The Effect of Reinforcement on Stability of Slopes

Seyed Abolhasan. Naeini, Naeem. Gholampoor, and Rahele. Rezaei Kashki

***Abstract*—** Nowadays, the usage of steel bars and polymeric geosynthetics as reinforcement tools is increasingly becoming widespread in engineering practice. A large number of experimental and numerical studies have been conducted to understand the working mechanism of these reinforcements in soil medium. Likewise, this study develops and extends the current understanding of the working mechanism of steel bars as well as geosynthetics when they are used to stabilize slopes. The effect of parameters such as water level, cohesion and distance of reinforcements are numerically investigated on the stability of a slope using commercial finite element application, PLAXIS and compared with the previous studies. The results demonstrated that regardless of the type of reinforcement, increasing water level or decreasing cohesion will have a negative impact on the stability of the slope. However, with the same conditions, usage of steel bars proved to better choice to enhance the stability of the slope.

***Keywords*—** Geogrid, PLAXIS, Slope stability, Steel bar.

I. Introduction

THE reinforced soil is a good technique and an economical alternative to stabilization of natural or artificial slopes as part of a civil engineering project. They are in some cases used to construct stable slopes at much steeper angles than would otherwise be possible. The analyze of stability of soil masses and performance of geosynthetic reinforced retaining structures subjected to various conditions, including layered or soft foundation, differential settlement and limited reinforced space ([1]–[4]), surcharge loadings ([5], [6]), seismic loadings [7]. Some literature of field studies reported the successful design and satisfactory performance of this type of structures ([8], [9]). However, the literature presents and discusses a rather limited number of failure cases in regards to a further understanding of their original design and failure mechanism ([10]-[18]). Another alternative for soil reinforcement is the steel bar or strand to the ground surface or the supported structure. Quite several experimental and theoretical models have been developed and used to qualitatively describe the principal mechanism, and benefit effects of stell bars on stability of slopes and earth retaining walls ([19]-[27]).

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The ultimate objective for this study is to create a numerical model of an existent geogrid reinforced slope in Nantou, Taiwan which attracted a lot of attention in the literature ([28]-[32]) and firstly, analyze it by PLAXIS software based on Finite Element Method at three ground water levels (GWL) and different soil cohesions and distance between reinforcement layers (DRL) of 0.5 and 1 m and these were compared with the conclusions of study performed by [32] for verifying the obtained results. Then, the steel bars substitute with geogrids in the model and analyses are repeated.

II. Modeling and Analysis

The numerical study of the reinforced slope has been done by PLAXIS based on Finite Element Method. This software enables to perform for the simulation of the linear or non-linear, time-dependent and anisotropic behavior of soil and/or rock from the most basic to the most advanced constitutive models. Since the behavior of slope can be defined as a two-dimensional analysis, geometry of slope as plane strain mode has been used for the Finite Element modeling. The soil profile has been modeled using 15 nodded triangular elements and the boundary conditions are defined by the standard fixities for static loading. In the standard fixities, vertical geometry lines for which the x-coordinate is equal to the lowest or highest x-coordinate in the model to obtain a horizontal fixity. The Mohr-Coulomb failure criterion is used as material model for non-linear behavior of the soils. 20 layers of geogrid are constructed at various depths of slope tah will be substituted with steel bars. In PLAXIS the geogrids and steel bars are considered as tensile elements and are computed by the axial stiffness named as "*EA*". The interface element was used to model interaction of soil-geogrid and soil-steel bar accurately. Factor of safety (*FS*) of slope in PLAXIS has been executed by reducing the strength parameters of the soil. This method is called as Phi-c reduction and the strength parameters (φ, c) are successively reduced until failure of the structure occurs in this approach. The total multiplier $\sum Msf$ is used to define the value of the soil strength parameters at a given stage in the analysis given by the (1):

$$\sum Msf = \frac{\tan\varphi_{input}}{\tan\varphi_{reduced}} = \frac{C_{input}}{C_{reduced}} \quad (1)$$

$\sum Msf$ is set to 1.0 at the start of a calculation to set all material strengths to their unreduced values. Until failure

occurs, the strength parameters are successively reduced automatically.

III. Geometric Properties Of Slope

As mentioned in previous, the slope considered for this study is located in Nantou, Taiwan and reinforced by woven geogrid layers. The slope profiles are shown in Fig. 1. In the analyses, a dry slope and the same with different ground water level (*GWL*) of 0 and 5 m above the clayey layer surface have been considered. Also, at each *GWL* conditions the distance between reinforcements varies from 1 to 0.5 m.

