Design charts for low-height geotextile-reinforced sand slopes

Emmanuel Baah-Frempong, Sanjay Kumar Shukla & Hang Vu
Edith Cowan University, Australia

ABSTRACT: Landscaping is one of the activities that takes place along with infrastructural developments in most cities all over the world. In landscaping projects, there is often a possibility of construction of low-height sandy slopes, typically varying in height from 1 m to 3 m. At certain locations, if a steep slope is required, it becomes essential to reinforce the slope with one or more geotextile layers at some specific spacing to prevent slope failure and enhance slope stability. In this paper, an attempt is made to analyze the effect of shear strength parameters on the factor of safety of low-height unreinforced and geotextile-reinforced sandy slopes, using the limit equilibrium analysis based on Slope/W software. The slope height has been considered 3 m, with angles ranging from 40° to 60°. The study has shown that increasing the cohesion and friction angle of the sandy soil improves the factor of safety of both unreinforced and reinforced slopes. The best improvement in factor of safety is observed in all the soils analyzed for cohesion of 1 kPa. Design charts, for estimation of the factor of safety, have been developed for all the slope angles and various soils considered. An illustrative example has been included so that the geotechnical engineers can understand how to use the design charts. A similar design chart can be prepared for other heights, including medium and high values.

Keywords: Geotextile, Reinforce, Design charts, Slope stability, Landscape, Infrastructural Development

1 INTRODUCTION

Infrastructural development in cities across the globe, including Perth, Western Australia, are often associated with landscape works. Figure 1 shows an example of landscape work in Perth, in which a stone wall has been utilized to support a low-height sandy soil which is the main soil type in Perth and its surrounding areas. However, some landscape projects may involve a low-height steep slope that may not need a stone wall support as shown in Figure 1. In such cases, the slopes can be reinforced with geosynthetic layers (geotextile or geogrid), to improve the stability, defined in terms of factor of safety *F* to an acceptable value. Geosynthetic layers have proven to be effective and economical in improving the mechanical properties of soils, and moreover, they allow to construct environmentally friendly and sustainable structures (Shukla et al. 2009; Berg et al. 2009).

Figure 1. Typical landscape work in Western Australia

The performance of geosynthetic reinforced slopes has been studied in the past by many researchers. These studies evaluated the effect of the following factors on the bearing capacity and settlement behavior of loaded footing placed on the slope crest: reinforcement type, number and vertical spacing between reinforcement layers, relative density of sand, slope angle, footing edge distance from the crest of slope and reinforcement length. (Lee and Manjunah 2000, Alamshahi and Hataf 2009, Gill et al. 2013, Naeini et al. 2012, Salih Keskin and Laman 2014). The outcome of these research has established that reinforcing slopes with geosynthetic layers significantly improves the bearing capacity of the footing and reduces settlement.

The literature shows that there is a limited study on the stability analysis of reinforced slopes that are not subjected to footing loads on the crest. A typical application of the outcome of such investigations is landscape works. Mehdipour et al. (2013) investigated the stability of slopes reinforced with with geocell layers. They established that the inclusion of geocell layers in the slope improved the factor of safety and reduced horizontal deformation. Baah-Frempong and Shukla (2018) have recently conducted a study on the influence of geosynthetic layer(s) on the stability of a 3-m height medium dense sandy slope with angles varying from the 40° to the 60°, and determined the optimum reinforcement layout that provides the maximum improvement in factor of safety. The study also provided insight into various practical aspects, which will be highly useful for civil/geotechnical engineers involved in landscape projects.

