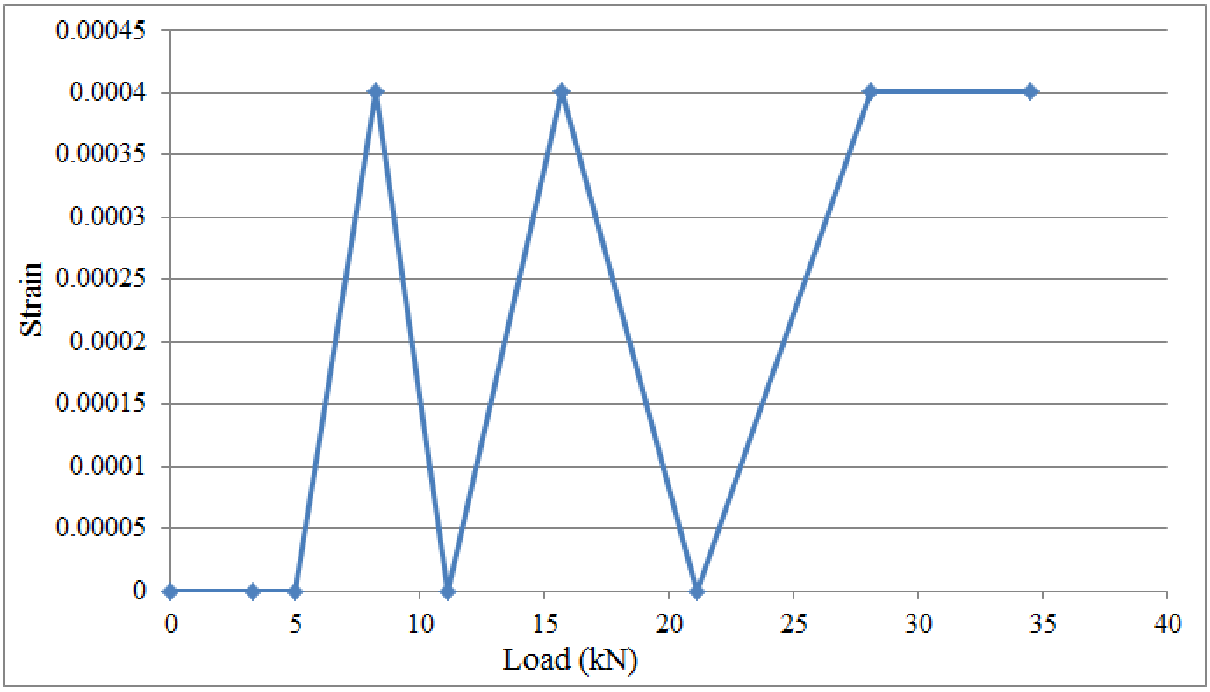


Fig 4.51 Graph of Nail Strain vs Load in nail 5.

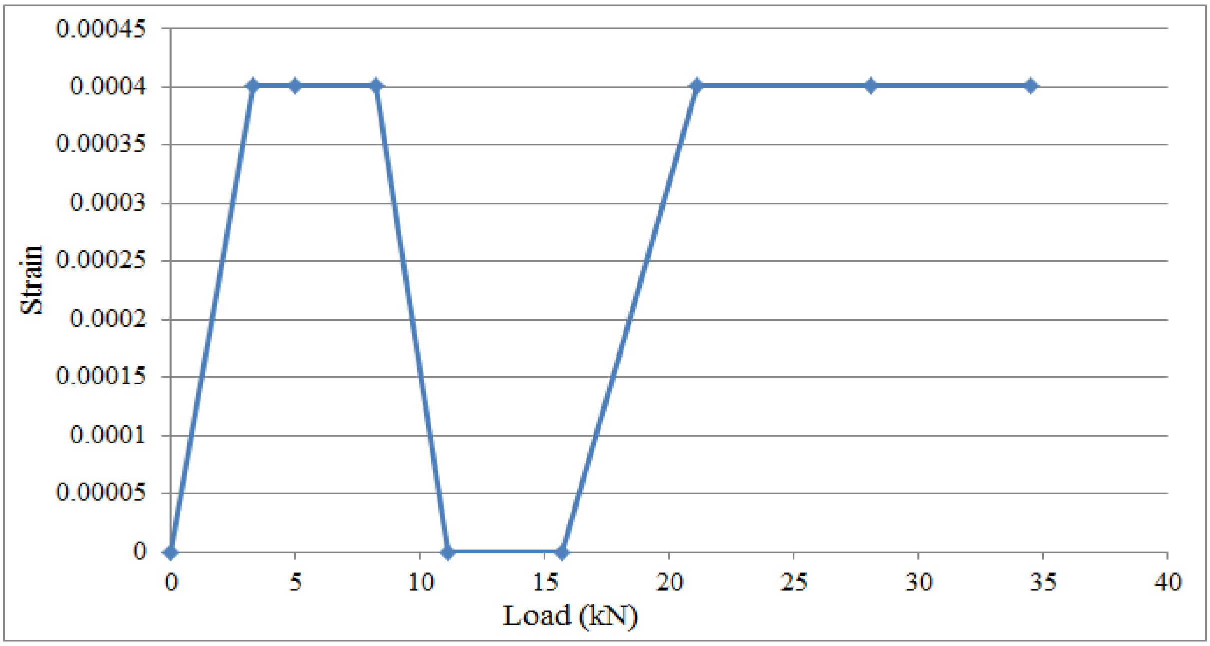


Fig 4.54 Graph of Nail Strain vs Load in nail 6

Maximum load was taken by nail 5 and 6 i.e. 8.075 KN means nail 6 is mobilised most and their plane is having maximum stress. Also displacements of slope are almost same (9cm and 9.6cm) on both the ends.

Table 4.8 Stress in soil at equal interval of time

Time (Seconds)	Load (kN)
0	0
10	3.3
20	5
30	8.2
40	11.1
50	15.7
60	21.1
70	28.1
80	34.5

Table 4.9 Lateral Displacement at left face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	9.6
5	8.5
10	6.9
15	4.2
20	2.7

Table 4.10 Lateral displacement at right face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	9
5	6
10	4.5
15	3.8
20	1

Results and discussions:-

When similar experiment was repeated with the nail inclination of 30° following results were observed which could be defined as follows.

Similar to 15° nail inclination experiment strains came at different time at different nails this time nail 4, 5, 6 got strain first and this could be due to overburden pressure on these nails force on nail 4 remained constant from 20 seconds to failure which came after 80 seconds of load application.

Maximum load was taken by nail 5 and 6 i.e. 8.075 KN means nail 6 is mobilised most and their plane is having maximum stress. Also displacements of slope are almost same (9cm and 9.6cm) on both the ends.

4.4.3 60° slope with 15° nail inclination

Third model testing was done on the slope of 60° with nail inclination of 15° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.28, 4.29.

Fig 4.4.3(a) Slope before failure **Fig 4.4.3(b) Slope after failure**

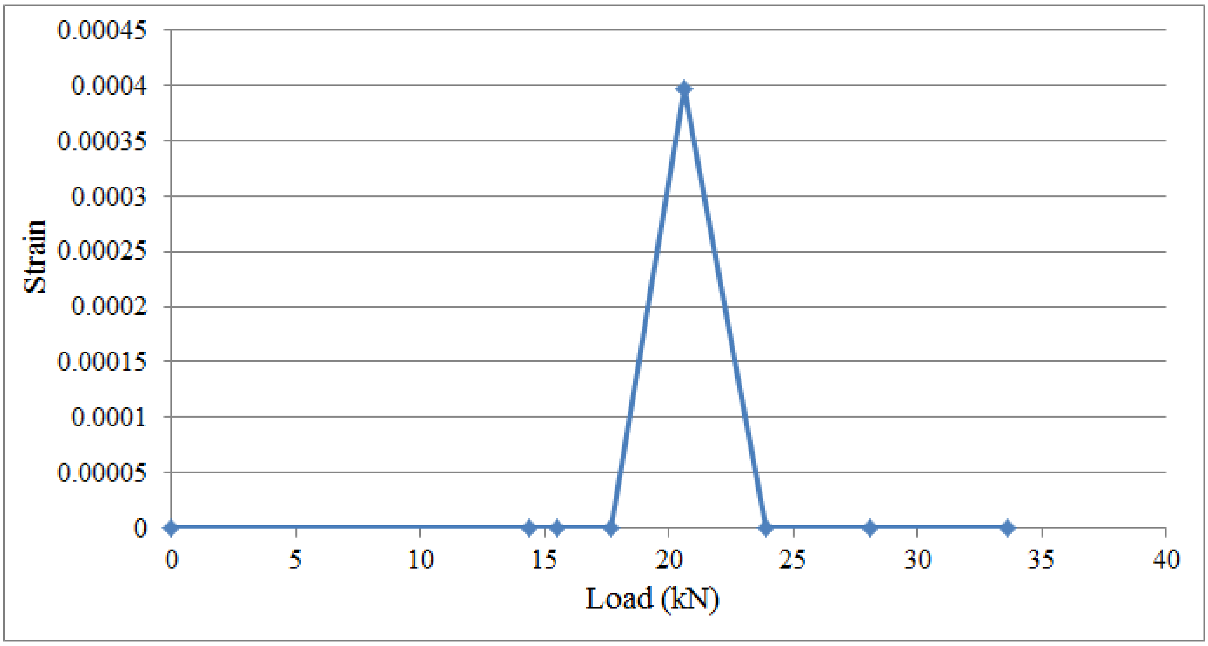


Fig 4.55 Graph of Nail Strain vs Load in nail 1.

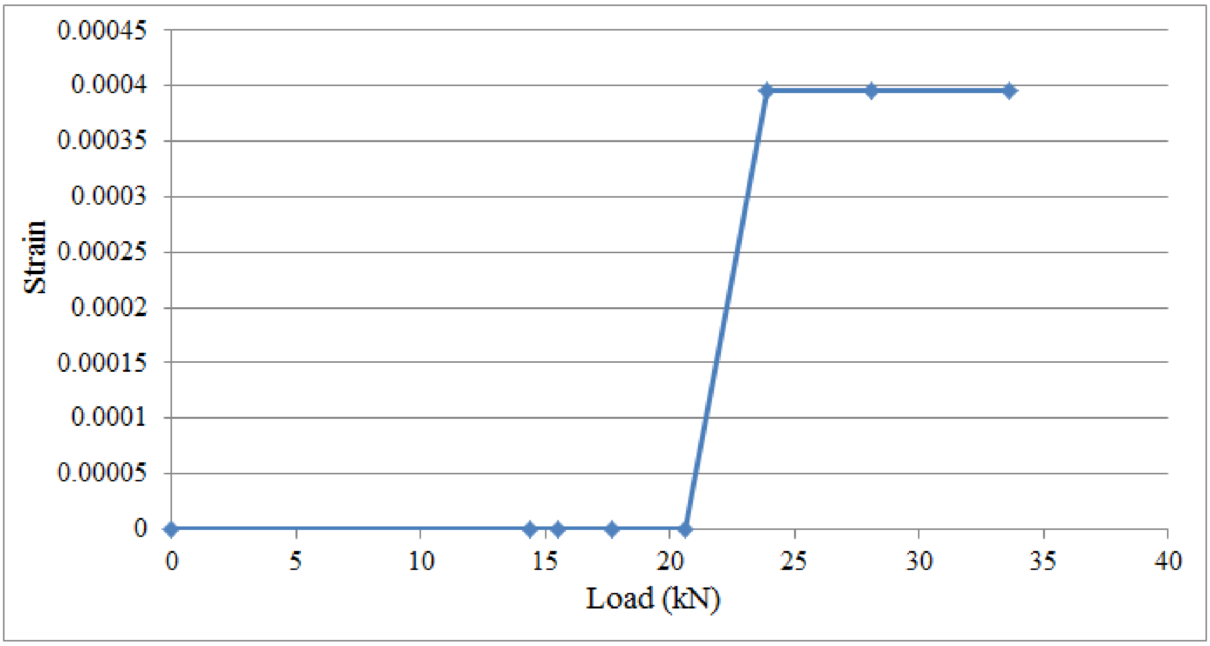


Fig 4.56 Graph of Nail Strain vs Load in nail 2.

When we compare the values of other nail forces the value of forces of helical nail came maximum times greater than that of screw nails. It could mean that in helical nails load distribution is much more uniform than screw nails it may be due to its bigger size of soil mass attached to helical nail.

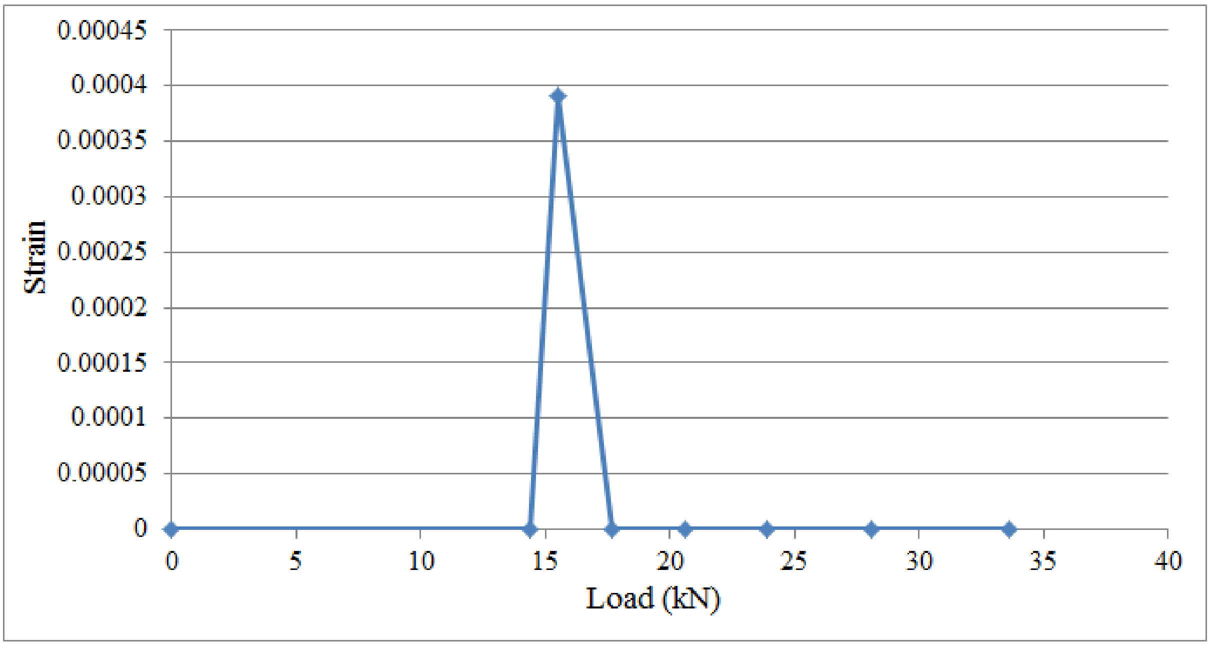


Fig 4.57 Graph of Nail Strain vs Load in nail 3.

