A STUDY ON SOIL NAILING FOR VARIOUS C-ϕ SOILS IN TAVANUR AREA

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PROJECT REPORT

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DECLARATION

We hereby declare that this project report entitled **“A STUDY ON SOIL NAILING FOR VARIOUS C-ϕ SOILS IN TAVANUR AREA’’** is a bonafide record of project work done by us during the course of study and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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Certified that this project report entitled **“A STUDY ON SOIL NAILING FOR VARIOUS C-ϕ SOILS IN TAVANUR AREA’’** is a record of project work done jointly by **ANEESHA, K. V., JINSA, C. M., RADHIKA DEVI, V. U. and RAGESH, K. T.** under my guidance and supervision and that it has not previously formed the basis of any degree, diploma, associateship, fellowship or other similar title of another University or Society.

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Symbols and abbreviations

0	-	Degree
<	-	Less than
µ	-	Micron
%	-	Percentage
Cm	-	Centimeter
et al	-	And others
e.g.	-	Example
fig.	-	Figure
gm	-	Gram
GRPS	-	Geogrid- Reinforced and Plie – supported earth Structures
i.e.	-	That is
IS	-	Indian Standards
KAU	-	Kerala Agricultural University
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
Kg	-	Kilogram
kN	-	Kilo Newton
m	-	Meters
m^2	-	Square meter
m^3	-	Cubic meter
mm	-	Milli meter

N	-	Newton
NIT	-	National Institute of Technology
Vs	-	Versus
w.r.t	-	with respect to

INTRODUCTION

Kerala state having an area of 38,863 km^2 is wedged between the Arabian Sea in the West and the Western Ghats in the East. Kerala’s topography consists of coastal plains gradually rising in elevation to the high hills of Western Ghats. 40% of the total area lies in the highland region forming the Western slopes of Western Ghats. A considerable part of all districts of Kerala except the coastal district of Alleppey falls within this region.

In Kerala, because of its undulating topography landslides and floods are the most commonly occurring natural hazards. The landslides in the state include rock falls, rock slips and debris flow. But the most prevalent disastrous type of earth movement noted in Kerala is the debris flow (urulpottal). Which is characterized by the swift and sudden down slope movement of highly water saturated overburdened earth, ranging in size from soil particles to boulders. Every year with the onset of monsoon, land slips and landslides are reported. Population growth and high rain fall are identified as the major driving forces behind the land sliding.

The term landslide includes a broad range of different types of motion whereby earth material is dislodged by falling, sliding and flowing under the influence of gravity. Landslide causes landscape changes which are threat to life and destruction of properties as well as agriculture. The failure of a mass of soil located beneath a slope is called slide. The stability of slopes should be very thoroughly analyzed since their failure may lead to loss of human life as well as economic loss. A variety of soil improvement or construction techniques are available to solve such problems. Steel, concrete and timber piles are commonly used for supporting settlement-sensitive structures such as buildings and bridges. They are also adopted for supporting embankments or slopes.

The soil stabilization is any process which improves the physical properties of soil such as increasing the shear strength, bearing capacity and resistance to erosion. The slope stability can be generally described as the inherent structural integrity of a slope to resist failure. Failure can occur as slides, cracks and slope movements. Erosion control is intended to provide surface slope stability to protect the face of the slope and to strengthen the portions of the slope below the surface by interlocking soil particles.

The soil nailing is a technique used to bring soil stability in areas where land slide may be a problem. The soil nail can prevent landslides by inserting steel reinforcement bars into the soil and anchoring them to the soil strata. It is called Soil Nail, because it’s like a nail being hammered into the soil, where the nails are the steel bars. Soil nailing is gaining popularity day by day. It is an emerging technology for in – situ stabilization and reinforcing the soil with steel bars or other materials. This is also a relatively simple technique for ground improvement which has made it popular among other methods.

Soil nailing can be used as a measure to treat unstable natural soil slopes or as a construction technique that allows the safe over-steepening of new or existing soil slopes. The technique involves insertion of relatively slender reinforcing elements into the slope. Soil nail components may also be used to stabilize retaining walls or existing fill slopes (embankments), thus it is normally undertaken as a remedial measure. Soil nailing is now a well established technique around the world. The soil nailing is not recommended to use either in clayey soils or in clean sands where the cohesion of the soil is minimum.

The basic concept of soil nailing is to reinforce and strengthen the existing ground by installing closely-spaced steel bars, into a slope as installation proceeds from top to down for the specified height of the slope. This process creates a reinforced section that is in itself stable and able to retain the soil behind it. The reinforcements are passive and develop their reinforcing action through nail-ground interactions as the ground deforms during and following construction.

The specific aim of this project is to introduce the concept of soil nailing and to provide guidance for selecting, designing and specifying soil nailing for those many applications to which it is technically suited and economically attractive.

The specific objectives of the study are given as:

1. To study the effects of soil nailing technique in different c- ϕ soils in Tavanur area.
2. To study the feasibility of soil nailing technique when compared to the prevailing retaining wall construction.
3. To develop a computer program for the design procedure of soil nailing technique for various soil properties and the nature of terrain.

REVIEW OF LITERATURE

2.1 Slope stabilization

The soil stabilization is alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. Slope stability rests upon the ability of a slope to resist stress excess to what is normally acceptable for the material property of the soil or rock inherent to the construction slope. Slope movements such as translational or rotational slope failures occur when shear stress exceeds shear strength of the materials forming the slope. The factors contributing to high shear stress includes lack of lateral support, excessive surcharges, lateral pressures and removal of underlying support. On the other hand low shear strength due to inherently weak materials, soil weathering (swelling, shirking and cracking) and low inter granular force due to seepage pressure also contributes to slope instability. The field of slope stability encompasses the analysis of static and dynamic stability of slopes of earth and rock-fill dams, slopes of other types of embankments, excavated slopes and natural slopes in soil and soft rock.

Choudhury *et al* (2008) conducted a study on slop stabilization with jute geotextile. In this process installation of geotextile is followed by seeding and plantation of saplings. As a result vegetation starts growing and the roots of vegetation take care of the soil which ultimately protects the slope from erosion, slides and other types of failure.

2.2 Soil reinforcement

The ground improvement and soil reinforcement have become necessary in view of shortage of space available for construction. Reinforcement of Soil can generally be subdivided into 2 categories, Reinforced Soils and In-situ Reinforcement. The later is often termed as “soil nailing”.

In the late 1960s, gravity walls comprised of earth masses reinforced with metal strips were introduced as an alternative to anchored structures. This lateral retention technique is called Reinforced Earth, which is economical since the main structural component is the in-situ earth. Its limitation especially in the case of temporary excavation shoring is that the full excavation must be carried out first and the wall erected from bottom to top. But the soil nailing proceeds almost in reverse direction. By using the in-situ soil, it allows for the simultaneous construction of the shoring support as the excavation progresses downwards.

Jie and Ken (2002) conducted a study on use of geogrid-reinforced and pile-supported earth structures. The field observations proved that the GRPS system creates a stiffened platform that spans weak soils and minimizes the differential settlement above the platform. Elimination of inclined piles and enlargement of pile spacing by using geogrids have made this system more cost-effective.

Sivakumar Babu *et al.* (2003) conducted a study on bearing capacity improvement using micro piles. The actual design for retrofitting was based on the assumption that the vertical component of the frictional force between the soil and the micro pile resists the additional load coming from the structure over and above the bearing capacity.

Ling *et al.* (2005) conducted a parametric study on the behavior of reinforced soil retaining walls under earthquake loading. The procedure utilized was nonlinear numerical algorithms that incorporated a generalized plasticity soil model and a bounding surface geosynthetic model. The reinforcement layouts, soil properties under monotonic and cyclic loadings, block interaction properties and earthquake motions were among major variables of investigation.

Sullivan (2007) studied the aspects for consideration in the design of reinforced earth structures. Conventional limit equilibrium analysis of soil nail systems does not allow for the stabilizing contribution of all the inclusions physical attributes or the aggregate of group effects.

Sivakumar Babu and Singh (2008) reported that four principal failure modes of soil nail walls, namely global stability, sliding stability, soil-nail pullout failure and nail tensile failure were considered to evaluate the influence of in-situ soil variability on the stability of a soil nail wall.

Lui *et al.* (2009) studied about reinforcement load and deformation mode of geosynthetic reinforced soil walls subject to seismic loading during service life .The results of this study indicate that it is rational to investigate the reinforcement load of reinforced soil walls subject to seismic loading without considering the previous long-term creep.

2.3 Soil nailing

The soil nailing is an in-situ earth reinforcement technique. Owing to numerous advantages such as quick construction, ease of application, less environmental impact etc. Slope stability practitioners are considering soil nailing as a viable alternative to the other earth retaining systems. In India, soil nailing is being extensively used for applications such as stabilization of side walls of approach roads for underpasses, temporary support for excavations below ground level and strengthening of rail/road side slopes.

