Stabilization of rock slops using geosynthetic materials as new approch and its comparison with conventional methods

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Abstract

This research sets out to review critically the current slope stability methods including geometry modification, rock bolt and wire mesh and to offer geogid box method as an alternative to conventional rock slope stability methods. Achieving the objectives of this research, the limit equilibrium (LE) and finite element (FE) analysis were conducted to predict the response of rock slopes to a broad range of possible scenarios, namely dry, half-saturated and saturated states; as well as, static, quasi-static and dynamic conditions. The results indicate that the factors of safety obtained through the geogrid box method are higher than those obtained through conventional reinforcement methods.

Keywords: Geometry modification, rock slope stability, geosynthetic box, rock bolt, limit equilibrium analysis**.**

Introduction

The use of geosynthetic material such as geotextiles and geogrids is now quite widespread for reinforcement of soil slopes. There has been wealth of research activities on this particular topic, most of which highlight the advantages of using this method over other reinforcement methods. Geotextiles and geogrids allow the building of railway and road cuttings and embankments with steeper sides, reducing the land required and disturbance to the local environment. Revegetation of these embankments or of the banks of rivers and waterways can also be promoted using appropriate materials. (Ahn et al. 2002; Horrocks and Anand 2000; Hryciw and Haji-Ahmad 1994; Palmeira et al. 2008; Viswanadham and Konig 2009). Unfortunately, in spite of extensive research on geogrid-reinforced soil slopes, there is no published research that encompasses the scope of stabilization of rock slopes using geogrid boxes. The present study introduces the geogrid box reinforcement method as a new approach to reinforce rock slopes and investigates whether the new approach can be a satisfactory alternative for the other conventional slope stabilization methods. Furthermore, there are only limited studies that compare the critical failure surfaces from the LE and FE analysis as the factor of safety appears to be the primary quantity of interest. Therefore, various LE and FE methods are employed to evaluate the factors of safety varying with a broad range of possible conditions.

Experimental procedure and case study

Identification of critical failure surface

Considering the maximum height of the trench, the largest eroded area, and exposure to possible fall, the rock slope perched along km 11+060 of Mianeh-Ardabil railway track, was identified as the critical zone for the subsequent analysis. depicts the profile of the site which comprises three equal benches over a total slope height of 48 m.

Site geology

The study area is located approximately along km 11+060 of Mianeh-Ardabil railway track.. The geotechnical units and engineering geological properties of the rocks exposed in the case study slopes are presented in Tables 1 and 2, respectively. As is observed, although this rock intrinsically enjoys high strength parameters, the erosion activity of two small streams has extremely decreased competency of the rock from the engineering point of view.

Rock type	Lithostratigraphy unit	Lithology
R-I	Eocene andesitic rock mass	Low weathered andesitic
R-II	Eocene andesitic rock mass	High weathered andesitic
R-III	Eocene volcanic rock mass	Tuff

Table 1 Geotechnical units obtained for the site

Parameter	**Symbol**	**Unit**	**Rock type**	**Value**
Cohesion	C	kPa	R-I	570
			R-II	50

			R-III	390
			R-used in geogrid box	140
Internal friction angle	φ	degree	R-I	60
			R-II	25
			R-III	55
			R-used in geogrid box	40
Unit weight	γ	kN/m^3	R-I	26.5
			R-II	24.5
			R-III	25
			R-used in geogrid box	26.5
Elasticity modulus	E	kN/m^2	R-I	6.067 e + 09
			R-II	3.77 e + 07
			R-III	2.42 e + 09
			R-used in geogrid box	6.06 e + 08
Poisson's ratio	ν	--	R-I	0.25
			R-II	0.32
			R-III	0.27
			R-used in geogrid box	0.25
Horizontal earthquake acceleration in quasi-static analysis	K_h	m/s^2	--	0.1g
Maximum earthquake acceleration	a	m / s^2	--	(0.2 - 0.3)g

Table 2 Required parameters for stability analysis

Plan 1: Conventional reinforcement method

This plan has been proposed and implemented by Farbar Consulting Engineers (FCE) organization (www.farbar-eng.com/Home-En.html). The proposed plan is a combination of various methods including, geometry modification, rock bolt installation, surface and subsurface drains implementation, shotcrete addition and wire mesh installation.