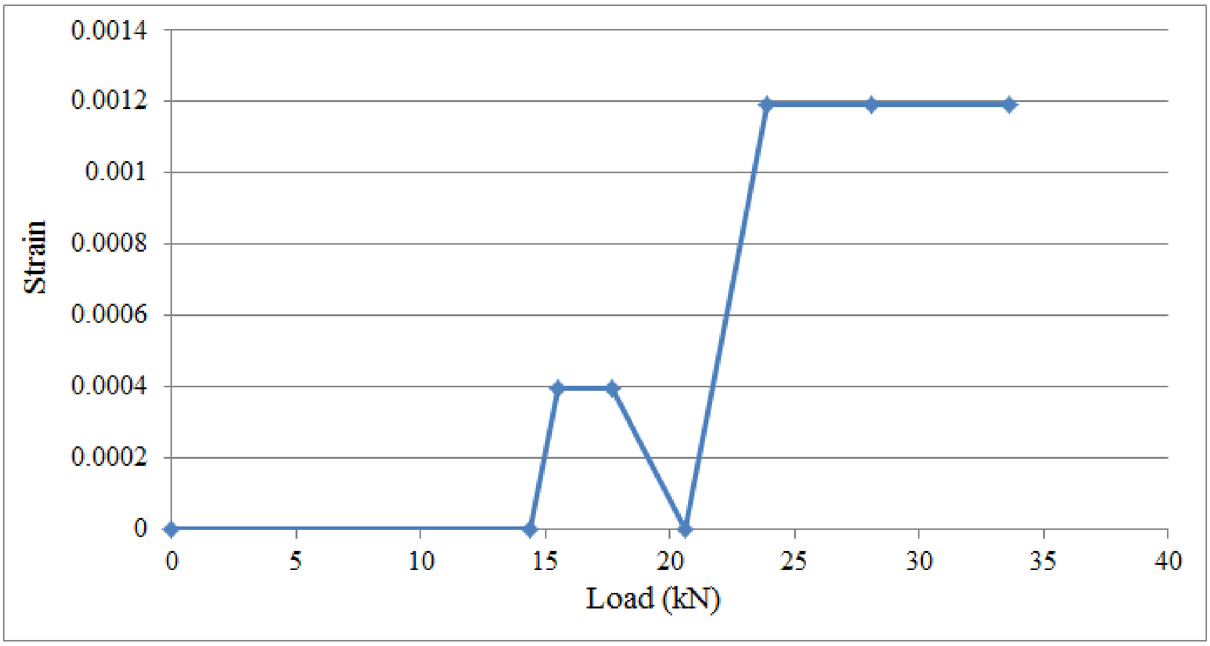


Fig 4.58 Graph of Nail Strain vs Load in nail 4.

Maximum nail force that we got in this experiment with 60° slope angle having 15° nail inclination is 23.96 KN on nail 4 showing that it got maximum mobilisation hence right face got minimum lateral displacement of 6 cm whereas left face have deflection of 7.5cm it means that nail 4 held soil firmly and restrained the displacement of right side as nail 4 is on right side of slope.

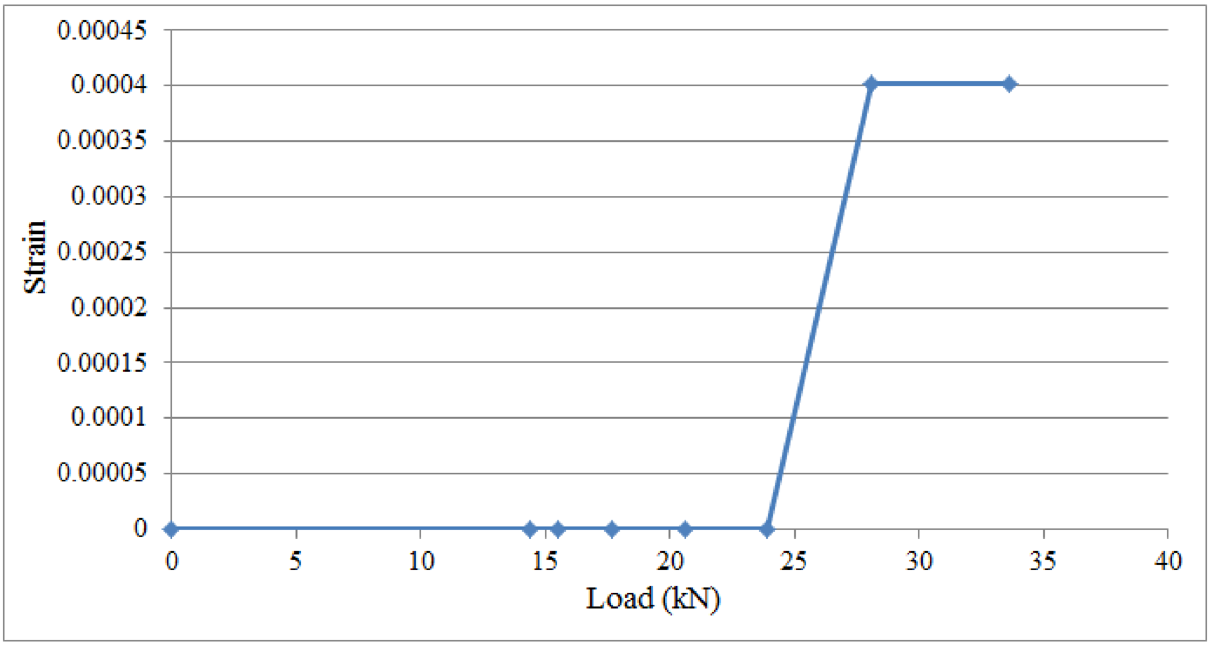


Fig 4.59 Graph of Nail Strain vs Load in nail 5.

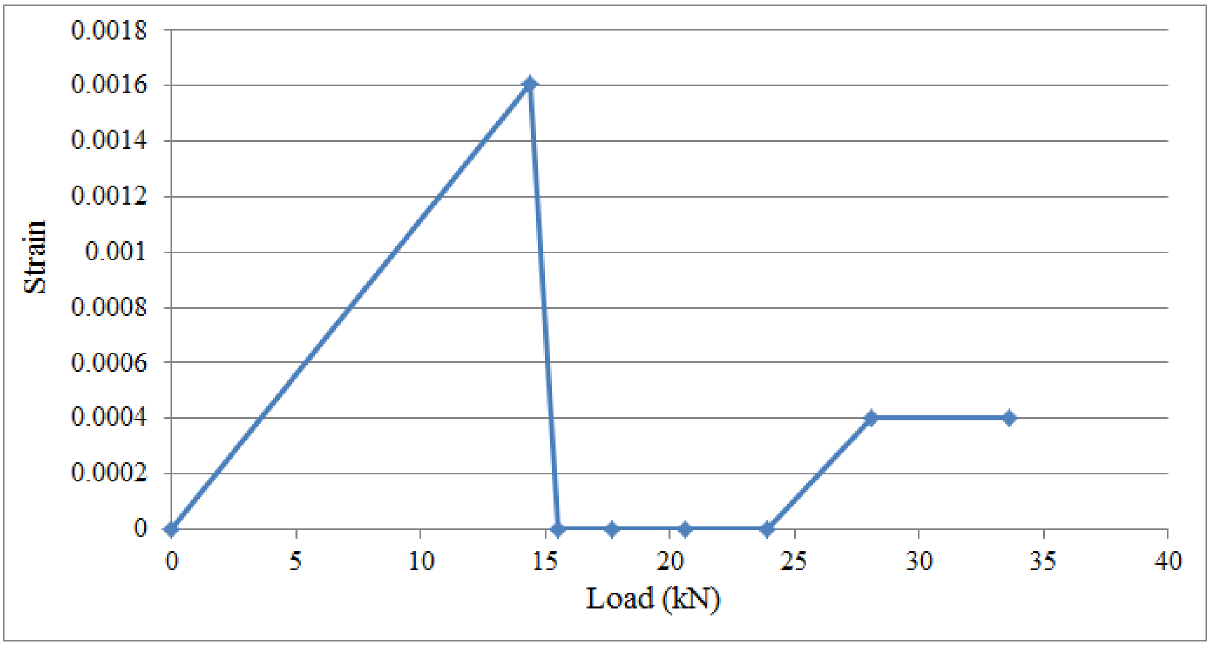


Fig 4.60 Graph of Nail Strain vs Load in nail 6.

Table 4.11 Stress in soil at equal interval of time

Time (Seconds)	Load (kN)
0	0
10	14.4
20	15.5
30	17.7
40	20.6
50	23.9
60	28.1
70	33.6

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Table 4.12 Lateral displacement at left face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	7.5
5	4.7
10	3.9
15	2
20	0.5

Table 4.13 Lateral displacement at right face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	6
5	3.5
10	2.5
15	1.8
20	0.3

Result and discussions:-

Maximum nail force that we got in this experiment with 60° slope angle having 15° nail inclination is 23.96 KN on nail 4 showing that it got maximum mobilisation hence right face got minimum lateral displacement of 6 cm whereas left face have deflection of 7.5cm it means that nail 4 held soil firmly and restrained the displacement of right side as nail 4 is on right side of slope.

4.4.4 60° slope with 30° nail inclination

Forth model testing was done on the slope of 60° with nail inclination of 30° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.20, 4.31.

Fig 4.4.4(a) Slope before failure

Fig 4.4.4(b) Slope after failure

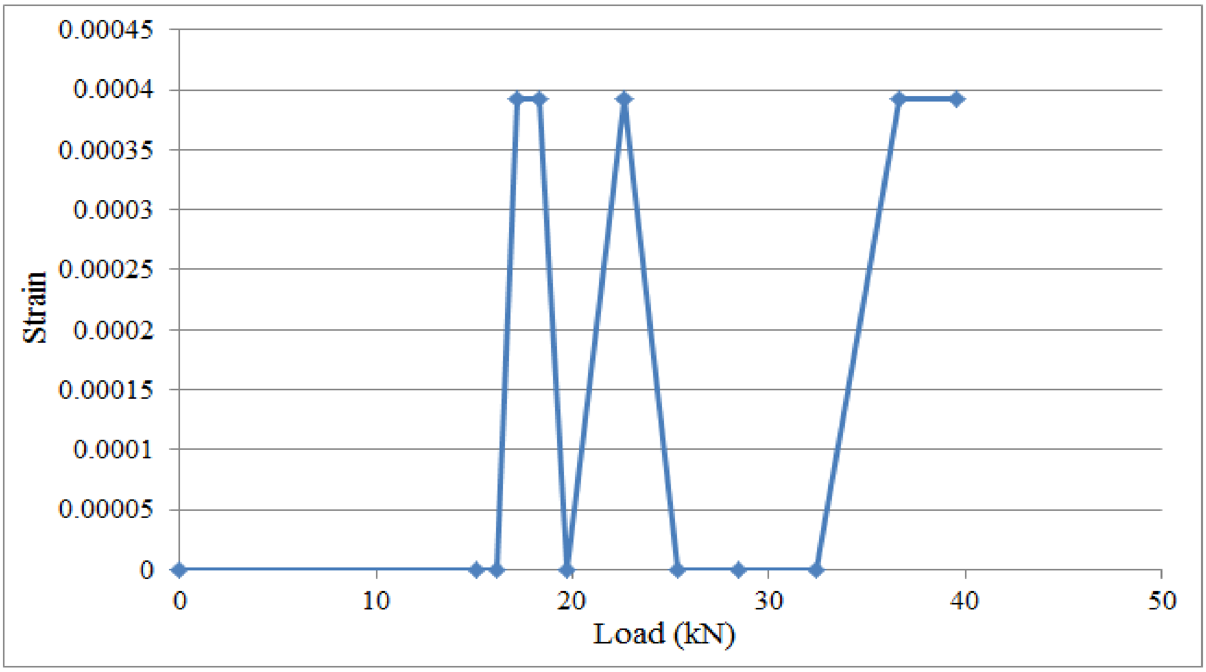

Fig 4.61 Graph of Nail Strain vs Load in nail 1.

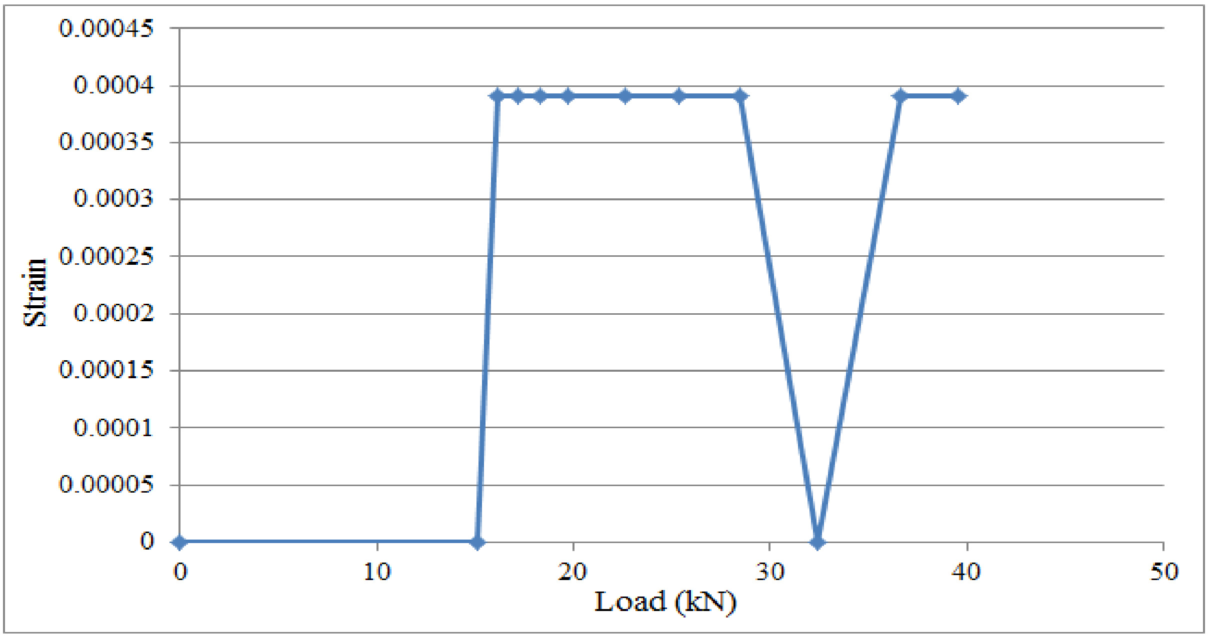

Fig 4.62 Graph of Nail Strain vs Load in nail 2.

