Geotech Geol Eng (2019) 37:2007–2014
https://doi.org/10.1007/s10706-018-0740-3

ORIGINAL PAPER

Significance of Surface Eco-Protection Techniques for Cohesive Soils Slope in Selangor, Malaysia

Meldi Suhatril · Normaniza Osman · Puteri Azura Sari · Mahdi Shariati · Aminaton Marto

Received: 22 January 2018 / Accepted: 8 November 2018 / Published online: 16 November 2018

Abstract Rapid infrastructure development in Malaysia especially in Selangor causes drastic change in landscape and clearing of more vegetated areas. This has gradually lead to slope instability problems that causes enormous loss affecting human lives, destruction of property and environment. Thus, conservation practices by incorporating vegetation to enhance slope stability is much needed alternative to the conventional technique of stabilization. Limited studies had been done in discovering the effectiveness of vegetative covers in relation to slope and soil parameters. Hence, in this paper, a parametric study is carried out to discover the relationship between some of the various vegetation species and different soil types as well as slope angles. Conventional limit equilibrium methods are applied in the analysis considering the soil shear strength parameters, unit weight of soil, as well as slope geometry. Typical scenarios of cut-slope along highways in Selangor are simulated in order to obtain comparable results from the stability assessment by means of calculating the factor of safety. The modelling showed that shallow slip failure can be prevented when sufficient number of roots of a certain tensile force interact with the slip plane, increasing the overall factor of safety of the slope. The percentage of FOS increased due to the vegetation effects can reach up to 43% with slope angles ranging between 15° and 25°. Moreover, based on the parametric study, silty soils showed more significance in contributing to the increase in FOS when incorporating vegetation.

M. Suhatril (✉) · P. Azura Sari · M. Shariati (✉)
Department of Civil Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
e-mail: meldi@um.edu.my

M. Shariati
e-mail: mahdishariati@utm.my; shariatimehdi@yahoo.com

N. Osman
Institute of Biological Sciences, Faculty of Science, University of Malaya, 50603 Kuala Lumpur, Malaysia

M. Shariati · A. Marto
Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia

M. Shariati
Faculty of Civil Engineering, University of Tabriz, Tabriz, Iran

Keywords Eco-protection · Factor of safety · Landslides · Slope stability · Vegetation

1 Introduction

Landslides or slope failures are naturally occurring phenomena known as geological erosion. However, artificially altered land by excavation, deforestation and urbanization also contributed to these detrimental effects. Hence, the combination of uncontrollable natural events i.e. earthquakes and rainstorms as well as human land use practices can trigger disastrous slope failures Varnes (1958).

Malaysian economy has been moving steadily on the fast lane resulting in rapid infrastructure development including highway and other transport systems with drastic change in landscape. The demand for more land area increases thus making clearing of more vegetated areas seems inevitable. These massive and expensive construction projects are usually sited on, or pass through upland areas, which inevitably involve cutting of vegetation cover and hillslopes. Nordin (1995) explains that the cause of slope instability problems may be due to poor environmental planning and conservation practices due to the demands of fast completion of the construction projects.

Hence, in order to mitigate slope failures effectively, in-depth understanding of geological conditions is vital. Furthermore, potentially unstable areas should be identified and prevented while implementing corrective measures to assist in minimizing these slope failures (Truong et al. 2008). Beside internal structural weakness, slope instability due to uncontrolled surface erosion is often overlooked. Surface protection of slopes has been proven effective and economical. Thus, it should also be considered significantly as other conventional techniques of slope stabilization.

Vegetative cover provided by grass seeding or hydro seeding is usually fairly effective against erosion whereby deep-rooted plants such as trees and shrubs may provide some structural strengthening for the ground (Gray 1996). However, information on the most suitable vegetation types with relation to soil types and slope angles that can be effectively used to stabilize typical slopes in Selangor is scarcely available.

Various species of different vegetation types found in Malaysia which are suitable for slope protection has been reported (Normaniza et al. 2008; Osman et al. 2011; Osman and Barakbah 2006, 2011). In this study, the effects of grasses, shrubs and trees as surface protection for slopes are discussed. However, due to availability, ease of growth and high root pull-out strength and tensile strength being reported (Ali 2010; Normaniza et al. 2008; Norris 2008), *Vetiver zizanioides* (grass), *Melastoma malabathricum* (shrubs) and *Leucana Leucophales* (trees) are selectively chosen for this parametric study.

2 Methodology

After reviewing different approaches of slope stability analysis, suitable methods that take account of the effect of vegetation in the analysis are identified. The influences of vegetation on Factor of Safety (FOS) of a slope can be modelled by method of slices in the limit equilibrium approach.

