An experimental and analytical study of slope stability utilizing Flexible facing for Soil nail wall

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Abstract

Soil Nailing is a technique used for retaining earth using the steel elements which are basically used to retain certain excavations and also to stabilize the steep cut slopes.[1] The force acting axially on the reinforcing member is a tensile force or it can be compression in few cases. In the present research work a physical model was prepared and the stress strain behaviour was studied along with the displacement in horizontal and vertical directions. Thereafter FEM analysis was done using the Plaxis 3D software and validation of results was done. On comparison of results, it was found that the soil nails are able to take up the tensile stresses to certain extent and are helpful in stabilizing the slope.[2]. In the present study three different facing material were compared i.e Conventional Facing consisting of wire mesh and shotcrete, Bamboo facing and Jute Gunny bag Facing. As far as experimental results are concerned maximum stresses were taken up by conventional facing. In the present research as the major focus is on finding some alternative material. So as an alternate to this bamboo facing and jute gunny bag facing has been considered for study so from the results of bamboo facing it can be concluded that this facing could serve well in the field conditions when the slope is around 60 to 70 degrees.

***Keywords**: Soil Nail wall, Stress, Displacements, Plaxis 3D, Physical Model*

1. Introduction

The technique of soil nailing is suitable in areas where there is limited overhead clearance. These reinforcing elements are placed in the drilled boreholes and thereafter they are grouted along the whole length. [3]The construction technique of soil nail construction proceeds in top-down fashion as opposite to the construction of mechanically stabilized earth retaining walls. Soil nails are installed at sub horizontal inclination.

The basic mechanism of soil reinforcement relies on tensile force developing in the reinforcement to resist those developing in the soil. The mechanism by which soil nails develop tensile resistance requires some relative moments between the soil and the nails. [4]The magnitude and distribution of movements will depend on the type of structure, type of construction and spacing between the nails.[5]

Soil nails are used to stabilize slopes. As higher height slopes are not stable so due to that we use soil nails those are basically steel bars. These bars take up the stresses and help the slope to stabilize or withstand. [6]Soil nailing is a technique used for retaining earth using the steel elements which are basically used to retain certain excavations and also to stabilize steep cut slopes. The forces acting axially on the reinforcing members is a tensile force or it can be compressive in few cases.

The technique of soil nailing is basically suitable in areas where there is limited overhead clearance. These reinforcing elements are placed in the drilled boreholes and thereafter they are grouted along the whole length. The construction technique of soil nail proceeds in top-down fashion as opposite to the construction of mechanically stabilized earth retaining walls. Soil nails are installed at sub horizontal inclination.[6] Basic mechanism of soil reinforcement relies on tensile force developing in the reinforcement to resist those developing in the soil. The mechanism by which soil nails develop tensile resistance requires some relative moment between the soils and nails. The magnitude and distribution of movements will depend on type of structure, type of construction and spacing between the nails.[7]

Singh V.P and Babu G.L (2009) In order to analyze the performance and stability of soil nail wall the numerical simulation is utilized. In the present research the results of finite element based plain strain simulations of typical soil nail wall indicate that the advanced soil models considered in the study have less influence on overall stability of soil nail wall.[8]

Cheng Yu Hong et al. (2012) A simple soil nail interface model was prepared and analysed for the pull-out behaviour. It was considered only in the passive zone where as shear and bending were not accounted. It was remarked that the pull-out force was dependent on varying factors for purely elastic zone and for elastic- plastic zone. In former, the maximum pull-out force was directly proportional to nail diameter and inversely proportional to the nail length. Whereas, for the latter it was directly proportional to the length of plastic zone, nail diameter and inversely proportional to the nail length.[9].

Jayanandan midhula and Chandrakaran.S (2015) has done the comprehensive study on soil nailed structure using plaxis 2D. In this study the comparison was done for the cut with and without the nailing. Upon the application of load it was observed that there was reduction in the deformation by around 41% and increment in the FOS was increased 1.2 times as compared to slope without nails.[10]

Tao Sun et al., (2017) [11]The research was aimed at using an alternate facing i.e. replacing the rigid reinforced concrete facing with the flexible woven geomembrane facing. The model was used to determine the horizontal and vertical displacements under the loading which proved this alternation was good as it did not exhibit large horizontal as well as vertical deformations and the overall slope was stable. But it also guided that this alternate is only limited to the structures of lesser importance where a bit more displacements are not of a great problem.