The effective angle between the slope surface and nail is 90°, so the load taken by the slope is higher than the previous slope of nail inclination of 15°. The nails shows the higher values of strain as compared to previous experiment. This shows that when effective angle between the slope surface and nail is 90°, the slope can take higher load and nails take higher load and thus stabilizing the slope. The slope angle being 60° but still it is able to take load near to the load taken by 45° slope is because of this reason only.

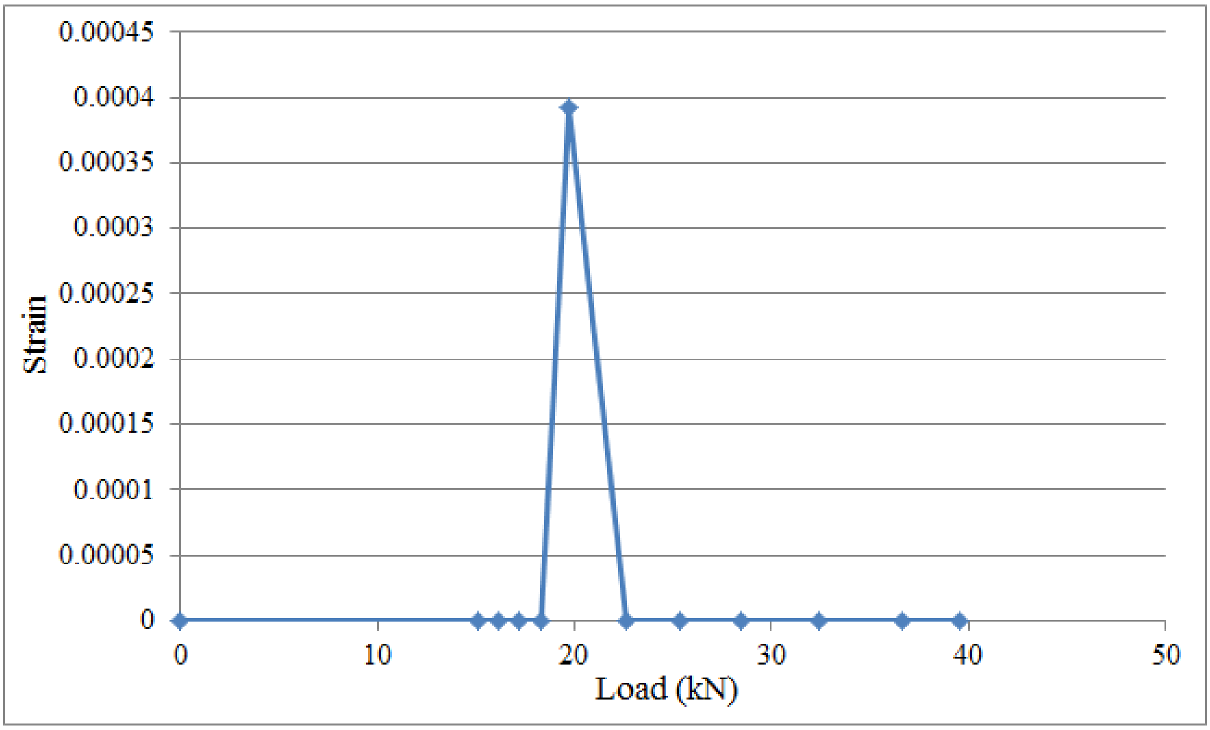

Fig 4.63 Graph of Nail Strain vs Load in nail 3.

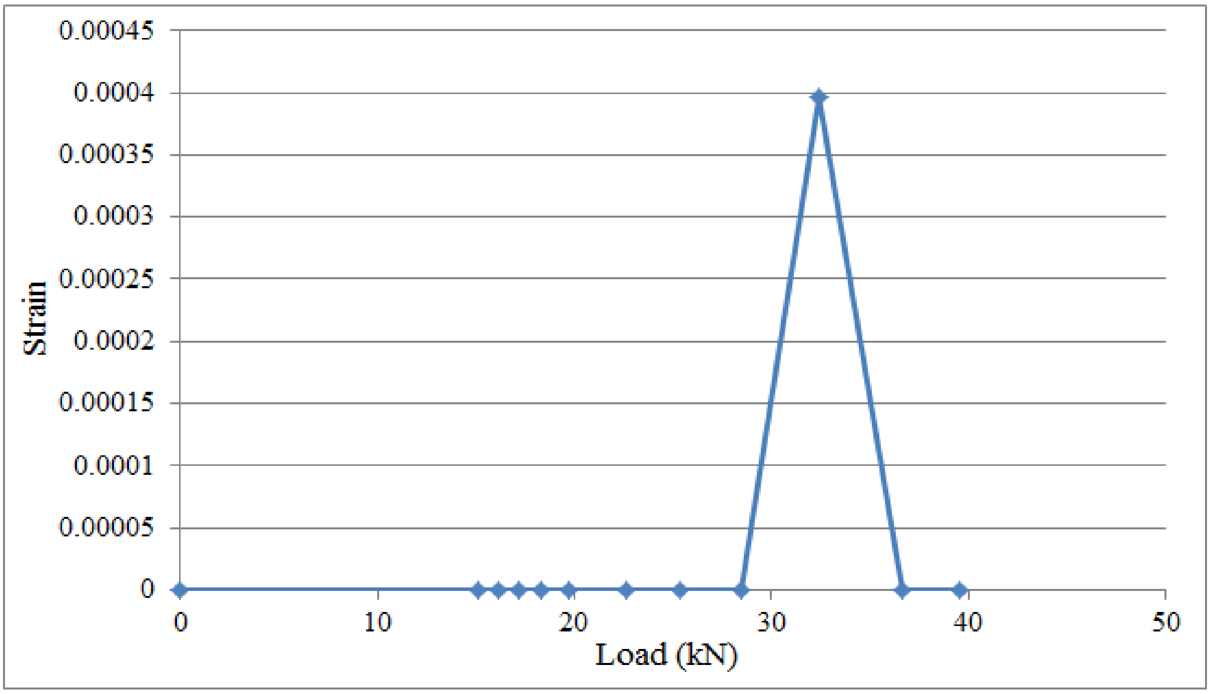

Fig 4.64 Graph of Nail Strain vs Load in nail 4.

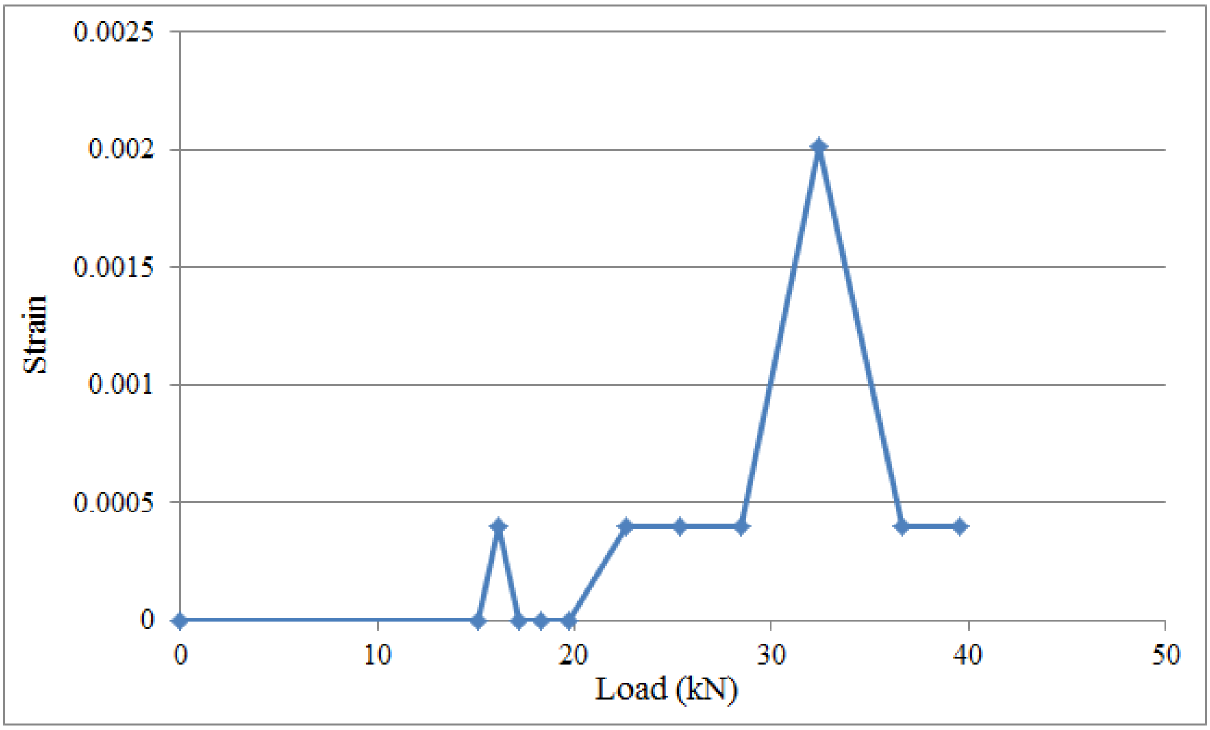

Fig 4.65 Graph of Nail Strain vs Load in nail 5.

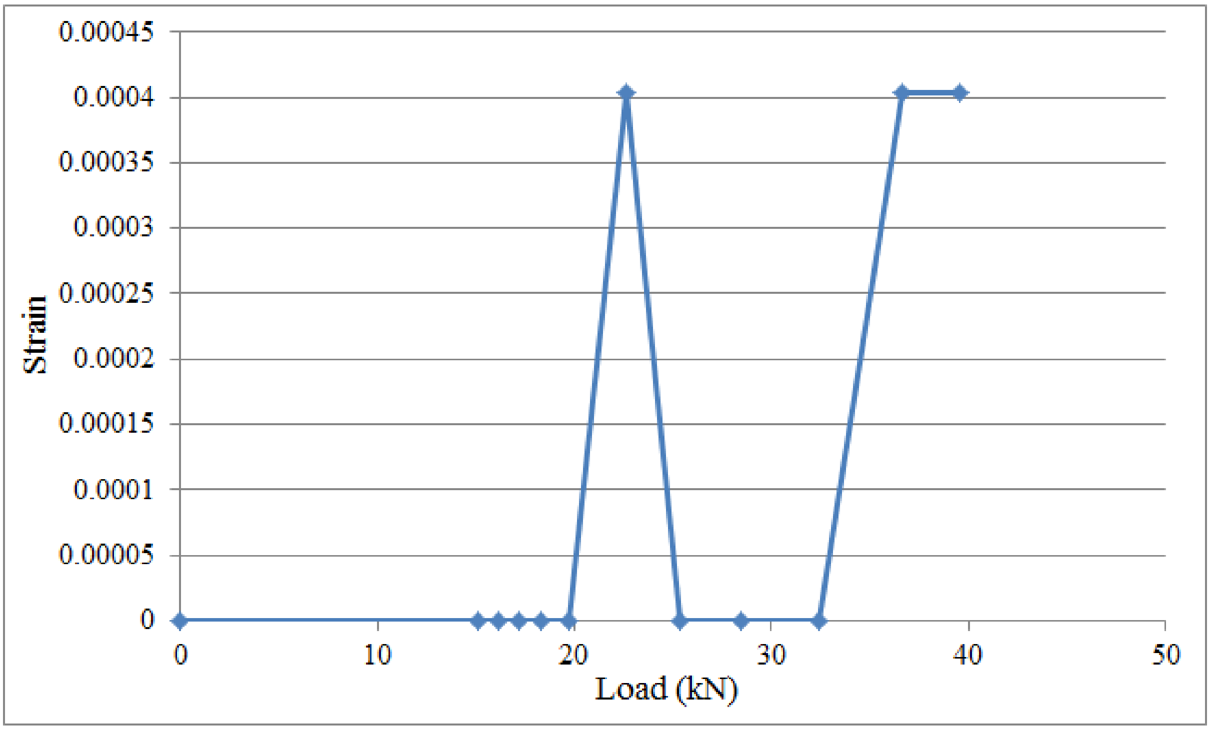

Fig 4.66 Graph of Nail Strain vs Load in nail 6.

Nail 5 of 40.48 KN hence acquiring maximum mobility but it decreased at the time of failure. As nail 5 is in left side of slope but lateral displacement is also on the side of nail 5 which is totally opposite to previous slopes but when forces at failure were seen then nail 6 was having higher value than nail 5.

Table 4.14 Stress in soil at equal interval of time

Time (Seconds)	Load (kN)
0	0
10	15.1
20	16.2
30	17.2
40	18.3
50	19.7
60	22.6
70	25.4
80	28.5
90	32.4
100	36.6
110	39.6

Table 4.15 Lateral displacement at left face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	12
5	8.5
10	6
15	3.2
20	1.2

Table 4.16 Lateral displacement at right face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	9
5	6.5
10	6
15	4.3
20	1.8

Results and discussions:-

After doing experiment with slope of 60° with nail inclination of 30° we found out that maximum nail force came out in nail number 5 of 40.48 KN hence acquiring maximum mobility but it decreased at the time of failure. As nail 5 is in left side of slope but lateral displacement is also on the side of nail 5 which is totally opposite to previous slopes but when forces at failure were seen then nail 6 was having higher value than nail 5 hence it explained that maximum force is not the governing factor but force at failure is the governing factor for lateral displacement.

4.4.5 90° slope with 15° nail inclination

Fifth model testing was done on the slope of 90° with nail inclination of 15° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.32, 4.33.