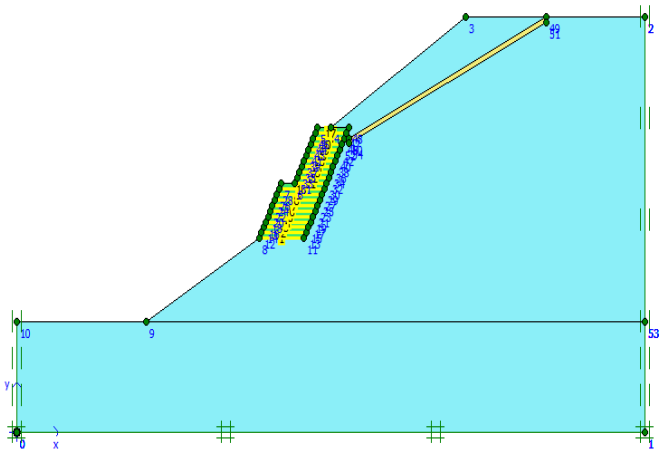

Fig. 1 The slope profile

IV. Characteristics Of The Studied Materials

As shown in Fig. 1 the considered slope is composed of three parts of embankment, retaining section and clay layer. The physical and mechanical properties of these parts are presented in Table I and Table II, respectively. As described, in this study *GWL* is varied. Thus, in Tables I and II two kinds of properties are presented for clay layer as dry clay and saturated clay.

A single product geogrid with an axial stiffness of *EA*= 5128 kN/m was used in this paper. The geogrid was modeled as an elastic element during the computations. As described, this study investigates factor of safety at various cohesions. For this purpose, the analyses are performed in initial cohesion and 0, 0.2, 0.4, 0.6 and 0.8 of it. The axial stiffness (*EA*) of steel bars which was obtained from Rankine's theory of active pressure [33] is equal to 18.5×10^5 kN/m for upper 10 m of slope and 11.12×10^5 kN/m for next 10 m of it.

TABLE I
The Physical Properties Of Slope Sections

Part	γ_{uvsat} (kN/m^3)	γ_{sat} (kN/m^3)	k_x (m/day)	k_y (m/day)
Embankment	18	19	8.65e-5	8.65e-5
Retaining section	22	23	0.864	0.864
Dry clay	20	21	8.65e-5	8.65e-5
Wet clay	20	21	8.65e-5	8.65e-5

TABLE II
The Mechanical Properties Of Slope Sections

Part	E (kPa)	ν	C (kPa)	φ (degree)
Embankment	8500	0.35	54	28
Retaining section	68000	0.3	13	49
Dry clay	30000	0.33	20	28
Wet clay	30000	0.33	0.2	28

V. Results And Discussions

The numerical analyses are performed on slope reinforced with two types of reinforcements at three *GWL*s and different soil cohesions and distance between reinforcement layers (*DRL*).

As shown in Fig. 2, in order to verify the results obtained from Finite Element Method (FEM), a comparison conducted between results from this study and same for study performed by [32] based on Limited Equilibrium Method. It is revealed from figure that the comparison between FEM and Limited Equilibrium analyses shows good correspondence of results at all slope conditions.

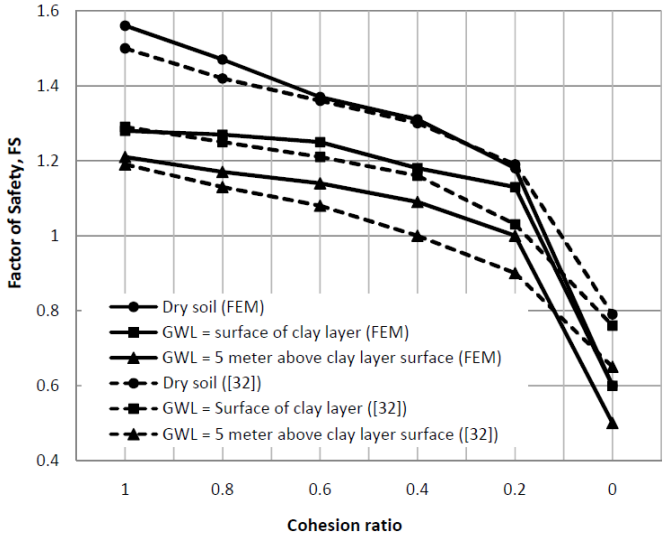

Fig. 2 Comparison between FEM analyses results and results of [32] for DRL equal to 1 m

