Numerical Analysis of the Effects of Soil Nail on Slope Stability

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ABSTRACT
Soil nailing is one of the good techniques for the improvement of natural and artificial slope. By the application of soil nails the stability can be increased of an unstable slope. The appropriate position of reinforcement can give the ultimate result, and it will be solution of reducing cost. In this paper, an attempt has been made to show the stability of a reinforced dry slope at different nail angles with horizontal axis, and determine the optimum nail inclination to get maximum factor of safety. The analysis was based on numerical analysis by using SLOPE/W (Geo-slope 2007). The factor of safety has been determined using the limit equilibrium (LE) method within the Morganstern-Price method along with Mohr-Coulomb expression. The results show that the factor of safety (FOS) of slope increases with the application of soil nail. The results also show that with the increase of inclination the factor of safety of the slope increases, but after reaching the maximum value further increases of inclination it decreases. The optimum angle of nail was found at 30^o with the horizontal.

Keywords
Slope stability, Factor of safety, Soil nail, Numerical Analysis, Limit Equilibrium Method.

1. INTRODUCTION
The slope stability analyses are performed to assess the safe and economic design of human-made or natural slopes (e.g. embankments, road cuts, open-pit mining, excavation, and landfills). In assessment of slopes, engineers primarily use factor of safety (FOS) values to determine how close or far slopes are from failure. When FOS is greater than 1, resistive shear strength is greater than driving shear stress and the slope is considered stable. When FOS close to 1, shear strength is nearly equal to shear stress and the slope is close to failure, if FOS is less than 1 the slope should have already failed [1], Thus, there are various process to improve the slope stability, soil nailing is one of them. In this paper an attempt has been made to show the effects of variation of nail inclination on stability of a dry slope, and determine the optimum nail inclination for maximum FOS.

Soil nailing is an in-situ soil reinforcement technique, which has been used during the last three decades. This technology was first reported to apply for the permanent support of retaining walls in a cut in soft rock in France in 1961. Besides, in North America, soil nails were first introduced for temporary excavation support in Vancouver, in the late 1960's and early 1970's. It was continued to grow in the 1970's, in France and Germany.

Soil nailing is being used at present to stabilize natural slopes, cut or excavation, walls in stiff clays, granular soils and also soft rocks. Unlike the conventional systems that serve to retain soil behind a vertical cut, this procedure is based on the concept of soil reinforcement. The concept of soil nailing is to reinforce the ground by closely spaced nails to increase the overall shear strength of soil. There are usually using steel bar inserted into the soil either by simple driving or by grouting in predrilled borehole. Soil nail slopes behave like a reinforced soil wall although there is some major difference between these two techniques. The action of grouting the reinforcement leads to the advantage of greatly enhanced pullout resistance because of the increased surface area and roughness. The presence of grout may also provide increased corrosion protection [2].

Presently, stability of slope can be analyzed using several geotechnical software. GEOSLOPE is one them developed by GEOSLOPE International, Canada, based on limit equilibrium principles which also incorporates a finite element package, developed specifically for the analysis of deformation and stability of geotechnical structures. It includes stability modeling (SLOPE/W), seepage modeling (SEEP/W), stress and deformation modeling (SIGMA/W), dynamic modeling (QUAKE/W), thermal modeling (TEMP/W), containment modeling (CTRAN/W) and vadose zone modeling (VADOSE/W) [3]. SLOPE/W is a component of a complete suite of geotechnical products called Geo Studio. SLOPE/W uses limit equilibrium theory to compute the factor of safety of earth and rock slopes. In the present study, SLOPE/W module has been used for stability modeling of the slope. The comprehensive formulation of SLOPE/W makes it possible to easily analyze both simple and complex slope stability problems using a variety of methods to calculate the factor of safety. SLOPE/W has application in the analysis and design for Geotechnical, Civil, and Mining engineering projects. Limit equilibrium has the ability to model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore water pressure conditions using a large selection of soil models [2].

SLOPE/W can be used to analyze the stability of a wedge of soil that has been reinforced with a structural component such as a pre-stressed anchor, a soil nail, geo-fabric or some other material. While modeling using, SLOPE/W, the following are mainly required to be satisfied

- Type of analysis: Bishop, Ordinary and Janbu, Morganstern-Price.
- Strength parameters: c and φ, unit weight of soil γ.
- •Piezometric line while considering pore water pressure conditions.
- •Vertical and horizontal seismic coefficient for pseudo-static seismic loads.

- Type of reinforcement: Soil nails, Anchors, Geo-fabric [4].

2. METHODOLOGY

In this study SLOPE/W has been applied to analyze the stability of the slope. The CSS searching techniques Entry-exit method is used. The most common LE based method (M-PM), which is incorporated in SLOPE/W, was considered for analysis purpose.