Fig 4.4.5(a) Slope before failure **Fig 4.4.5(b) Slope after failure**

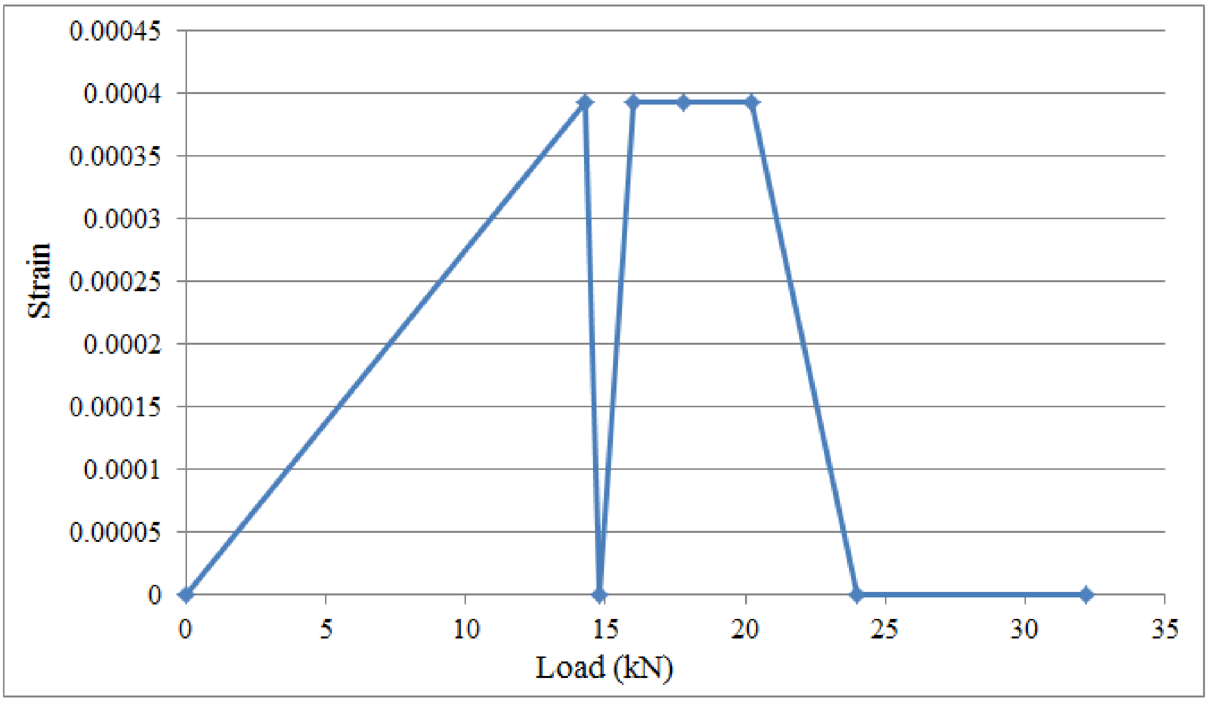

Fig 4.67 Graph of Nail Strain vs Load in nail 1.

90° being the least stable slope it take least load. Strain generated in nails is also less because the effective angle between slope surface and nail is greater than 90°. With increase in load the strain in nails 1 and 2 increases but goes to zero after some time even when the load is increasing. This is because the most of the load now is taken by the lower level nails.

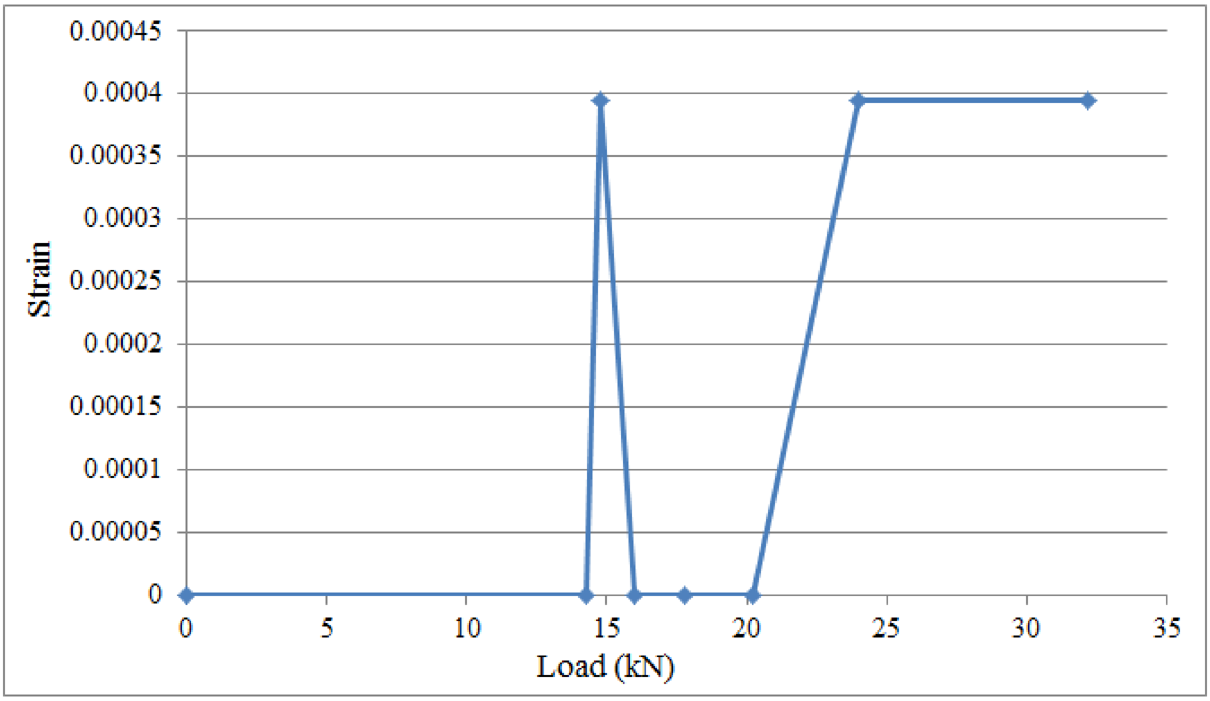

Fig 4.68 Graph of Nail Strain vs Load in nail 2.

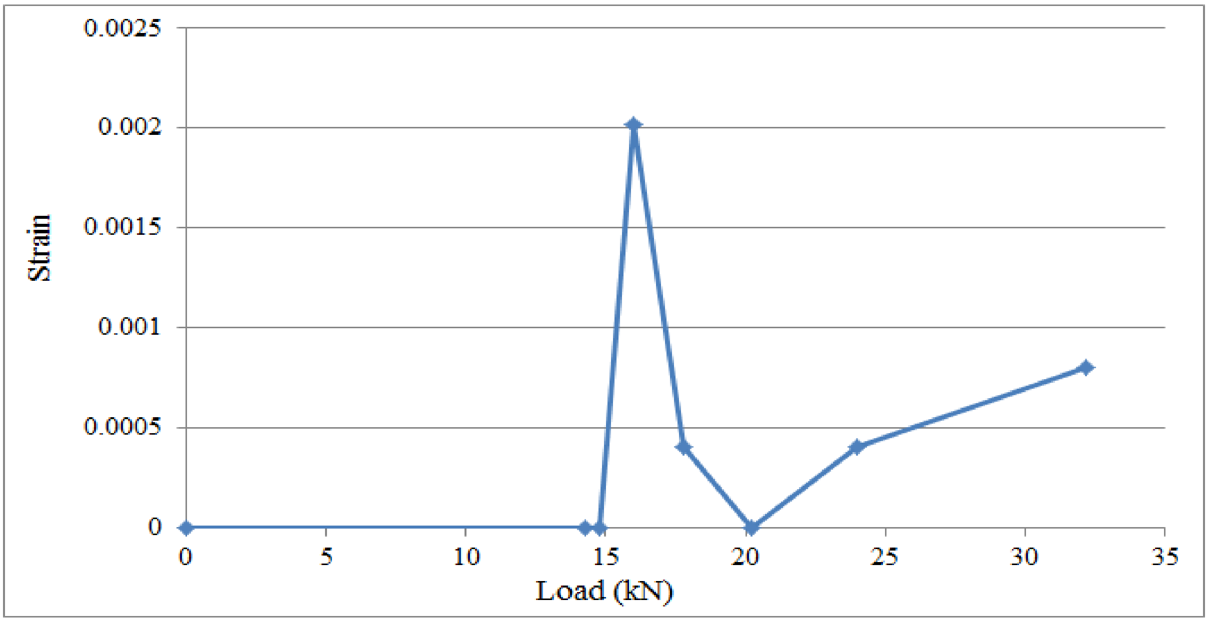

Fig 4.69 Graph of Nail Strain vs Load in nail 3.

In the experiment with the slope of 90° and nail inclination of 15° we found out that maximum nail force came out in nail no 3 of 16.1655 KN hence acquiring maximum mobility at the time of failure. As nail 3 is in left side of slope and lateral displacement is also less on the side of nail 3 (left side) which is totally proves the lesser displacement of left side as compared to right side.

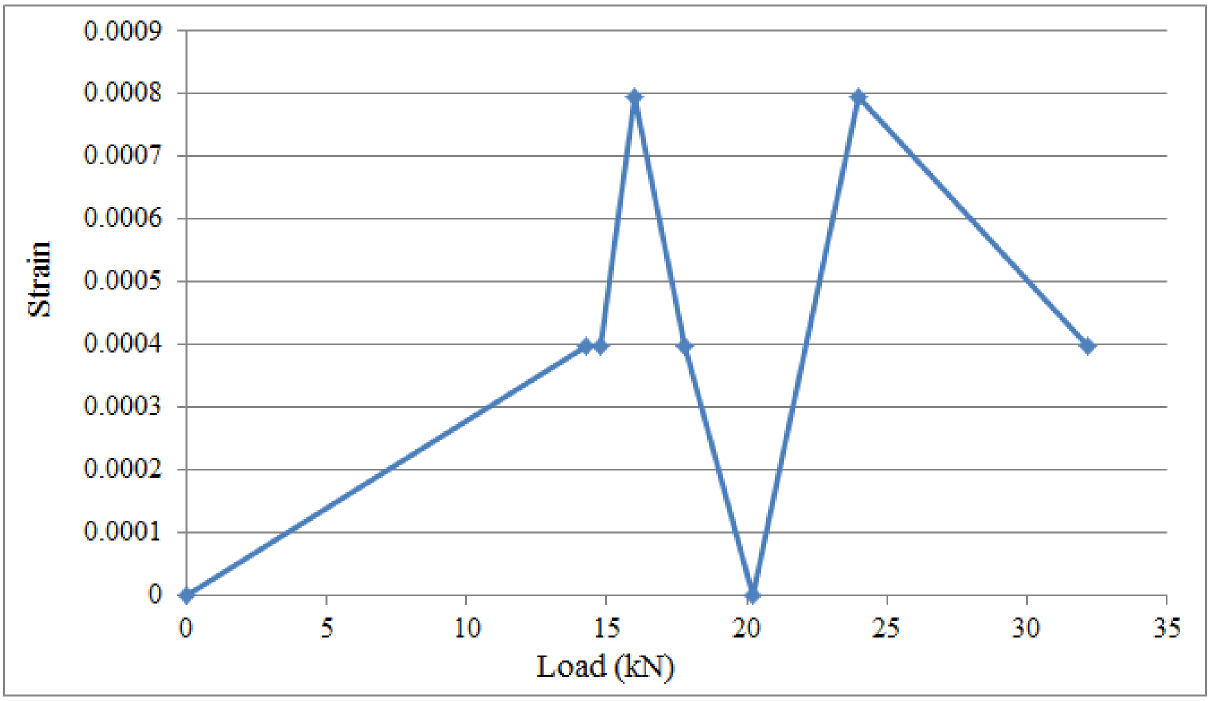

Fig 4.70 Graph of Nail Strain vs Load in nail 4.

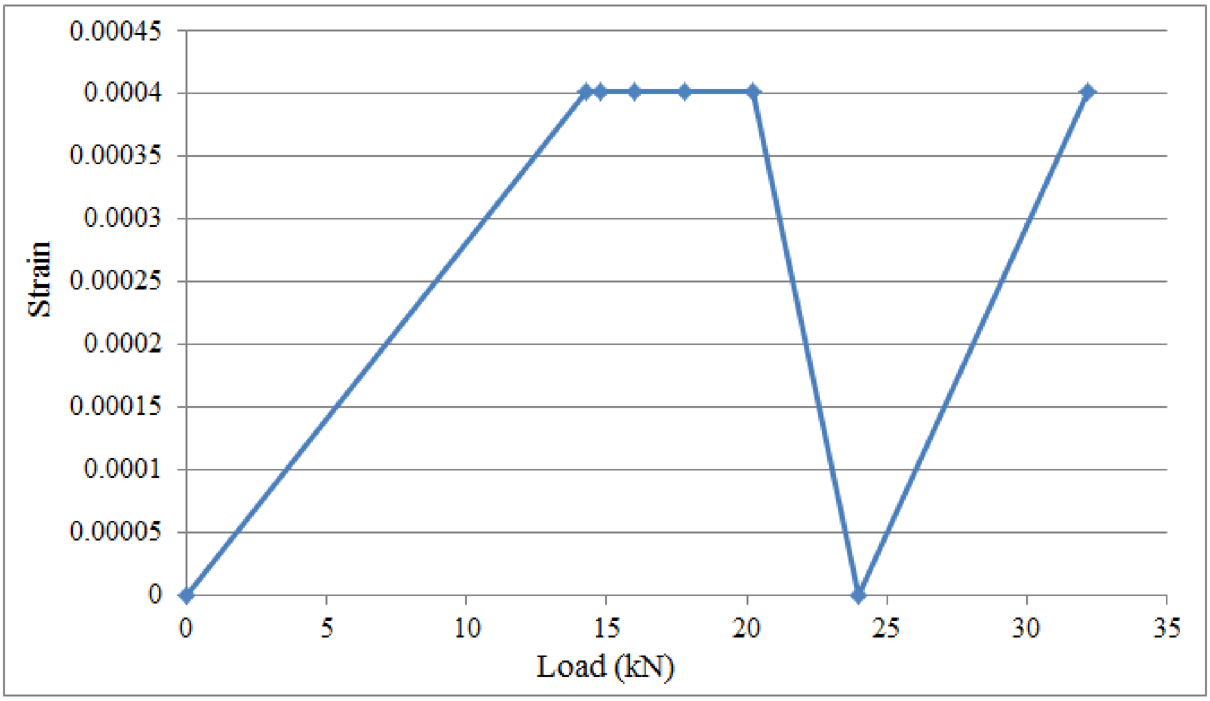

Fig 4.71 Graph of Nail Strain vs Load in nail 5.