Fig. 3 plotted the variations of factor of safety versus cohesion ratio (reduced cohesion on initial cohesion) and *GWL*. As indicated in Fig. 3, at all *GWL*s and each type of reinforcement reduction in soil cohesion caused to decrease in factor of safety. Also, the figure shows that by increase of *GWL* because of increase in pore water pressure and reduction in effective stress and consequently decreases of shear strength of soil the factor of safety decreases.

From the Fig. 3 at same conditions of *GWL* and *DRL* factor of safety for slope reinforced with steel bars is more than the same reinforced with geogrid, in other words, steel bar reinforcing is a good choice to improve stability of slopes specially slopes with high *GWL*.

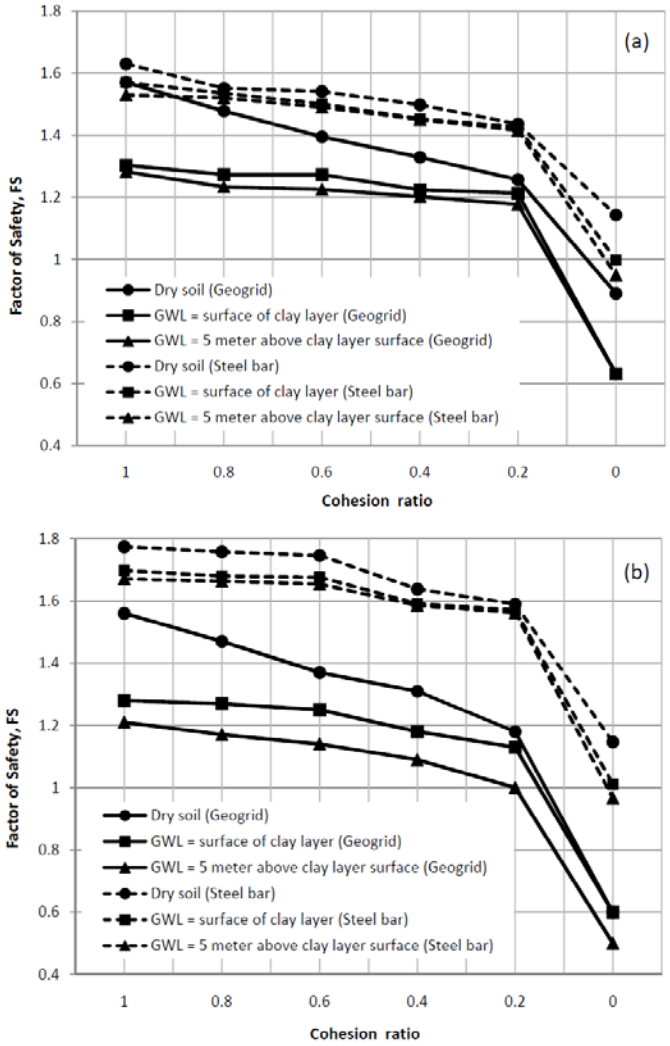

Fig. 3 Variations of factor of safety versus cohesion ratio and *GWL* at *DRL* equal to (a) 0.5 m and (b) 1 m, for two reinforcements

As described, *DRL* is one of variable parameters considered in this study. Fig. 4 indicates the variation of factor of safety versus cohesion ratio and *DRL* for each *GWL* considered in this study.

As shown in Fig. 4, for geogrids decrease of *DRL* from 1 to 0.5 m caused to increase of factor of safety at all cohesion ratios and *GWL*s. As indicated, this increment in factor of safety is more obvious for *GWL* of 5 meter above clay layer surface. Because, in this condition the pore water pressure is more than other conditions. Though, the role of *DRL* or number of geogrid layers to increase of tensile strength of soil and thwart the effect of pore pressure on reduction in shear strength is more salient at this *GWL*. From the figure, the value of safety factor for steel bars at all *GWL*s increases by increase of *DRL*. This is because of high length and thickness of steel bars in these conditions.