A soil nailed retaining structure is comprised of three main elements such as the soil being retained, the artificially introduced earth reinforcements and the facing. Such a structure attains the capability of self-support from the shear and tensile strengths of the reinforcing, which increase the overall shear strength and self-supportability of the in-situ soil. These tension elements are typically steel reinforcing bars, driven or drilled and grouted into place.

The soil nailing being a new area of research in engineering, not much of literature is available. However some investigators have contributed some works on soil nailing. Soil nailing was evolved from the New Austrian tunneling method which is a system for underground excavations in rock. This method consists of passive steel reinforcement in the rock followed by the application of reinforced shotcrete. This concept of combining passive steel reinforcement and shotcrete has also been applied to the stabilization of rock slopes since the early 1960s.

The first application of soil nailing was implemented in 1972 for a railroad widening project near Versailles in France. The soil nails were used to stabilize an 18 m high slope consisting of sandy soil. Germany was the next country to investigate soil nailing. From 1975-1981 the University of Karlsrushe and the construction company Baur collaborated to establish a research program. This program conducted full scale testing of experimental walls with different configurations and developed analysis procedures for use in design. The United States first used soil nailing in 1976 for the support of a 13.7 m deep foundation excavation in dense silty sands.

Kouji Tei (1993) conducted a study which is concerned with the interaction mechanism between the soil and nail, the failure mechanism and suitable design procedure for nailed slopes in sand. The interaction mechanism of a nail was studied by caring out a number of pull–out tests, direct shear tests of nailed sand and interface tests using two uniform sands.

Chow Chee-Meng1 & Tan Yean-Chin (2005) conducted a study on various design methods on soil nailing and subsequently recommendations are made for design method for soil nail to be adopted for Malaysian practice to ensure safe and economical design of soil nail in line with international practice.

Plate 2.1 20m high soil nailed slope in Kuala Lumpur

Sivakumar Babu and Singh (2008) conducted a study on reliability analysis of soil nail walls. They reported that correlation between in-situ soil cohesion and angle of internal friction are found to influence soil nail wall stability significantly. In general, reliability analysis provided a better insight into the assessment of stability of soil nail wall.

Muthukumar and Premalatha (2009) conducted an experimental investigation on optimum design of nailed soil wall to find the influence of nail rigidity number in the failure surface and nail displacement. The SNAILZ program is used to understand the influence of nail rigidity number in the global and local stability of nailed soil wall. A simplified method for optimum design of nailed wall is proposed for sandy deposit

2.3.1 Material for soil nailing

The nails used in soil nailing structures are generally steel bars or other metallic elements that can resist tensile stresses and bending moments. The nails are not pre – stressed but are closely spaced (e.g. one driven nail per 1 m^2 and one grouted nail per 4 m^2) to provide an anisotropic apparent cohesion to the native ground. Nails should be installed soon after excavation by driving or drilling. Driven nails in most of the cases are steel bars with diameter 20 mm up to 50 mm. The nails are driven into the ground at any desired inclination using a vibro percussion or hydraulic hammer which requires no pre drilling. Because of smaller contact area of driven nails they are usually closely spaced (2 to 4 bar per m^2). The advantage with driven nail is that nail installation is faster than other types of nails. In collapsible soil where a grout hole cannot stand unsupported, driving is the only viable alternative. Nail driving is difficult in soil containing boulders and it's another disadvantage is of lower apparent coefficient of friction between nail and soil.

Kouji Tei (1993) reported that flexibility of a nail significantly influences the interaction mechanism. Both the interaction parameter and apparent friction coefficient differ between a flexible and a stiff nail. Theoretical consideration indicates that the mobilization of nail forces is dominated by the relative stiffness between soil and nail. Increasing the diameter of a nail produces a smaller apparent friction coefficient.

Osicki *et al.* (2003) conducted a study on application of air launched soil nails as an innovative remediation technology to landslide on the Saskatchewan highway network. This paper documents the site conditions and how air launched soil nails have proven to be an innovative remediation technique for landslides and managing risk at this site.

Mittal *et al.* (2008) reported that apparent coefficient of friction between nail and soil plays an important role in determining the stability of nailed cuts. To obtain the value of apparent coefficient of friction laboratory pull-out tests were performed. The purpose of pull out test was to study the effect of nail diameter, nail length, surcharge intensity and method of placing of nails on the coefficient of friction between soil and nail interface.

Lui (2009) studied about the soil nail hole measurement with the objective of the study was to understand the possible extent of hole deviation and over break in soil-nail drilling works.

2.3.2 Grout

Grout for soil nails is required to fill the annular space between the nail bar and the surrounding soil. Grout for soil nail walls is commonly a neat cement grout with the water-cement ratio typically ranging from 0.4 to 0.5. Grout mix shall be prepared in accordance with IS: 9012. Grout shall have a minimum 28 days characteristic strength of 20 MPa. For filling up nail holes, grout shall be pumped shortly after the nail bar is placed in the drill hole to reduce the potential for hole squeezing or caving. In solid nail bar applications the grout may be injected by Tremie methods through a grout pipe, which is previously inserted to the bottom of the drill hole until the grout completely fills the drill hole.

Zhou *et al.* (2011) developed a three-dimensional (3D) finite element (FE) model to simulate the pullout behavior of a soil nail in a soil-nail pullout box under different overburden and grouting pressures. It was reported that in soil-nail construction cement slurry is injected through pipes into drill holes by a pressure pump. The applied pumping pressure depends on the field conditions such as the distance and height between the cement slurry and drill holes.

2.3.3 Facing

The soil nail walls are generally provided with the following two types of facings. They are temporary facing and permanent facing.

2.3.3.1 Temporary facing

Temporary facing shall be constructed by providing reinforcement in the form of welded wire mesh (conforming to IS: 1566) throughout the wall face and by additional bearing plates and which is subsequently shotcreted in accordance with IS: 9012. Overall temporary facing thickness shall vary from 75 mm -200 mm.

2.3.3.2 Permanent facing

Permanent facing may be constructed as cast-in-place reinforced cement concrete conforming to IS: 456, precast concrete or any suitable material to achieve desired strength and aesthetics. Reinforcement in the permanent facing may be adopted in the form of welded wire mesh or reinforcement bars in either direction. Permanent facing shall be connected to the temporary facing by means of headed-studs (usually four numbers per plate) welded on the bearing plates installed during construction of temporary facing. Minimum thickness of permanent facing shall not be less than 200 mm.

Kouji Tei (1993) reported that roughness and bending stiffness of the facing wall considerably influence the stability and displacement of the nailed slope respectively. Draining of the water significantly influences both the earth pressure on the facing wall and the displacements of the nailed slope. Horizontal displacements of the facing wall were decreased by increasing the length and/or friction of the nail.

2.3.4 Some soil nailing works carried out in India

The soil nailing technique is gaining popularity day by day. Since soil nailing is a new area of research not so much review is available. However some investigators have contributed works in soil nailing. In India the successfully carried out soil nailing works are Hero Cycles factory in Ludhiana, landslide control in Nainital, hotel construction Meerut, construction of underground car parking in Lucknow, construction of via-duct in New Delhi, for retaining natural slope in IIM campus Calicut and landslide control in sides of Konkan railway.

MATERIALS AND METHODS

This chapter mainly deals with the materials used and methods followed for the design of soil nailing. The various laboratory experiments and testing procedures done for the design are listed as follows.

3.1 Area of study

The study was conducted at K.C.A.E.T campus, Tavanur, Malappuram district. It is situated at 10^0 52’30” North latitude and 76^0 East longitudes.

3.2 Field tests

The field tests were conducted for identification and characterization of soil properties. Both disturbed and undisturbed soil samples were collected from three different locations of study area. The selected locations were the area near to the river side boundary of the farm, area near coconut orchard and area near to the pond from which sample 1, sample 2 and sample 3 where collected respectively. Laboratory testing of the collected soil samples were carried out to determine the moisture content, grain size distribution, unit weight, specific gravity and shear strength.

3.2.1 Determination of water content

The moisture content of collected soil samples were determined by oven drying method. In this method, after weighing the soil samples were kept in an oven at 105 to 110^0C for 24 hours. Final weight of the dried sample was noted. The moisture content was calculated by using the equation

$$w = \frac{M_2 - M_3}{M_3 - M_1} \times 100$$

Where, w = water content (%)

M_1= mass of the container in gm

M_2 = mass of the container and wet soil in gm

M_3 = mass of container and dry soil in gm

3.2.2 Determination of specific gravity by density bottle

The specific gravity of soil is determined by density bottle method. In this method, the empty weight of the density bottle, weight of bottle with soil sample, weight of bottle including water and soil samples and the weight of bottle filled with distilled water were noted. Then specific gravity can be calculated by,

$$G = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)}$$

Where, G = specific gravity

M_1 = mass of density bottle in gm

M_2 = mass of bottle and dry soil in gm

M_3 = mass of bottle, soil and water in gm

M_4 = mass of bottle and water in gm

The test was repeated for different soil samples and the average of the obtained value was taken.