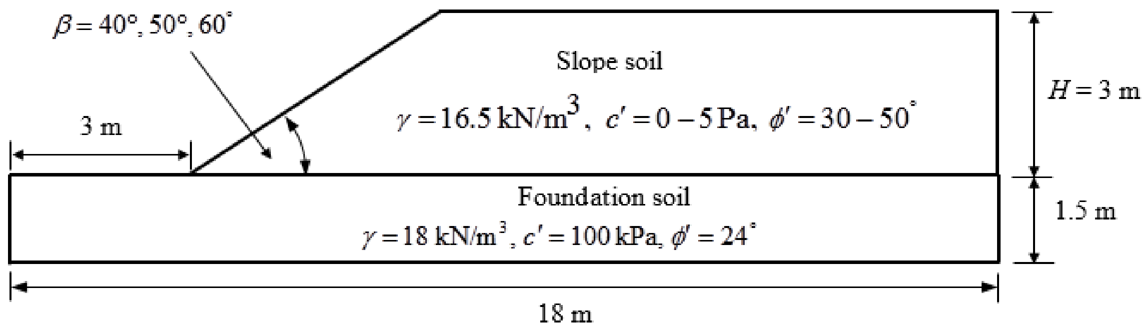
Design charts are tools used for preliminary assessment of slope stability and estimating the strength parameters of failed slopes to assist in planning remedial stabilization works. However for low-risk slopes with steep angles and low heights (1 m to 3 m), design charts are adequate to evaluate the stability without carrying out stability analysis in significant details. Researchers in the past have produced several design charts for reinforced slopes (Ingold 1982; Jewell et at. 1984; Leshchinsky and Reinschmidt 1985; Jewell 1991; Mandal and Joshi 1996; Michalowski 1997; Zhu et al. 2014)

Ingold (1982) presented an analytical study of embankments reinforced with geosynthetic layers. The study used infinite slope to assess the possibility of minor instability at the reinforced slope face and developed design chart to determine whether there is a sufficient factor of safety against surficial instability. Jewell et al. (1984) utilized a two-part wedge analysis to develop charts for preliminary design of steep geogrid reinforced slopes with angles varying from 30° to 80°. Leshchinsky and Reinschmidt (1985) evaluated the stability of a membrane reinforced slopes using analytical methods and established that there exist two possible failure within the slope: rotational and translational. The investigation also produced design charts which show a relationship between the soil properties, slope geometry and factor of safety. Jewell (1991) improved the existing reinforced slope design charts produced by Jewell et al. (1984) to use less reinforcement material but maintained the same level of safety. The new design charts replaced the existing ones and can be used to analyse reinforced slopes with angles ranging from 30° to 90°. Mandal and Joshi (1996) investigated the stability of clay embankment constructed over soft soil with geosynthetic layer placed at the embankment-soft soil foundation interface. They presented design charts that utilize the slope height, foundation layer thickness, embankment and foundation soil properties to estimate the required tensile strength of the geosynthetic layer to provide adequate slope stability. Michalowski (1997) analyzed the stability of slopes with geosynthetic layers installed at equal vertical spacing throught the slope height. The investigation produced design charts that can determine the required reinforcement strength and length to prevent slope failure. Zhu et al. (2014) prepared charts for quick assessment of the stability of stacked geotextile tubes. The charts allowed the factor of safety to be evaluated base on the slope geometry and material (soil and geotextile) properties.

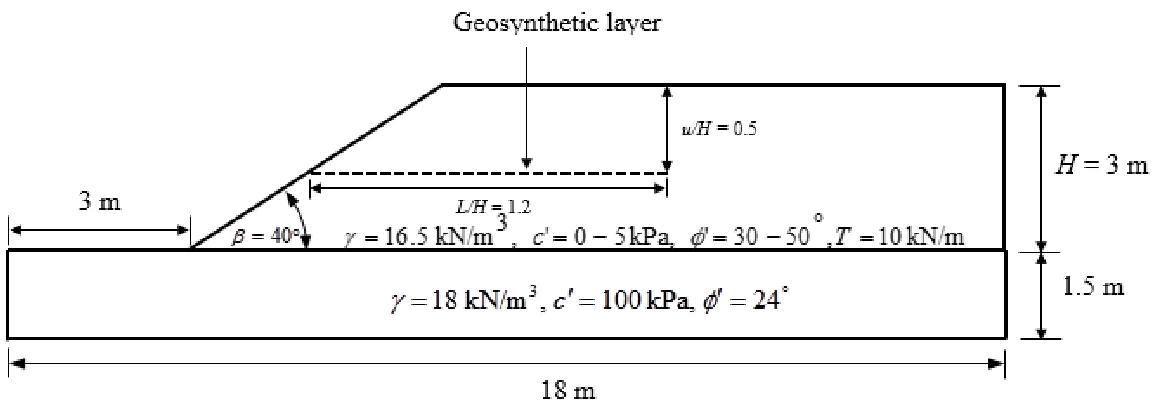
Although previous studies have produced slope design charts for reinforced slopes, none of these was purposely developed for direct use by landscape developers in estimating the factor of safety of reinforced low-height sandy slopes, although landscape development involves multi-million projects in most countries, especially developed ones. Therefore, in this paper, an attempt is made to develop stability charts of a 3-m high geotextile-reinforced sandy slope, for angles ranging from 40° to 60° using the limit equilibrium method, as commonly dealt with developers.