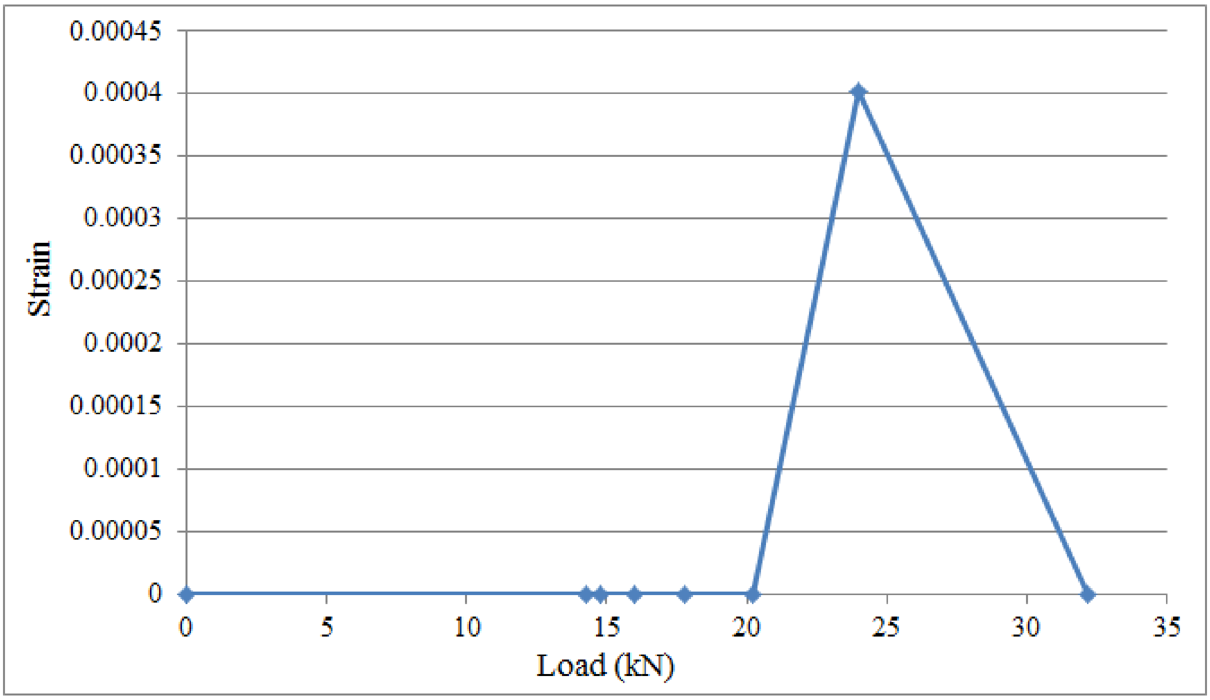

Fig 4.72 Graph of Nail Strain vs Load in nail 6.

Table 4.17 Stress in soil at equal interval of time

Time (Seconds)	Load (kN)
0	0
10	14.3
20	14.8
30	16
40	17.8
50	20.2
60	24
70	32.2

Table 4.18 Lateral displacement at left face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	10.9
5	8.1
10	7.7
15	5.4
20	4.7

Table 4.19 Lateral displacement at right face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	11.5
5	8.3
10	7.2
15	5.2
20	4.6

Results and discussions:-

90° being the least stable slope it take least load. Strain generated in nails is also less because the effective angle between slope surface and nail is greater than 90°. With increase in load the strain in nails 1 and 2 increases but goes to zero after some time even when the load is increasing. This is because the most of the load now is taken by the lower level nails. In the experiment with the slope of 90° and nail inclination of 15° we found out that maximum nail force came out in nail no 3 of 16.1655 KN hence acquiring maximum mobility at the time of failure. As nail 3 is in left side of slope and lateral displacement is also less on the side of nail 3 (left side) which is totally proves the lesser displacement of left side as compared to right side.

4.4.6 90° slope with 30° nail inclination

Sixth model testing was done on the slope of 90° with nail inclination of 30° and the results which were obtained. For load and strain values refer to ANNEXURE Table 4.34, 4.35.

Fig 4.4.6(a) Slope before failure

Fig 4.4.6(b) Slope after failure

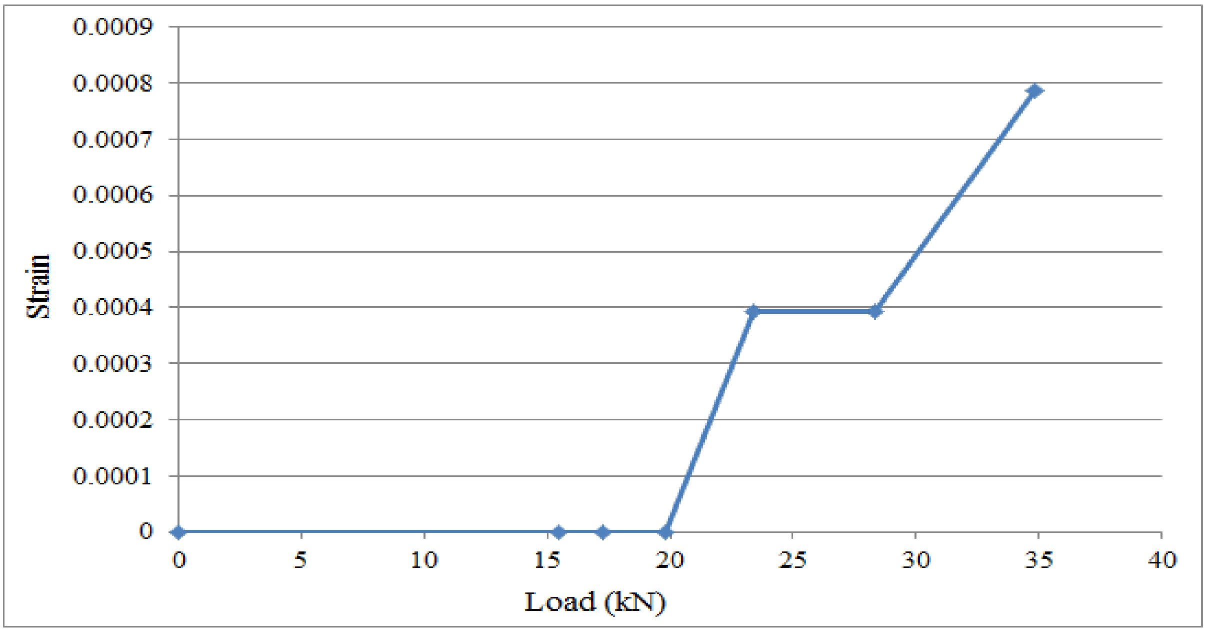

Fig 4.73 Graph of Nail Strain vs Load in nail 1.

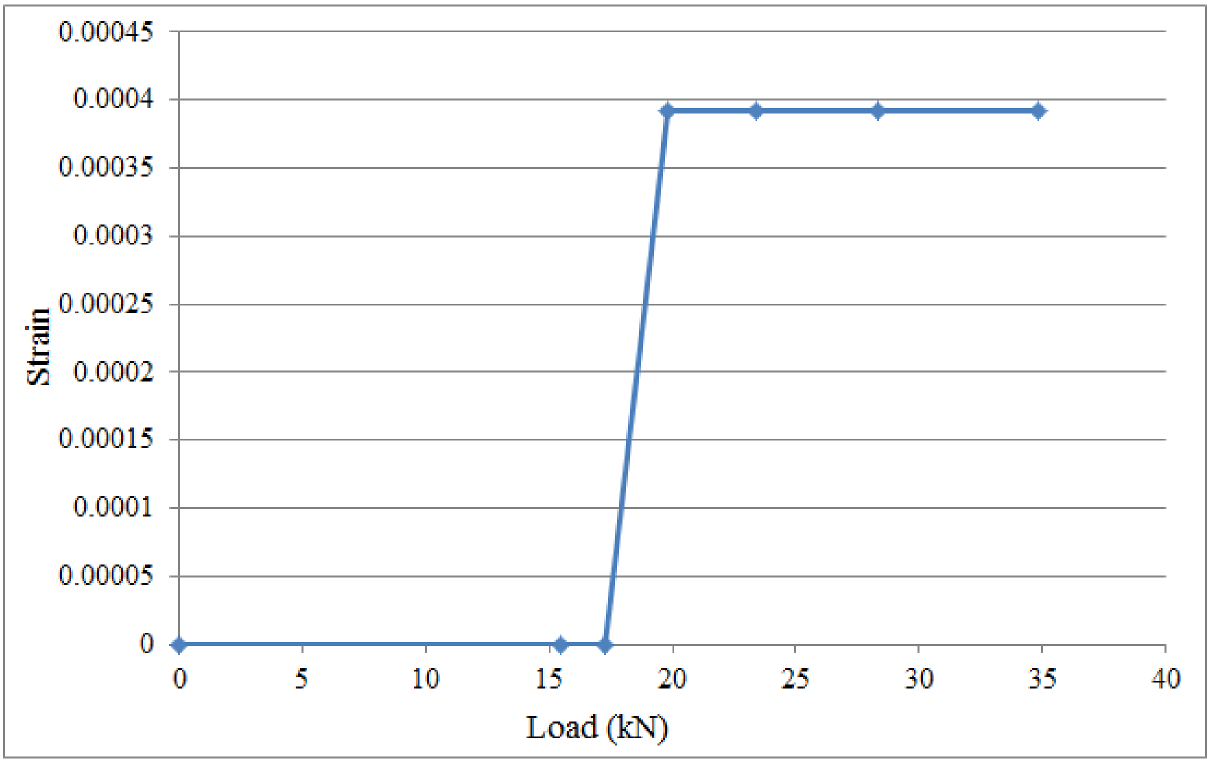

Fig 4.74 Graph of Nail Strain vs Load in nail 2.

In this experiment the effective angle between the slope surface and nail is 120°. So it takes even less load than the previous one. The variation of strain is less because the slope failed very early before we could get the higher variation of strain in nails. In 90° slope the load is spread over less area so they tend to fail early and take less load.

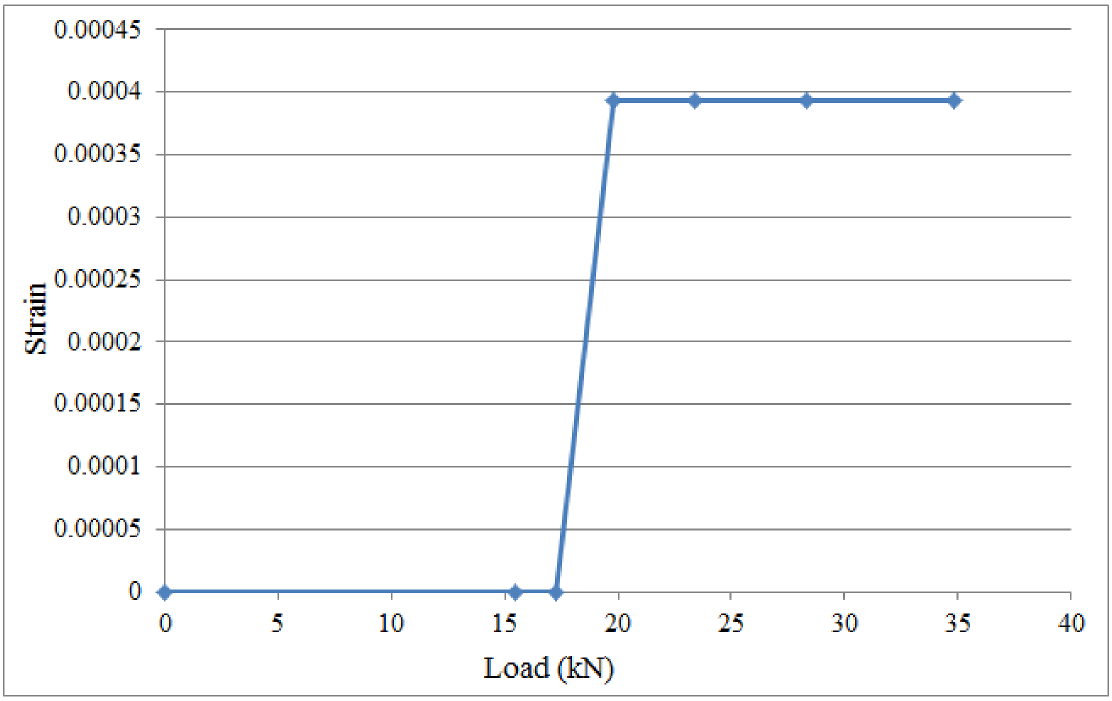

Fig 4.75 Graph of Nail Strain vs Load in nail 3.

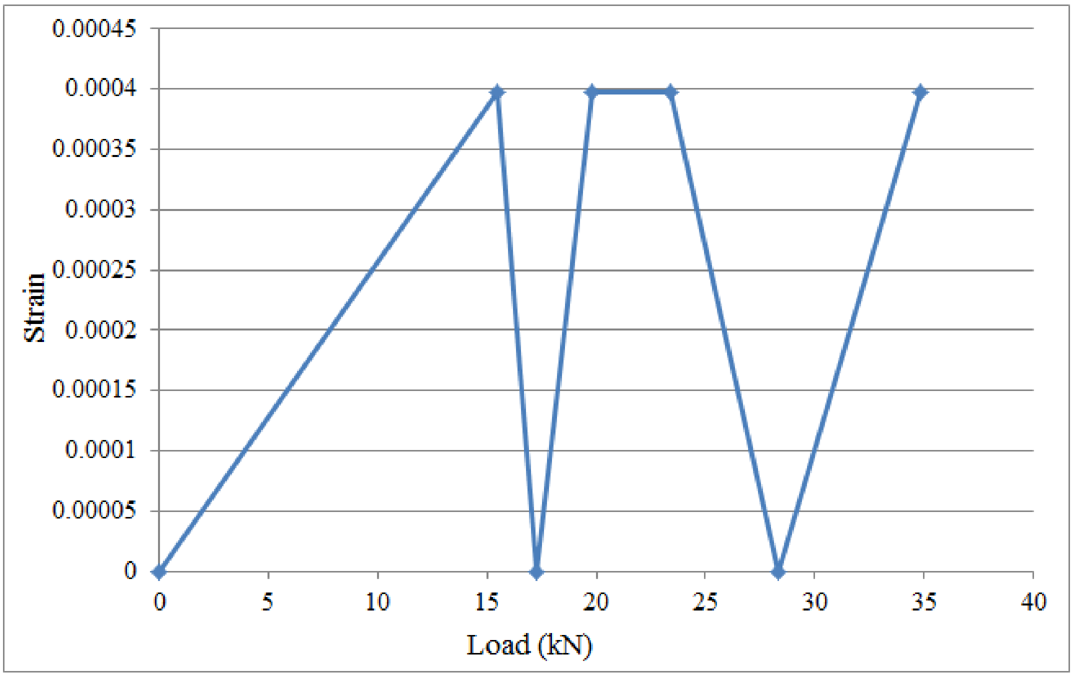

Fig 4.76 Graph of Nail Strain vs Load in nail 4.