3.2.3 Determination of bulk density and bulk unit weight

Determination of field density was done by using core cutter method. In this method, volume and empty weight of the core cutter were noted, then core cutter and dolly assembly was driven into the soil with the help of a rammer. The core cutter containing soil was dug out from the plot, dolly was removed and excess soil was trimmed off. Then mass of core cutter full of soil was found. Then bulk density was calculated by using the formula,

$$\rho = \frac{M}{V}$$

Where, ρ= bulk density in gm/cm^3

M= mass of soil in gm

V= volume of soil in cm^3

Bulk unit weight was calculated as,

$$\gamma = \rho g$$

Where, γ = bulk unit weight in kN/m^3

ρ = bulk density in gm/cm^3

g = acceleration due to gravity in m/s

Three samples were tested for each location and the average of the obtained values was taken as the bulk density.

3.2.4 Determination of grain size distribution

The grain size distribution of soils from the selected three plots was done by sieving. Here dry sieve analysis was carried out using 4.75mm, 2mm, 1mm, 600µm, 425µm, 300µm, 212µm, 150µm, 75µm size sieves. Sieving is done using sieve shaker. Weight of soil retained in each sieves were taken. The mass retained in the receiver is then subjected to fine sieving. Fine sieving is done by hydrometer method. The gradation curve was plotted with particle size and cumulative percentage finer.

3.2.5 Determination of shear strength

The shear strength of soil was determined by direct shear test under undrained condition. The direct shear apparatus consists of a two piece shear box of square cross-section. The lower half of the shear box rigidly held in the position in a container which rests over the slides or rollers and which can be pushed forward at constant rate by geared jack driven either by electric motor or by hand. The upper half of the box butts against proving ring. The sample to be tested was compacted into required bulk density in the shear box and was held between metal grids. Metal grids have linear serrations which were oriented perpendicular to the direction of the shearing force. Normal load was applied on the specimen from a loading yoke bearing upon steel ball of pressure pad. Normal stress can be found out by the following equation.

$$\sigma = \frac{N}{A}$$

Where, σ = normal stress in kg/cm^2

N = normal load in kg

A = area of shear box in cm^2

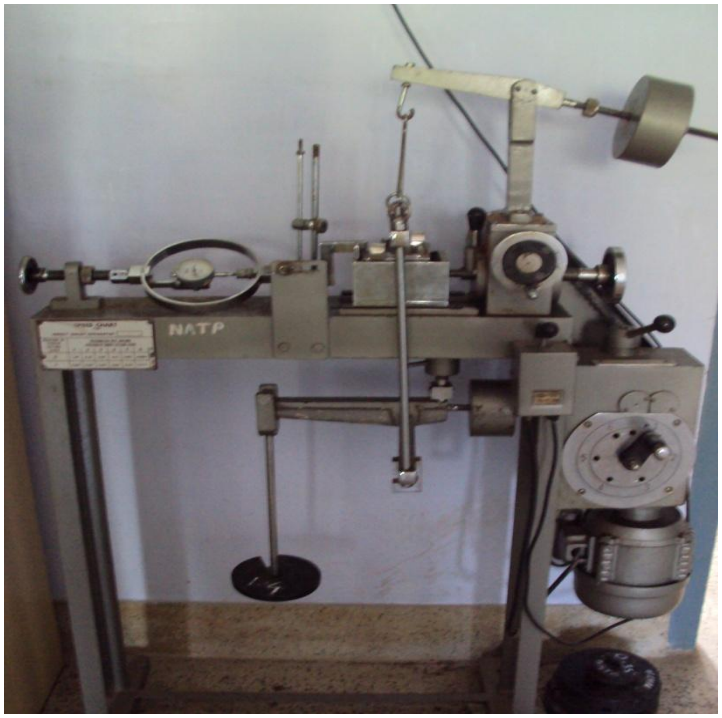


Plate 3.1 Direct shear apparatus

Shearing force was applied to the lower box through the geared jack. The movement of the lower part of the box was transmitted to the upper part of box through the specimen and hence to the proving ring. The deformation of proving ring indicates the shear force. Shear stress can be calculated by the following relation.

$$\tau = \frac{S}{A}$$

Where, τ = shear stress in kg/ cm^2

S= shear force in kg

A = area of shear box in cm^2

The shear force, S at failure corresponding to a particular normal load N is measured with the help of proving ring. By increasing normal load the test was repeated for identical specimens and corresponding shear force was noted. A graph was plotted with shear stress as ordinate and normal stress as abscissa, which gives the failure envelope for the soil under test. From the graph C (cohesion of soil) and ɸ (angle of internal friction) for each soil sample was noted.

3.3 Design procedure for soil nailing

The most important consideration in proper design and installation of any retaining structure is to recognize and compensate the fact that the retained material will tend to move outward and downward due to gravity. This creates lateral earth pressure behind the wall which depends on the angle of internal friction (ɸ), the cohesive of soil (c) of the retained material, as well as the direction and magnitude of the movement of retaining structure. It was proposed to design soil nailing for a height of 5m in the selected site which has an inclination of 80^0 with horizontal. The nails used for this particular design were epoxy coated MS rods. Design steps were as follows,

3.3.1 Determination of coefficient of earth pressure

Lateral earth pressure is the pressure that soil exerts in the horizontal plane. Lateral earth pressure coefficient K, is the ratio of lateral (horizontal) earth pressure to vertical earth pressure ($K = \sigma_h/\sigma_v$). Thus horizontal earth pressure is assumed to be directly proportional to the vertical earth pressure with proportionality constant k at any given point in the soil profile. Active earth pressure develops when the wall is free to move outward such as a typical retaining structure and the soil mass stretches sufficiently to mobilize its shear strength. Active earth pressure co efficient, Ka

$$Ka = \left[\frac{\sin(\alpha - \varphi)}{(\sin\alpha)^{1.5} + \sin\varphi\,(\sin\alpha)^{0.5}}\right]^2$$

Where, α = inclination of face to horizontal

φ = angle of internal friction

Co efficient of earth pressure at rest, Ko

$$Ko = 1 - \sin\varphi$$

3.3.2 Determination of nail length

Length of soil nail within the potential failure wedge L' is given in m as

$$L' = (H - h)\frac{\tan(\theta - (90 - \alpha))}{\cos(90 - \alpha)}$$

Where,

H = total height of the wall in m

h = depth of each nail from top in m

Depth of soil above the active adherence length of the nail, h' is given as

$$h' = h + L'\sin(10)$$

Generally length of the soil nail was taken as 60- 80% of the total height H, here it was taken as 75% of height. Active length of nail beyond failure plane, La is given as,

$$La = 0.75H - L'$$

3.3.3 Determination of nail friction

In case of a soil nailed wall, the potential failure plane can be considered to be inclined at an angle $\theta = 90 - \frac{1}{2}(\alpha + \varphi)$ to the vertical. The friction acting on the nail, F_N is given by,

$$F_N = L_a \tan\mu\gamma\, h'd[2 + (\pi - 2)k_0]$$

Where,

La = active length of nail beyond failure plane in m

d = diameter of soil nails in m

h'= depth of soil above active adherence length of nail in m

K_o= coefficient of earth pressure at rest

γ = unit weight of the soil sample determined as per the procedure given in section 3.2.3.

The value of $\tan\mu$ is taken as 0.8 tan φ (since friction coefficient of nail is 80% of that of soil). The friction force must be check against permissible tension force.

$$\text{Permissible tension force} = \frac{\text{ultimate pullout strength}}{\text{factor of safety}}$$

And, ultimate pullout strength=π x d x bond strength of the soil

In this case ultimate pull out strength of the nail was 60 kN and factor of safety 3 was taken. Permissible tension force, P_{TF} was obtained as 60/3.

