Landslide Stabilization Using Reinforced Earth Technique Case Study: One Sample Of Landslide in Mazandaran, Iran

Reza Rasouli[1,*], Abbas Tahmasebipoor [2], Mohammad Hajiamiri[3]

[1-] University lecturer, Department of Civil Eng, Mazandaran Institute of Technology, Iran
[2-] M.S. in Civil Eng. -Soil Mechanics and Foundations, Khazar Ab Consulting Engineering Co
[3-] University Faculty Member, Department of Mechanic Eng, Mazandaran Institute of Technology, Iran
[*]Corresponding author: reza.rasouli255@gmail.com

Abstract*:* Landslide is one of the natural phenomena that are the cause of high death toll and financial losses in Iran every year. Incidence of destructive landslides in rough country and mountainous areas under the effect of human activities and geological problems is a common phenomenon that causes economic damages to roads, transmission lines, irrigation channels, forests and residential areas. There are many methods to stabilize sliding slope of failure such as modifying slope geometry, biomechanical stabilization, drainage, retaining wall construction and etc. As a result, soil reinforcement method using "Geosynthetics" for stabilization of sliding slope has rarely been investigated. Due to costly and inefficient stabilization methods in some cases as well as availability and low cost of polymer materials (Geosynthetics) for reinforcing, it is necessary to study the stabilization using reinforced earth technique as a new and economic method. This study investigates a stabilization sample of landslides in Mazandaran Province, using reinforced soil system and studies the effect of different soils and reinforcement characteristics on stability of sliding masses. Limit equilibrium and finite element methods beside "GEO-SLOPE" software have been used for analyzing.

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1. Introduction

Slope stability is one of subjects in which civil engineers are interested. Importance of this issue is increasingly clear when sliding a slope makes huge and irrecoverable damages whether sliding a natural slope has caused to a village be buried or collapse of earth dam slope due to sliding have victimized thousands of people. There are different methods for slope stabilization. One of which is using the soil reinforcement method in order to increase its strength against failure. Soil reinforcement idea was introduced by Casagrande and Terzaghi in 1930 for the first time but reinforcing soil structures was actually initiated in 1960 when Vidal reinforced non-cohesive soil with horizontal layers made of metal strips. In 1968, construction of the first reinforced soil structure was completed. Today, regarding the weakness of metal elements against corrosion as well as their high costs, geosynthetic materials are used in most cases. In this study, it has been dealt with reinforced soil technique to stabilize sliding occurred in slopes in Savadkooh area. Slide points are positioned on the way of Sharghelt village to Imam-kola. There are many factors related to sliding occurrence in this area including rising ground water table, water abundance in sliding site because of heavy precipitation in the area, artificial vibrations caused by vehicle traffic from Sharghalt to Aalam-kola especially heavy machinery traffic crossing from/to Tamar village in order to excavate diversion tunnel of Alborz dam, insufficient drainage, lack of rooted trees and scouring the toe and foot of slope by surface runoff and groundwater. In order to investigate slope stabilization in mentioned area, SLOPE/W software has been implemented which is based on Limit Equilibrium method and Mohr-Coulomb Failure Criterion.

2. The study area

The study site is located in Savadkooh town, Shirgah district, Mazandaran Province, north of Iran, between Sharghalt and Aalam-kola, at latitude 36.14° North and longitude 46.52° East. Area location has been shown in Figure 1 and Figure 2.

