Model Testing of Reinforced Soil Slope with Flexible Facing

Pravesh Kumar Sharma, Amanpreet Tangri, Shalika Mehta

Abstract*: Soil nailing is a cost-effective way to reinforce soil, including inserting a threaded rod into a naturally unstable slope to increase overall stability or to enter the cutting ramp during top-down excavation. Retained soil, resistant reinforcements and exterior facing are the main elements of the soil nail formation. Their composite interaction is used to measure the efficiency of the soil nail structure in terms of deformation and strength. Even though international regulations deal with the possibility of using rigid or flexible exterior facing, the effects of stiffness are not adequately studied and estimated. Therefore, the aim of this paper is to test the strength of different materials such as HDPE hexagonal slope protection geonet, strata base biaxial polypropylene geonet, HDPE drainage geonet, expanded metal mesh utilized for flexible facing. The experiments are carried out with four nails positioned in horizontal as well as in vertical position in the soil model prepared in Chandigarh University Campus. From the experiment, it is observed that the expanded metal mesh material performs well among other material with maximum stress of 80 Kg/cm^2. Also, a comparison of maximum stress between flexible facing (with & without facing) and flexible facing with rigid facing is performed. It is being analyzed that the rigid facing has tolerated maximum stress about 98 Kg/cm^2 compared to soil slope with flexible facing and soil slope without facing.

Index Terms*: Soil nailing, physical model, pressure dial gauge, steel bar, flex sensor, digital multi-meter, electric switch, pressure hydraulic jack (bottle jack)

I. INTRODUCTION

The soil is a material composed of organic and inorganic materials found on the surface of the earth, which varies with its structure and composition. Soil nailing is a cost-effective reinforcement mechanism, which is used as a remedy in unstable natural slopes or as a retraining structure for excavation slopes [1]. The soil nailing is used to strengthening the soil by installing nails on its slope surface, whether it is natural soil or existing fill. The soil nails are made of metal or polymeric material and can be: installed in a pre-drilled hole and then grouted, drilled and integrated both (grouted and drilled) technique or either inserted using a displacement method. The most common soil nails are mounted at a sub-level angle [2]. Compared with other retaining structures, soil nailing allows for reduction of excavated soil volume; minimize the utilization of building materials and Implementation time [3]. The soil nailing first application was the Couterre project in France and Germany presented by Plumelle et al.[4] in the year 1990 and by Stocker in 1976 respectively[5]. Even though numerous researchers have been carried out their studies in this field and there are several national norms or guidelines have been existing, which plays an essential role in controlling deformation. But, the overall stability of the excavation leading edge or slope is not fully understood yet.

The nails used in the soil nailing process are typically steel or polymer fiber (FRP) elements that resist tensile, shear as well as bending forces. The facing is the final element of the work in a soil nailing technique and it is produced not only in function of the spacing of the nails, but it depends also on the type of the structure, temporary or permanent [6].

On this issue, the Code (IS2720-1983) is used to determine the index properties and compaction features of soil.

The soil facing can be categorized into three types namely hard facing, flexible faxing and soft facing [7].

- Hard surface, must perform stable functions so that the slope between the nail and the shell should maintain dimension as well as the greatest expected instability
- Flexible facing is used to provide the necessary constraints to the slope region between the bearing plates and Erosion control. In this research, we are using flexible facing, with different ideal conditions:
- Residual soil, weathered rock with no unfavorable orientation.
- Dense sand and gravel with adequate cohesion.
- The soil above the water table.
- Soil nailing has proven to be very cost effective for shoring for temporary excavation and stabilizing unstable slopes [8].

Soil nailing find application in numerous fields such as mitigating landslide, retaining structure, slope stability, roadway cuts, and tunnel portals and so on.

The utilization of a flexible facing system allows an engineer to construct green slopes. Also, the utilization of soft facing system contributes to providing erosion free vegetation. Soil nailing offers a number of advantages that help extensive use of this technique in numerous countries (Abramson et al 1995) [9]:

- Economy: As a result of the economic assessment of several projects the soil nailing scheme find to be cost-effective compared to the existing tieback wall.
- The rate of construction: When drilling rigs are put into operation, one can achieve a higher construction speed.