3.3.4 Determination of lateral earth pressure

Lateral earth pressure per meter, L_{EP} is given by

$$L_{EP} = \frac{1}{2} \times \left(\gamma H K_a - 2C\sqrt{K_a}\right) \times (H - Z_0)$$

Where,

C= cohesive strength of the soil in kN/m^2

Z_0= depth in m, at which the earth pressure is zero and can be found out by the equation,

$$Z_0 = \frac{2C}{\gamma\sqrt{K_a}}$$

Lateral earth pressure per vertical row of soil nails, L_{PV} can be obtained by multiplying the L_{EP} with the desired horizontal spacing. Then the overall adherence safety factor can be found out using the relation,

$$\text{adherence safety factor} = \frac{\sum \mathrm{F_N}}{\mathrm{L_{PV}}}$$

3.3.5 Determination of tension in soil nail

The tension developed in each soil nail can be assumed to be lateral earth pressure acting over the area of the slope face that is supported by the soil nail. In the case of both soil nailed wall and reinforced soil walls, the reinforcement restrains the lateral movements particularly at the top of structure. In this region, the lateral earth pressure coefficient is therefore close to K_o. However these structures tend to have a fairly uniform reinforcement distribution, making the lower most reinforcement the most critical level in the tension design calculations. For this location, the earth pressure coefficient can safely be assumed to be K_a. Therefore tension (T) in the nail can be taken as,

$$T = K_a \gamma h_m SV$$

Where,

h_m = depth of lowest soil nail in m

S = horizontal spacing between soil nails in m

V = vertical spacing between soil nails in m

Tensile safety factor can be found out using the relation

Tensile safety factor = Ultimate strength of the nail / Tension in the soil nail

RESULTS AND DISCUSSION

Soil samples from the selected locations were tested to analyze there properties .The influence of various soil properties on slope stability were studied and the design of soil nailing was done accordingly. This chapter highlights the results obtained from the study.

4.1 Moisture content of soil samples

The moisture content of the soil samples was determined by oven dry method as mentioned in section 3.2.1. It is obtained as 9.15%, 7.93% and 9.98% for soil sample 1, soil sample 2 and soil sample 3 respectively.

4.2 Specific gravity of samples

The specific gravity of the samples was determined by using density bottle as mentioned in the section 3.2.2. Specific gravities are 2.37, 2.31 and 2.37 respectively for the three soil samples (Appendix I).

4.3 Bulk density and bulk unit weight

The bulk density and bulk unit weight were determined by core cutter method as mentioned in the section 3.2.3. The bulk densities of collected samples are 1.82, 1.72 and 1.86 (Table 4.1) and bulk unit weights are 17.893, 16.892 and 18.325 for sample 1, sample 2 and sample 3 respectively.

Table 4. 1. Bulk density and bulk unit weight of the selected samples

Samples	Mass of core cutter (gm)	Mass of core cutter with soil (gm)	Mass of soil (gm)	Volume of core cutter (cm^3)	Bulk density (gm/ cm^3)	Bulk unit weight (kN/m^3)
Sample 1	927	2727	1800	957.47	1.88	18.4428
	1076.5	2992	1915.5	1020.5	1.87	18.3447
	984.5	2664	1679.5	981.25	1.71	16.7947
Average					1.82	17.8934
Sample 2	927	2549	1622	957.47	1.69	16.6181
	1076.5	2755	1678.5	1020.5	1.65	16.1375
	984.5	2777	1792.5	981.25	1.83	17.9229
Average					1.72	16.8928
Sample 3	927	2898	1971	957.47	2.06	20.189
	1076.5	2953.5	1877	1020.5	1.839	18.0406
	984.5	2661.5	1677	981.25	1.709	16.7653
Average					1.868	18.3251

4.4 Grain size distribution

The grain size distribution was determined by dry sieving and hydrometer method as mentioned in 3.2.4.The gradation curve of the sample is given in Appendix II. From the gradation curve it is clear that the soil under study area is uniformly graded.

4.5 Shear strength

The shear strength of the samples was determined by using direct shear apparatus. The method was mentioned in 3.2.5. Failure envelopes of each soil samples were plotted and from that c and ϕ values of the samples were obtained.

4.5.1 Soil sample 1

The shear strength of the sample 1 is in between 0.2 – 0.66 kg/cm^2 (Table 4.2). Figure (4.1) represents the failure envelope of soil sample 1. The Y- intercept of the graph gives the cohesion factor c and angle of the failure envelope with the horizontal gives the angle of internal friction ϕ. It is observed that sample 1 has a ϕ- value of 40^0 and a c- value of 7.36kN/m^2.

Table 4. 2. Shear strength of soil sample -1

Weight added (kg)	Lever arm, La	Proving ring reading	Normal load (kg)	Normal stress , σ (kg/cm^2)	Load (kg)	Shear stress, τ (kg/cm^2)
1.42	5	33	7.1	0.2	7.2	0.2
2.84	5	105	14.2	0.4	22.78	0.63
4.25	5	108	21.25	0.6	23.43	0.65
5.66	5	110	28.3	0.8	23.76	0.66

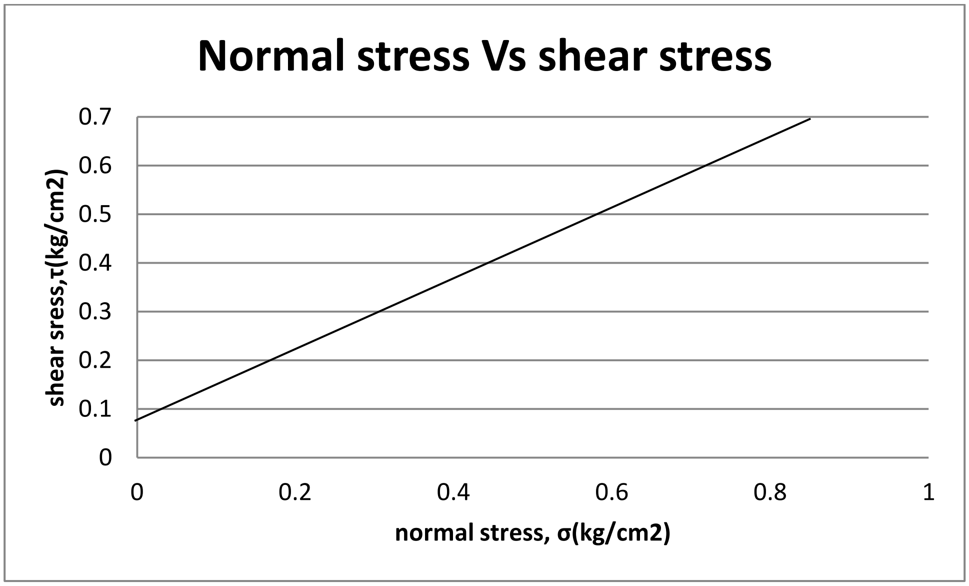


Fig. 4.1. Normal stress versus shear stress curve for sample

4.5.2 Soil sample 2

The shear strength of sample 2 is tabulated in table 4.3. Figure (4.2) represents the failure envelope of soil sample 2. From this it is observed that sample 2 has a ϕ- value of 26.5^0 and a c- value of $19.62 kN/m^2$.

Table 4. 3. Shear strength of soil sample - 2

Weight added (kg)	Lever arm, La	Proving ring reading	Normal load (Kg)	Normal stress , σ (kg/cm^2)	Load (kg)	Shear stress, τ (kg/cm^2)
1.42	5	51	7.1	0.2	11.067	0.307
2.84	5	72	14.2	0.4	15.625	0.434
4.25	5	84	21.25	0.6	18.228	0.506
5.66	5	118	28.3	0.8	25.606	0.711

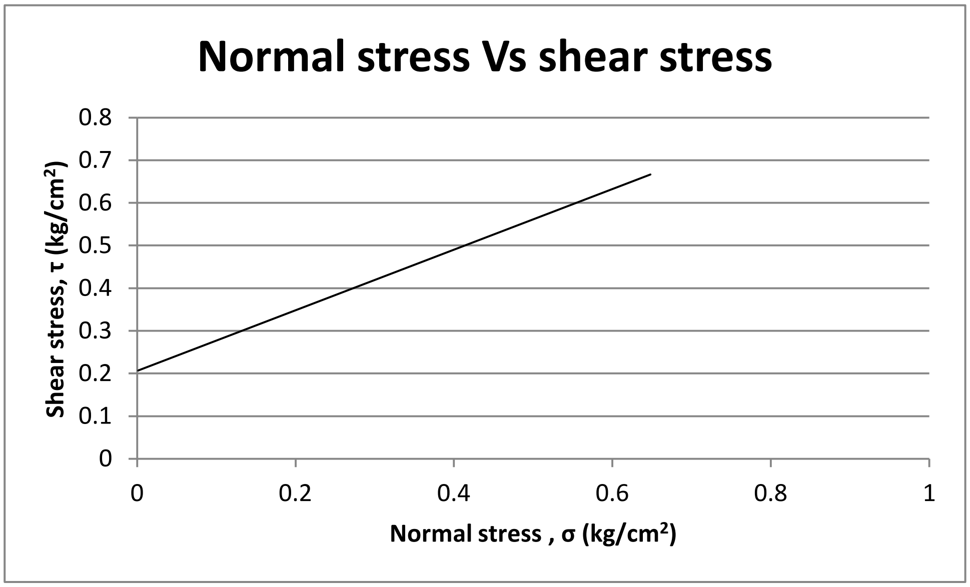


Fig. 4.2. Normal stress versus shear stress curve for sample 2

4.5.3 Soil sample 3

The shear strength of sample 3 is shown in the table 4.4. Figure (4.3) represents the failure envelope of soil sample 3. From this it is observed that sample 3 has a ϕ- value of 35^0 and a c- value of $17.17 kN/m^2$.