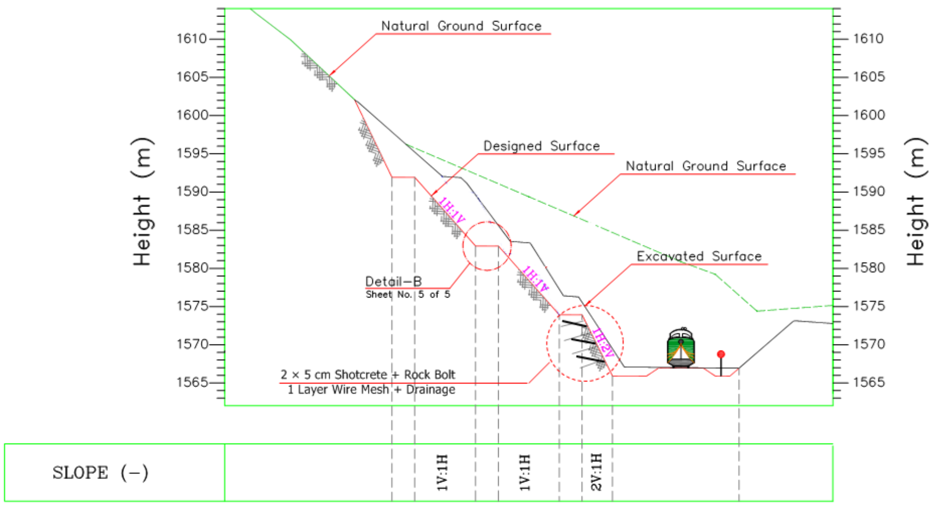

Fig 1: Illustrative schematic of plan 1

Plan 2: Geogrid box method

Geosynthetics are planar products manufactured from polymeric materials (the synthetic) used with soil, rock, or other geotechnical-related material (the geo) as part of a civil engineering project or system. To reinforce the rock slope, horizontal geogrid boxes were installed in two 8 m high benches. Considering the differences between the rock and soil slopes, the analytical methods and design considerations used for soil slopes reinforcement cannot be generalized to rock slopes analysis. Therefore, in our previous research, five design considerations were presented to investigate the effect of height and width of geogrid boxes on the factor of safety and the best one was selected . In this design, at the forepart of each bench the width of geogrid box is 10 m, the width of the upper box is 9.5 m and the 0.5 m reduction in the box width will be continued so that the box width at the end of each bench reaches 6.5 m (Figure 7). The calculations were carried out for different conditions with a maximum height of 8 m for each bench by placing a thickness of 1 m for every reinforcement layer. Figure 8 depicts the schematic of geogrid box and the confined crushed rocks.Considering the dimensions of geogrids, the area occupied by geogrid is 0.2 of total area (Figure 2).

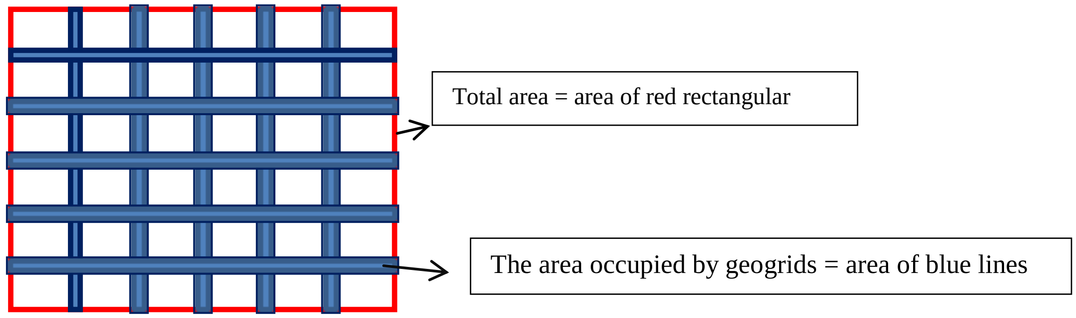

Fig 2: Schematic of geogrid in interaction with rock mass

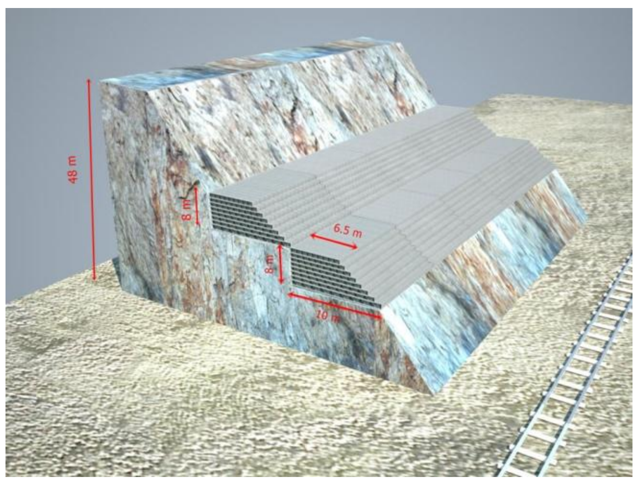

Fig3: Schematic of plan 2

Computer simulation

In this study, the finite element program PLAXIS and limit equilibrium program SLIDE have been used to evaluate the stability analysis of the rock slope in static and quasi static conditions. Moreover, for dynamic analysis in the finite element program the earthquake records from Tabas earthquake were used. This earthquake occurred in South Khorasan Province of Iran.