Nail 4 shows the variation in the strain values whereas the nail 3 remains steady after load of 19.8 kN. The slope did not mobilized much as the maximum value of displacement is 9cm of left face and 8cm on right face (Table 4.21 and 4.22).

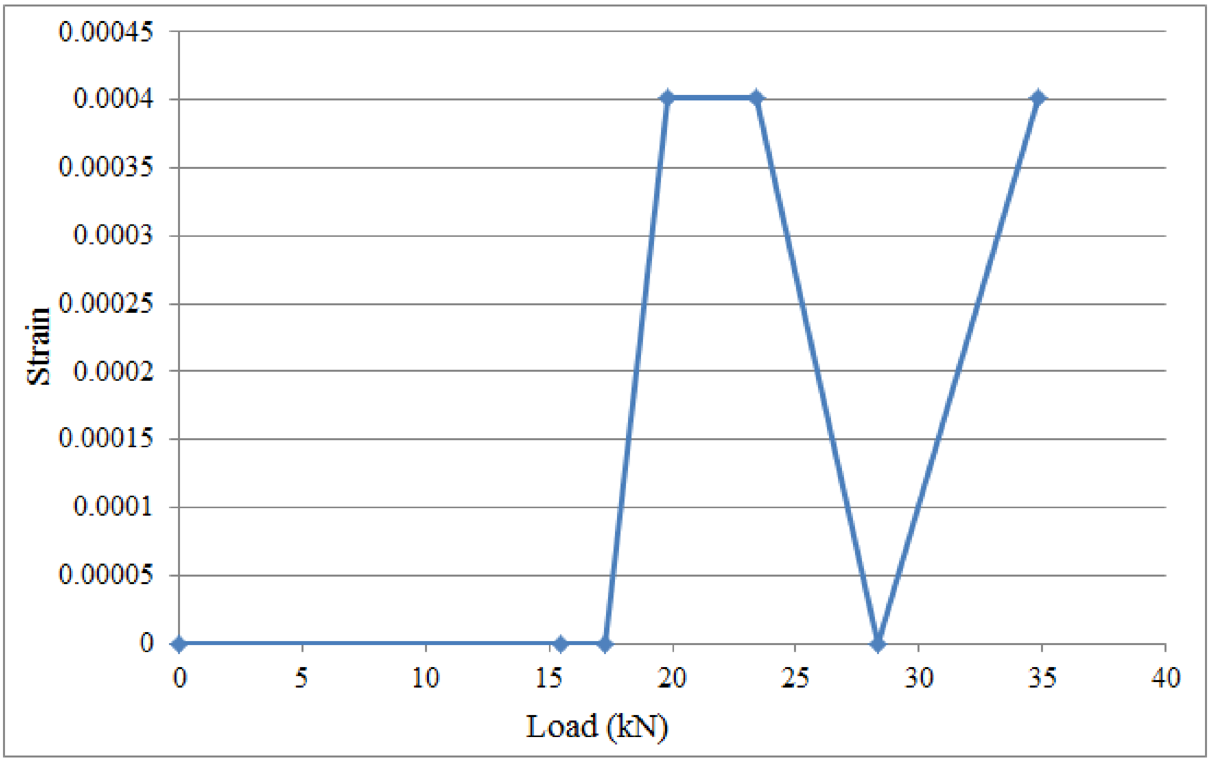

Fig 4.77 Graph of Nail Strain vs Load in nail 5.

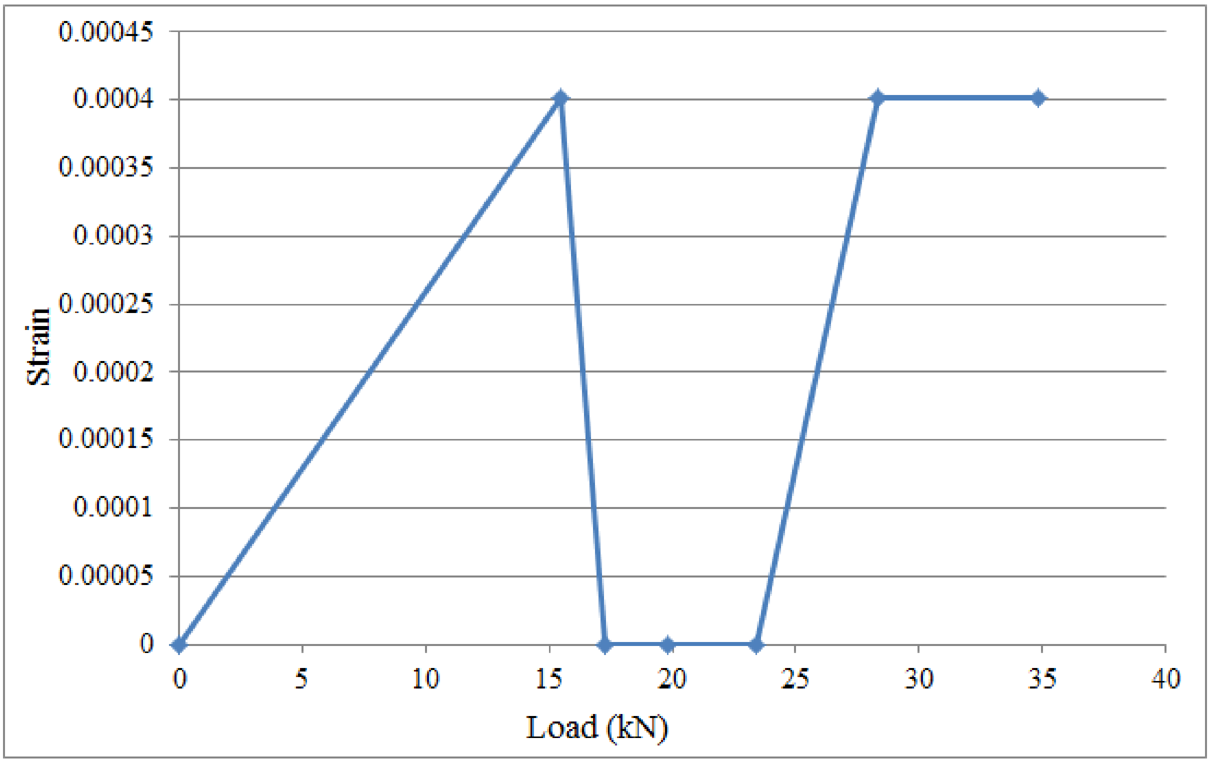

Fig 4.78 Graph of Nail Strain vs Load in nail 6.

Discussion and result:-

In the experiment with the slope of 90° and nail inclination of 30° we found out that maximum nail force came out in nail no 1 of 15.818 KN hence acquiring maximum mobility at the time of failure by seeing this result we could say that left face will have less lateral deflection but if we compare the nail forces of other nails which are inserted in parallel then the case is just opposite nail 4 and 6 are having greater nail forces than nails 5 and 3 due to which face left faced larger lateral deflection. By this we can conclude that the lateral deflection is governed by the nails inserted at the bottom of the slope no matter how higher is the value of nail force at top nails.

Table 4.20 Stress in soil at equal interval of time

Time (Seconds)	Load (KN)
0	0
10	15.5
20	17.3
30	19.8
40	23.4
50	28.3
60	34.8

Table 4.21 Lateral displacement at left face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	9
5	7.5
10	5.8
15	4.1
20	2.4

Table 4.22 Lateral displacement at right face

Ht. From Bottom (in cm)	Horizontal Displacement (in cm)
0	8
5	7.1
10	5.7
15	4.2
20	2.9

CHAPTER 5

CONCLUSIONS

5.1 General

We performed soil slopes of 45°, 60° and 90° with nail inclination 15° and 30°. We also want to say that using screw and helical nails is better than drilling nails because by using drilling nails we may disturb the normal soil strata and damage the slope but in screw and helical nails there is no such case. Also screw and helical nails gives better load bearing capacity.

5.2 Conclusions

After doing the model testing on the slope of 45º, 60º, 90º with screw nails and helical nails at the nail inclinations of 15 º and 30 º we can compare following things.:

- Strains in the nails do not come immediately after the application of load and for different nails at different location strains come at different times.
  This shows that soil first bonds with the nail on application of load and when perfect grip is made then soil and nail body get mobilised as one body and stresses generated in soil 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.
- Strain came later in upper nails but the values of strain reported in the upper nails were higher as compared to nails inserted near to the toe. But this was only seen in 60º slope and 45º slope whereas in 90º slope strains at lower values were higher. It may be because of 90º slope fails before more strain could be generated in nails and due to failure grip between soil and nail loosen up.
- In the slopes of 60º and 45º the strain values at 15º nail inclination were higher for top nails whereas when nail inclination is increased to 30º strain values were lesser than that of 15º and opposite for lower nails. Which shows that nail inserted at lower angle with horizontal at top (15º) and higher angle (30º) at bottom are more effective for slope stability.
- In 90º slope there was not any effect seen of changing the inclination with 15º slope upper nails were having more strain than 30º but difference is very less. Same result

was with lower nails unlike 45º slope and 60º slope whose strain pattern just got reversed. By this we can conclude that nail inclination do not have very significant role on 90º slope hence hybrid nail installation could not be adopted as explained in research paper of C.Y Ceuk K.K.S Ho and A.V.T Lam (refer chapter 2).

- As discussed above text the nail spacing should be at least eight times the diameter of nail so that one nail do not influence other otherwise stress could be transferred from one nail to other.

For Helical Nails:

- **45° slope with nail inclination of 15°**

Strain came later in upper nails but the values of strain reported in the upper nails were higher as compared to nails inserted near to the toe but the reverse happened in helical nails as strain values were very higher for lower nails than upper.

Nail force value is very high in the case of helical nails it reached maximum of 31.66 kN where as in helical nail it is only 5.6 kN. And even slope with helical nail is more stable because it failed later than that of screw nails.

- **45° slope with nail inclination of 30°**

Maximum of nail force value is little higher in the case of screw nails it reached maximum of 10.42 kN where as in helical nail it is 8.062 kN but if we compare the values of other nail forces the value of forces of helical nail came maximum time greater than that of screw nails.

- **60° slope with nail inclination of 15°**

Maximum of nail force value is little high in the case of screw nails it reached maximum of 29.0 kN where as in helical nail it is 23.96 kN but if we compare the values of other nail forces the value of forces of helical nail came maximum times greater than that of screw nails. It could mean that in helical nails load distribution is much more uniform than screw nails it may be due to its bigger size of soil mass attached to helical nail.

- **60° slope with nail inclination of 30°**

In this orientation of slope and nail we could see that in screw nails the mobilisation of nails takes place in lesser interval of time conforming that stresses are distributed to nails where as in helical nails first took strains and maximum of nail stress dropped to zero in between it means in between soil gets loosened up loosening the grip between nails and soil mass.

- **90° slope with nail inclination of 30°**

  Nail force value is very high in the case of helical nails it reached maximum of 16.166 kN where as in helical nail it is only 10.17 kN. And even slope with helical nail is more stable because it failed later than that of screw nails. Forces in screw nails remained almost constant or became zero where as in helical nail forces fluctuated a bit in between also.

- **90° slope with nail inclination of 15°**

  Here both of the helical and screw nails showed same loading pattern nail force increased from zero to a certain value ad remained almost constant and again dropped to zero after a while. The difference was that in helical nail forces had greater magnitude than that of screw nails.

  .

5.3 Future Scope of Study

- To study the behavior of soil when reinforced with different types of nails under pre stressed state as pre stressed nails can add to passive earth pressure.
- To conduct comparative study between load bearing capacity of soil slope with screw nails and helical nails and confirm which gives better result in dynamic condition.
- Seepage effect on soil reinforcement is not considered so it could be studied in future.
- Studies could be conducted for different water table positions as water table can change effective stress parameters.
- Experiment conducted was for sand same it could be studied for clays.

- We did study by changing the nail type but further scope for this experiment could be analyzing slope stability by changing facing type.
- Our method of installing the nails was by screwing it into the soil mass but same experiment could be done by changing the method of nail installation it could be done by drilling or by giving an impulse by hammering it into soil.
- Size and length of the nails was taken uniform throughout the slope while doing this experiment, but it could also be studied by installing different lengths of nails at different parts of slope.

