Economic Analysis of Reinforced Slopes Using Slope/W for Different Boundary Conditions

Tinshukh Patel, Jigisha Vashi, Anand Daftardar, and Prateek Somani

Abstract Soil slopes can be either natural or manmade. Design and study of soil slopes involve a critical activity i.e. analyzing its stability. Ascertaining the stability can help preventing a slope failure and also help in redesign of failed slope. It involves identifying the critical failure surface approximately and determining corresponding factor of safety. Stability of slope is ascertained by means of factor of safety to a slope's critical failure surface. Slope failures caused by landslide are one of the most important geotechnical hazards that can cause severe damage to important structures and human lives. With advent of software programming, computer modeling, analyzing and examining slope stability problems for the different analytical methods developed has become an easy task. A slope of height 5 m is analyzed for Dhule district of Maharashtra region using locally available soil using a renowned geotechnical slope stability software Slope/W considering static condition in the present study. A dry and partially saturated slope stability study is also conducted to validate the slope's safety in a flooded situation. The observed factor of safety is lacking; thus, strengthening was required by reinforcement. Two different tensile strength geotextiles were used as reinforcement material which aims to ensure stability, safety and economy over its life span. Several models were analyzed and the research findings for the above data were compared. Slope's factor of safety changes in boundary conditions from dry to partly saturated to unreinforced to reinforcement for a given slope configuration. This study recommended a stable and economical reinforced slope using geotextile in both dry and partly saturated conditions which can be of great help to prevent the failure.

Keywords Limit equilibrium method · Slope stability · Factor of safety · Reinforcement · Economy

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1 Introduction

Slopes can be natural or manmade. Soil/Rock mass usually tend to have an inclined sloping face which may be either supported or unsupported. Sloping mass loses contact due to destabilizing forces and undergoes a downward movement rapidly, known as landslide or slope failure. Failure of slopes cause damage to infrastructure, loss of life and decrease the quality of soil. Hence, design of stable slope is the main interest of geotechnical engineers. In the recent era, attention is given to use reinforcement of soil for analyzing slopes to reduce the deformations by increasing the stability of slopes. The modern concept of soil reinforcement was developed by [1]. According to Vidal's theory, the only contact between soil and horizontal reinforcing elements is friction caused by gravity.

In slope stability analysis the parameters affecting are impacting the results for FS are the slope geometry, its boundary conditions and soil properties. The slope stability evaluations are irrelevant unless proper input of these parameters are utilized in the computations. Many authors have highlighted the importance of the quality of the input parameters [2]. When the slope configuration and soil characteristics are known, the analysis of slope stability is performed using computer programmes. The selection of a certain slope stability analysis approach is contingent on field circumstances and failure data to comprehend the failure cause. The conventional methods of stability analysis of slopes are based on limit state design using Slope/W [3] software was used in the present study. Limit equilibrium methods (LEMs) used for this research include Bishop's simplified method (BSM), which is mostly used to estimate the global stability of homogenous soil slopes with circular slip surfaces. The sliding mass is divided into slices, to assess the stability of slopes and derive the associated FS. The Bishop approach has been determined to be sufficiently accurate in terms of tiny deviations from actual slope FS. While researchers have not fully understood the theoretical causes of this phenomenon [4, 5] suggests that its accuracy is comparable to more complex methods developed in subsequent years (e.g., Spencer method). According to [6, 7], the FS is unaffected by the inclination of the interslice forces, hence the Bishop method's assumptions have less impact on the results.

While analyzing slope geometry, if the factor of safety obtained is unsatisfactory then, reinforcement is provided for the stability of the slope [8]. Two different strength geotextiles are used as reinforcement for static condition and optimum reinforcement material with optimum layers required for slope stability is proposed in this study. The economic design of a reinforced slope is concluded by analyzing the geotextile's cost calculation.

2 Materials and Methodology

Analysis of road slope is carried out using locally available silty loose sand from Dhule district of Maharashtra region. Table 1 shows the mechanical and physical characteristics of silty, loose sand used in slope analysis.

The properties of the TF-41 geotextile and TF-42 geotextile used in this study were provided by Techno fabrics Geo-synthetics Pvt. Ltd.‟ in Surat, Gujrat, India (Table 2). In the current research, the values of reduction factors (RF) for the geotextile are $RF_{\text{Installation Damage}} = 1.05$ calculated as per ASTM D4595 Test Method, $RF_{\text{Environmental impacts}} = 1.1$ as per ASTM D5322, and $RF_{\text{creep}} = 1.46$ as per ASTM D5262. These reduction factor values were identified by the manufacturing enterprise via direct testing and measurement.

2.1 *Slope Stability Analysis*

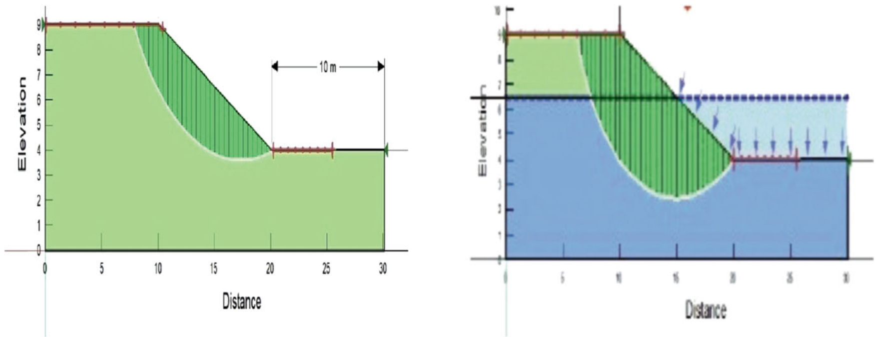
For the stable slope analysis two approaches were considered as boundary condition. The slope is analyzed with the barrow material from Dhule district of Maharashtra region and the properties in dry conditions (DC) and partly saturated condition (PSC)