2. SLOPE PROPERTIES AND REINFORCEMENT LAYOUT DETAIL

The configuration of the slopes and soil properties, along with geosynthetic reinforcement layout considered in this study are shown in Figure 2 (a-d). The geosynthetic arrangement in Figure 2 (b-d) is the optimum layout determined by Baah-Frempong and Shukla (2018) from studying the effect of geosynthetic layers on the stability of a 3-m high, medium dense, sandy slope with γ=16.5 kN/m^3 , c'=0.8 kPa, ϕ'=37° and slope angle, β=40°, 50°, 60° . The geosynthetic layer in the 40° slope has an optiumum depth (u) to height (H) ratio (u/H) of 0.5, a length L to height H ratio (L/H) of 1.2 and tensile strength T=10 kN/m. The 50° and 60° slopes on the other hand have two geosynthetic layers. The top and bottom layers in the 50° slope are positioned at u/H=0.14 and u/H=0.5 with corresponding L/H =1.2 and L/H =0.8. Similary, u/H of the top and bottom geosynthetic layers in the 60° slope are respectively 0.19 and 0.5. The top layer has L/H =1.8 and the bottom layer L/H =0.8. The geosynthetic layers in the 50° slope have optimum T=15 kN/m while those within the 60° slope have T=10 kN/m.



(a)



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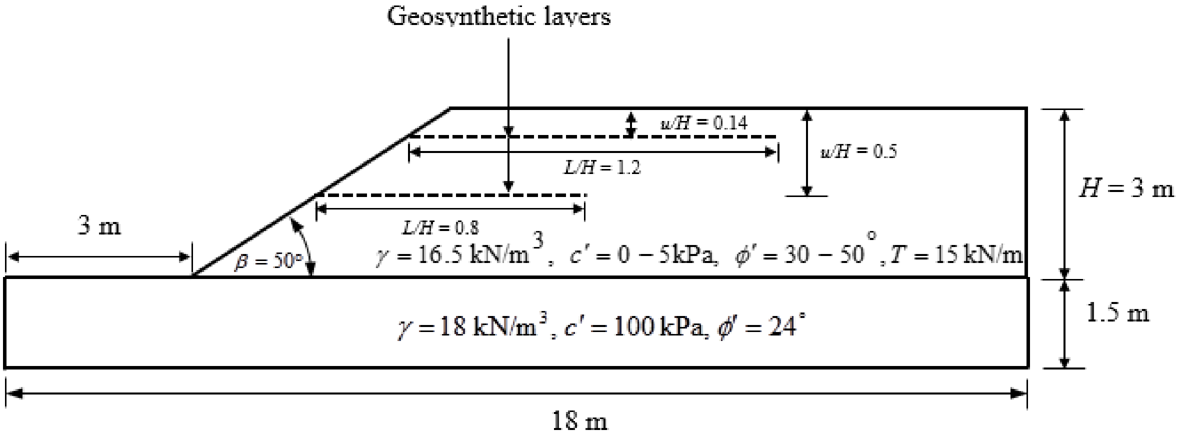