Table 4. 4. Shear strength of soil sample -3

Weight added (kg)	Lever arm, La	Proving ring reading	Normal load (kg)	Normal stress , σ (kg/cm^2)	Load (kg)	Shear stress, τ (kg/cm^2)
1.42	5	56	7.1	0.2	12.152	0.34
2.84	5	79	14.2	0.4	17.143	0.48
4.25	5	96	21.25	0.6	20.83	0.58
5.66	5	119	28.3	0.8	25.82	0.717

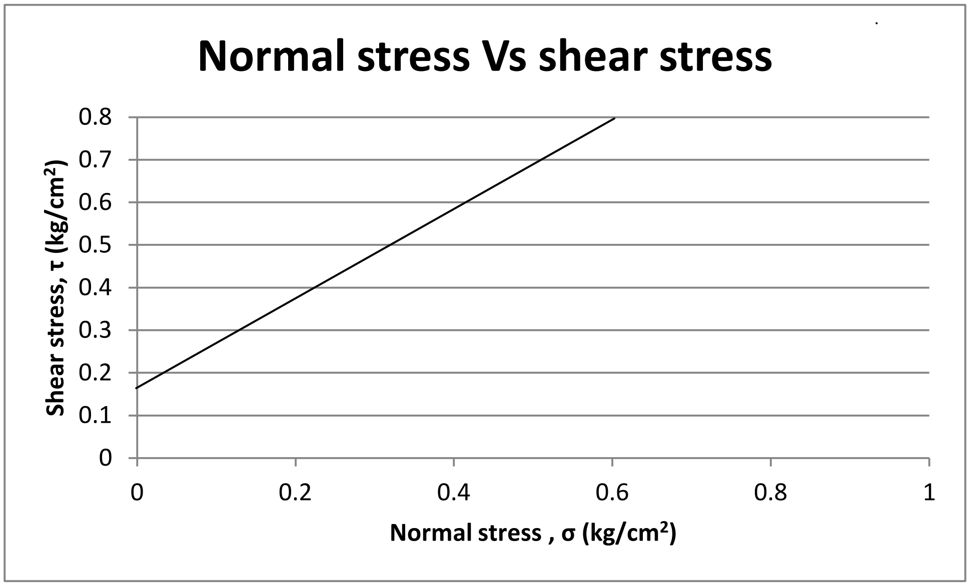


Fig. 4.3. Normal stress versus shear stress curve for sample 3

4.6 Design of soil nailing

Design was done for a wall of 5m height having an angle 80^0 with horizontal in the selected area. The procedure was mentioned in the section 3.2.6. Nails are usually installed at an angle of inclination 10^0 -20^0 with the horizontal, otherwise there is a possibility of void formation while grouting. In these design, angle of inclination of nail was assumed as 10^0. Fig. 4.1 represents the sectional view of a single nail. Design of soil nail wall for three types of c- ϕ soils is mentioned below.

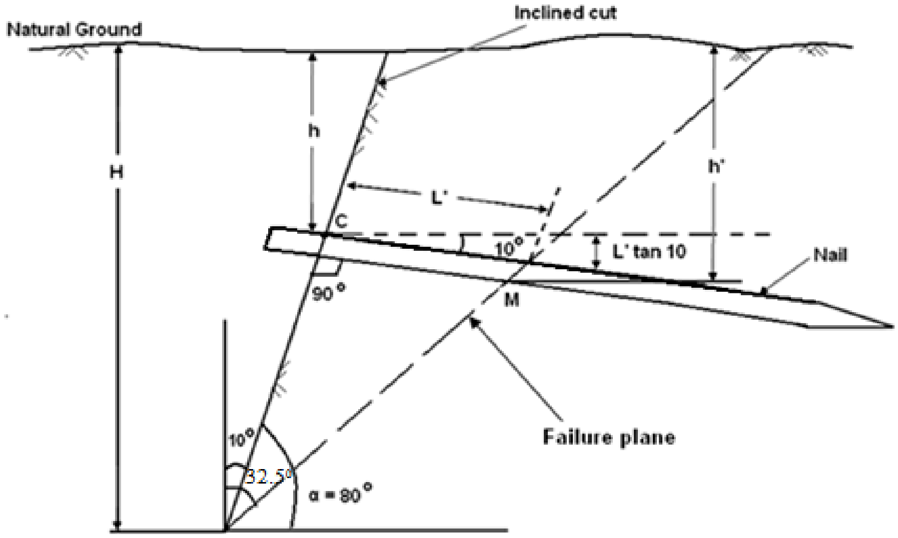


Fig. 4.4. Section showing a single nail

4.6.1 Design for sample 1

The assumptions made prior to the design include the diameter of M.S bar as 16mm, vertical spacing (V) as 1m and horizontal spacing(S) as 1m. Then it was checked for various factor of safety such as overall adherence safety factor and tensile safety factor.

Active earth pressure, $K_a = 0.158$

Earth pressure at rest, $K_0 = 0.357$

Table 4.5 Computation of friction in soil nails for sample 1

Depth (h) m	L'=(5-h)x0.3696	h'=h+L'sin 10	La=3.75-L'	F_N = 0.4625Lah'
0.5	1.6632	0.7888	2.0868	0.7613
1.5	1.2936	1.725	2.456	1.96
2.5	0.924	2.661	2.826	3.478
3.5	0.5544	3.596	3.196	5.31
4.5	0.1848	4.532	3.565	7.47
			Total ($\sum F_N$)	18.98

Frictional force in soil nail corresponds to each depth are shown in the table 4.5. From this it is clear that none of the developed frictional forces exceed the permissible tension force, 20 kN. Therefore the total frictional force for a single vertical row of soil nails is 18.98 kN.

Lateral earth pressure L_{EP} per m = 12.13 kN

Lateral earth pressure per vertical row = 12.13 kN

Overall adherence Factor of Safety =1.56

Tension in soil nail T = 12.71kN

Tensile factor of safety =4.71

Since the overall adherence safety factor and tensile safety factor are greater than one, the design is safe.

4.6.2 Design for sample 2

The assumptions made prior to the design include the diameter of M.S bar as 16mm, vertical spacing (V) as 1m and horizontal spacing(S) as 1.5m. Then it was checked for different safety factors.

Active earth pressure, Ka = 0.2091

Earth pressure at rest, K_0 = 0.4260

Table 4.6 Computation of friction in soil nails for sample 2

Depth (h) m	L'=(5-h)x0.4206	h'=h+L'sin 10	La=3.75-L'	F_N = 0.408Lah'
0.5	1.89	0.83	1.86	0.63
1.5	1.47	1.75	2.28	1.63
2.5	1.05	2.68	2.69	2.95
3.5	0.63	3.61	3.12	4.59
4.5	0.21	4.54	3.54	6.55
			Total ($\sum F_N$)	16.36

Frictional force in soil nail corresponds to each depth are shown in table 4.6. From this it is clear that none of the developed frictional forces exceed permissible tension force, 20 kN. Therefore the total frictional force for a single vertical row of soil nails is 16.355kN.

Lateral earth pressure L_{EP} per m = 1.56 kN

Lateral earth pressure per vertical row =2.35 kN

Overall adherence Factor of Safety = 6.95

Tension in soil nail T =25.86 kN

Tensile factor of safety =2.32

Since the overall adherence safety factor and tensile safety factor are greater than one, the design is safe

4.6.3. Design for sample 3

The assumptions made prior to the design include the diameter of M.S bar as 18mm, vertical spacing (V) as 1m and horizontal spacing(S) as 1.5m. Then it was checked.

Active earth pressure, Ka = 0.3128

Earth pressure at rest, K_0 = 0.5460

Table 4.7 Computation of friction in soil nails for sample 3

Depth, h (m)	**L'=(5-h)X0.5062**	**h'=h+L'sin 10**	**La=3.75-L'**	**F_N = 0.324Lah' (kN)**
0.5	2.28	0.89	1.47	0.43
1.5	1.77	1.81	1.97	1.16
2.5	1.26	2.72	2.48	2.19
3.5	0.76	3.63	2.99	3.52
4.5	0.25	4.54	3.49	5.15
			Total ($\sum F_N$)	12.46

Frictional force in soil nail corresponds to each depth are shown in table 4.8. From this it is clear that none of the developed frictional forces exceeds the permissible tension force, 20 kN. Therefore total frictional force for a single vertical row of soil nails is 12.46 kN.

Lateral earth pressure L_{EP} per m = 1.89 kN

Lateral earth pressure per vertical row = 2.83 kN

Overall adherence Factor of Safety = 4.39

Tension in soil nail T =35.66 kN

Tensile factor of safety =1.68

Since the overall adherence safety factor and tensile safety factor are greater than one, the design is safe.