Fig. 1: Sliding site location

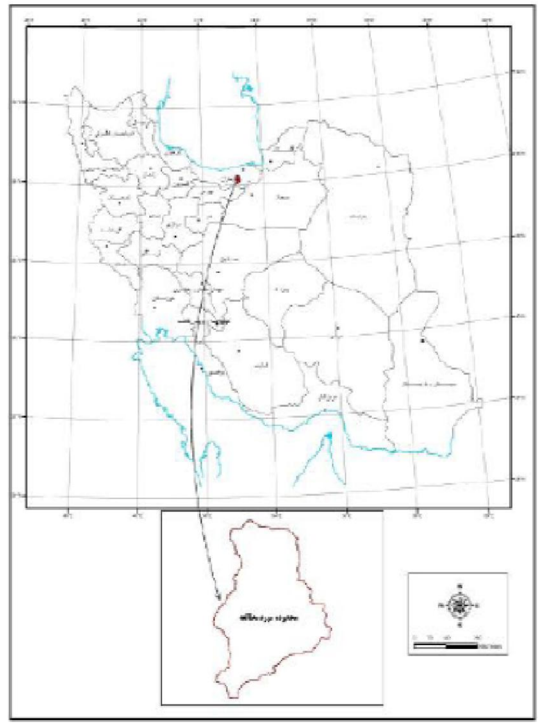
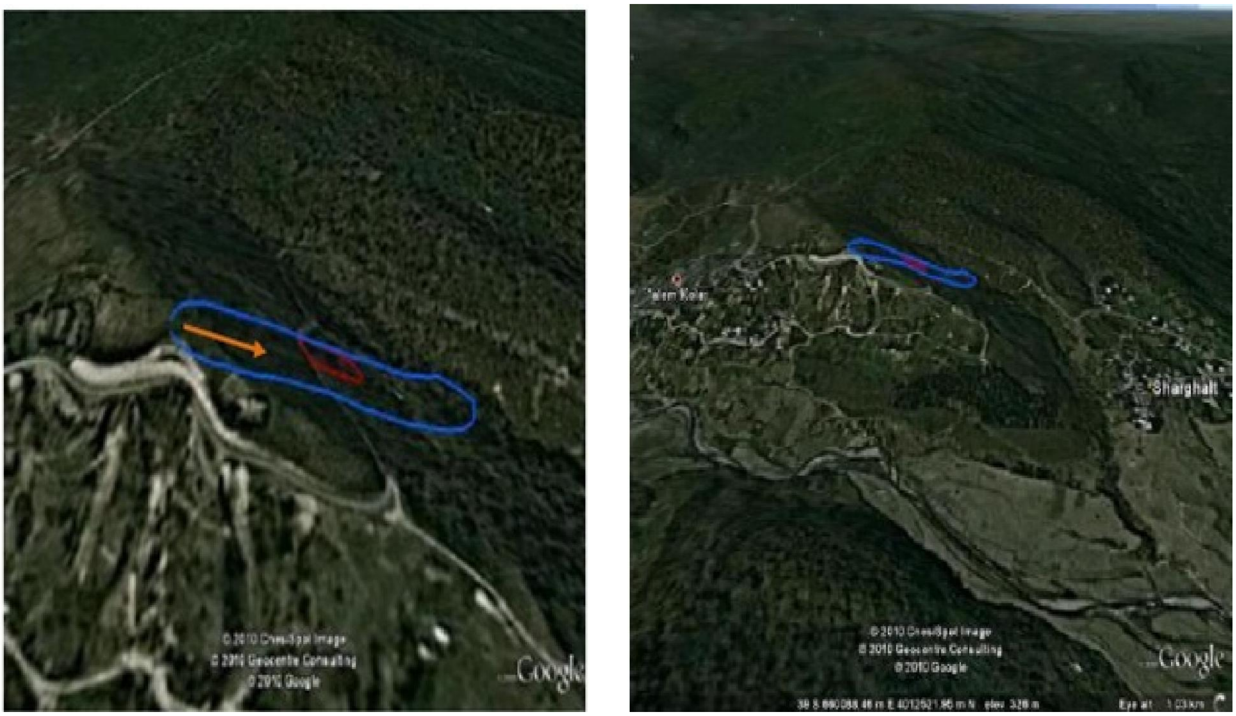


Fig. 2: Study area position

Geological parameters and characteristics which are mainly based on field observations and land surveys have important role in analyzing site conditions with respect to instability. Generally, indicators discussed in this section are as investigating sliding history of the site and surrounding areas, geometry of drifting mass and its effects on the soil and the structure, occurrence mechanism and investigating occurrence factors, classifying sliding types and also properties of materials involved in sliding. Also, the sliding area is mountainous with V-shape valleys. Dominant litho logy in the site and surrounding areas indicates that they are composed of clay and marl which the former with 5-7m thickness is on top of the latter. The studied area includes a traditional sliding outcrop which in quartz era, had multiple slide activities under saturation conditions and dynamic loadings resulted from historical earthquakes. Spreading marl-nature formations in the area as well as steep profile of hillsides influenced by tectonic governed on the area has resulted in spreading some slide formations in the area. Slope Surfaces have occurred in high-plasticity clay soils and saturation conditions on marl foundation. In the studied site, two landslides were observed. The former is the larger and main slope (landslide 1) that the time of its first main motion goes back to the ancient times and the time of its last motion is new type. Another slope is smaller and new which is located under the communication road between two villages, Sharghalt and Aalam-kola (landslide 2). The positions of these two landslides have been shown in following Figure 3.



(a) **(b)**

Fig. 3: (a) and (b) Positions of landslides in the studied area.

(a) **(b)**

Fig. 4: (a) and (b) Images from ancient landslides –landslide 1.

(a)

(b)

Fig. 5: (a) and (b) Images from new landslide under the communication road between Sharghelt and Aalam-kola - landslide 2.

Land use in mentioned area for two decades ago has been livestock in addition to crossing road between both villages. Of course, livestock and poultries had no effect in the landslide site but the road was effective in sliding because of reduction in clay layer strength. According to the visit conducted in the site, the layer on which the landslide has been occurred is of marl. The sliding has been occurred in clays located on the marl layer and still is occurring. Layer alignment on the site is no longer measurable except for landslide toe which has marl layer outcrop and alignment of these layers is at northeast-southwest and both layers have the same steepness alignment. Some motions are observed on left edge of the road which is not by site landslide and these motions are related to made ground which has been cut by dozer from mount-sided wall (on the right) in order to conduct road building operations and has been filled on the opposite side. Tilting and bending of tree trunks indicate that in addition to swift motions, there are slow motions in the site as well (Figure 6). Common methods to estimate ground motion parameters in the studied area include probabilistic and analytic methods. This estimation is conducted based on past tectonic and seismic data in the area. According to the investigations, maximum horizontal and vertical acceleration of ground motion in the area are 0.24g and 0.17g, respectively, for design baseline levels.

Fig. 6: Bending and tilting of tree trunks located on sliding mass.

