INVESTIGATION ON EFFECTS OF SOIL SLOPE ON THE FAILURE MECHANISM OF SOIL NAILED STRUCTURES

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Abstract:In this modern era, improvement of ground is necessary for every projects. Various ground improvement techniques have been developed over the past few years. Increasing the load carrying capacity by inserting steel bars generally termed as soil nails was one of the techniques. In this study, hollow aluminium tubes were used as soil nails for improving the ground performance. Further these tests are compared with normal unreinforced soil. Parameters considered for the study are nail inclination and soil slope. Three nail inclinations were considered for the study i.e. 0^0,15^0& 30^0 with horizontal and two soil slopes i.e. 45^0 and 60^0 and by considering the parameters such as soil material, nail material, slope height, nail length and nail pattern as constant parameters. Model tests were performed for soil slope with different conditions of nail inclination. Obtained results were compared with the conventional unreinforced soil slope for each case and curves for load vs. settlement were developed for the same. From experimental results, Soil slope with 0^0 nail inclination with horizontal gives the maximum load carrying capacity in all cases, followed by 15^0 nail inclination with horizontal and then 30^0 nail inclination with horizontal.

Keywords–**Soil nail, Reinforced, Unreinforced, Backfill.**

1.INTRODUCTION

1.1 GENERAL:

Soil nailing is a relatively new versatile construction technique to retain, rehabilitate and stabilise natural and man-made earth structures. After its initial development in Europe, the method has been adopted in many countries and routinely used in many construction projects where stabilisation of slopes and excavations are required. The conventional process of soil nailing simply comprises inserting reinforcing inclusions to passively strengthen soils. The inclusion of nail is typically in the form of reinforcement steel bar that is placed at an angle below horizontal in a drilled borehole and subsequently encased in cement grout. From a design perspective, the ultimate pull-out capacity of a nail is of prime practical importance. It is only determined by field pull-out tests and, hence, the average mobilised friction strength is evaluated over the entire length of the soil nail and is taken as the design value. It is well reported that this value is highly dependent on the complex internal friction mechanism developed at the soil-nail interface. This interface shear behaviour is somewhat well known for the conventional grouted nails and can be estimated with a certain degree of accuracy. However, for more complicated nail shapes, very little is known about this mechanism that generates the pull-out resistance force.

1.2 CONCEPT OF SOIL NAILING:

The function of soil nailing is to strengthen or stabilize the existing steep slopes and excavations as construction proceeds from the top to bottom. Soil nails develops their reinforcing action through soil-nail interaction due to the ground deformation which results in development of tensile forces in soil nail. The major part of resistances comes from development of axial force which is basically a tension force. Conventionally, shear and bending have been assumed to provide little contribution in providing resistance (Dey, 2015). The effect of soil nailing is to improve the stability of slope or excavation through

By Increasing the normal force on shear plane and hence increase the shear resistance along slip plane in friction soil.

By Reducing the driving force along slip plane both in friction and cohesive soil.

In soil nailing, the reinforcement is installed horizontally or gently inclined parallel to the direction of tensile strain so that it develops maximum tensile force develops. Soil nails are passive inclusions, which improve shearing resistance of soil. The soil nail system can be divided into active and passive region as shown in Figure. During the slope failure, active region tends to deform which results in axial displacement along soil nails which are placed across the slip plane. This results in the development of tensile forces in soil nail in the passive zone which resists the deformation of active zone. This tension force results in increment of the normal force coming on slip plane and reduces the driving shear force. The soil nails are embedded in passive region through which it resists the pull-out of nail from slope through friction between nails and soil. Based on the above two mechanisms, the required amount of nail length should be placed in resistive zone. In addition, the combined effect of nail head strength and tension force generated in active zone must be adequate to provide the required nail tension at the slip surface (Byrne et al. 1998).