2.1 Stability analysis of a dry slope without nail

In the analysis of slope stability the slope model is drawn using SLOPE/W. The physical properties of the soil were considered as described in the Table 1. The slope angle is 45^o (1V:1H). The factor of safety of the slope without nail is 1.340.

Table 1. The soil properties for each layer of the slope

Layer	Cohesion, c (kPa)	Friction Angle, φ(^{o})	Unit Weight, γ (kN/m^3)
Upper soil layer	25	12	17
Middle soil layer	20	16	16
Lower soil layer	30	10	19

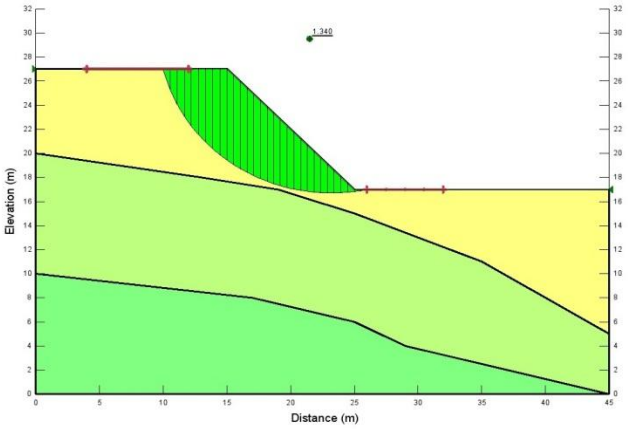


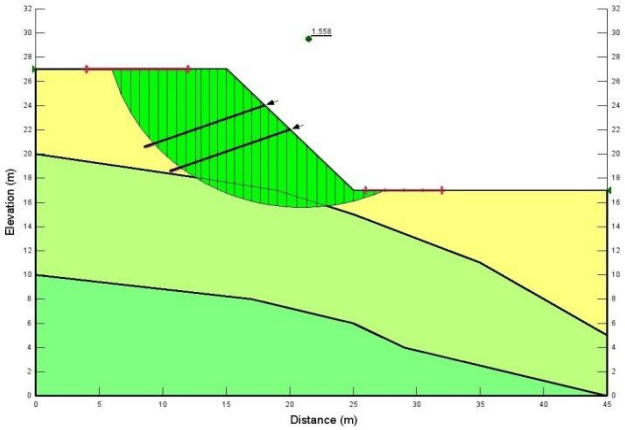
Fig 1: Slope stability analysis of a dry slope without soil nail

2.2 Stability analysis of a dry slope at various nail inclination

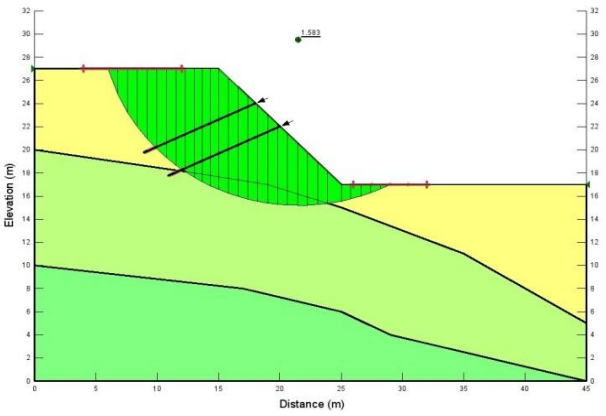
The geometry of the dry slope discussed in the earlier section is considered here. The stability is analyzed for different inclination of nail as 20^o, 25^o, 30^o, 35^o, 40^o, 45^o in the slope surface with the horizontal axis.

Table 2. Nail properties [5]

Property	value
Length	10m
Bond diameter	0.318m
Bond safety factor	1.5
Bond skin friction(F/Area)	100 kPa
Bar capacity	300 kN
Bar safety factor	1.5
Nail spacing	2m
Shear safety	1



(a)



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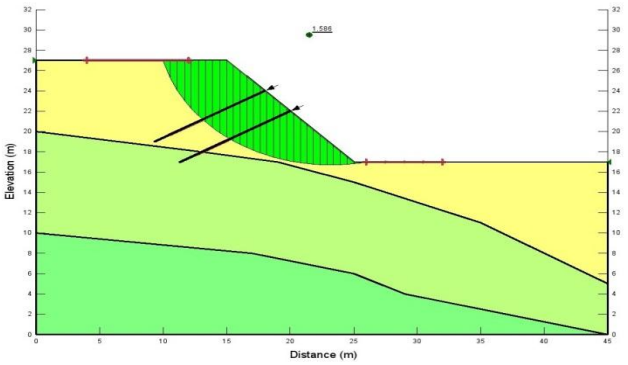