ANNEXURE A

Table 4.1 Particle size distribution table

SIEVE SIZE (MICRONS)	WEIGHT RETAINED (gm)	PERCENTAGE RETAINED	CUMMULATIVE RETAINED	PERCENTAGE FINER	LOG (d) (mm)
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

ANNEXURE B

Table 4.2 Readings of shear stress and strain at normal stress of 0.2 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	1	0.1	0.001667	35.94009983	0.0063995
20	2	0.2	0.003333	35.88039867	0.0128204
30	4	0.3	0.005	35.82089552	0.0256833
40	5	0.4	0.006667	35.7615894	0.0321574
50	6	0.5	0.008333	35.70247934	0.0386528
60	7	0.6	0.01	35.64356436	0.0451694
70	8	0.7	0.011667	35.58484349	0.0517074
80	9	0.8	0.013333	35.52631579	0.0582667
90	10	0.9	0.015	35.4679803	0.0648472
100	10	1	0.016667	35.40983607	0.0649537
110	11	1.1	0.018333	35.35188216	0.0715662
120	12	1.2	0.02	35.29411765	0.0782
130	13	1.3	0.021667	35.2365416	0.0848551
140	14	1.4	0.023333	35.17915309	0.0915315
150	14	1.5	0.025	35.12195122	0.0916806
160	15	1.6	0.026667	35.06493506	0.0983889
170	16	1.7	0.028333	35.00810373	0.1051185
180	16	1.8	0.03	34.95145631	0.1052889
190	17	1.9	0.031667	34.89499192	0.1120505
200	17	2	0.033333	34.83870968	0.1122315
210	17	2.1	0.035	34.7826087	0.1124125
220	18	2.2	0.036667	34.7266881	0.1192167
230	18	2.3	0.038333	34.67094703	0.1194083
240	18	2.4	0.04	34.61538462	0.1196
250	18	2.5	0.041667	34.56	0.1197917
260	19	2.6	0.043333	34.50479233	0.1266491

Table 4.3 Readings of shear stress and strain at normal stress of 0.4 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	5	0.1	0.001667	35.94009983	0.0319977
20	7	0.2	0.003333	35.88039867	0.0448713
30	10	0.3	0.005	35.82089552	0.0642083
40	11	0.4	0.006667	35.7615894	0.0707463
50	12	0.5	0.008333	35.70247934	0.0773056
60	13	0.6	0.01	35.64356436	0.0838861
70	14	0.7	0.011667	35.58484349	0.090488
80	15	0.8	0.013333	35.52631579	0.0971111
90	16	0.9	0.015	35.4679803	0.1037556
100	17	1	0.016667	35.40983607	0.1104213
110	18	1.1	0.018333	35.35188216	0.1171083
120	18	1.2	0.02	35.29411765	0.1173
130	19	1.3	0.021667	35.2365416	0.124019
140	19	1.4	0.023333	35.17915309	0.1242213
150	20	1.5	0.025	35.12195122	0.1309722
160	20	1.6	0.026667	35.06493506	0.1311852
170	21	1.7	0.028333	35.00810373	0.1379681
180	21	1.8	0.03	34.95145631	0.1381917
190	23	1.9	0.031667	34.89499192	0.1515977
200	24	2	0.033333	34.83870968	0.1584444
210	24	2.1	0.035	34.7826087	0.1587
220	25	2.2	0.036667	34.7266881	0.1655787
230	25	2.3	0.038333	34.67094703	0.1658449
240	26	2.4	0.04	34.61538462	0.1727556
250	26	2.5	0.041667	34.56	0.1730324
260	27	2.6	0.043333	34.50479233	0.179975
270	27	2.7	0.045	34.44976077	0.1802625
280	27	2.8	0.046667	34.39490446	0.18055
290	28	2.9	0.048333	34.34022258	0.1875352

Table 4.4 Readings of shear stress and strain at normal stress of 0.8 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	3	0.1	0.001667	35.94009983	0.0191986
20	7	0.2	0.003125	35.88785047	0.044862
30	9	0.3	0.004688	35.83203733	0.0577695
40	10	0.4	0.00625	35.77639752	0.0642882
50	13	0.5	0.007813	35.72093023	0.0837044
60	15	0.6	0.009375	35.66563467	0.0967318
70	16	0.7	0.010938	35.61051005	0.1033403
80	17	0.8	0.0125	35.55555556	0.1099688
90	18	0.9	0.014063	35.50077042	0.1166172
100	19	1	0.015625	35.44615385	0.1232856
110	20	1.1	0.017188	35.39170507	0.129974
120	21	1.2	0.01875	35.33742331	0.1366823
130	22	1.3	0.020313	35.28330781	0.1434106
140	23	1.4	0.021875	35.2293578	0.1501589
150	24	1.5	0.023438	35.17557252	0.1569271
160	24	1.6	0.025	35.12195122	0.1571667
170	25	1.7	0.026563	35.06849315	0.1639648
180	25	1.8	0.028125	35.01519757	0.1642144
190	26	1.9	0.029688	34.96206373	0.1710425
200	26	2	0.03125	34.90909091	0.1713021
210	27	2.1	0.032813	34.85627837	0.1781602
220	27	2.2	0.034375	34.80362538	0.1784297
230	28	2.3	0.035938	34.75113122	0.1853177
240	28	2.4	0.0375	34.69879518	0.1855972
250	29	2.5	0.039063	34.64661654	0.1925152
260	29	2.6	0.040625	34.59459459	0.1928047
270	30	2.7	0.042188	34.54272864	0.1997526
280	30	2.8	0.04375	34.49101796	0.2000521
290	31	2.9	0.045313	34.43946188	0.2070299
300	31	3	0.046875	34.3880597	0.2073394
310	31	3.1	0.048438	34.33681073	0.2076489
320	32	3.2	0.05	34.28571429	0.2146667

Table 4.5 Readings of shear stress and strain at normal stress of 0.2 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	2	0.1	0.00167	35.94009983	0.012799074
20	3	0.2	0.00333	35.88039867	0.019230556
30	4	0.3	0.005	35.82089552	0.025683333
40	4	0.4	0.00667	35.7615894	0.025725926
50	5	0.5	0.00833	35.70247934	0.032210648
60	6	0.6	0.01	35.64356436	0.038716667
70	7	0.7	0.01167	35.58484349	0.045243981
80	7	0.8	0.01333	35.52631579	0.045318519
90	8	0.9	0.015	35.4679803	0.051877778
100	8	1	0.01667	35.40983607	0.051962963
110	9	1.1	0.01833	35.35188216	0.058554167

Table 4.6 Readings of shear stress and strain at normal stress of 0.4 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	2	0.1	0.00167	35.94009983	0.012799074
20	3	0.2	0.00333	35.88039867	0.019230556
30	5	0.3	0.005	35.82089552	0.032104167
40	6	0.4	0.00667	35.7615894	0.038588889
50	6	0.5	0.00833	35.70247934	0.038652778
60	6	0.6	0.01	35.64356436	0.038716667
70	7	0.7	0.01167	35.58484349	0.045243981
80	7	0.8	0.01333	35.52631579	0.045318519
90	8	0.9	0.015	35.4679803	0.051877778
100	8	1	0.01667	35.40983607	0.051962963
110	9	1.1	0.01833	35.35188216	0.058554167
120	9	1.2	0.02	35.29411765	0.05865
130	10	1.3	0.02167	35.2365416	0.065273148
140	10	1.4	0.02333	35.17915309	0.06537963
150	10	1.5	0.025	35.12195122	0.065486111
160	11	1.6	0.02667	35.06493506	0.072151852

Table 4.7 Readings of shear stress and strain at normal stress of 0.6 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	3	0.1	0.00167	35.94009983	0.019198611
20	4	0.2	0.00333	35.88039867	0.025640741
30	5	0.3	0.005	35.82089552	0.032104167
40	6	0.4	0.00667	35.7615894	0.038588889
50	7	0.5	0.00833	35.70247934	0.045094907
60	7	0.6	0.01	35.64356436	0.045169444
70	8	0.7	0.01167	35.58484349	0.051707407
80	8	0.8	0.01333	35.52631579	0.051792593
90	9	0.9	0.015	35.4679803	0.0583625
100	9	1	0.01667	35.40983607	0.058458333
110	9	1.1	0.01833	35.35188216	0.058554167
120	9	1.2	0.02	35.29411765	0.05865
130	10	1.3	0.02167	35.2365416	0.065273148
140	11	1.4	0.02333	35.17915309	0.071917593
150	11	1.5	0.025	35.12195122	0.072034722
160	11	1.6	0.02667	35.06493506	0.072151852
170	11	1.7	0.02833	35.00810373	0.072268981
180	12	1.8	0.03	34.95145631	0.078966667

Table 4.8 Readings of shear stress and strain at normal stress of 0.2 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	1	0.1	0.00166667	35.94009983	0.006399537
20	2	0.2	0.00333333	35.88039867	0.01282037
30	3	0.3	0.005	35.82089552	0.0192625
40	4	0.4	0.00666667	35.7615894	0.025725926
50	6	0.5	0.00833333	35.70247934	0.038652778
60	7	0.6	0.01	35.64356436	0.045169444
70	8	0.7	0.01166667	35.58484349	0.051707407
80	10	0.8	0.01333333	35.52631579	0.064740741
90	11	0.9	0.015	35.4679803	0.071331944
100	11	1	0.01666667	35.40983607	0.071449074
110	12	1.1	0.01833333	35.35188216	0.078072222
120	13	1.2	0.02	35.29411765	0.084716667
130	13	1.3	0.02166667	35.2365416	0.084855093
140	14	1.4	0.02333333	35.17915309	0.091531481
150	15	1.5	0.025	35.12195122	0.098229167
160	16	1.6	0.02666667	35.06493506	0.104948148
170	17	1.7	0.02833333	35.00810373	0.111688426
180	18	1.8	0.03	34.95145631	0.11845
190	19	1.9	0.03166667	34.89499192	0.12523287
200	20	2	0.03333333	34.83870968	0.132037037
210	21	2.1	0.035	34.7826087	0.1388625
220	22	2.2	0.03666667	34.7266881	0.145709259
230	22	2.3	0.03833333	34.67094703	0.145943519
240	23	2.4	0.04	34.61538462	0.152822222
250	23	2.5	0.04166667	34.56	0.15306713
260	23	2.6	0.04333333	34.50479233	0.153312037
270	23	2.7	0.045	34.44976077	0.153556944
280	24	2.8	0.04666667	34.39490446	0.160488889
290	24	2.9	0.04833333	34.34022258	0.160744444
300	24	3	0.05	34.28571429	0.161
310	25	3.1	0.05166667	34.23137876	0.167974537

Table 4.9 Readings of shear stress and strain at normal stress of 0.4 kg/cm²

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	7	0.1	0.00166667	35.94009983	0.044796759
20	9	0.2	0.00333333	35.88039867	0.057691667
30	11	0.3	0.005	35.82089552	0.070629167
40	14	0.4	0.00666667	35.7615894	0.090040741
50	15	0.5	0.00833333	35.70247934	0.096631944
60	18	0.6	0.01	35.64356436	0.11615
70	19	0.7	0.01166667	35.58484349	0.122805093
80	20	0.8	0.01333333	35.52631579	0.129481481
90	21	0.9	0.015	35.4679803	0.136179167
100	22	1	0.01666667	35.40983607	0.142898148
110	23	1.1	0.01833333	35.35188216	0.149638426
120	24	1.2	0.02	35.29411765	0.1564
130	24	1.3	0.02166667	35.2365416	0.156655556
140	24	1.4	0.02333333	35.17915309	0.156911111
150	24	1.5	0.025	35.12195122	0.157166667
160	24	1.6	0.02666667	35.06493506	0.157422222
170	24	1.7	0.02833333	35.00810373	0.157677778
180	24	1.8	0.03	34.95145631	0.157933333
190	24	1.9	0.03166667	34.89499192	0.158188889
200	24	2	0.03333333	34.83870968	0.158444444
210	24	2.1	0.035	34.7826087	0.1587
220	24	2.2	0.03666667	34.7266881	0.158955556
230	24	2.3	0.03833333	34.67094703	0.159211111
240	25	2.4	0.04	34.61538462	0.166111111
250	26	2.5	0.04166667	34.56	0.173032407

Table 4.10 Readings of shear stress and strain at normal stress of 0.8 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	6	0.1	0.00166667	35.94009983	0.038397222
20	10	0.2	0.00333333	35.88039867	0.064101852
30	12	0.3	0.005	35.82089552	0.07705
40	15	0.4	0.00666667	35.7615894	0.096472222
50	16	0.5	0.00833333	35.70247934	0.103074074
60	18	0.6	0.01	35.64356436	0.11615
70	19	0.7	0.01166667	35.58484349	0.122805093
80	20	0.8	0.01333333	35.52631579	0.129481481
90	22	0.9	0.015	35.4679803	0.142663889
100	24	1	0.01666667	35.40983607	0.155888889
110	26	1.1	0.01833333	35.35188216	0.169156481
120	27	1.2	0.02	35.29411765	0.17595
130	27	1.3	0.02166667	35.2365416	0.1762375
140	27	1.4	0.02333333	35.17915309	0.176525
150	28	1.5	0.025	35.12195122	0.183361111
160	28	1.6	0.02666667	35.06493506	0.183659259
170	28	1.7	0.02833333	35.00810373	0.183957407
180	29	1.8	0.03	34.95145631	0.190836111
190	30	1.9	0.03166667	34.89499192	0.197736111
200	32	2	0.03333333	34.83870968	0.211259259
210	33	2.1	0.035	34.7826087	0.2182125
220	34	2.2	0.03666667	34.7266881	0.225187037

Table 4.11 Readings of shear stress and strain at normal stress of 1 kg/cm^2

Dial Gauge	Proving Ring	Horizontal Displacement (mm)	Strain	Corrected Area (cm^2)	Shear Stress (kg/cm^2)
10	2	0.1	0.00166667	35.94009983	0.012799074
20	8	0.2	0.00333333	35.88039867	0.051281481
30	13	0.3	0.005	35.82089552	0.083470833
40	18	0.4	0.00666667	35.7615894	0.115766667
50	22	0.5	0.00833333	35.70247934	0.141726852
60	23	0.6	0.01	35.64356436	0.148413889
70	23	0.7	0.01166667	35.58484349	0.148658796
80	23	0.8	0.01333333	35.52631579	0.148903704
90	23	0.9	0.015	35.4679803	0.149148611
100	24	1	0.01666667	35.40983607	0.155888889
110	24	1.1	0.01833333	35.35188216	0.156144444
120	25	1.2	0.02	35.29411765	0.162916667
130	26	1.3	0.02166667	35.2365416	0.169710185
140	27	1.4	0.02333333	35.17915309	0.176525
150	28	1.5	0.025	35.12195122	0.183361111
160	29	1.6	0.02666667	35.06493506	0.190218519
170	29	1.7	0.02833333	35.00810373	0.190527315
180	30	1.8	0.03	34.95145631	0.197416667
190	32	1.9	0.03166667	34.89499192	0.210918519
200	33	2	0.03333333	34.83870968	0.217861111
210	33	2.1	0.035	34.7826087	0.2182125
220	33	2.2	0.03666667	34.7266881	0.218563889
230	33	2.3	0.03833333	34.67094703	0.218915278
240	34	2.4	0.04	34.61538462	0.225911111
250	35	2.5	0.04166667	34.56	0.232928241
260	35	2.6	0.04333333	34.50479233	0.233300926
270	35	2.7	0.045	34.44976077	0.233673611
280	36	2.8	0.04666667	34.39490446	0.240733333

ANNEXURE C

Table 4.12 Strain values in screw nails with equal interval of time of 45° slope at 15° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	0.000435346
20	0.000438228	0	0	0.000447152	0	0
30	0.000438228	0	0	0	0.000443511	0
40	0	0.000436199	0	0	0	0.000435346
50	0	0.000436199	0.0004371	0	0.000443511	0.000435346
60	0	0.000873503	0	0	0.000443511	0.000435346
70	0	0.000436567	0.0004371	0	0	0.000435346
80	0	0.000436567	0.0004371	0	0.000443511	0
90	0	0	0.0004371	0	0	0