3. Geotechnical studies

In order to identify subsurface texture, permeability and compressibility of studied area foundation and also geological engineering investigations, total of 3 exploratory boreholes with 47m total length was excavated, as shown in Figure 7. Excavating boreholes was conducted in alluvium with minimum 101mm in diameter by rotary and continuous coring method. To identify compressible texture, SPT test was implemented at an average spacing of about 2m.

Also, by means of single core barrel completely dry disturbed samples were obtained and soil classification laboratory tests including sieve analysis, hydrometer analysis, Atterberg limits and moisture content tests were conducted on them.

Additionally, some undisturbed samples, if possible, were obtained during excavating exploratory boreholes, on which direct shear, triaxial UU and unconfined compression tests were conducted.

3.1 Subsurface texture: according to the tests, the materials are composed of CL and CH . In other words, dominant subsurface texture in surcharge materials is of CL type soil. In addition, liquid limit (plasticity index) of materials lies in the range of 40 (18) to 56 (31) with mean 48 (25) and SD 6.1 (4.6). Stone part of boreholes was completely of marl stone type.

3.2 Compressible texture: Of total 6 SPT tests conducted in plan area, it can be concluded that dominant compressible texture of the soil is stiff and in some places very stiff.

3.3 Mechanical properties: In order to identify strength of foundation materials in studied area, unconfined compression, triaxial UU and direct shear mechanical tests was conducted on alluvial undisturbed samples accompanied by triaxial, unconfined compression and rock density (saturated and submerged) tests. The results have been shown in Tables 1-6.

Table 1: The results of unconfined compress strength test on undisturbed samples of foundation

Borehole Number	depth (m)	Natural Moisture (%)	Dry Density (kN/m^3)	q_U (kN/m^2)
BH1	2.50-3.00	36.3	13.4	55
BH3	4.00-5.00	35	13.6	29

Table 2: The results of triaxial UU test on the undisturbed samples of foundation

Borehole Number	depth (m)	C (kg/cm^2)	φ (°)
BH1	2.50-3.00	0.12	8
BH3	4.00-5.00	0.18	4

Table 3: The results of direct shear test on the undisturbed samples of foundation

Borehole Number	depth (m)	C' (kg/cm^2)	Φ' (°)
BH1	2.50-3.00	0.00	31
BH3	4.00-5.00	0.08	23

Table 4: The results of rock density tests in dry and saturated modes

Borehole Number	depth (m)	dry (g/cm^3)	Saturated (g/cm^3)
BH1	9.50-10.00	2.684	2.721
BH2	10.00-10.50	2.611	2.659

Table 5: The results of triaxial test of rock samples of foundation

Borehole Number	depth (m)	C (MPa)	φ (°)
BH1	9.50-10.00	3.82	44.7
BH2	10.00-10.50	4.55	45.9
BH3	7.50-8.00	3.99	44

Table 6: The results of compressive strength test on rock samples

Borehole Number	Depth (m)	C_c (kg/cm^2)
BH1	11.50-12.00	10.53
BH3	12.00-12.50	125.7

4. Stability analysis

There are many analytical methods to evaluate stability of man-made or natural slopes. During stability analysis, selecting appropriate analysis method is of great importance. Analysis results generally are expressed as safety factors (absolute strength to actual strength). Nowadays, the most applicable methods of slope stability analysis are Limit Equilibrium methods. This is because of their simplicity and much experience obtained by them. In this study, sliding slope stability analysis was conducted in two (static and quasi-static) conditions using Limit Equilibrium software SLOP/W version 5.16. This software is of software sets Geo Office or Geo Studio. SLOP/W software is available from 1977 in primitive format. This software was first provided by D. G. Fredlund, Saskatchewan University, Canada and was named PC-SLOP/W, then renamed to SLOP/W.

In this software, stability analysis is done using Slices method and applying various methods such as Fellenius (that mentioned in the software as ordinary method), Bishop, Janbu, Morgenstren-Price, Spencer, GLE methods and etc. Based on these methods, soil mass on top of failure surface is sliced to small sections for assumptive failure surface. Then, the values of driving and resisting forces are determined. Afterwards, safety factor is obtained as total resisting forces to total driving forces ratio. This computational procedure iterated for various failure surfaces by which one safety factor is computed for each failure. Minimum safety factor is considered as safety factor of respective slope stability. This software like all of Limit Equilibrium methods applies effects of earthquake forces in slope stability quasi-statically. This is done by applying horizontal earthquake acceleration coefficient and vertical earthquake acceleration coefficient, if needed, as a fraction of gravitational acceleration.

In order to investigate sliding slope stability, two critical cross sections, A-A and B-B, has been considered. Location of these cross sections has been shown in Figure 7. Stability analysis has been done for each cross section in two modes, static and quasi-static, in effective soil stress conditions. The results of analysis are presented in Figures 8-10. For modeling loads resulted from machinery traffic, static equivalent load, 10t, has been applied on each axel of crossing vehicle.