From the above design for sample1 with angle of internal friction 40^0, the design becomes safe under the given 16 mm diameter bar at 1 m vertical and 1 m horizontal spacing. For sample 2 with an angle of internal friction 26.5^0, the design becomes safe under the given16 mm diameter bar at 1 m vertical and 1.5 m horizontal spacing and for sample 3 with angle of internal friction 35^0, the design becomes safe under the given 18 mm diameter bar at 1 m vertical and 1.5 m horizontal spacing. By comparing the above three results it is clear that failure of a slope is critically affected by the variation of angle of internal friction of soil, cohesion and unit weight of the soil.

4.7 Estimation and cost evaluation of soil nail wall with respect to cantilever retaining wall

The cost for soil nail walls is a function of several factors including terrain condition, site accessibility, size of the wall, type of facing, corrosion protection requirements for the nail, availability of experienced workers in soil nailing and shotcreting. Estimated cost for soil nail wall and cantilever retaining wall for a 5 x 5 m wall is given in table 4.8 and table 4.9. By comparing these two, it is clear that soil nail wall is more cost effective than the cantilever retaining wall and it can provide 55% of saving in cost as compared to retaining wall.

Table 4.8. Estimated cost for soil nail wall of 25 m^2

Sl no.	Quantity	Description of work	Unit	Cost per unit	Amount
1	3.5m^3	Earth work	m^3	134	469
2	12 hr	Hole drilling	hr	1670	20040
3	60 kg	Nail, bearing plate, centralizer etc	kg	38	2280
4	8 hr	Nail installation	hr	600	4800
5	20 nails	Grouting	nail	150	3000
6	25 m^2	Geo composite	m^2	130	3250
7	25 m^2	Welded mesh	m^2	35	875
8	5 m^3	Shortcreting	m^3	8120	40600
9	-	Labour cost	-	-	11000
	-	Other expenses	-	-	3000
		Total			89314

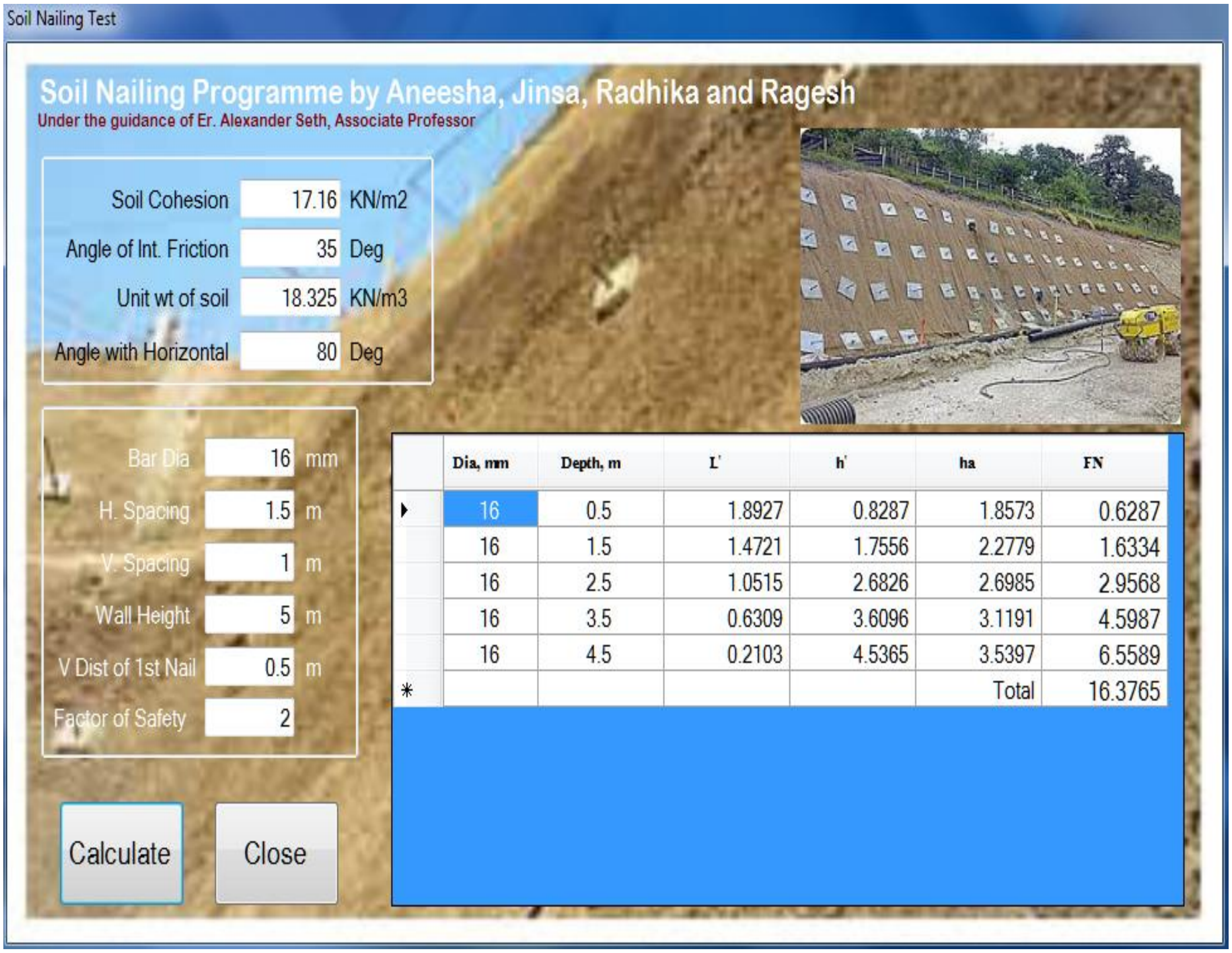
Table 4.9. Estimated cost for retaining wall of 25 m^2

Sl no.	Quantity	Description of work	Unit	Cost per unit	Amount
1	$5m^3$	Earth working	m^3	134	670
2	$7.5m^3$	Base slab	m^3	9800	73500
3	$12.5m^3$	Retaining wall	m^3	8700	108750
4	-	Labour charge	-	-	12500
5	-	Other expenses	-	-	3000
		Total			198420

4.8 Computer program for the design of soil nail wall

A computer program was developed in visual basic 2005 which gives various data for the design and implementation of soil nail wall by the inputs entered. The code for the program is given in Appendix III. The basic inputs given for design are unit weight of soil, cohesion factor of soil, angle of internal friction of soil, spacing, height of wall, and inclination of wall with horizontal. The major out put obtained is the diameter which is safe under the given soil condition and spacing.

The designed program gives the safe diameter and spacing by checking three safety factors such as frictional safety factor, overall adherence safety factor and tensile safety factor under the given soil properties. At particular depth if the design is not safe under the given diameter and spacing of nail, it itself change the diameter till it becomes safe while the spacing remains same. The diameter is assumed to vary in available sizes from16mm to 40 mm, which is sufficient for a small scale work. The user interface of the program is given below.



Soil Nailing Programme by Aneesha, Jinsa, Radhika and Ragesh

Under the guidance of Er. Alexander Seth, Associate Professor

Soil Cohesion 17.16 KN/m2
Angle of Int. Friction 35 Deg
Unit wt of soil 18.325 KN/m3
Angle with Horizontal 80 Deg

Bar Dia 16 mm
H. Spacing 1.5 m
V. Spacing 1 m
Wall Height 5 m
V Dist of 1st Nail 0.5 m
Factor of Safety 2

	Dia, mm	Depth, m	L'	h'	ha	FN
▸	16	0.5	1.8927	0.8287	1.8573	0.6287
	16	1.5	1.4721	1.7556	2.2779	1.6334
	16	2.5	1.0515	2.6826	2.6985	2.9568
	16	3.5	0.6309	3.6096	3.1191	4.5987
	16	4.5	0.2103	4.5365	3.5397	6.5589
*					Total	16.3765

Plate 4.1 User interface of the program

SUMMARY AND CONCLUSIONS

The soil nailing is a relatively new technique which is typically used to stabilize the existing slopes. It is used where top to bottom construction is advantageous compared to the other retaining wall system. The applications of soil nailing include stabilization of free board of river bank, side slope stabilization of roads, railways, agricultural lands etc. Soil nail has the distinct advantage of strengthening the slope without excessive earthworks. It has direct construction method and also relatively less maintenance throughout the life. The equipments required for execution of soil nailing work are easily available. The soil nailing is a systematic and quick operation also requires less working space when compared to retaining wall construction. The soil nailing performs well even in seismically active regions.