Mohammad Abubakar Navved et al., (2019) [12]A case study was done in order to study causes of failure and to evaluate remedial measures on a fort built in 18^{th} century and renovated ever since several times a portion of which collapsed due to failure of retained slope during earthquake. The studies suggested various possible reasons of instability of the slopes, out of which the seepage of water was the main reason along with the earthquake. The best remedial measure suggested was the reconstruction of the wall along with the reconstruction of the damaged slope using the soil nailing technique along with grouting.

Tao-Yang et al., (2020) [11]Using the 3 dimensional rotational failure mechanism, the FOS of soil nailed slopes subjected to seismic forces was evaluated applying the stress reduction method and kinematic approach of limit analysis to replace the traditional evaluation using 2-D limit equilibrium method. The results were compared to validate the results obtained by the proposed approach. The various parameters of the soil nails were studied and both the tensile and pullout failures of soil nail were taken into consideration. This new approach proved to be an efficient design tool to evaluate the FOS of soil reinforced slope and also provides a set of chart to assess the slope safety rapidly.

C. Prakasam, et al., (2020)[13] In the present research work, a case study on the slope stability investigation was done with the help of 2D limit Equilibrium model using Roc Science software. In this case study, the slope along NH-05 near Jhakri, HP, India was considered having soil coarse to fine loamy. The various lab tests were performed such as Atterberg's limit, particle size distribution, and shear tests and various parameters such as c, $\phi$and γ were found to be 10.28 kPa, 18.8° and 14.1 KN/m^3 respectively. The studies suggested the provision of bench slop of 10 m height and 4m width of interval of each subsequent bench and an optimum angle of 70°. Also, the FOS of 1.2 was suggested for reinforced bench slope for stability purpose.

Anant K. Kokane et al., (2020)[14] For the analysis of nail forces, force distribution in vertical and horizontal in nailed vertical cuts subjected to seismic forces, this paper aims at providing novel closed form solutions using a limit equilibrium concept based on pseudo-dynamic approach. It was concluded that the increase in the amplitude of initial vertical base acceleration increases the demand of the tensile force. The bottom most nail had the largest nail force when subjected to seismic forces. The study recommended that for deeper cuts and for greater S-wave frequencies, individual nail optimization is required as the horizontal inertia force governed the nail force demand than the vertical force demand due to horizontal orientation of nails.

Shinde P.B and Gaikwad Arati (2022) utilized soil nailing during development of infrastructure. The project was solved using FEM analysis which address stability of structure along with deformation due to soil nail wall during load transfer in reinforcement.[15]

2. Material and Methodology

The Soil used for the experimentation was collected from Mohali district of Punjab and the testing was done in order to categorize the soil. Various properties of soil are mentioned below in Table no. 1.

Table 1. Properties of soil

Properties	Values
Water Content (%)	11
Specific Gravity	2.56
Optimum moisture content (OMC) (%)	7.3
Maximum dry density (MDD) (g/cc)	1.98

Coefficient of Uniformity	5.6
Coefficient of Curvature	0.64
Unconfined Compressive Strength (Kg/cm^2)	0.118

From the above results the soil was categorized as poorly graded sand.

The soil was filled in the physical model which was constructed using Perspex sheet. The dimensions of the model were taken 60cm, 50cm, and 40 cm i.e length, height, and breadth respectively. Nails used for experimentation were made of HYSD steel having length of 31.5 cm (0.7H Height of Soil Nail wall). Flex sensors were placed on the steel bars in order to measure the strain in nails on the applications of load. The experiment on the physical model were performed by considering the slope angle of 60 degree. Six nails were considered in the rectangular arrangement for studying the stress- strain behaviour of soil along with the vertical and horizontal displacements along with the nail arrangement in the rectangular pattern. The Horizontal and vertical spacing was kept as 11.25 cm respectively. On application of load the stress was calculated by considering the load value from the bottle jack and the area is calculated by considering the top surface on which the load is applied. The sensors were attached to the digital multimeter and the stain was calculated by using the following formula.

$$Strain = \frac{\Delta R/_R}{\sum_c}$$

Here $\sum_c$ stands for gauge factor, its value lies between 2 to 2.5 and for 200 KΩ, the value of gauge factor is 2.1.

Testing was performed on the soil nail physical model. the testing includes measurement of stress – strain in the nails. The tests were carried out in cohesionless soil. Basic mechanism of soil nailing is that reinforcement resist the tensile forces developed in the soil. The soil and nails require relative movements for development of tensile resistance. So, it is considered to be passive system. With the increase in population the roadway construction is being expanded. This construction work becomes complex during the construction in hilly areas, ghat sections etc.