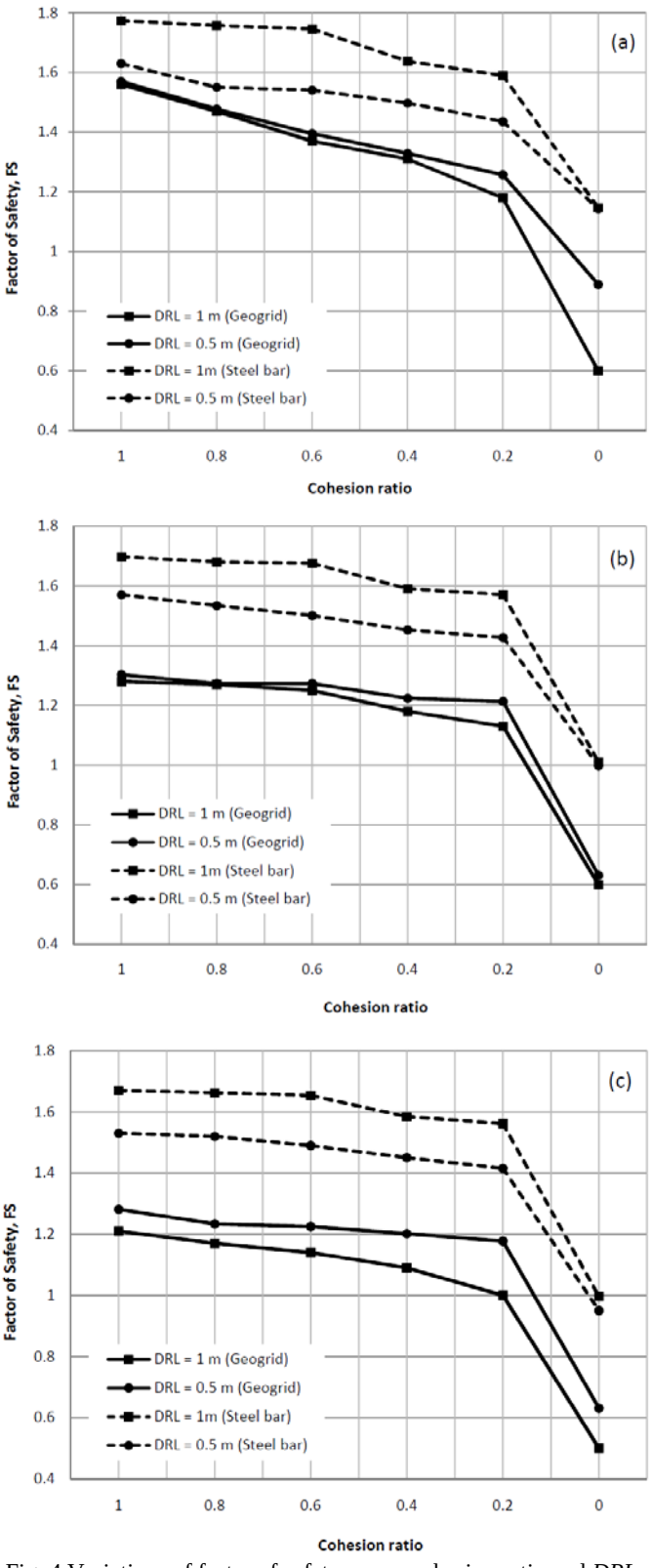

Fig. 4 Variations of factor of safety versus cohesion ratio and *DRL*s at *GWL* of (a) dry soil (b) surface of clay layer (c) 5 m above clay layer surface, for two reinforcements

VI. Conclusion

The numerical analyses are performed by PLAXIS software

based on Finite Element Method on reinforced slope with two types of reinforcements at three *GWL*s and different soil cohesions and *DRL*s of 0.5 and 1 m. the conclusions are as followed:

- The decrease of soil cohesion caused to reduction in factor of safety at all *GWL*s. Also, by increase of *GWL* the factor of safety decreases.
- in slope reinforced with geogrid Decrease of *DRL* from 1 to 0.5 m caused to increase of factor of safety but same for reinforced slope with steel bar leads to increase of factor of safety at all cohesion ratios and *GWL*s specially, at *GWL* of 5 m above clay layer surface.
- At the same conditions, steel bars are better choice to improve the stability of slope than geogrid layers, specially in slopes with high *GWL*.
- Comparison between Finite Element analyses conducted in this study and Limited Equilibrium analyses performed by [32] shows good correspondence of results at all conditions of geogrid reinforced slope.

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