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Pravesh Kumar Sharma, Civil Engineering Department, Chandigarh University, Gharuan Mohali, India.

Amanpreet Tangri, Civil Engineering Department, Chandigarh University, Gharuan Mohali, India.

Shalika Mehta, Civil Engineering Department, Chandigarh University, Gharuan Mohali, India.

• Performance: During the earthquake, soil nailed slope performed well [10].

Soil nailing also has some limitations. The main constraint for a flexible facing system is to attain a steeper tendency because stability and erosion control cannot be guaranteed as it is to finding a rigid system. Therefore, the use of flexible facing is not recommended where significant relocations are likely to develop [11].

To improve the understanding of the role of facing on the resistant method of soil nailing, this document presents the results of an experiment conducted on a small scale physical model made up of sandy silty soil slope unbreakable with soil nailing and carried to fall down by surcharge loading. Before designing the physical model, Index properties of soil are determined as described in the subsequent section [12].

A. *Index properties of soil*

Initially, the soil is collected from Chandigarh university campus and then the index properties are tested on the basis of code (IS2720-1983). The properties such as moisture content, specific gravity, sieve size analysis, consistency limit, unconfined compression test, standard proctor test have been analyzed [13]. The values are listed in table 1.

Table 1. Index Properties of Soil

Properties	Values
Water Content (%)	11
Specific Gravity	2.56
Liquid Limit (%)	17.59
Plastic Limit (%)	10
Plasticity Index	7.59
Optimum moisture content (OMC)(%)	7.3
Maximum dry density(MDD) (g/cc)	1.98
Unconfined Compressive Strength(Kg/cm^2)	0.118

II. PHYSICAL MODEL

The model is designed having length, width and height of (60cm ×40cm ×50 cm) with a slope angle of 60° as depicted in figure 1.

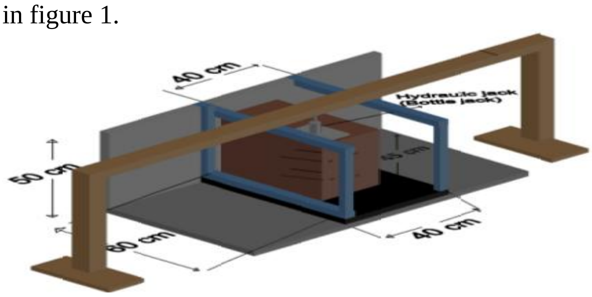

Fig. 1 Physical Model

The model is designed as per the code-US –FHWA-NHI-14-007-FHWA-GEC 007 February 2015. The soil is well graded collected from “Chandigarh University” campus. The soil has different features such as Average particle diameter of D_{30}=0.19mm with non-uniformity coefficient of C_{non} =5.6, Curvature coefficient C_c=0.64, therefore, $C_{non}=D_{60}/D_{10}$ =5.6, where, D_{60}=0.56 and D_{10}= 0.1 respectively.

The deposition of soil is stopped temporarily and the nails of length 45 cm are installed 2 in horizontal direction and 2 in the vertical direction with a horizontal and vertical spacing of 13.3 cm, 15 cm (centre to centre) respectively. As per the code (US –FHWA-NHI-14-007-FHWA- GEC 007 February 2015, the nail length can be varied from 0.7H to H. here H= 45cm [15]. Perspex sheet (acrylic sheet) of thickness 8mm is used. The components used in the physical model are described below.

Pressure hydraulic jack (bottle jack)

Pressure hydraulic jack of bottle jack having weight 5 ton is used and placed in between the Perspex sheet. It is used to lift heavy loads and works on the principle of screw action [14].

Pressure dial gauge

It is mainly utilized to damp the vibration and pressure spikes. As it is filled with fluid therefore, it also works as a lubricant and guards the gauge. As it is sealed properly, therefore, helps to work effectively in a corrosion environment.

Steel Bar

A steel bar of diameter 10mm and length of 45cm is used in this research work.