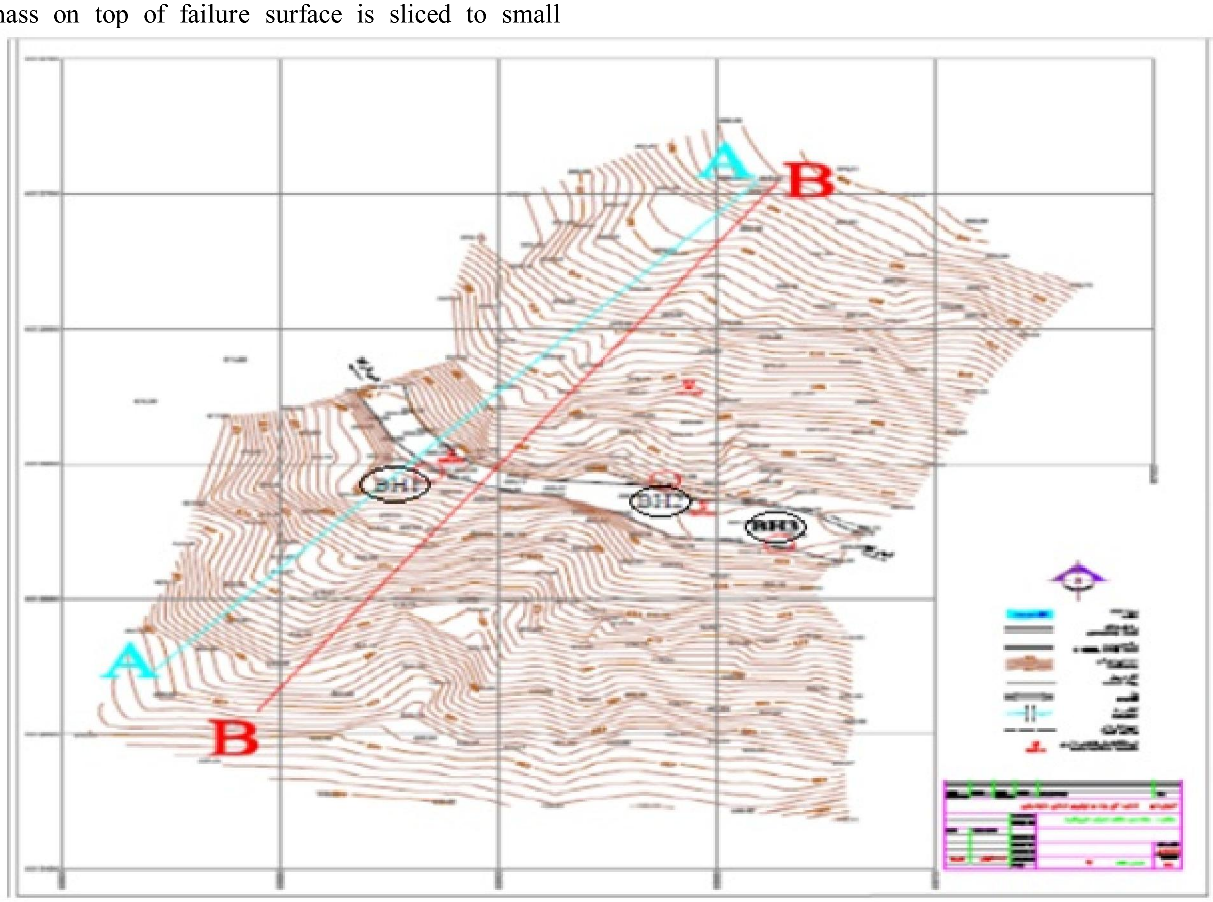


Fig. 7: Critical cross sections, A-A and B-B, and location of exploratory boreholes.