1.3 ADVANTAGES OF GABIONS:

- Soil nail walls require smaller rows than most other competing systems. This is also true for ground anchors as soil nails are typically shorter.
- Soil nail walls are less disruptive to traffic and cause less environmental impact compared to other construction techniques such as drilled shafts or soldier pile walls, which require relatively large equipment.
- The installation of soil nail walls is relatively fast.
- Soil nail wall installation is not as restricted by overhead limitation as in the case of soldier pile installation. This advantage is particularly important when construction occurs under a bridge.
- Soil nailing may be more cost-effective at sites with remote access because the smaller equipment is more readily mobilized.
- Soil nails are installed using equipment that is multipurpose and can be used for other substructure elements such as underpinning or protection of adjacent, movement-sensitive structures.
- Soil nail walls are relatively flexible and can accommodate comparatively large total and differential movements.
- The measured deflections of soil nail walls are usually within tolerable limits in roadway projects when the construction is properly controlled.
- Soil nail walls have performed well during seismic events.
- Soil nail walls have more redundancy than anchored walls because the number of reinforcing elements per unit area of wall is larger than for anchored walls.
- Conventional soil nail walls tend to be more economical than conventional concrete gravity walls taller than approximately 12 to 15 ft.
- Soil nail walls are typically equivalent in cost or more costeffective than ground anchor walls when conventional soil nailing construction procedures are used.

1.4 OBJECTIVES OF WORK:

Our main work in this project is

- To find out load carrying capacity of both unreinforced soils and soil nailed soils.
- To examine type of failures for both unreinforced and soil nailed soils.
- To find out optimum angle for slopes 45° and 60° based on load carrying capacity.
- To examine the influence of slope on load carrying capacity.
- To examine the bending of nails.

2. LITERATURE REVIEW

S. Rawat & A. K. Gupta,“An Experimental and Analytical Study of Slope Stability by Soil Nailing”. Electronic Journal of Government and Economics,2016 (21.17), pp 5577-5597, had showed that the failure pattern and load- settlement plots for the soil slopes of 45° and 60° are reinforced with the nails at three different nail inclinations of 0°, 15° and 30° by model testing. The unreinforced and reinforced slopes are also analysed by using a Finite Element package PLAXIS 3D (Brinkgreve 2001). The results obtained from the model testing are validated by the analytical results from Finite Element Method. It is found that soil slope of 45° with nail inclination of 0° shows the maximum increase in load bearing.

A.karthikeyan, Santhosh kumar sahu&S.Amuthan,“A case study on soil nailed retaining wall in hilly area” Indian Geotechnical Conference 2017,GeoNEST 2017; deals with a case study for Hotel project at Kodaikanal, Tamil Nadu and given details in comparison of conventional and soil nailed retaining wall and also design and construction details to the particular site conditions, pull out test were also done to confirm the designed nail capacity and concluded that soil nailed wall was economical than the conventional retaining wall by performing cost analysis.

Surendra Singh &Dr.A.A.Shrivasthava,“Effect of soil nailing on stability of slopes” international journal for research in Applied Science and Engineering Technology,2017 ISSN:2321-9653, had showed the failure pattern, load vs settlement plots and variation of strain in nails during loading for three different inclinations of 0°, 15° and 30°with horizontal and with horizontal and vertical spacing of 0.1m to a slope angle of 60° with horizontal and the nails are installed in square, diamond and in staggered arrangements. They also calculated the factor of safety for both unreinforced and reinforced slopes by Culmann's method & by the data from a report on soil nailing for stabilization of steep slopes near railway tracks submitted to RDSO respectively.

The conclusions of their research are as follows:

- The nails driven at 0° to the horizontal plane are the most efficient followed by 15°and 30°.
- The nails arranged in staggered pattern shows best results followed by square nail pattern and diamond nail pattern.
- The maximum strain is obtained for the topmost nail followed by middle and bottommost nail respectively.

Ou-Ling Tang et al,“Stability analysis of slope under different soil nailing parameters based on the GeoStudio” DOI 10.15273/ijge.2015.02.010, had investigated the influence of different soil nailing parameters such as nail inclination, nail horizontal space, nail diameter and nail length on the safety factor of a slope and the slope stability is analyzed by the GeoStudio software with different analysis methods such as Morgenstern-price method, Spencer method, Janbu method, Ordinary method, Bishop method & Strict slice method and developed the plots between saftey factor vs soil-nail dip angle, safety factor vs. soil-nail horizontal space, safety factor vs soil-nail diameter and safety factor vs soil-nail length .