Flex sensor

The flexible sensor is just like a variable resistor. As the nails bend, the resistance of the flexible sensor increases. Sensors like this are used in Nintendo Power Glove. Four sensors are installed inside the nails and extended to interconnect with the four copper wires to the main electric board [16]. A multi-meter is attached to the switch to measure the resistance sensed by flex sensor and then strain is calculated by using the formula written below:

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

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.

Miscellaneous components

The other components such as copper wire (1mm), bearing plate and hexagonal washer with digital multimeter and switch are used [17].

III. MATERIALS AND METHODS

In this research work High Density Polyethylene (HDPE) geonets are used. HDPE geonet has high pressure bearing ability, anti-uv and aging resistance, strong tensile strength, flexibility and consistently reliable, ability to control soil erosion, easily installation, cost effective, long service life.
Applications:- slopes, dams, railways, highways, railways.

For the execution of the work mainly four materials having 100 % covering ration are used as listed in the table below:

Table 2. Material Used

Type of Material	Thickness (mm)
HDPE hexagonal slope protection geonet	5

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Strata base biaxial polypropylene geonet	6
HDPE Drainage geonet	7.5
Expanded metal mesh	6

HDPE hexagonal slope protection geonet material of thickness 5mm is used for slope protection system geonet core consists of thick vertical ribs and distinct ribs at the top and bottom. It can also play a role in isolation and basic reinforcement. The values of stress and strain observed by using this material are listed in table 3. The value of strain is calculated by connecting digital multimeter with the sensors that are fixed inside the nails. Also, an electric board is attached to four different copper wires. This switch comprises of four On/Off switches, each connected with four different nails such as switch 1 is connected to nail-1, and switch 2 is connected to nail 2 and so on. In this way, the strain is calculated by switching ON the switch regarding a particular nail, while remaining others switches off.

Table 3. Observation using HDPE hexagonal slope protection geonet of 5mm

	Strain			
Stress (Kg/cm^2)	Nail-1	Nail-2	Nail-3	Nail-4
5	0.045	0.052	0.031	0.056
10	0.076	0.056	0.066	0.113
15	0.138	0.119	0.135	0.121
20	0.215	0.182	0.205	0.181
50	0.284	0.256	0.280	0.210

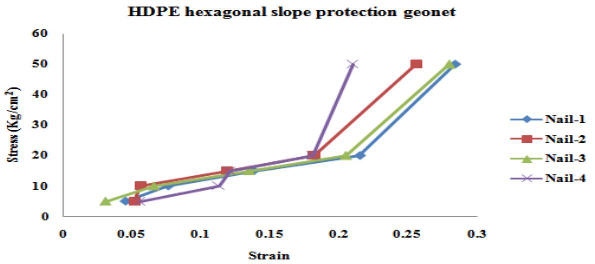

Fig. 3 Stress vs. Strain of HDPE hexagonal slope protection geonet of 5mm

Fig. 3 represents the graphical representation of Stress versus strain measured for four different nails that are grouted under the soil. X-axis and y-axis represent the Stress or load (Kg/cm^2) and strain respectively. From the figure, it is clear that HDPE hexagonal slope protection geonet of 5mm can tolerate 50 Kg/cm^2 of the load with a maximum strain of 0.284.

Table 4 Observation using Strata base biaxial polypropylene geonet of 6mm

	Strain			
Stress(Kg/cm^2)	Nail-1	Nail-2	Nail-3	Nail-4
5	0.021	0.028	0.020	0.034
10	0.072	0.071	0.057	0.071
15	0.097	0.109	0.161	0.173
20	0.308	0.219	0.430	0.351
55	0.427	0.358	0.665	0.499

Strata base biaxial polypropylene geonet material is prepared by using extruded polypropylene with excellent stiffness, structural reinforcement, and high stability features. It reduces the lateral expansion of the substrate, thereby improving structural performance and also decreasing aggregate thickness. The values of stress and strained measured with this material is listed in table 4.