In the present research the focus is on addressing the problem of stability of structure along with deformation due to nailing in the wall when the force transfers in the reinforcement. Soil nailing basically consider passive reinforcement commonly. Tensile stress will be applied on nails in the response investigation of the deformation of retained material during the process.

The experimental model setup is given as below fig 1 (a) which shows the arrangement of six nails in the rectangular pattern which is a commonly used pattern. The spacing between the nails i.e horizontal and vertical is kept constant (fig 1(b)). Thereafter the facing was applied at the front face of the model and on the application of load the strain was studied in different nails.

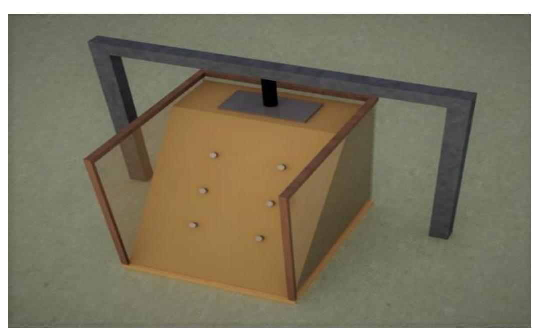


Figure 1(a) Physical model Setup

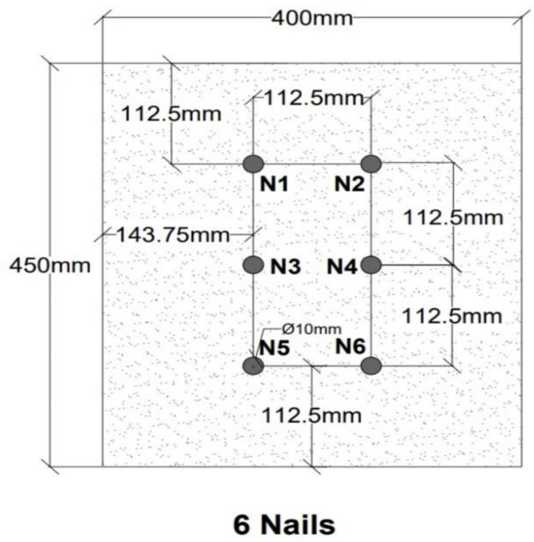


Figure 1(b) Nail arrangement

3. Results of physical model

As mentioned earlier the testing on physical model was done by considering three different types of facing materials i.e conventional facing, bamboo facing and jute gunny bag facing. Upon application of load the strain was checked in the nails and the results are mentioned below. The results are discussed in the tabular form in table No. 2,3, and 4 for conventional facing, Bamboo Facing Material and Jute Gunny Bag Facing.

Table No 2. Stress Strain reading while using Conventional facing.

Stress (N/mm^2)	Strain in nail 1	Strain in nail 2	Strain in nail 3	Strain in nail 4	Strain in nail 5	Strain in nail 6
0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.980	0.020	0.004	0.006	0.026	0.035	0.002
1.960	0.024	0.006	0.008	0.001	0.017	0.002
2.940	0.036	0.047	0.025	0.013	0.067	0.014
3.920	0.036	0.073	0.039	0.015	0.143	0.032
4.900	0.046	0.076	0.080	0.046	0.149	0.082
5.880	0.089	0.076	0.082	0.046	0.162	0.082
6.860	0.112	0.079	0.102	0.046	0.175	0.082
7.840	0.167	0.084	0.126	0.083	0.200	0.095
8.820	0.171	0.081	0.123	0.085	0.208	0.108
9.800	0.180	0.108	0.131	0.099	0.212	0.163
10.780	0.204	0.130	0.131	0.104	0.231	0.169

Table no 3. Stress strain readings using Bamboo material facing.

Stress (N/mm^2)	Strain in nail 1	Strain in nail 2	Strain in nail 3	Strain in nail 4	Strain in nail 5	Strain in nail 6

0	0	0	0	0	0	0
0.98	0.049	0.103	0.024	0.002	0.017	0.021
1.96	0.069	0.123	0.015	0.009	0.033	0.06
2.94	0.069	0.12	0.055	0.061	0.057	0.096
3.92	0.097	0.186	0.074	0.067	0.071	0.118
4.9	0.125	0.189	0.158	0.106	0.126	0.148
5.88	0.179	0.263	0.22	0.2	0.212	0.201
6.86	0.247	0.306	0.305	0.241	0.284	0.271
7.84	0.293	0.378	0.334	0.282	0.284	0.316
8.82	0.383	0.511	0.487	0.334	0.327	0.363
9.41	0.449	0.511	0.501	0.388	0.382	0.414

