AN EXPERIMENTAL AND ANALYTICAL STUDY OF SLOPE STABILITY BY SOIL NAILING

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Abstract - *Soil nailing is a widely accepted method for the improvement of natural and artificial slope as well as used for temporary and permanent earth support, slope stabilization purpose and retaining walls on many projects in the universe. In this paper, an experimental and analytical test carried out for the unreinforced and reinforced soil slope by applying a gradual increasing surcharge load. However, the experimental analysis is done by model testing and the analytical analysis is done with finite element software Plaxsis 3D. Hence the soil slopes are constructed by using sand size soil with two different soil slope angles of 45° and 60° with the horizontal. Then with these soil slopes angles nails are injected at three different nail inclinations of 0°, 15° and 30°. During the testing program, the behaviour of reinforced and unreinforced soil slopes under the increasing surcharge loading the failure slip surface, maximum load carrying capacity of the slope and the settlement are observed. Moreover various slopes are analysed by FES-Plaxsis 3D and a comparable study is carried out with experimental data.*

Key Words: unreinforced, reinforced model testing, finite element, failure pattern, soil nail inclination, surcharge load, settlement, load carrying capacity

1. INTRODUCTION

In recent years, soil nailing has been widely used by civil engineers and geotechnical engineers for stabilizing the steep slopes or carryout ground improvement. Researchers have employed model testing programmes and numerical modelling methods to find out the most critical failure surface, maximum load carrying capacity and settlement. However the verification of these parameters is only made by carrying out a comparable study between the model testing and analytical testing results. With the recent advances the validation of soil nail models can be done using Finite Element software packages like PLAXIS 3D, ABACUS, GEO5 etc.

In the present study, soil slopes is constructed by using sand size soil with two different slope angles of 45° and 60° respectively. The failure surface pattern and the load-settlement studies are carried out for these slopes by applying an increasing surcharge load on the slope crest. The soil slopes of 45° and 60° are reinforced with the nails at three different nail inclinations of 0°, 15° and 30°. The behaviour of reinforced soil slopes are studied under the increasing surcharge loading until slope failure. The failure slip surface and the load carrying capacity of the nailed slopes are observed during the testing program. The unreinforced and reinforced slopes are also analysed by using a Finite Element package PLAXIS 3D with same respective slope angles and nail inclinations. The results obtained from the model testing are comparable with the analytical results from Finite Element Method.

1.1 OBJECTIVE OF THE STUDY

•To study the properties of nature of the soil and reinforced material (soil nails).

•To study the response of the unreinforced soil slope and soil nailed slope by applying gradual increasing of surcharge load which is carried out by both experimentally (Model testing) and analytically (Finite element software PLAXIS 3D) .

•To observe the load bearing capacity vs. settlement and failure pattern of the slope angles of 45° and 60° without reinforcement and with reinforced by installing soil nails at three different inclination of 0°, 15° and 30°.

•Finally to find the soil nailed slope angle, inclination of soil nails, failure pattern, maximum bearing capacity and settlement of the reinforced soil (soil nailing) slope model.

2. EXPERIMENTAL TESTING AND RESULTS

Backfill Material:

The backfill material used for the construction of slopes is taken from Yercard (hills station), Salem district, Tamil Nadu.

FIG -1: Backfill Material

Preliminary tests of soil identification are carried out in the laboratory to determine the backfill properties.

Table-1: Properties of the backfill material

Properties	Result
Index properties	
Material	Sand
Grain size distribution	Well graded sand SW
Specific gravity (G)	2.58
Liquid limit (W_L)	15.4 %
Plastic limit (W_P)	13.20 %
Engineering properties	
Maximum dry density (ρ_d)	2.02 g/cm³
Optimum moisture content (w)	10 %
Value of Cohesion (c)	1.8 kg/cm²
Angle of internal friction (ϕ)	26°

Nails:

Hollow Aluminium pipes are used as nails for the soil slopes.

FIG -2: Nailing Material

Table -2: Properties of the nail

Property	Value
Material	Aluminium (Hollow pipes)
Length of the nail L	150mm
Cross-section area, A	78.5 mm²
Modulus of elasticity of nail E_{Nail}	69 GPa

Table -3: EXPERIMENTAL RESULTS FOR UNREINFORCED SOIL SLOPES

Slope angles	Unreinforced	
	Load (N)	Settlement (mm)
45°	14100	7.6
60°	10300	12.3

Table -4: EXPERIMENTAL RESULTS FOR REINFORCED SOIL SLOPES

Slope angles	Nail inclination	Reinforced	
		Load (N)	Settlement (mm)
45°	0°	21100	6.2
	15°	18826	6.9
	30°	14350	8.4
60°	0°	16452	10.3
	15°	15610	11.2
	30°	12437	11.7

The failure pattern of unreinforced and reinforced soil slopes which undergo a circular slip failure for both 45° and 60° slope angle.

3. ANALYTICAL ANALYSIS BY USING FINITE ELEMENT PACKAGE PLAXIS 3D AND RESULTS

Modeling of the slope:

Analytical set up by using finite element package PLAXIS 3D-Foundation v1.5

Table -5: MATERIAL PROPERTIES OF SOIL SLOPE AND NAILS

Property	Value
Material model	Mohr-Coulomb
Type of material behavior	Drained
Unit weight of soil above phreatic line (γ_{unsat})	15.27 kN/m³
Unit weight of soil below phreatic line (γ_{sat})	20.14 kN/m³
Young's modulus of soil (constant) (E)	50000 kN/m²
Poisson's ratio (constant) (υ)	0.3
Cohesion (c)	1.8 kN/m²
Friction angle (constant) (φ)	26°
Length of Soil Nail (L)	150 mm
Young's Modulus of Elasticity of Soil Nail (E_{nail})	69 GPa

Table -6: FINITE ELEMENT ANALYSIS RESULTS FOR UNREINFORCED SOIL SLOPES

Slope angles	Unreinforced	
	Load (N)	Settlement (mm)
45°	17892.56	1.4
60°	11485.21	1.9

Table -7: FINITE ELEMENT ANALYSIS RESULTS FOR REINFORCED SOIL SLOPES

Slope angles	Nail inclination	Reinforced	
		Load (N)	Settlement (mm)
45°	0°	28327.52	2.5
	15°	25320.17	2.7
	30°	21230.85	2.1
60°	0°	22825.14	3.8
	15°	20362.31	4.1
	30°	19429.20	4.5

The failure pattern of unreinforced and reinforced slopes have circular slip surface failure for both 45° and 60° slope angle.

4. CONCLUSIONS

From the present study it can be analysed by both experimental and analytical that soil nailed slopes leads to increase the stability of slopes.

1) The failure pattern of unreinforced and reinforced soil slopes of both 45° and 60° slope angle undergone a circular slip failure, it can be concluded that nailed soil slopes tends to rotational failure.
2) Load carrying capacity of unreinforced and reinforced soil slope of angle 45° is found to be increased than the unreinforced and reinforced soil slope of angle 60°, it can be concluded that slope angle of 45° is more effective.
3) Reinforced soil slope of angle 45° at an inclination of 0° tends to increase the load carrying capacity compared to the other inclination of 15° and 30°.
4) However, a small settlement is occurred in the slope crest of both unreinforced and reinforced soil slope of various angles at various inclinations which can be acceptable according to the boundary conditions.
5) It can be concluded that reinforced soil slope of angle 45° at an inclination of 0° having rotational failure, maximum load bearing capacity and settlement within the limit compared to other soil slope in model testing and analytical testing.

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