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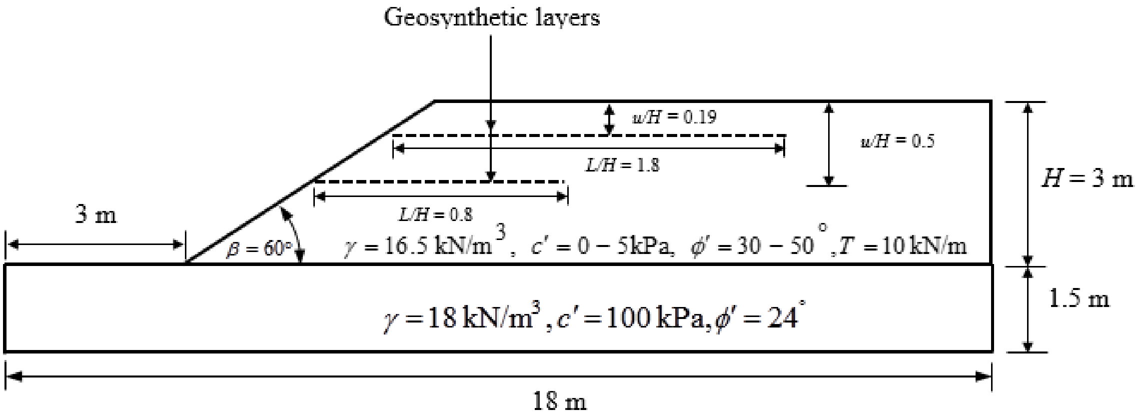


(d)

Figure 2. Slope geometry, reinforcement layout and soil parameters used in the study: (a) 40°, 50°, 60° unreinforced slope; (b) 40° reinforced slope; (c) 50° reinforced slope; (d) 60° reinforced slope.

3. STABILITY ANALYSIS AND DEVELOPMENT OF DESIGN CHARTS

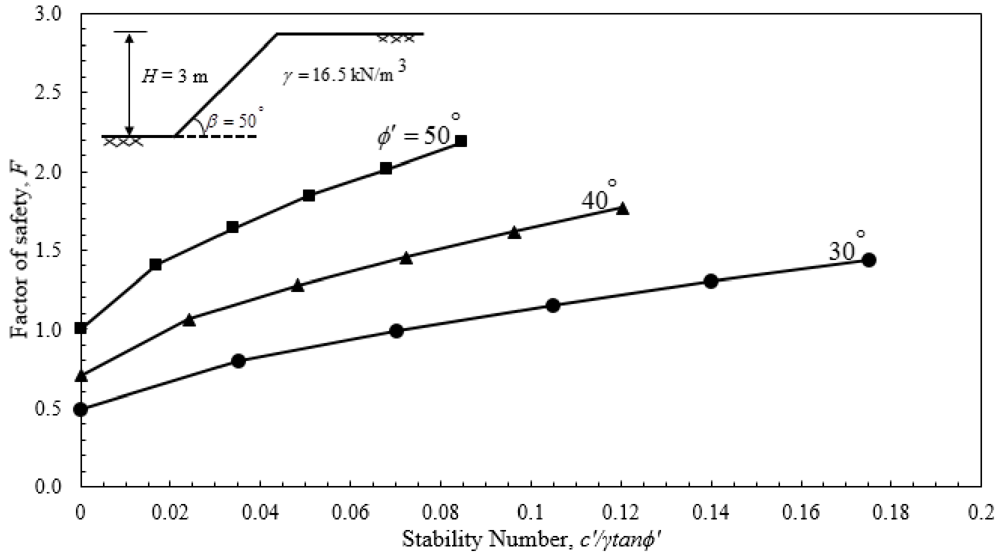
The stability analysis of the slopes presented in Figure 2 (a-d) was carried out using the limit equilibrium method (LEM) provided in a commercial software, Slope/W. It should be noted that Slope/W has also been used by other researchers (Sun and Zhao 2013, Seward et al. 2011) to develop stability charts. The slope stability modelling was conducted by adopting the Morgenstern-Price method of analysis, auto-locate critical slip surface search technique, Mohr-Coulomb soil model and reinforcement fabric option in the software. Details on the modelling process has been discussed by Baah-Frempong and Shukla (2018)