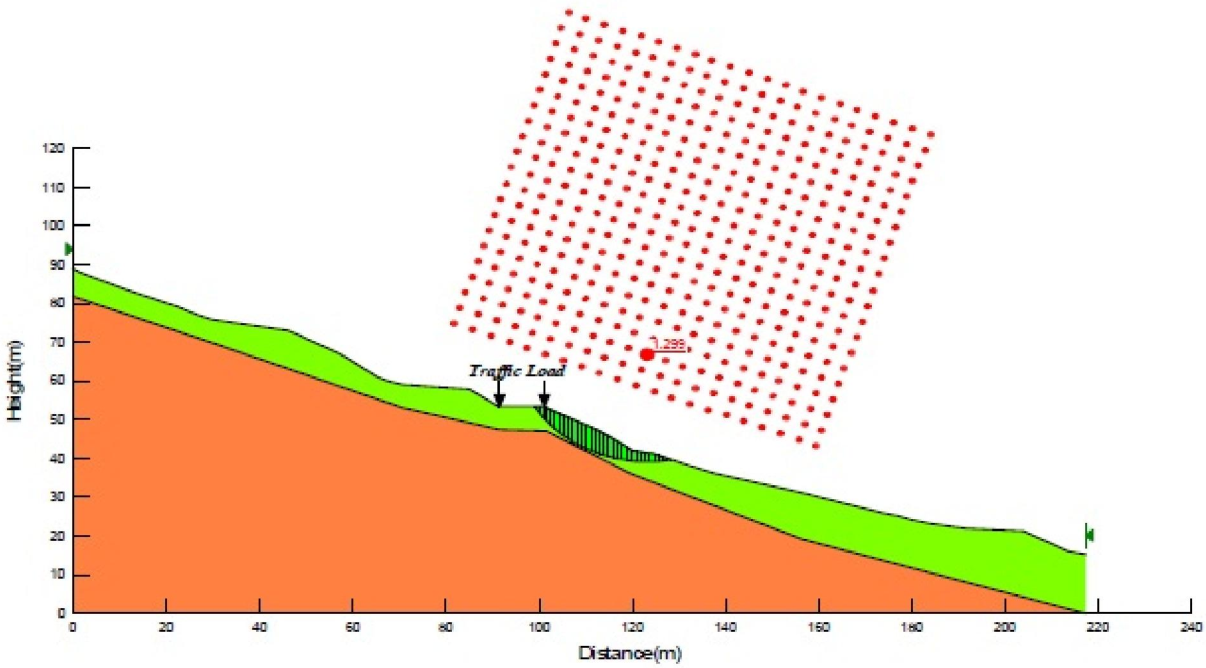


Fig. 8: Slope stability in A-A section in effective soil stress conditions (static mode)

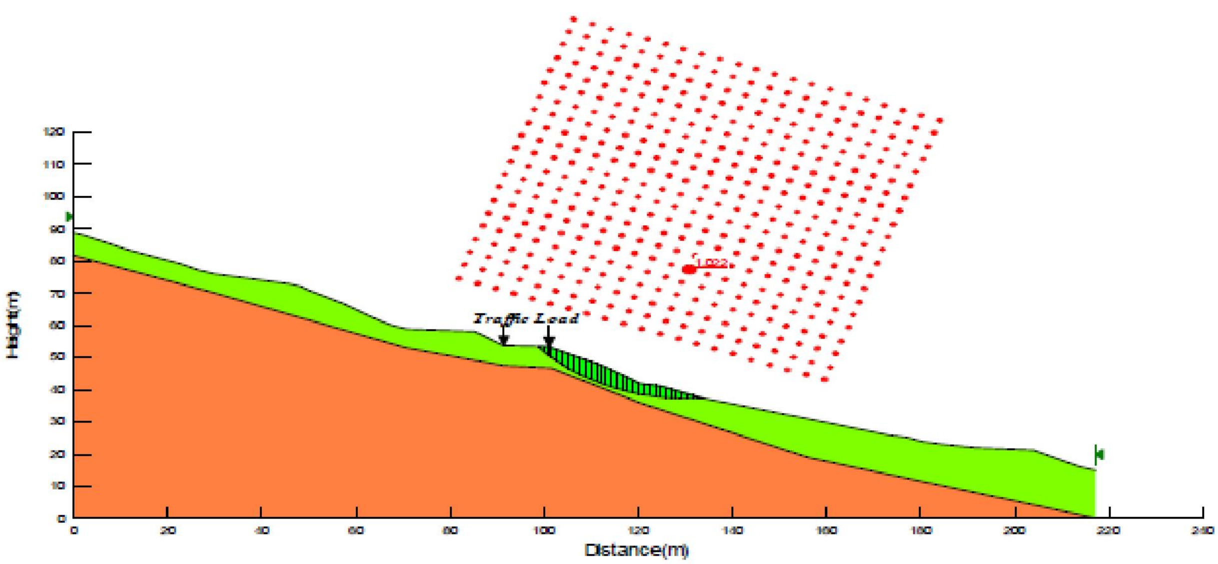


Fig. 9: Slope stability in A-A section in effective soil stress conditions (quasi-static mode)

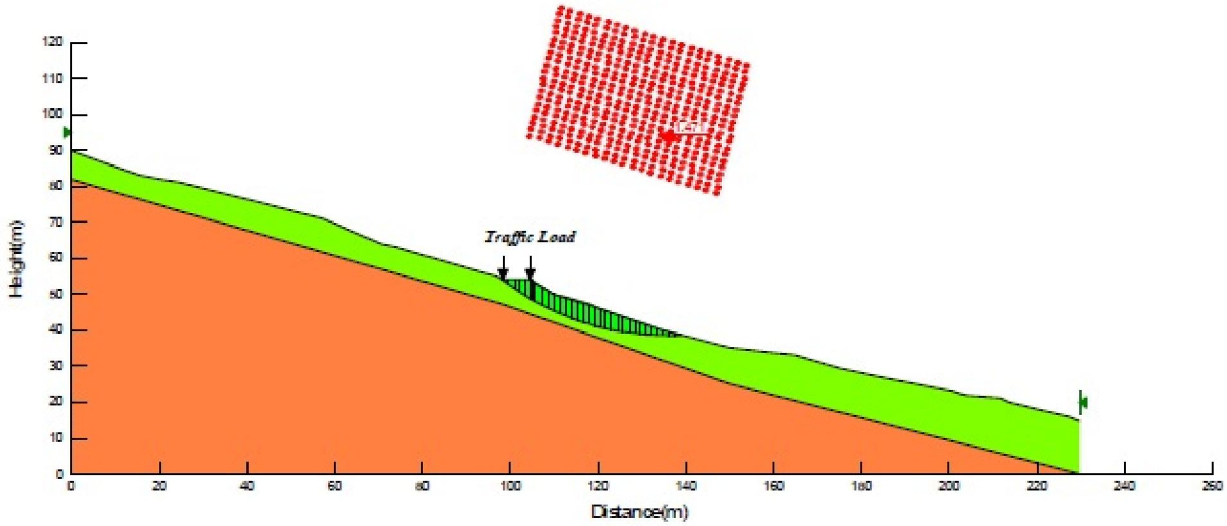


Fig. 10: Slope stability in B-B section in effective soil stress conditions (static mode)