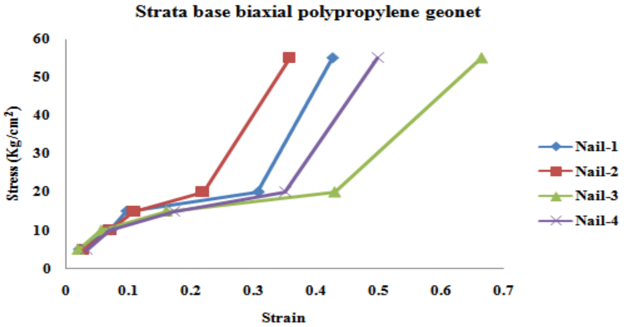

Fig. 4 Stress vs. Strain for Strata base biaxial polypropylene geonet.

The figure above represents the pictorial representation of measured parameters. From the figure, it is clear that load up to 55 Kg/cm^2 is bear by the Strata base biaxial polypropylene geonet with a maximum strain of 0.665 at nail-3.

Table 5. Observation using HDPE Drainage Geonet 7.5mm

	Strain			
Stress (Kg/cm^2)	Nail-1	Nail-2	Nail-3	Nail-4
5	0.361	0.285	0.328	0.116
10	0.379	0.468	0.362	0.162
15	0.458	0.522	0.432	0.225
20	0.488	0.704	0.515	0.298
60	0.695	0.798	0.615	0.328

The 3rd material used in the proposed work is HDPE Drainage Geonet. This material utilized the HDPE Bi-planer property and can find application in Slope protection, maintain stable drainage for a long time, can withstand a high compressive load, susceptible to corrosion resistance, long service life, and convenient construction, shorten construction period and reduce costs with slope stabilization and soil erosion control. The values of strain measured with respect to stress are listed in table 5, whereas the graphical representation is depicted in figure 5.

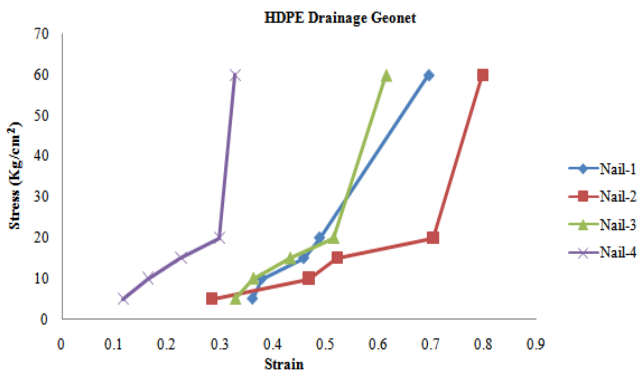

Figure 5 Stress vs. Strain for HDPE Drainage Geonet.

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The stress and strain measured by devices named as pressure hydraulic jack (bottle jack) and multimeter is shown in figure 5. As the stress is applied by pressure hydraulic jack (bottle jack) increased from 5 to 20 Kg/cm^2 the soil remains stable. As the stress level increases up to 60 Kg/cm^2, deep cracks appeared in the proposed soil model. Thus, it is concluded that the flexible material HDPE Drainage geonet of 7.5mm can work effectively up to 60 Kg/cm^2.

Table 6. Observation using expanded metal mesh of 6 mm

	Strain			
Stress(Kg/cm^2)	Nail-1	Nail-2	Nail-3	Nail-4
5	0.047	0.135	0.662	1.047
10	0.088	0.198	0.725	1.092
15	0.125	0.238	0.748	1.178
20	0.162	0.310	0.810	1.258
80	0.225	0.365	0.858	1.342

The expanded metal mesh is a sheet of metal that is cut and stretched to form a regular pattern of metal mesh material (usually a diamond shape). It is usually used for fences, as well as metal slats that support stucco/plaster. This material is stronger compared to equivalent wire mesh weight because the material is flat, allowing the metal to remain intact. Another benefit of expanding metal mesh is that the metal is never completely cut and reconnected, allowing the material to maintain its strength.These products are known for their low cost, rust resistance, precise composition, long life, easy maintenance, durability, fine surface, high quality, precise size, wear and corrosion resistance, no do pants, custom sizes, and high special features and so on. These products come from reliable suppliers in the industry and are offered at relatively low prices, taking into account the financial constraints of the customers. The values of stress and strain observed by this material are listed in table 6.