The concluding remarks:

- The safety factor increases first and then decreases with the increase of soil-nail dip angle. The optimum soil-nail dip angle for reinforcing the slope lies between 10°and 25°.
- The safety factor decreases with the increase of soil nail horizontal spacing and the horizontal spacing ranges from 1m to 2m is the right spacing to use.
- The safety factor increases linearly with the increase of soil-nail diameter and the optimum diameter for the soil slope of 74.5° is between 0.08m & 0.12m.
- The optimal soil- nail length for the slope of 74.5° is approximal between 0.7 to 1.1 times of height of slope.
- The change in soil nail dip angle is not sensitive to the safety factor, while the change of soil-nail horizontal spacing, soil-nail diameter & soil-nail length are sensitive.

3. EXPERIMENTAL WORK

3.1 GENERAL:

The main aim of this study is to determine the load settlement behaviour of unreinforced and reinforced soil mass with soil nails and there by evaluating the improvement in the load carrying capacity of reinforced soil mass over the unreinforced soil mass. In this work hollow aluminium tubes were used as a soil nails. A total of 8 number of tests has been done, one with a soil slope of 45^0 with horizontal and another with a soil slope of 60^0 with horizontal and in slope angle, tests were conducted under 4 number of conditions i.e. unreinforced, 0^0 nail inclination, 15^0 nail inclination & 30^0 nail inclination. Effect of surcharge loading on various conditions of soil mass on load settlement characteristics were studied. In this chapter the description of the experimental work carried out is mentioned

3.2 UNIVERSAL TESTING MACHINE:

Servo hydraulic Universal Testing Machine (UTM) with a load frame capacity of 2000 kN is used to apply an increasing surcharge load on the crest of soil slopes. The continuous application of the surcharge load is simulated by applying the load at a rate of 10 N/s.

3.3 MODEL BOX:

A box of dimension 50 cm x 22 cm x 35 cm is fabricated by using glass of 6mm thickness as shown in Figure 4. The dimensions of model box are determined by the maximum vertical and horizontal test space available in the Universal Testing Machine.

3.4 BACKFILL MATERIAL:

The backfill material used for the slopes is collected from GIET College of Engineering (Rajamahendravaram). Preliminary tests of soil identification are carried out in the laboratory to determine the backfill properties.

Sl. No	Property	Result
1	Material	Sand
2	Grain size distribution	Well graded sand (SW)
3	Specific gravity	2.67
4	Relative Density	33.5%
5	Cohesion (c)	1.37 kN/m^2
6	Angle of friction (ϕ)	30°

3.5 NAILS:

Hollow aluminium tubes of specified length are used as nails for the soil slopes

Sl. No	Property	Result
1	Material	Aluminium
2	Cross-sectional area (A)	25.13 mm2
3	Length of the nail (L)	150 mm
4	Modulus of Elasticity (E)	69 Gpa

3.6 BEARING PLATE:

A rectangular bearing plate of dimension (0.15 X 0.18 X 0.004)m is used. The dimension of bearing plate is selected considering the effect of rigid wall of box. The effect of stress can be observed nearly upto 1.5B in either direction for rectangular footing. The above concept is taken from the textbook, Principles of Foundation Engineering (seventh edition) by B.M. Das. Thus in the present case the width of plate is such chosen so that the edge of footing is at a distance of 2B from either direction, where B is the width of footing. Thus the stress will be distributed well within the wall and hence wall will not affect the stress distribution.

4. PHYSICAL MODELLING

4.1 PREPARATION OF UNREINFORCED SLOPES:

Well graded sand is used to prepare slopes at predetermined slope angles of 45° and 60° respectively by adding 5% water to the soil. The slope is prepared in layers of thickness 50 mm each. A layer 50 mm thick is made as the base layer completely along the length of model. The layer is formed by placing soil in box and lightly compacting it after every 50 mm. A fine layer of red dye (Gulal) is used in between the layers for identification offailure pattern of the slopes. The procedure is repeated till a complete height of 300 mm is achieved as shown in below figures. A crest width of 150 mm and the base width of 500 mm is maintained for all the slope angles.

4.2 PREPARATION OF REINFORCED SLOPES:

The procedure for preparation of reinforced soil slope is same as that for unreinforced soil slope except that the nails are installed at their respective position during the process. The nails are installed at predetermined inclination of 0°, 15° and 30° to horizontal with the help of a protractor. 6 hollow nails, each of length 15 cm are inserted at the face of the slope in an arrangement of 3 rows x 2columns. The horizontal spacing is kept 10 cm whereas the vertical spacing is kept 10 cm (for square nail pattern only).