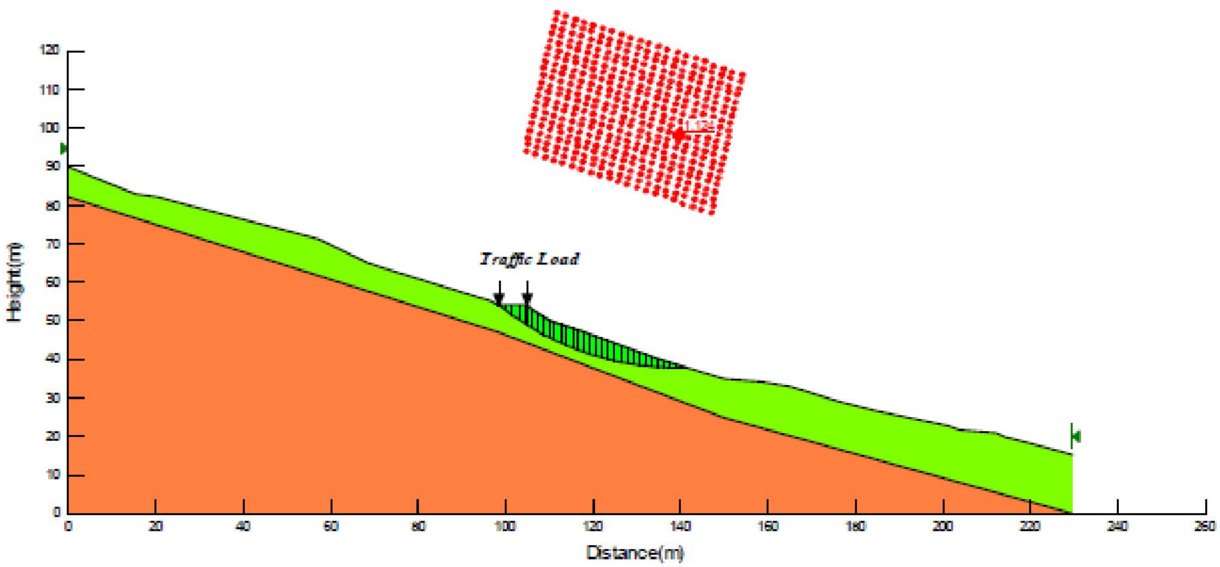


Fig. 11: Slope stability in B-B section in effective soil stress conditions (quasi-static mode)

Minimum safety factor values for sliding slope has been presented for A-A and B-B cross sections in static and quasi-static modes in Table 7.

Table 7: The results of stability analyses

	Static Mode	Quasi-static Mode
Section A-A	1.299	1.022
Section B-B	1.471	1.124

The results of stability analysis are shown that minimum safety factor in static mode is 1.299 and in quasi-static, 1.022 which are related to section A-A, applying effective soil stress parameters. In should be noted that reference safety factor for sliding in static and quasi-static modes has been considered 1.4 and 1.1, respectively.

5. Sliding slope stabilization using reinforced soil system

Reinforced soil is composed of soil structure which has been reinforced by such materials as metal strips, polymer fibers and geosynthetic plates. One of the most common materials used in reinforced soil systems is geosynthetic. Geosynthetic is a flat plate-shape product manufactured by polymeric materials and is used accompanied with soil and rock. Using geosynthetic has been increasingly developed during three decades. Geosyntetics are produced in various types and applications. Geosynthetics are classified in different types including geotextile, geogrid, geonet, clay-liner geomembrane, geopipe and geocomposite. Each geosynthetic has one main function but it can also have one or more additional functions. Geotextile is one of the most applicable subset of geosynthetics and is composed of weaving polymeric fibers as a fabric or of mixing fibers and creating a non-woven continuous plate. Geotextiles generally are classified in two group, woven and non-woven. Whereas non-woven geotextiles have more permeability and they provide drainage from compacted layers of soil, woven textiles are more resistive and stronger and they are more used to increase the stability.

Generally, reinforced soil can be considered in two system types, discrete system and composite system. In composite system, reinforcement component is no longer modeled directly and discretely and its influence is only considered by replacing reinforced soil by a homogenous, non-uniform soil mass with reinforced soil properties. The interaction between reinforcement and soil is investigated in this method not at all. But, in discrete or structural method, reinforcement component is modeled independently. In order to explain reinforced soil mechanisms, it is required to consider reinforced soil mass as a discrete system. In this system, part of shear forces of unstable soil mass are transferred within interface by two forms, friction and cohesion, to the reinforcement components. Friction is a component proportional to vertical stresses resulted from shear strength. Cohesion is related to shear strength in interface of different materials (here soil and reinforcement) and is independent of vertical stresses. As a result of this internal mechanism of stress transfer, soil mass just in sliding threshold is off limit mode and soil condition will be stable.