Parameter	**Symbol**	**Unit**	**Value**
Axial stiffness	EA	kN/m	1.5 e + 05
Bending stiffness	EI	kNm^2/m	37.2
Poisson’s ratio	ν	--	0.2

Table 3 Rock bolt parameters in PLAXIS

Parameter	**Symbol**	**Unit**	**Value**
Spacing	S	M	3
Rock bolt capacity	N_p	kN	1 e + 10

Table 4 Rock bolt parameters in SLIDE

Parameter	**Symbol**	**Unit**	**Value**
Axial stiffness	EA	kN/m	6.3 e + 06
Bending stiffness	EI	kNm^2/m	4.8 e + 04
Poisson's ratio	ν	--	0.15

Table 5 Shotcrete and wire mesh parameters

Parameter		**Symbol**	**Unit**	**Value**
Tensile Strength		N_p	kN/m	200
Pull out resistance	Cohesion	C	kN/m^2	5
	Friction angle	φ	Degree	40
Equivalent axial stiffness		EA	kN/m	1.71 e + 04

Table 6 Geogrid parameters

Results and discussions

Stability analysis of the excavated slope

The safety factors obtained for the excavated slope in different conditions are shown in Table 7. Results demonstrate the excavation of the slope has distinctly decreased the factors of safety. As expected, the most critical situation was observed at the saturated state.

	Factor of safety (FE based software)	**Factor of safety (LE based software)**

	Static	Quasi-static	Dynamic	Static			Quasi-static		
				BSM	SM	JGM	BSM	SM	JGM
Dry	1.13	1.00	1.05	1.24	1.28	1.26	1.13	1.13	1.15
Half-saturated	1.19	0.94	0.98	1.20	1.24	1.22	1.09	1.07	1.10
Saturated	1.08	0.91	0.94	1.21	1.07	1.04	0.98	0.98	0.92

Table 7 Factor of safety for excavated slope in PLAXIS and SLIDE

Stability analysis for plan 1

The results of stability analysis using geometry modification and rock bolt system which includes other components such as shotcrete, welded wire mesh, subsurface and surface drainage are shown in Table 8.

	Factor of safety (FE based software)			**Factor of safety (LE based software)**					
	Static	Quasi-static	Dynamic	Static			Quasi-static		
				BSM	SM	JGM	BSM	SM	JGM
Dry	2.59	2.24	2.33	3.19	3.20	3.20	2.78	2.81	2.79
Half-saturated	2.59	2.22	2.30	3.18	3.18	3.19	2.78	2.80	2.77
Saturated	2.57	2.20	2.27	3.17	3.16	3.16	2.76	2.78	2.74

Table 8 Factor of safety for plan 1 in PLAXIS and SLIDE

Slope stability analysis for plan 2

The results of stability analysis for plan 2 are presented in Table 9.

	Factor of safety (FE based software)	**Factor of safety (LE based software)**

	Static	Quasi-static	Dynamic	Static			Quasi-static		
				BSM	SM	JGM	BSM	SM	JGM
Dry	1.70	1.44	1.52	1.83	1.75	1.75	1.56	1.53	1.48
Half-saturated	1.64	1.39	1.48	1.78	1.72	1.71	1.50	1.50	1.45
Saturated	1.40	1.30	1.39	1.68	1.66	1.64	1.33	1.37	1.40

Table 9 Factor of safety for plan 2 in PLAXIS and SLIDE

As can be observed, implementing plan 2 has appreciably increased the factors of safety and in all conditions the least favorable safety factor of 1.3 has been satisfied.

In comparison with plan 1, using plan 2 causes cost reduction due to decrease in amount of excavation, reduction in labor, omitting some of the machinery and utilizing the existence material in the place, as well as reduction in construction time. This method also can be satisfactorily used to meet a variety of geological conditions and various support requirements. Installing geogrid also allows the slope to stand at steeper angles than would normally be achieved without reinforcement, since the slope reinforcement by geosynthetics provides a tensile strength component within the reinforced rock zone. Furthermore, due to smaller dimensions of geogrid openings than that of the crushed rocks, it seems that geogrid box can be used as drainage. However, flow and seepage analysis through both the experimental and software analysis should be conducted to determine quantitatively this effect. Obviously further work to address this issue would be very useful.

Conclusions

Over the last decades, the beneficial use of reinforcement materials like geosynthetics to increase the stabilization of soil slopes has been clearly established. However none of them has investigated reinforcement of rock slopes with geogrid boxes. The present paper introduces an intervention of landslide stabilization carried out through the technique of the rock-reinforcement with geogrid boxes. Two plans for reinforcing the rock slope placed in the study area were investigated. The objective was accomplished by comparing results from the LE and FE analyses using different commercially available programs. Results indicated that installing geogrid box can be used as a satisfactory alternative for the conventional reinforcement methods. It was reported that, implementing geogrid boxes not only does increase the factor of safety, but also it can be used as drainage in the reinforced system.

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