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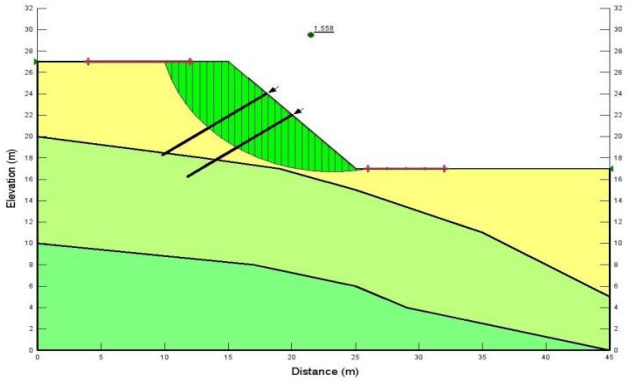
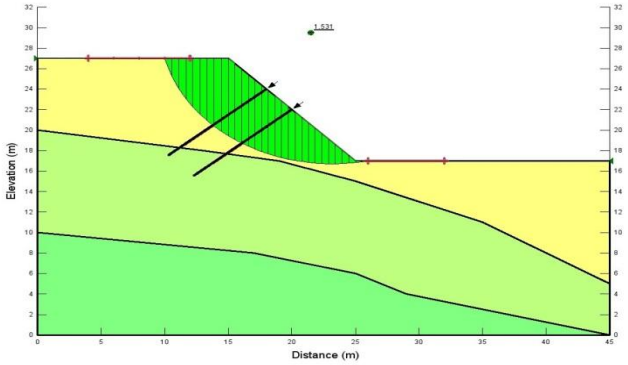
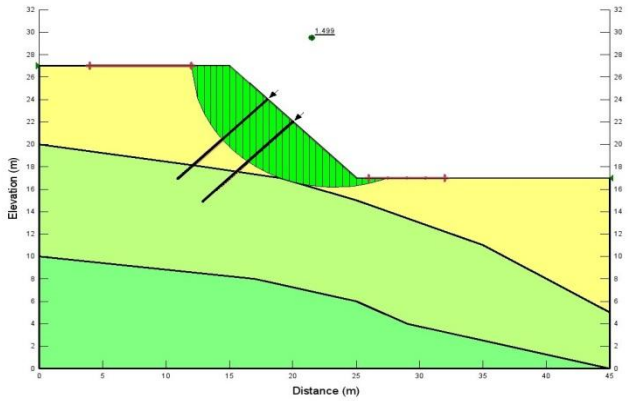


(d)



(e)



(f)

Fig 2: Shows the factor of safety of dry slope at different nail inclination (a) 20^o, (b) 25^o , (c) 30^o , (d) 35^o , (e) 40^o , (f) 45^o

Figure 3 shows the variation of factor of safety for various nail inclination

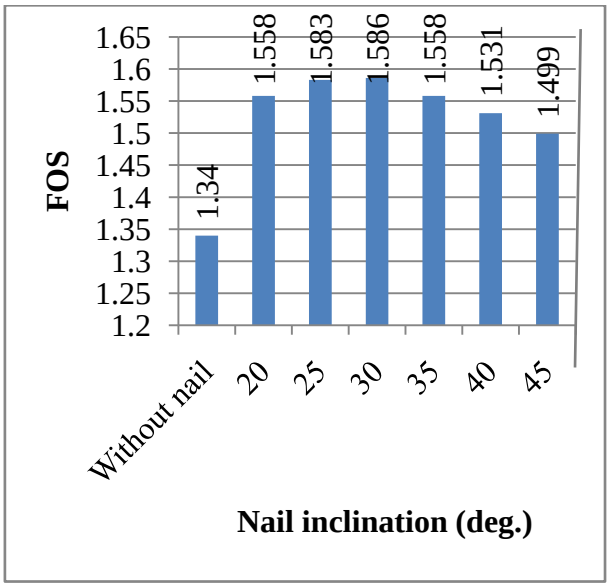


Fig 3: Diagram of factor of safety of dry slope for various inclination of nail

It is observed that within the use of nail the factor of safety increases. It is also observed that with the increase of nail inclination the factor of safety increases, and at 30^o it gives the maximum factor of safety and after that for increasing nail inclination the factor of safety decrease.

3. CONCLUTIONS

The analyses were carried out to evaluate the effects of variation of nail inclination on dry slope. From the above investigation, the main conclusions can be summarized as follows:

- The study of slope stability problems by using the computer based geotechnical software code SLOPE/W provides more understanding viewing all the detailed force on each slice, to understand failure mechanisms, and the distribution of variety of parameters along the slip surface with respect to the factor of safety.
- The factor of safety of a slope increase with the use of nail.
- • From the result of analysis, it is found that the variation of nail inclination have significant influence on the factor of safety of the slope stability problem.
- The factor of safety of a dry slope increases with the increase of nail inclination, but after a certain inclination of nail it decreases.
- The optimum nail inclination improves the factor of safety by 18%.

4. REFERENCES

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