The design is done for a height of 5m having an angle 80^0 with horizontal. Nails are usually installed at an angle of inclination 10^0 -20^0 with the horizontal, otherwise there is a possibility of void formation while grouting. Nail material selected in this particular study was epoxy coated MS rod, since it is economic and corrosion resistive. Grout for soil nails is commonly a neat cement grout, which fills the annular space between the nail bar and the surrounding ground. The water cement ratio for grout used in soil nailing applications typically ranges from 0.4 to 0.5. For facing of the nailed wall commonly shortcreting is practiced, for which water-cement ratio of 0.4 is adopted. The nail length preferred in soil nailing is usually 0.6 to 0.8 times of the total wall height.

This study provides an insight into the design of soil nail walls with respect to the variation of in-situ soil properties. The failure of soil nail wall is critically affected by the variation of angle of internal friction of in-situ soil in comparison to unit weight and cohesion. In particular, correlation among in-situ soil cohesion and angle of internal friction is very important for stability considerations and it should be considered in the analysis and design of soil nail walls. The results show that the soil nailing technique provides a feasible, efficient and economical alternative to the conventional retaining structures, especially for supporting vertical or nearly vertical cut made in soil for various slope stability applications.

The estimation and costing when compared to cantilever retaining wall reveals that soil nail wall is more feasible than the retaining wall. The cost for soil nail wall is a function of several factors such as nature of terrain, accessibility of site, size of wall, type of facing, corrosion protection requirements for nails, availability of experienced workers specialized in soil nailing and shotcreting, and regional conditions. From this analysis it is clear that soil nail wall is more cost effective than the cantilever retaining wall and it can provide 55% of saving in cost when compared to later.

A computer program was developed in Visual Basic 2005 which gives various data for the design and implementation of soil nail wall by the inputs entered for various parameters pertaining to soil. The basic inputs given for design are unit weight of soil(γ), cohesion factor of soil, angle of internal friction of soil (ϕ), spacing of nail (VS & HS), height of wall (WH) and inclination of wall with the horizontal ($\propto$). The major output obtained was the diameter of nail which is safe under the given soil conditions and spacing.

The specific conclusions that are drawn out from the current study are:

1. Failure of a slope is critically affected by the variation of angle of internal friction of soil.
2. The soil nailing is a good option as a retaining structure in the area of study.
3. The designed soil nail wall could provide 68% of saving in cost as compared to cantilever retaining wall.
4. The program developed can be used to design soil nail wall by considering various parameters of soil to be retained and the nature of terrain.

Scope for further study

1. This study can be extended by using other design methods.
2. The design of the nailed wall can be modified by considering the strength of facing material and nail head.
3. The study can also be extended by analyzing the pullout strength of nail and other failure modes of the wall.
4. The design should consider the surcharge load if there any.

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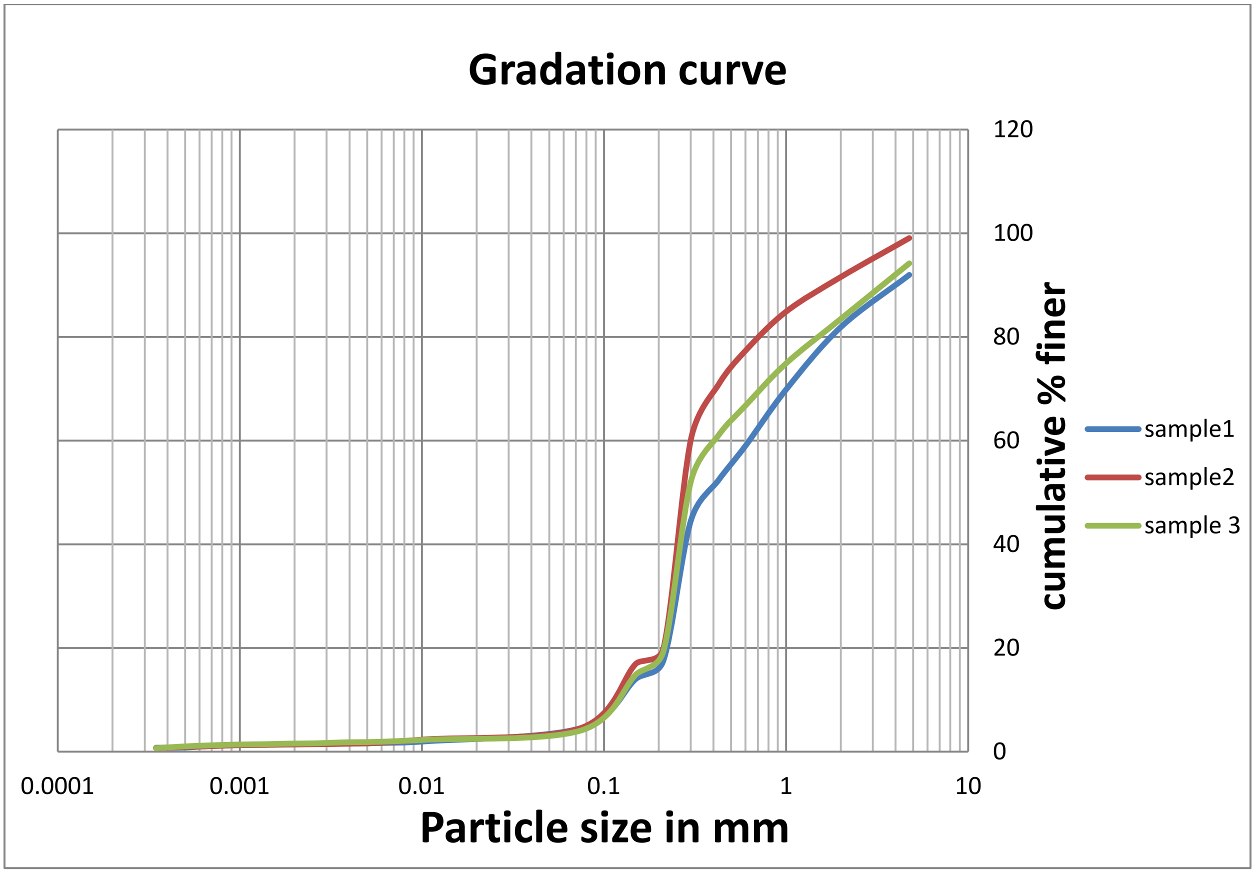
APPENDIX I

Specific gravity of the selected soil samples

Samples	**Dry mass of bottle , M_1 (gm)**	**Mass of bottle with soil, M_2 (gm)**	**Mass of bottle with soil and water, M_3 (gm)**	**Mass of bottle with water, M_4 (gm)**	**Specific gravity ,G**
Sample 1	12.5	38.0	84.5	69.5	2.42
	14.5	40.0	86.0	71.5	2.31
	20.5	45.5	90.0	76.5	2.38
Average					2.37
Sample 2	16.0	41.0	83.5	69.5	2.27
	15.0	40.5	82.5	68.0	2.31
	27.5	53.5	93.0	78.0	2.36
Average					2.31
Sample 3	14.5	40.0	82.5	67.5	2.42
	14.5	40.0	86.5	71.5	2.42
	26.5	51.5	91.0	77.0	2.27
Average					2.37