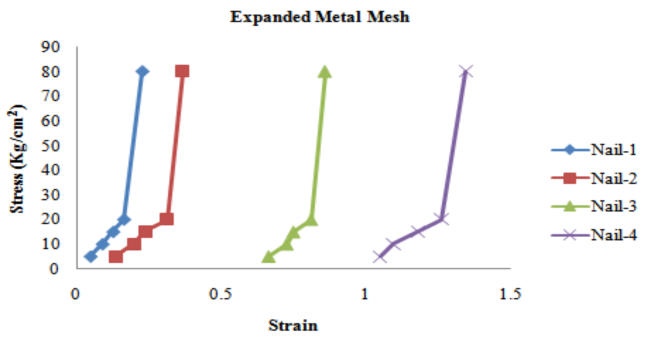

Fig. 6 Stress vs. Strain for Expanded Metal Mesh

Fig. 6 represents the graph between stress and strain observed while using expanded metal mesh as a flexible material. From the graph, it is observed that the stress tolerated by expanded metal mesh material in the designed model is about 80 Kg/cm^2 with a maximum strain of 1.342 observed by nail-4.

IV. COMPARISON BETWEEN NATURAL REINFORCED SOIL SLOPE WITHOUT FACING, RIGID FACING AND FLEXIBLE FACING.

In this section, the stress measured with rigid facing and natural soil slope without facing is discussed. Also, the comparison among maximum stress tolerated by different materials as discussed above is represented in tabular form as well as in graphical form.

Table7. Natural soil slope without facing

	Strain			
Stress (Kg/cm^2)	Nail-1	Nail-2	Nail-3	Nail-4
5	0.400	0.165	0.689	0.445
10	0.435	0.182	0.898	0.637
15	0.512	0.186	0.952	0.667
20	0.520	0.730	1.057	0.667
25	0.574	0.754	1.073	0.677

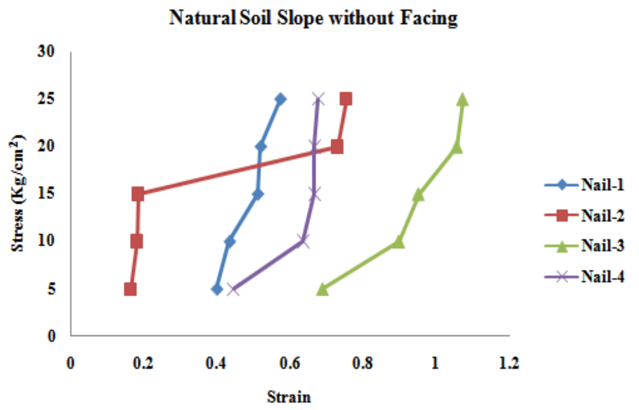

Fig.7 Stress vs. Strain natural soil slope without facing

Fig.7, demonstrated the graph plotted for the values of stress vs. strain measured for four nails named as Nail-1, nail-2, nail-3 and nail-4 respectively used for without facing of soil slope failure at an angle of 60°. For without facing, maximum stress that can be tolerated by the soil is about 25 Kg/cm^2.

Table 8. Rigid Facing Slope

	Strain			
Stress (Kg/cm^2)	Nail-1	Nail-2	Nail-3	Nail-4
5	0.148	0.162	0.316	0.223
10	0.199	0.258	0.368	0.262
15	0.238	0.348	0.421	0.321
20	0.268	0.416	0.468	0.358
98	0.310	1.462	0.528	0.415

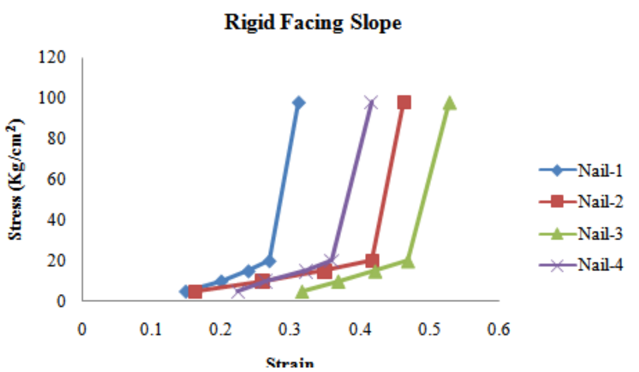

Fig. 8 Stress vs. strain with Rigid Facing

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Fig.8, exemplify the graph plotted for the values of stress vs. strain calculated for four nails that are installed in the designed physical model in which rigid facing is used. For rigid facing, maximum stress that can be tolerated by the soil is about 98 Kg/cm^2.