One of important applications of reinforced soil is construction of reinforced slopes. Using the reinforcement in earth slopes is done to:

1. Increase stability and feasibility of more steep slopes
2. Improve compressibility conditions

Stability evaluation methods for reinforced slopes are generally classified in two groups, Limit Equilibrium and Stress-Strain methods.

Limit Equilibrium analyses are the most applicable methods to analyze the stability of reinforced slopes. Overall process for this analysis method is composed of two stages:

1. Selecting appropriate failure surface,
2. Calculating required loads for proper function of slope based on selected failure surface and calculating safety factor,
3. Designing reinforcement components in order to achieve respective safety factor

Main advantages of Limit Equilibrium analysis are simplicity, accordance with actual behavior of slope and conservative design as a result of safety factor selection for failure surfaces and reinforcement components. Assumptions related to reinforced slope Limit Equilibrium analysis, in addition to assumptions for non-reinforced slopes, are inclination angle and the distribution format of reinforcement components forces on supposed failure surface.

High permeability non-woven geotextiles can be used to reinforce cohesive saturate soil. Of course, the reinforcement has also acceptable tensional strength. Clay reinforced drainage has a significant role to improve behavior of reinforced clay via geotextile layers. Surplus pore pressures cause to increase effective stress and stability as well. Also, surplus pore pressures between soil and reinforcement resulted in rise in effective stress along supported length and as a result, increasing pulling resistance. Beside two above mechanisms, increasing effective stress along geotextile, especially non-woven, will cause to improve mechanical properties of the reinforcement.

In this study, non-woven geotextile has been used to reinforce slop with 15kN/m axial resistance. Also, in order to make required analyses for reinforced slope design, Limit Equilibrium method and SLOP/W version 5.16 software was applied.

After required analyses being done to appropriate safety factors for sliding slope stability and investigating various modes, the most optimum mode was considered to design reinforcement system for sliding earth, details of which are presented in Figure 12.

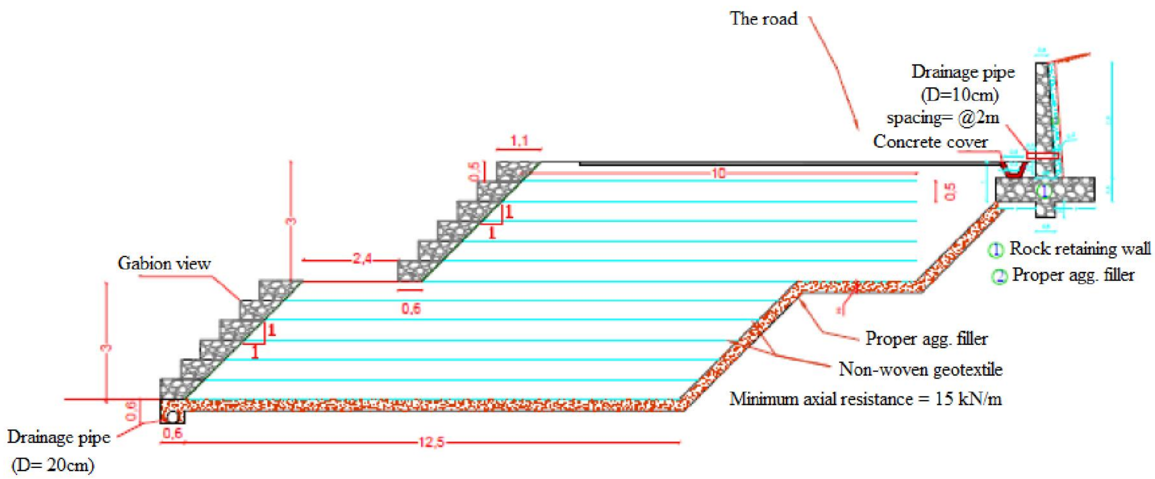


Fig. 10: The most optimum mode for stabilization system designation for sliding earth

As it can be seen, slope has been reinforced by two 3m steps with 0.5m spacing between geotextile layers. Under this reinforced system, a filler system (D=30cm) has been embedded which transfers drained water from body of reinforced fill into the drainage system located in slope toe and then drains out of sliding body by a 20cm pipe.

Stability analyses of sliding slope in critical cross section A-A has been presented for optimum mode, shown in Figure 10 and the results has been obtained for two modes, static and quasi static, shown in Figures 11 and 12, respectively. As it can be seen, safety factors against sliding after stabilization for this critical cross section have been 1.390 and 1.679 in both static and quasi-static modes, respectively which are more than minimum requirements for safety factor.