APPENDIX II



Gradation curve for the soil samples from dry sieve analysis

APPENDIX III

Computer program in Visual Basic 2005 language from the design of soil nailed wall

```
Public Class Forml

    Private Sub btCalculate_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles btCalculate.Click

        Dim c, fi, root, alpha As Double

        Dim barDia, HS, VS, WH As Double

        Dim TopDist As Double

        Dim Ka, Ko As Double

        Dim angle As Double

        Dim FactorSafety As Double

        FactorSafety = 2

        c = 17.16

        fi = 35

        root =18.325

        alpha = 80

        ‘barDia = 0.016

        HS = 1.5

        VS = 1

        WH = 5

        TopDist = 0.5
```

```
If Me.txt FactorOfSafety.Text = “ “ Then

    Me.txt FactorOfSafety.Text = FactorOfSafety.ToString

End If

If Me.txtC.Text = “ “Then

    Me.txtC.Text = c.ToString

End If

If Me.txtFi.Text = “ “Then

   Me.txtFi.Text =  fi.ToString

End If

If Me.txtRoot.Text = “ “Then

   Me.txtRoot.Text =  root.ToString

End If

If Me.txtAlpha.Text = “ “Then

   Me.txtAlpha.Text =  alpha.ToString

End If

If Me.txtBarDia.Text = “ “Then

   Me.txtBarDia.Text =  barDia.ToString

End If

If Me.txtHS.Text = “ “Then

   Me.txtHS.Text =  HS.ToString

End If
```

```
If Me.txtVS.Text = “ “Then
   Me.txtVS.Text =  VS.ToString
End If
If Me.txtWH.Text = “ “Then
   Me.txtWH.Text =  WH.ToString
End If
If Me.txtTopDist.Text = “ “Then
   Me.txtTopDist.Text =  TopDist.ToString
End If

c = Me.txtC.Text
fi = Me.txtFi.Text
root = Me.txtRoot.Text
alpha = Me.txtAlpha.Text
FactorSafety = Me.txtFactorofSafety.Text
barDia = Me.txtBarDia.Text
barDia = barDia/1000
HS = Me.txtHS.Text
VS = Me.txtVS.Text
WH = Me.txtWH.Text
TopDist = Me.txtTopDist.Text
```

```
          ‘---------------------------------------- Add required rows for Datagrid
          Dim INumber As Integer
          INumber = Iteration Number (TopDist, VS, WH)
          Me.DGFN .Rows.Clear( )
          Dim i As Integer
          For I = 1 To INumber
             Me.DGFN.Rows.Add( )
          Next
          ‘--------------------------------------------------------- Find Ka
          Dim numerator As Double, denominator1 As Double, denominator2 As Double
          angle = ConvertToRadians(alpha – fi )
          numerator = Math.Sin(angle)
          angle = ConvertToRadians(alpha)
          denominator1 = (Math.Sin(angle))
          denominator1 = denominator1 ^ 1.5
          denominator2 = Math.Sin(ConvertToRadians(fi) ) *
(Math.Sin(ConvertToRadians(alpha) ) ) ^ 0.5
          Ka = (numerator/(denominator1+denominator2) ) ^ 2
          Ka = Math.Round(Ka, 4)
          ‘-------------------------------------------Find Ko
          angle = ConvertToRadians(fi)
```

```
Ka = Math.Round (1-Math.Sin (angle), 4 )

‘----------------------------------------Add values in Datagrid

Dim tan_myu as Double, FailureplaneAngle As double

Dim LPrime As Double

Dim hPrime As Double

Dim ha As Double

Dim FN As Double

Dim sumFN As Double

Dim  UltimatePullOutStrength As Double

tan_myu = 0.8 * Math.Tan (ConvertToRadians(fi) )

tan_myu = Math.Round(tan_myu, 4)

FailurePlaneAngle = 90- (alpha+fi)/2

‘Dim FactorOfSafety As Double

Dim PermissibleTensionForce As Double

Dim rr As DataRowView

Dim FNOkay As Boolean = False

Dim Test As Long

rr = Me.SoilDataBindingSourse.Current

‘FactorOfSafety = 2

For I = 0 To INumber -1

   While Not FNOkay
```

```
                              LPrime =  ( (WH – (i* VS+ TopDist) ) *
Math .Tan (ConvertToRadians (FailurePlaneAngle – (90- alpha))) /
(Math .Cos (ConvertToRadians(90- alpha))
                               LPrime = Math.Round( LPrime, 4)
                               hPrime = (i * VS + TopDist) +LPrime  *
(Math .Sin (ConvertToRadians(90- alpha))
                                 hPrime = Math.Round( hPrime, 4)
                                 ha  =(0.75 * WH - LPrime)
                                haPrime = Math.Round( ha, 4)
                                 FN = ha* tan_myu* root*  haPrime* barDia *(2+ ( Math.PI-2 *Ko)
                                 FN = Math.Round( FN, 4)
                                 UltimatePullOutStrength =rr.Item (”ups”)
                                  PermissibleTensionForce =UltimatePullOutStrength/ FactorSafety
                                 If FN >PermissibleTensionForce Then
                                       FNOKay = False
                                       Test =Test +1
                                       Me.SoilDataBindingSourse.MoveNext( )
                                       If Test >Me. SoilDataBindingSourse.Position Then
                                          Me.SoilDataBindingSourse.MoveFirst( )
                                        MsgBox( “No solution after a depth of ”&(i-1)*VS+TopDist &
”m”)
```

```
                        Exit Sub

                  End If

                  rr = Me.SoilDataBindingSourse. Current

                  UltimatePullOutStrength = rr.Item(“ups”)

                  barDia =rr.Item(“barDia”)

                  barDia = barDia/1000

                  Else

                  FNOkay = True

                  End If

            End While

            ‘----------------------------------Check FN Value

            sumFN = sumFN +FN

            Me. DGFN.Rows (i). Cells (1). Value = i* VS + TopDist

            Me. DGFN.Rows (i). Cells (2). Value = LPrime

            Me. DGFN.Rows (i). Cells (3). Value = hPrime

            Me. DGFN.Rows (i). Cells (4). Value = ha

            Me. DGFN.Rows (i). Cells (5). Value = FN

            Me. DGFN.Rows (i). Cells (0). Value =barDian* 1000

            FNOkay= False

Next

Dim DepthLowerNail As Double
```

```
DepthLowerNail = i-1*VS + TopDist

Me. DGFN.Rows (i). Cells (4). Value = “Total ”

Me. DGFN.Rows (i). Cells (5). Value =  sumFN

 ‘Me.1bKa.Text = “Ka=” & Ka

‘Me.1bKo.Text = “Ko =” & Ko

‘Me.1bTanMu.Text =”TanMu= ” & tan_myu

‘Me.1bInclination.Text =”  Failure Plane Angle =” & Failure Plane Angle

Dim CriticalDepth As Double

CriticalDepth = 2 * c / (root Ka ^0.5)

Dim Base As Double

Base = root * Ka – (2 * c* Ka ^ 0.5)

            Dim LateralEarthPressure As Double, LEP_ per _ VerticalRow As Double

            LateralEarthPressure = Base / 2 * (WH - CriticalDepth)

            LEP_per_VerticalRow = LateralEarthPressure *HS

            Dim AdherenceSafetyFactor As Double

             AdherenceSafetyFactor = sumFN / LEP_per_VerticalRow

            If AdherenceSafetyFactor > 1 Then

               ‘ MsgBox (“ The Design is Safe based on Overall Adherence”)

            Else


                 MsgBox (“ The Design is UnSafe with respect to Adherence Safety Factor”)
```

```
            Exit Sub
            End If
            Dim TensionOnNail As Double, Tensile Safety Factor As Double
            TensionOnNail = Ka * root * DepthLowerNail * HS * VS
            Tensile Safety Factor = UltimatePullOutStrength / TensionOnNail
             If Tensile Safety Factor > 1 Then
                 ‘ MsgBox (“ The Design is Safe based on Tension in Soil Nail”)
        Else
                MsgBox (“ The Design is UnSafe with respect to Tensile Safety Factor”)
                Exit Sub
            End If
End Sub
Private Function ConvertToRadians (ByVal angle As double) As Double
            ConvertToRadians = angle * Math.PI/180
End Function
Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As System. EventArgs)
Handles MyBase .Load
            ‘TODO; This line of code loads data into the ‘SoilDataSet.SoilData’ table.You
can move, or remove it, as needed.
            Me.SoilDataTableAdapter.Fill(Me.SoilDataSet.SoilData)
            Me.Text.ToUpper( )
            ‘Me. 1bAlpha. Text = Chr(62)
```

```
            btCalculate_Click(Me, Nothing)

 End Sub

 Private Function Iteration Number (ByVal top As Double, ByVal interval As Double, ByVal WallHeight As Double) As Integer

            Dim effectiveHeight As Double

            effectiveHeight = WallHeight – top

            Iteration Number = Math. Truncate (effectiveHeight / interval) + 1

 End Function

 Private Sub btClose_Click (ByVal sender As System. Object, ByVal e As System. EventArgs) Handles btClose.Click

            Me.Close ( )

 End Sub

 End Class
```

APPENDIX IV

Ultimate bond stress for different soil types

Soil type	Unit ultimate bond stress (kN/m^2)
Clay	40-60
Clayey silt	40-100
Sandy clay	100-200
Very dense silty sand	120-240
Dense silty sand	80-100
Silty sand	50-75
Non-plastic silt	20-30

A STUDY ON SOIL NAILING FOR VARIOUS C-ϕ SOILS IN TAVANUR AREA

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ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfillment of the requirement for the degree of

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In

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Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

Department of Irrigation & Drainage Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR- 679 573, MALAPPURAM,

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ABSTRACT

The soil nailing technique is adopted to reinforce the earth for the stabilization of the slopes. The soil nail wall is constructed by the installation of iron bars or iron nails into the soil which has to be retained. The nails are installed from top to bottom at suitable angle with horizontal and vertical spacing through out the specified height of the slope. We have selected soil samples from three locations in the campus of KCAET, Tavanur. For our study various engineering properties of the soil samples were determined. The soil nail wall design was done by incorporating those engineering properties of soil and the nature of the terrain. An epoxy coated MS rod with diameter above 16mm was used as nail The estimation and costing when compared to cantilever retaining wall reveals that soil nail wall is more feasible than the retaining wall. From the cost analysis we found that, soil nail wall gives 55% saving in cost than retaining wall construction. A computer program was developed in Visual basic 2005 which gives various outputs for the design from the given inputs. It was concluded that the designed soil nail wall system can be strongly recommended for the stabilization of free board of river bank, side slope stabilization of roads, railways, agricultural lands etc.