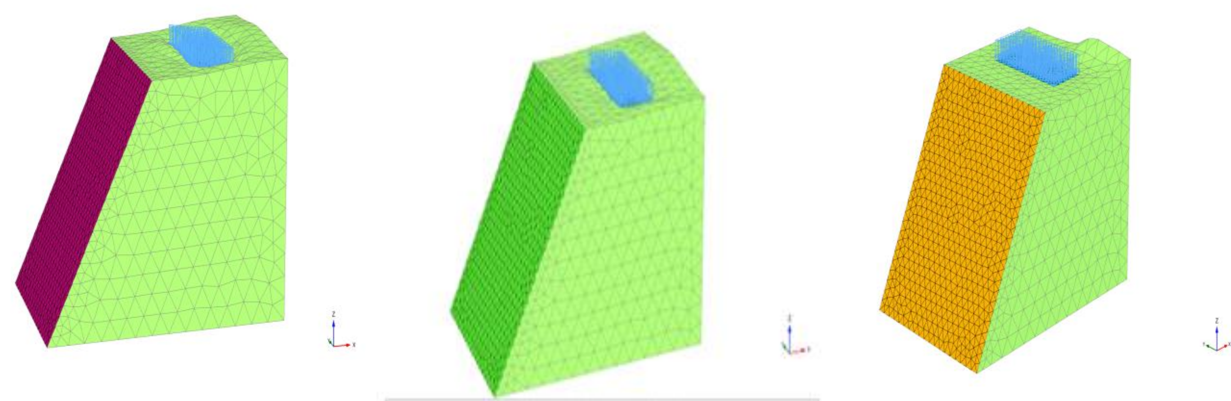
Table no 4. Stress strain reading using Jute Gunny Bag facing.

Stress (N/mm^2)	Strain in nail 1	Strain in nail 2	Strain in nail 3	Strain in nail 4	Strain in nail 5	Strain in nail 6
0	0	0	0	0	0	0
0	0.048	0.13	0.019	0.026	0.055	0.098
0.98	0.088	0.148	0.033	0.062	0.103	0.161
1.96	0.091	0.151	0.057	0.089	0.129	0.184
2.94	0.116	0.2	0.083	0.123	0.166	0.224
3.92	0.182	0.244	0.138	0.186	0.199	0.198
4.9	0.243	0.284	0.174	0.22	0.353	0.224
5.88	0.337	0.385	0.205	0.224	0.353	0.194
6.86	0.391	0.527	0.294	0.378	0.733	0.366
7.64	0.682	0.646	0.313	0.372	0.853	0.419

From the results mentioned above in table no 2,3 and 4 it can be inferred that the maximum stresses have been taken by the conventional facing as compared with the other two. The results shows that the bamboo facing is also able to take up 9.41N/mm^2 of stress before its failure. In order to find out the alternative facing bamboo facing can be used as it has taken up reasonable amount of stress as compared to the conventional facing. The reason behind the same can be as bamboo material having high stiffness and there is increase in shear resistance along the potential slip surface in frictional soil. The maximum strains are obtained in upper set of nails i.e Nail 1 and Nail 2

4. Numerical Modelling

After performing the testing on the physical model, the FEM analysis was performed for the validation of the results using the Plaxis 3D software. In order to analyse the first step to be followed is to define geometry of parts. Thereafter the creation of material definitions is done and in the next step assigning of material properties to the section and section to parts is done. The next step consists of specifying element types and mesh parts, assemble parts into model and create analysis steps. Apply the boundary conditions, loads, constraints and interaction. Thereafter the analysis is submitted and post processing analysis is done thereafter. As discussed, all the materials were analyzed and the deformations were studied. The results of numerical modelling are presented below:

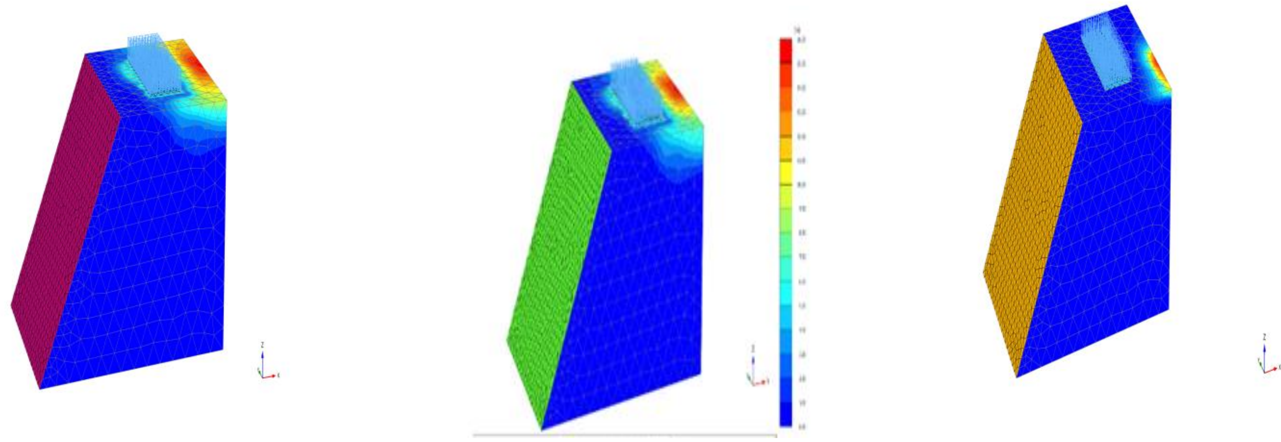


(a) (b) (c)

Fig No.2 Deformed Shape (a) Conventional Facing (b) Bamboo Facing (c) Jute gunny bag facing

In the above figure no 2. The deformed shapes are shown for various facing materials for the soil nail wall by using Plaxis 3D. on the application of the load the deformations are developed in the model and the nails starts taking up the load which further transfer the load to the nails below. When the nails have taken up the maximum load and not able to transfer further then the failure is observed for the slope.

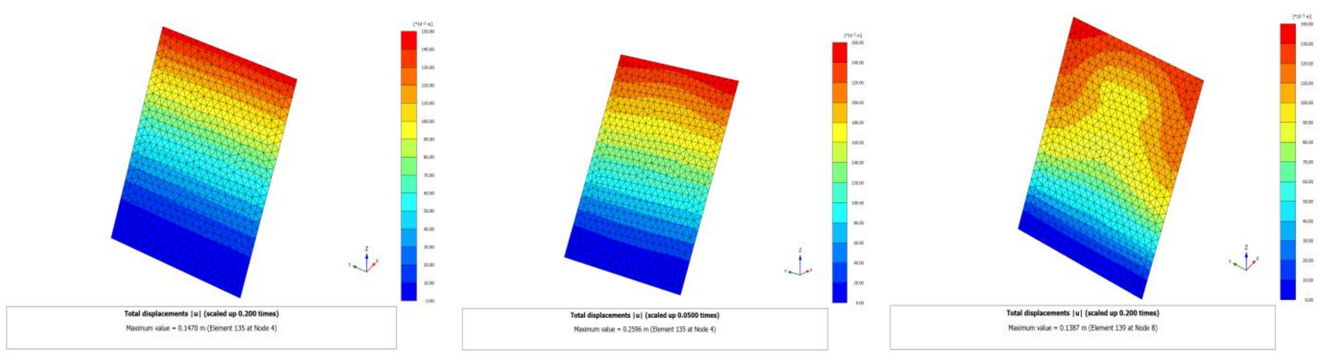
As depicted in Figure no.3 below Total displacement is being compared for three types of facing material for soil nail wall. As the conventional facing is able to take up higher stresses so the displacement is less in this case and vice versa for jute gunny bag.



(a) (b) (c)

Fig No.3 Total Displacement shading (a) Conventional Facing (b) Bamboo Facing (c) Jute gunny bag facing

Facing displacement is being compared for three types of facing material for soil nail wall. It is depicted in the figure no.4 below that maximum facing displacement at the upper ends in visible in the case of jute gunny bag facing and minimum for the conventional facing. Maximum stresses are taken up by the upper set of nails due to which maximum strains were also visible in the same set as per experimental results.



(a) (b) (c)

Figure no 4 Facing Displacement (a) Conventional Facing (b) Bamboo Facing (c) Jute gunny bag facing

5. Conclusions:

1. From the physical model results it can be concluded that soil nails are able to take up the tensile stresses and able to stabilize the wall.
2. On comparing the experimental and analytical results it can be concluded that the stresses are considerably reduced due to the application of flexible facing as compared to the conventional facing.
3. As Soil nails are able to stabilize the slopes so therefore this technique could be used to prevent landslides as well.
4. As per the results from the present study bamboo facing can be used for the soil nail wall as bamboo is able to take up stresses comparable with conventional facing.

6. References

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