4.3 TESTING PROCEDURE

The constructed soil model is mounted on the universal testing machine. A bearing plate of size 150 mm x 180 mm x 4 mm is placed on the crest slope for uniform load distribution. A gradual increasing surcharge load is applied by the UTM at a loading rate of 10 N/s. The load and the corresponding settlement of the crest at which the slope fails is observed. The slope considered to be failed when it collapse down at a particular load. The slopes are then installed with nails at different inclinations and load is applied at the crest.

5. RESULTS AND DISCUSSIONS

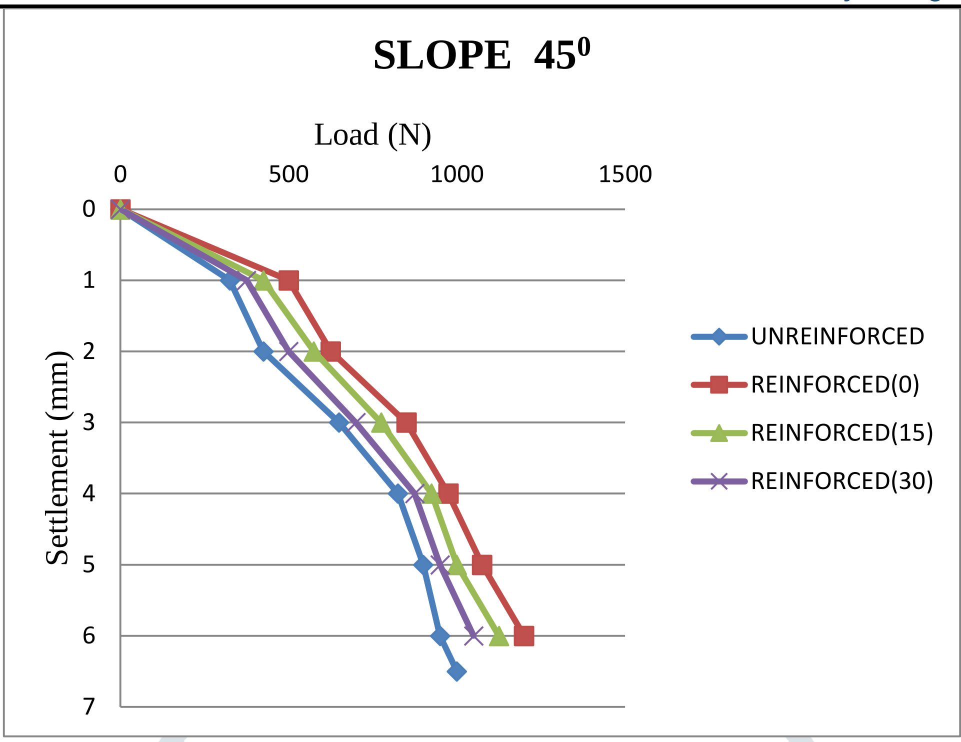
5.1GENERAL:

A series of model experiments are performed on reinforced and unreinforced soil mass for finding the load vs. settlement behaviour for various conditions of variable parameters such as soil slope and nail inclination. In this chapter, results of all the study is explained in detail

5.2 FOR SOIL SLOPE OF 45^0:-

The unreinforced and reinforced slopes for a soil slope of 45^0 are found to have a circular slip surface failure under the surcharge loading. it is observed that the unreinforced soil slopes initially have a settlement of the crest which ultimately leads to the failure of the slope. A slope failure is observed for 45° slope angle.

The 45° reinforced slope are observed to have a circular slip failure pattern as shown in Figure. The failure pattern for all reinforced slope angle (0^0, 15^0 & 30^0) is found to have the settlement of slope crest similar to unreinforced slopes. It is observed from the deformation of tracer layer that the similar settlement of the slopes has occurred. However, displacement of toe of the slopes incase of reinforced slopes is found to be smaller as compared to unreinforced slopes.