Based on the model validation carried out by Baah-Frempong and Shukla (2018) using data reported by Zonberg et al. (1998) and Tiwari and Samadhiya (2016) for reinforced slopes, a parametric study was carried out on the 40°, 50°, and 60° slopes (unreinforced and reinforced) as presented in Figure 2 (a-d) by varying the slope soil strength parameters (*c'* from 0 to 5 kPa and *ϕ'* from 30° to 50°), while keeping the slope height, geosynthetic layout and soil unit weight constant, to determine their effect on the factor of safety, *F*. The range of *c'* and *ϕ'* adopted in the study are typical of sandy soils often encountered in landscape projects.

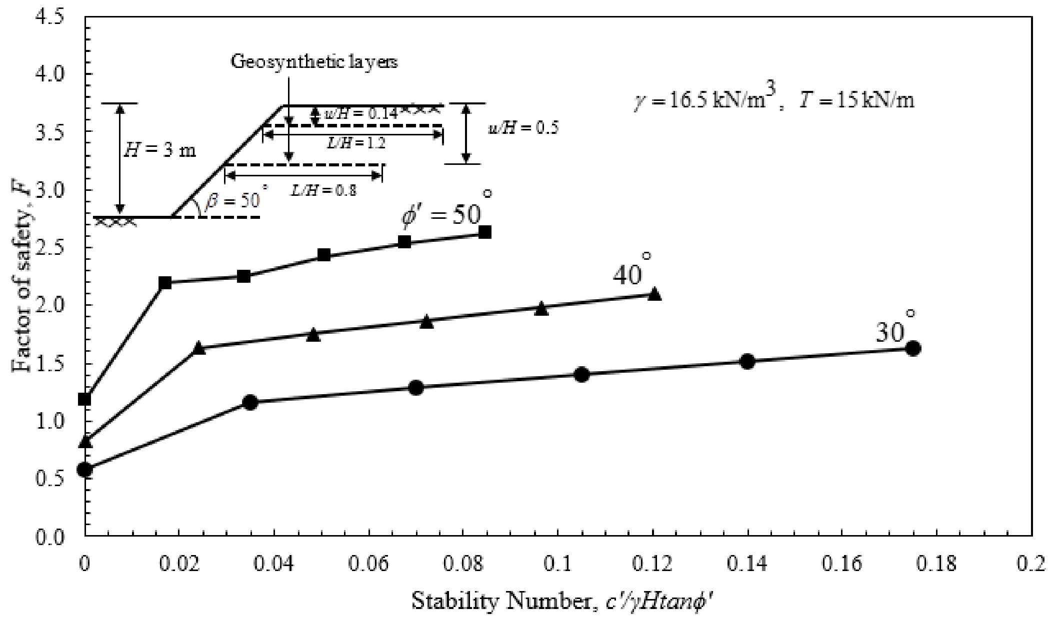
Six cases in all were analyzed and a dimensionless stability number (*N*) defined in Eq. (1) (Michalowski 2002) was calculated for each case analyzed. Typical relationship between *F* and *N* for each analysis is presented as design charts in Figure 3 (a-b).

$$N = c'/\gamma H \tan \phi' \quad (1)$$

where *c'* and *ϕ'* are the effective shear strength parameters of the slope soil, and *γ* and *H* are unit weight of soil and slope height, respectively.



(a)



(b)

Figure 3. Typical design chart: (a) 50° unreinforced slope; (b) 50° reinforced slope.

It is observed that *F* improves with an increase in *N* and *ϕ'* values in both unreinforced and reinforced slope irrespective of the slope angle. It is further noticed that for a constant value of *ϕ'*, *N* increases with increasing *c'* and for a fixed value of *c'*, *N* decreases with an increase in *ϕ'*.

The benefit derived from reinforcing the slopes (β=40°, 50°, 60°) with geosynthetic layer(s) is evaluated using a non-dimensional parameter called improvement factor (*IF*) defined in Eq. (2) (Mehdipour et al. 2013).

$$IF = F_r / F_{ur} \tag{2}$$

where F_r and F_{ur} are the factors of safety for reinforced and unreformed slopes, respectively.