Table 4.13 Load values in screw nails with equal interval of time of 45° slope at 15° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	5.19718147
20	0	0	0	5.33813	0	0
30	0	0	0	0	5.2946515	0
40	5.23158465	5.20737	0	0	0	5.19718147
50	5.23158465	5.20737	5.21812	0	5.2946515	5.19718147
60	0	10.4279	0	0	5.2946515	5.19718147
70	0	5.21176	5.21812	0	0	5.19718147
80	0	5.21176	5.21812	0	5.2946515	0
90	0	0	5.21812	0	0	0

Table 4.14 Strain values in screw nails with equal interval of time of 45° slope at 30° nail inclination

Time (Second)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0.55555556	0.55303	0.55304	0.55304	0.553039	0.55304
10	0.5087005	0.55324	0.55304	0.55304	0.553039	0.55304
20	0.46184544	0.55346	0.55304	0.55304	0.553039	0.55304
30	0.41499038	0.55367	0.55304	0.55304	0.553039	0.55304
40	0.36813532	0.55388	0.55304	0.55304	0.553039	0.55304
50	0.32128026	0.5541	0.55304	0.55304	0.553039	0.55304
60	0.27442521	0.55431	0.55304	0.55304	0.553039	0.55304
70	0.22757015	0.55452	0.55304	0.55304	0.553039	0.55304
80	0.18071509	0.55473	0.55304	0.55304	0.553039	0.55304
90	0.13386003	0.55495	0.55304	0.55304	0.553039	0.55304
100	0.08700497	0.55516	0.55303	0.55304	0.553039	0.55304

Table 4.15 Load values in screw nails with equal interval of time of 45° slope at 30° nail inclination (in kN)

Time (Second)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	5.22046	0	0	0	0	0
20	0	0	0	0	0	0
30	0	0	0	0	0	0
40	0	0	0	0	0	0
50	5.21601	0	0	0	0	0
60	5.21601	0	0	0	0	0
70	5.21601	0	0	0	0	0
80	5.21601	0	5.21991	0	5.35805	0
90	10.4276	5.21045	5.21991	5.376693	5.35805	0
100	10.4276	0	5.21991	5.376693	5.35805	0

Table 4.16 Strain values in screw nails with equal interval of time of 60° slope at 15° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0.000437	0	0.0008783	0
20	0	0	0.000437	0.000441	0.0004393	0
30	0	0.0004408	0.000437	0.000441	0.0004393	0
40	0	0.0004408	0.000437	0	0.0004393	0
50	0.000443	0.0004408	0.000874	0.000441	0.0004393	0.000432
60	0	0	0.000437	0.000441	0.0004393	0
70	0	0.0008581	0.000874	0.000441	0.0004393	0.000432
80	0	0.00069	0.000437	0.000441	0.0004393	0.000432
90	0.000443	0.0007465	0.000437	0.000441	0.0004393	0.000432
100	0	0.0007065	0.000874	0.000441	0.0004393	0
110	0	0.0008811	0.001311	0.000441	0.0004393	0

Table 4.17 Load values in screw nails with equal interval of time of 60° slope at 15° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	5.212583	0	10.484793	0
20	0	0	5.212583	5.2648527	5.2446628	0
30	0	5.2618334	5.212583	5.2648527	5.2446628	0
40	0	5.2618334	5.212583	0	5.2446628	0
50	5.28835	5.2618334	10.42962	5.2648527	5.2446628	5.153497
60	0	0	5.212583	5.2648527	5.2446628	0
70	0	10.243688	10.42962	5.2648527	5.2446628	5.153497
80	0	8.2376904	5.212583	5.2648527	5.2446628	5.153497
90	5.28835	8.9122744	5.212583	5.2648527	5.2446628	5.153497
100	0	8.4344319	10.42962	5.2648527	5.2446628	0
110	0	10.519175	15.65112	5.2648527	5.2446628	0

Table 4.18 Strain values in screw nails with equal interval of time of 60° slope at 30° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0.000453	0	0.000442	0	0
20	0.00045	0	0	0.000442	0.000441	0
30	0.00091	0	0.000444	0.000442	0.000441	0.00044
40	0.00045	0.00129	0.000444	0.000884	0.000441	0.00044
50	0.00045	0.000636	0.000444	0.000884	0.000441	0.00044
60	0.00045	0.000973	0.000444	0.000884	0.000441	0.00044
70	0.00045	0.000976	0.000444	0.000442	0.000441	0.00044
80	0.00045	0.001255	0.000444	0.000442	0.000441	0.00044

Table 4.19 Load values in screw nails with equal interval of time of 60° slope at 30° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	5.404291	0	5.274997	0	0
20	5.41712	0	0	5.274997	5.2589	0
30	10.8391	0	5.295878	5.274997	5.2589	5.21156
40	5.41712	15.39526	5.295878	10.55465	5.2589	5.21156
50	5.41712	7.587321	5.295878	10.55465	5.2589	5.21156
60	5.41712	11.61086	5.295878	10.55465	5.2589	5.21156
70	5.41712	11.64786	5.295878	5.274997	5.2589	5.21156
80	5.41712	14.97898	5.295878	5.274997	5.2589	5.21156

Table 4.20 Strain values in screw nails with equal interval of time of 90° slope at 15° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0.0008527	0
20	0	0	0	0	0.0008527	0
30	0	0	0.0004355	0	0.0008527	0.000580849
40	0	0	0	0	0.0008527	0.000580849
50	0	0.000434	0	0	0.0008527	0.000580849
60	0	0.000434	0	0	0.0008527	0.000580849
70	0	0.000434	0	0	0.0008527	0.000580849
80	0	0	0	0	0.0008527	0.000580849
90	0	0	0	0	0.0008527	0.000580849
100	0.0004394	0	0	0	0.0008527	0.000580849
110	0.0004394	0	0.0004355	0	0.0008527	0.000580849
120	0.0004394	0	0.0004355	0	0	0
130	0.0004394	0	0.0004355	0	0	0
140	0.0004394	0	0.0004355	0	0	0

Table 4.21 Load values in screw nails with equal interval of time of 90° slope at 15° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	10.179876	0
20	0	0	0	0	10.179876	0
30	0	0	5.1988944	0	10.179876	6.934200419
40	0	0	0	0	10.179876	6.934200419
50	0	5.180656	0	0	10.179876	6.934200419
60	0	5.180656	0	0	10.179876	6.934200419
70	0	5.180656	0	0	10.179876	6.934200419
80	0	0	0	0	10.179876	6.934200419
90	0	0	0	0	10.179876	6.934200419
100	5.2460823	0	0	0	10.179876	6.934200419
110	5.2460823	0	5.1988944	0	10.179876	6.934200419
120	5.2460823	0	5.1988944	0	0	0
130	5.2460823	0	5.1988944	0	0	0
140	5.2460823	0	5.1988944	0	0	0

Table 4.22 Strain values in screw nails with equal interval of time of 90° slope at 30° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	0.0004412
20	0	0	0	0	0	0.0004412
30	0.0004339	0	0	0	0	0.0004412
40	0	0	0	0	0	0.0004412
50	0.0004339	0	0	0	0	0.0004412
60	0.0004339	0	0.00043	0	0.00044	0
70	0.0004339	0	0	0	0.00044	0
80	0.0004339	0	0	0	0.00044	0
90	0.0004339	0	0.00043	0	0.00044	0
100	0	0.0004362	0.00043	0	0.00044	0
110	0	0.0004362	0.00043	0.00044	0.00044	0
120	0	0.0004362	0.00043	0.00044	0.00044	0

Table 4.23 Load values in screw nails with equal interval of time of 90° slope at 30° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	5.2665246
20	0	0	0	0	0	5.2665246
30	5.180039	0	0	0	0	5.2665246
40	0	0	0	0	0	5.2665246
50	5.180039	0	0	0	0	5.2665246
60	5.180039	0	5.17332	0	5.252095	0
70	5.180039	0	0	0	5.252095	0
80	5.180039	0	0	0	5.252095	0
90	5.180039	0	5.17332	0	5.252095	0
100	0	5.207768	5.17332	0	5.252095	0
110	0	5.207768	5.17332	5.23006	5.252095	0
120	0	5.207768	5.17332	5.23006	5.252095	0

Table 4.24 Strain values in helical nails with equal interval of time of 45° slope at 15° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0.000393	0.0008	0	0.000402
20	0.000395	0	0	0.0008	0	0
30	0	0	0	0.0012	0	0
40	0.000791	0	0	0.0012	0	0
50	0.000395	0.00039	0	0.0008	0.000402	0
60	0.001583	0.00039	0	0.0004	0.000402	0.000402
70	0.000789	0.00039	0	0.0012	0.000402	0.000402
80	0.000395	0.00039	0.001575	0.0012	0.000803	0

Table 4.25 Load values in helical nails with equal interval of time of 45° slope at 15° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	7.90689	15.942	0	8.087073
20	7.938153	0	0	15.942	0	0
30	0	0	0	23.903	0	0
40	15.89711	0	0	23.903	0	0
50	7.938153	7.90032	0	15.942	8.076105	0
60	31.82202	7.90032	0	7.9747	8.076105	8.079963
70	15.86938	7.90032	0	23.903	8.076105	8.087073
80	7.938153	7.90032	31.6683	23.903	16.14512	0

Table 4.26 Strain values in helical nails with equal interval of time of 45° slope at 30° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	0.000402
20	0	0	0	0.00039656	0	0.000402
30	0	0	0	0.00039656	0.00040066	0.000402
40	0	0	0.000396	0.00039656	0	0
50	0	0	0.000396	0.00039656	0.00040066	0
60	0	0	0	0.00039656	0	0.000402
70	0.0003933	0.000392	0	0.00039656	0.00040101	0.000402
80	0.0003933	0	0	0.00039691	0.00040101	0.000402

Table 4.27 Load values in helical nails with equal interval of time of 45° slope at 30° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	8.075108
20	0	0	0	7.97332362	0	8.075108
30	0	0	0	7.97332362	8.05570863	8.075108
40	0	0	7.9621583	7.97332362	0	0
50	0	0	7.9621583	7.97332362	8.05570863	0
60	0	0	0	7.97332362	0	8.075108
70	7.9070546	7.875343	0	7.97332362	8.0627437	8.075108
80	7.9070546	0	0	7.98033914	8.0627437	8.075108

Table 4.28 Strain values in helical nails with equal interval of time of 60° slope at 15° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	32.32304
20	0	0	7.8666938	7.9810173	0	0
30	0	0	0	7.9810173	0	0
40	7.993531	0	0	0	0	0
50	0	7.968163	0	23.964131	0	0
60	0	7.968163	0	23.964131	8.066879	8.070109
70	0	7.968163	0	23.964131	8.066879	8.070109

Table 4.29 Load values in helical nails with equal interval of time of 60° slope at 15° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	0.001608
20	0	0	0.0003913	0.0003969	0	0
30	0	0	0	0.0003969	0	0
40	0.0003976	0	0	0	0	0
50	0	0.0003963	0	0.0011919	0	0
60	0	0.0003963	0	0.0011919	0.0004012	0.000401
70	0	0.0003963	0	0.0011919	0.0004012	0.000401

Table 4.28 Strain values in helical nails with equal interval of time of 60° slope at 15° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	32.32304
20	0	0	7.8666938	7.9810173	0	0
30	0	0	0	7.9810173	0	0
40	7.993531	0	0	0	0	0
50	0	7.968163	0	23.964131	0	0
60	0	7.968163	0	23.964131	8.066879	8.070109
70	0	7.968163	0	23.964131	8.066879	8.070109

Table 4.29 Load values in helical nails with equal interval of time of 60° slope at 15° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	0.001608
20	0	0	0.0003913	0.0003969	0	0
30	0	0	0	0.0003969	0	0
40	0.0003976	0	0	0	0	0
50	0	0.0003963	0	0.0011919	0	0
60	0	0.0003963	0	0.0011919	0.0004012	0.000401
70	0	0.0003963	0	0.0011919	0.0004012	0.000401

Table 4.30 Strain values in helical nails with equal interval of time of 60° slope at 30° nail inclination

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	0
20	0	0.000391	0	0	0.000402	0
30	0.00039	0.000391	0	0	0	0
40	0.00039	0.000391	0	0	0	0
50	0	0.000391	0.0003921	0	0	0
60	0.00039	0.000391	0	0	0.000402	0.0004033
70	0	0.000391	0	0	0.000402	0
80	0	0.000391	0	0	0.000402	0
90	0	0	0	0.0003961	0.002013	0
100	0.00039	0.000391	0	0	0.000402	0.0004033
110	0.00039	0.000391	0	0	0.000402	0.0004033

Table 4.31 Load values in helical nails with equal interval of time of 60° slope at 30° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	0	0	0	0	0	0
20	0	7.85227	0	0	8.081998	0
30	7.88288	7.85227	0	0	0	0
40	7.88288	7.85227	0	0	0	0
50	0	7.85227	7.8844706	0	0	0
60	7.88288	7.85227	0	0	8.081998	8.1092162
70	0	7.85227	0	0	8.081998	0
80	0	7.85227	0	0	8.081998	0
90	0	0	0	7.9650107	40.48106	0
100	7.88288	7.85227	0	0	8.081998	8.1092162
110	7.88288	7.85227	0	0	8.081998	8.1092162

Table 4.32 Strain values in helical nails with equal interval of time of 90° slope at 15° nail inclination

Time (Seconds)	Strain 1	Strain 2	Strain 3	Strain 4	Strain 5	Strain 6
0	0	0	0	0	0	0
10	0.000393	0	0	0.000397777	0.0004012	0
20	0	0.0003945	0	0.000397777	0.0004012	0
30	0.000393	0	0.002016	0.000795905	0.0004012	0
40	0.000393	0	0.000403	0.000397777	0.0004012	0
50	0.000393	0	0	0	0.0004012	0
60	0	0.0003945	0.000402	0.000795905	0	0.00040147
70	0	0.0003945	0.000804	0.000397777	0.0004012	0

Table 4.33 Load values in helical nails with equal interval of time of 90° slope at 15° nail inclination (in kN)

Time (Seconds)	Nail 1	Nail 2	Nail 3	Nail 4	Nail 5	Nail 6
0	0	0	0	0	0	0
10	7.900836	0	0	7.997781634	8.066281	0
20	0	7.9312572	0	7.997781634	8.066281	0
30	7.900836	0	40.53811	16.00262269	8.066281	0
40	7.900836	0	8.093412	7.997781634	8.066281	0
50	7.900836	0	0	0	8.066281	0
60	0	7.9312572	8.086323	16.00262269	0	8.07196794
70	0	7.9312572	16.16557	7.997781634	8.066281	0

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