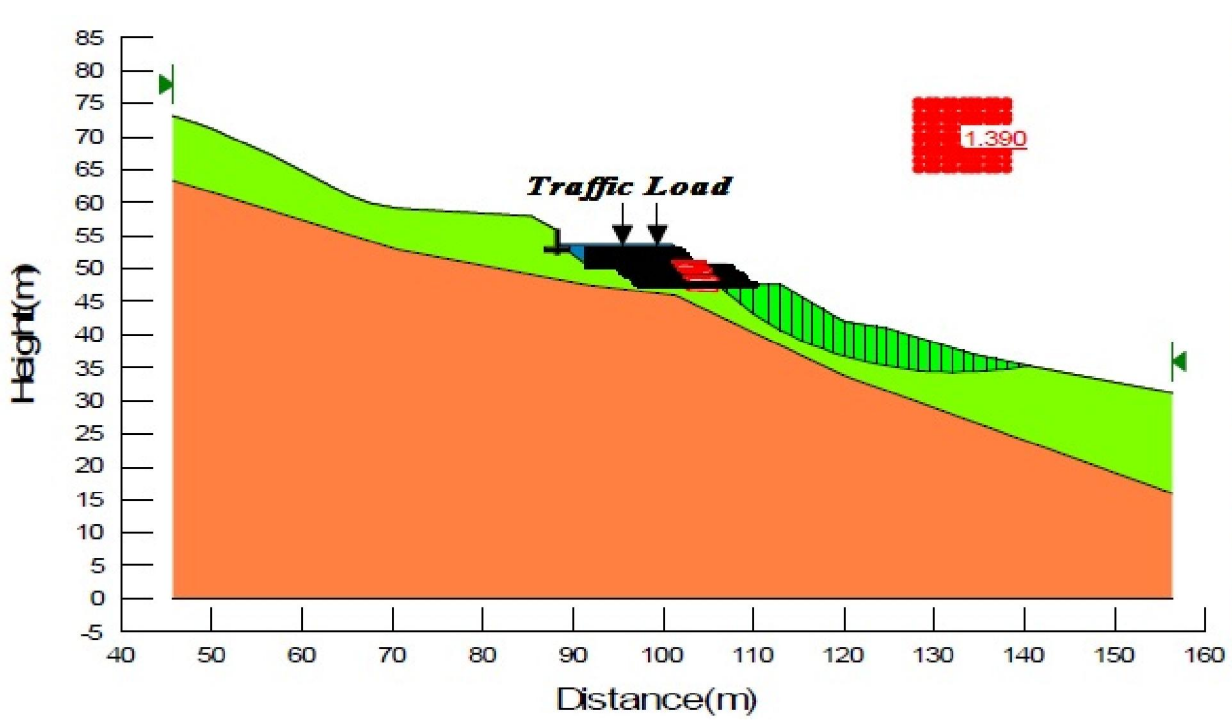


Fig. 11: Slope stability in A-A cross section in option 2 after sliding stabilization (static mode)

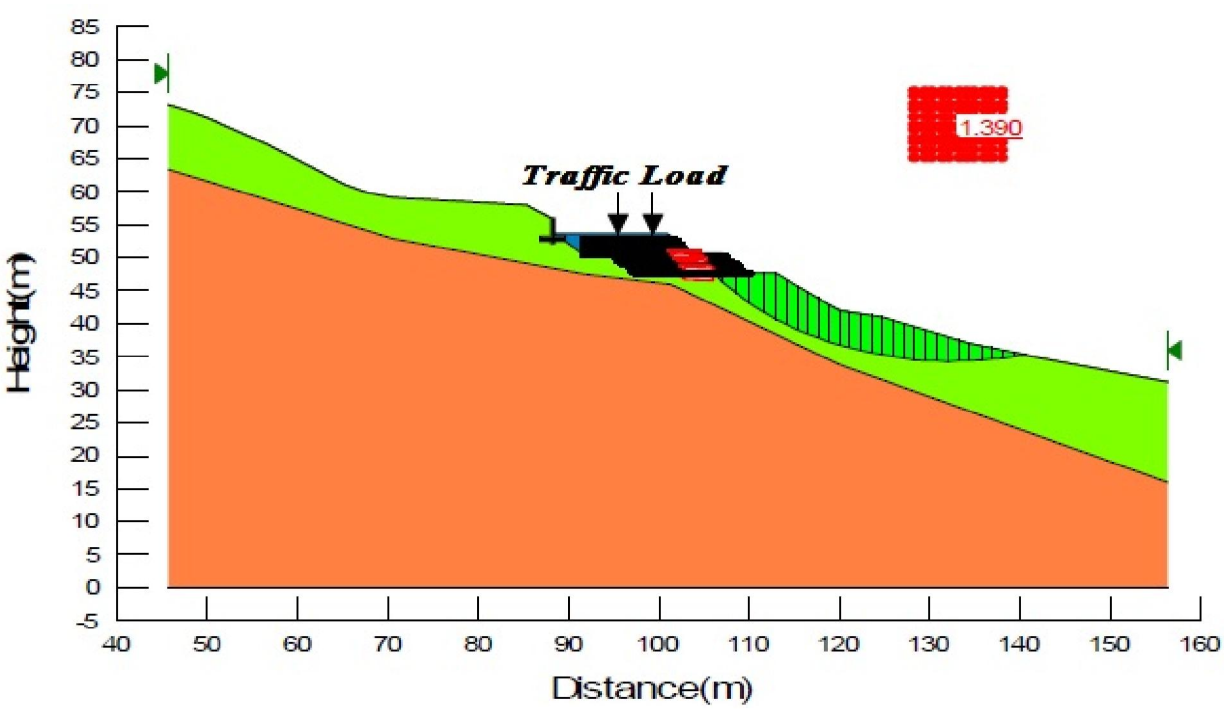


Fig. 12: Slope stability in A-A cross section in option 2 after sliding stabilization (quasi-static mode)

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