A typical variation of *IF* with *c'* for various ϕ' values is presented in Figure 4.

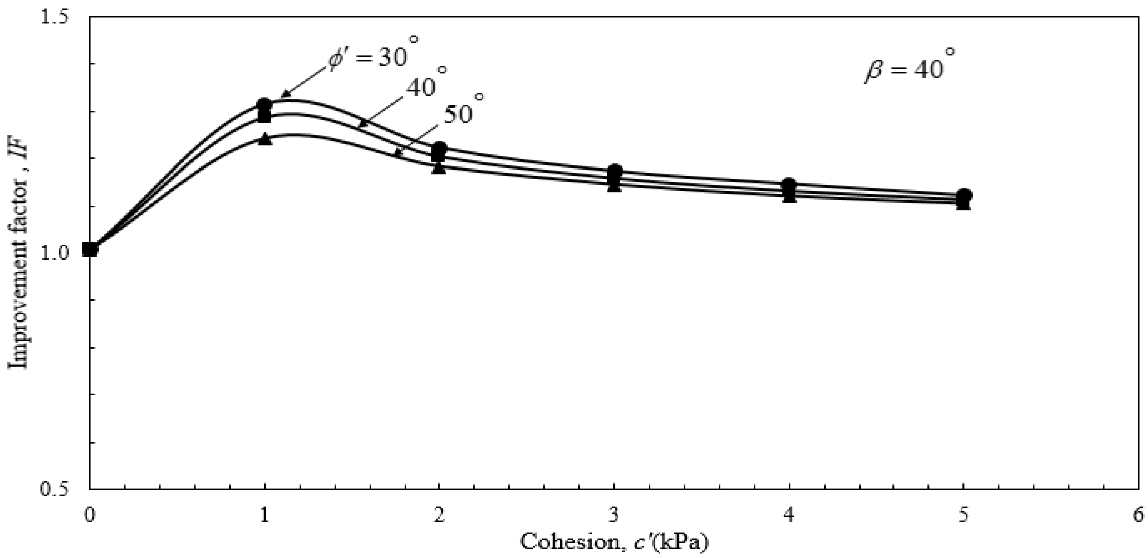


Figure 4. Variation of *IF* with *c'*

It is observed that placing geosynthetic layer(s) within the slopes increase the factor of safety. *IF* Increases with increasing *c'* to a maximum value at *c'*=1 kPa then reduces for c'>1 kPa. Thus, it can be stated that the maximum improvement in *F* is attained when *c'*=1 kPa

4. APPLICATION EXAMPLE

An example is presented here to demonstrate the application of the developed stability charts. Let us consider the following problem:
Determine the factor of safety of a reinforced and unreinforced sandy soil slope with $\beta=50^\circ$, $\gamma=16.5$ kN/m^3, $c'=1$ kPa, $\phi'=33^\circ$, and $H=3$ m

4.1 *Solution*

It is first required to calculate the stability number, $N = c'/\gamma H \tan\phi'$. For this case $N=0.03$. Using the calculated *N* value and the stability charts presented in Figure 3 (a-b), the factors of safety for the unreinforced and reinforce slopes are calculated to be 0.85 and 1.25, respectively. It is shown in this analysis that reinforcing the slope will improve *F* by 47% (almost double) from unstable state ($F<1$) to a stable condition (F = 1.25).

5. CONCLUSIONS

A parametric study has been conducted to determine the influence of soil strength parameters on the factor of safety of low-height (3 m) unreinforced and reinforced slopes with varying angles from 40° to 60°. The study was conducted using the limit equilibrium method, available in the commercial software, Slope/W. Based on the results and discussion, it is generally concluded that increasing the strength parameters of the sandy soil improves the factor of safety of both reinforced and unreinforced slopes. The maximum improvement in the factor of safety occurs at *c'*=1 kPa. Design charts have been developed for direct use by geotechnical engineers to estimate the factor of safety of low-height slopes for landscape development. The illustrative example explains how the design charts can be used by geotechnical engineers involved in landscape projects.

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