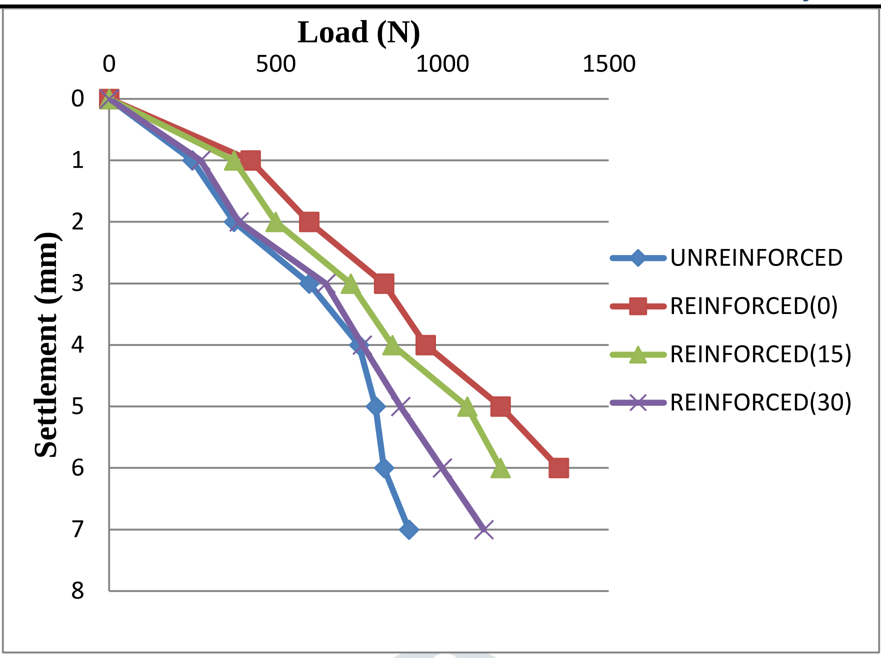


Slope Angle	Unreinforced		Nail Inclination	Reinforced	
	Load (N)	Settlement (mm)		Load (N)	Settlement (mm)
45^0	1000	6.5	0^0 15^0 30^0	1200 1125 1050	6 6 6

5.3 FOR SOIL SLOPE OF 60^0:-

As same as that of 45^0 soil slope, The unreinforced and reinforced slopes for a soil slope of 60^0 are found to have a circular slip surface failure under the surcharge loading. it is observed that the unreinforced soil slopes initially have a settlement of the crest which ultimately leads to the failure of the slope. A toe failure is observed for 60° slope angle.

The 60° reinforced slope are also observed to have a circular slip failure pattern as shown in Figure 20. The failure pattern for all reinforced slope angle (0^0 , 15^0& 30^0) is found to have the settlement of slope crest similar to unreinforced slopes. It is observed from the deformation of tracer layer that the similar settlement of the slopes has occurred. However, displacement of toe of the slopes in case of reinforced slopes is found to be smaller as compared to unreinforced slopes.



Slope Angle	Unreinforced		Nail Inclination	Reinforced	
	Load (N)	Settlement (mm)		Load (N)	Settlement (mm)
60^0	900	7	0^0 15^0 30^0	1350 1175 1125	6 6 7

6 CONCLUSIONS:

The following are the conclusions obtained from the experimental studies:

- From experimental results, Soil slope with 0^0 nail inclination with horizontal gives the maximum load carrying capacity in all cases, followed by 15^0 nail inclination with horizontal and then 30^0 nail inclination with horizontal.
- In experimental case soil nail inclination of 0^0 for soil slope of 45^0 showed an improvement of 120% in load carrying capacity when compared to that of unreinforced soil slope.
- In experimental case soil nail inclination of 0^0 for soil slope of 60^0 showed an improvement of 145% in load carrying capacity when compared to that of unreinforced soil slope.
- In experimental case soil nail inclination of 15^0 for soil slope of 45^0 showed an improvement of 112.5%in load carrying capacity when compared to that of unreinforced soil slope.
- In experimental case soil nail inclination of 15^0 for soil slope of 60^0 showed an improvement of 127.5% in load carrying capacity when compared to that of unreinforced soil slope.
- In experimental case soil nail inclination of 30^0 for soil slope of 45^0 showed an improvement of 105% in load carrying capacity when compared to that of unreinforced soil slope.
- In experimental case soil nail inclination of 30^0 for soil slope of 60^0 showed an improvement of 122.5% in load carrying capacity when compared to that of unreinforced soil slope.

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