Table 1 Characteristics of soil

Dry density (kN/m^3)	Cohesion (kPa)	Friction angle (Deg)	Void ratio
14.8	3.8	30	0.74
15.5	4.6	32	0.79
16.0	5.4	33	0.68

Table 2 Properties of geotextile

Properties		TF−41	TF−42
Mass per unit area		> 130 g/m^2	> 240 g/m^2
Tensile strength	Warp	> 30 kN/m	> 55 kN/m
	Weft	> 27 kN/m	> 40 kN/m
Elongation at designation load	Warp	< 30%	< 25%
	Weft	< 28%	< 25%
Trapezoidal tear strength	Warp	> 400 N	> 1100 N
	Weft	> 350 N	> 750 N
Puncture strength		> 400 N	> 600 N
Apparent opening size		< 75µ	< 150µ
Water permeability		> 9 L/m/s	> 32 L/m/s



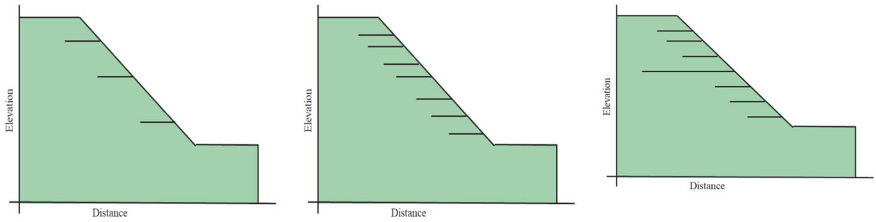
(a) Dry condition (b) Partly saturated condition

Fig. 1 Geometry of slope without reinforcing

are considered. Considered and assessed under static loading conditions, the determined factor of safety is less than 1.3 in both DC and PSC cases for a slope section with a ratio of 1:1.5. Therefore, reinforcement is essential for the evaluation of a stable and effective slope. Utilizing Bishop's approach, Slope/W Software was used to calculate the factor of safety under static loading circumstances. Figure 1 depicts the slope analysis and slope failure in the absence of reinforcement, based on a slope section height of 5 m.

2.2 Reinforcement with Geotextile

Initially, three coats of TF-41 geotextiles are utilised as reinforcement at equal intervals in height of the slope (Fig. 2a). The factor of safety increases somewhat, but the slope is still unstable. In the second stage, seven layers of TF-41 geotextiles were applied as reinforcement at a distance of 0.7 m apart (Fig. 2b). The factor of safety increased significantly in the DC scenario, while the slope was unstable in the PSC condition. By extending the intermediate layer of the TF-41 geotextile to 4.0 m to avoid local failures in that location, Fig. 2c indicates that the attained factor of safety is adequate in both the DC and PSC scenarios; hence, the slope is stable. In the subsequent instance, a high-strength TF-42 geotextile is used as reinforcement. Two-meter-long geotextiles are given at equal distances. The calculated factor of safety is satisfactory. The factor of safety gained following slope reinforcement is shown in Table 3. It is noticed that the factor of safety is sufficient after expanding the intermediate coat of the TF-41 geotextile using Bishop's approach in comparison to previously applied reinforcements for both DC and PSC cases. In the case of TF-42, however, because to its greater strength, three layers of the TF-42 geotextile are adequate for both DC and PSC slope stability in the location.



(a). Reinforcement with 3 layers

(b). Reinforcement with 7 layers

(c). Reinforcement with middle layer extended geotextile

Fig. 2 Geometry of slope with reinforcement

Table 3 Factor of safety of various models of slope

Slope without reinforcement		Geotextile		Reinforced slope with 3 layer	Reinforced slope with 7 layer	Extended layer of geotextile
DC	0.975	TF-41	DC	1.213	1.302	1.497
			PSC	0.962	1.165	1.381
PSC	0.681	TF-42	DC	1.472	–	–
			PSC	1.355	–	–

2.3 *Cost Analysis*

In order to know the most economical reinforced slope, local market price of the geotextile is a significant factor for this analysis. The cost of the TF-41 geotextile is 30 rs/- per sqm and the TF-42 geotextile is 40 rs/- per sqm as provided by the manufacturer considering taxes and excise duty. Table 4 shows the cost analysis of the geotextile for the reinforced slope. Hence, it can be seen that the 3 layered reinforced slope using the TF-42 geotextile over the 7 layer TF-41 geotextile reduces the cost by 42.85% and 50% in case of extended 7 layer of the TF-41 geotextile considering the factor of safety.

Table 4 Cost comparisons of various reinforced slopes

No. of layers of geotextile	3	7	7 layer with extended length
Quantity of geotextile required per layer in m^2	6000	14,000	16,000
Cost of TF-41 geotextile in Rs/-	180,000	420,000	480,000
Cost of TF-42 geotextile in Rs/-	240,000	–	–

3 Conclusion

For an effective and stable slope, it is necessary to lower the reinforcement's vertical spacing. In the case of DC, the slope is stabilized by seven layers of the TF-41 geotextile, with the center layer extending twice as far as the other layers, and three layers of the TF-42 geotextile. In the case of PSC, however, an extra layer of TF-41 and TF-42 geotextiles is necessary for slope stability. In both the DC and PSC cases, it was noted that the use of geotextiles with a greater tensile strength for slope reinforcement results in a cost reduction of 40 to 50 percent. However, for further investigation, geogrid may be used as reinforcement due to its simplicity of installation, which is noteworthy in contrast to many geotextile layers that need repeated compaction of soil.

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