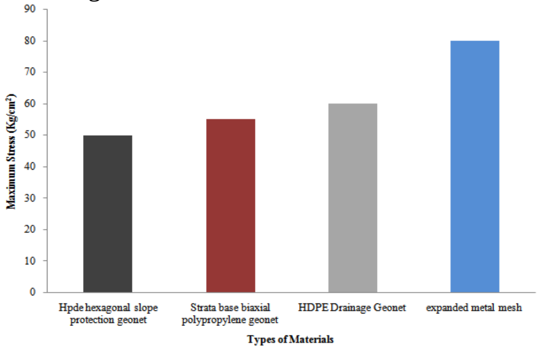

Fig. 9 Comparison of Stress for different types of materials

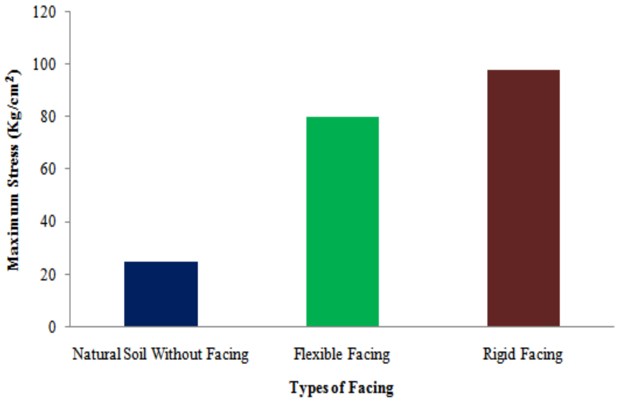

Figure 10 Comparison of Stress for different types of facing.

Figure 9 represents the evaluation of maximum stress observed for four different types of material used during the testing of soil nailing for flexible facing. From the figure, it is experienced that the expanded metal mesh performs well compared to the other three materials with maximum stress of 80 Kg/cm^2.

Figure 10 illustrated the maximum stress tolerated by different types of Facing used in soil nailing process. The blue, the green and the red color bar represent the maximum stress observed during the experiment. Form the figure it is clear that rigid facing has tolerated maximum stress about 98 Kg/cm^2 compared to flexible facing with and without facing.

V. CONCLUSION

Soil nails can be used to stabilize or strengthen the unstable natural slopes or as a construction technique that allows the safe over-steepening of new or existing soil slopes. To analyze the strength of the designed physical model stress with various values has been applied by utilizing Pressure hydraulic jack (bottle jack). It can be seen from the experimental results discussed above that natural soil slope without facing, flexible facing and rigid facing affect the performance of the soil nailing structure during excavation. The rigid facing bears maximum stress up to 98 Kg/cm^2 with a maximum strain of 0.528. Also, form the different material used in the designed physical model, it is determined that expanded metal mesh performs well compared to the other three materials with maximum stress of 80 Kg/cm^2. Also, the materials used in the research are economic friendly with green environmental effect.

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AUTHORS PROFILE

Pravesh Kumar Sharma is currently doing M.E in Civil Engineering, specialization of Construction Technology and Management at Chandigarh University, Gharuan, Mohali, India. He received his B.tech degree in Civil Engineering from Aman bhalla college of engineering and technology, kotli, Pathankot, under Punjab Technical University.

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Er. Amanpreet Tangri is currently Assistant Professor in Civil Engineering Department at Chandigarh University, Gharuan, Mohali, India. He received his B.tech degree in Civil Engineering and M.tech degree in Geotechnical Engineering.

Shalika Mehta is currently Assistant Professor in Civil Engineering Department at Chandigarh University, Gharuan, Mohali, India. He received his B.tech degree in Civil Engineering and M.tech in Civil Engineering.