Greenwood General Equation and Swedish methods can be adapted to include the effects of vegetation in the analysis (Ali et al. 2012; Greenwood 2006).

$$FOS = \frac{\sum\left[\left(c' + c'_v\right)l + \left((\mathrm{W} + W_v)\cos\alpha - (u + \Delta u_v)l - \left((U_2 + \Delta U_{2v}) - (U_1 + \Delta U_{1v})\right)\sin\alpha - D_w\sin(\alpha - \beta) + \mathrm{T}\sin\theta\right)\tan\emptyset'\right]}{\sum[(\mathrm{W} + W_v)\sin\alpha + D_w\cos(\alpha - \beta) - \mathrm{T}\cos\theta]} \quad (1)$$

$$FOS = \frac{\sum\left[\left(c' + c'_v\right)l + \left[\left((\mathrm{W} + W_v)z\cos\alpha - (u + \Delta u_v)l - D_w sin(\alpha - \beta) + Tsin\theta\right)\right)\right]\tan\emptyset'\right]}{\sum[(W + W_v)\sin\alpha + D_w\cos(\alpha - \beta) - \mathrm{T}\cos\theta]} \quad (2)$$

whereby

List of symbols

c’	= effective cohesion at base of slice,
c'_v	= enhanced cohesion due to roots,
l	= length along base of slice,
W	= weight of soil,
W_v	= weight of vegetation,
α	= inclination of base of slice to horizontal,
ø’	= effective angle of friction at base of slice,
u	= water pressure on base of slice,

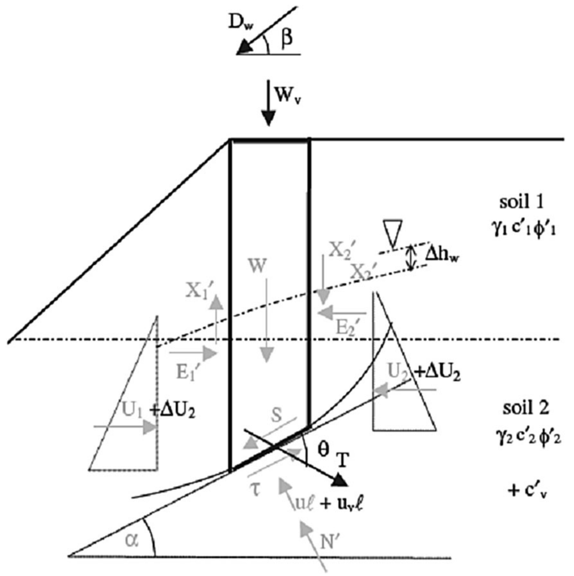

Fig. 1 Forces affecting each slice and additional forces due to vegetation and hydrological changes (Greenwood 2006)

Δu_v = change in water pressure due to vegetation,
U_1 and U_2 = interslice water forces on left and right-hand side of slice,
ΔU_{1v} and ΔU_{2v} = change in interslice water forces due to vegetation,
D_w = wind force,
T = tensile force of roots,
θ = angle of roots to slip surface

It should be noted that in practice, the tangential component of the root tensile force, T cos θ, is often assumed to be a positive restoring force and is added to the numerator in Eqs. 1 and 2. However, as it is a negative disturbing force, its deduction from the denominator is acceptable. According to Norris (2008), this approach is statistically correct as can be referred to the force diagram shown in Fig. 1. The calculated value will be identical for a value of Factor of Safety of 1.

A computer program SLOPE/W was utilised to model 14 different slopes in Selangor, adopting the limit equilibrium approach. The types of soil inclusive of the soil shear strength properties as well as slope angle of these slopes are extracted and shown in Table 1.

Concurrently, a spreadsheet program known as SLIP4EX, developed by Greenwood in 2006, was also used to model the slopes. Results in terms of FOS obtained from both analysis are then compared. Further modelling is then carried out using SLIP4EX to investigate the stability of vegetated slopes by the application of grasses. In order to study the effects of vegetation on the slope stability analysis, important input to be considered is the pull-out strength of the

Table 1 Properties of soil and slope angle for modelled slopes

Project ref.	Soil type	Soil shear strength parameters			Slope angle (°)
		Effective cohesion, c' (kPa)	Effective friction angle, ø' (°)	Unit weight, γ (kN/m^3)	
1a	Silt	2.1	33.7	25.7	15–25
1b	Clay	11.0	19.0	26.6	26–35
2a	Silt	5.5	32.5	15.0	< 15
2b	Silt	5.5	29.5	14.0	15–25
2c	Silt	6.5	31.0	14.5	< 15
5	Clay	8.7	10.5	11.1	< 15
6a	Clay	21.0	19.0	12.0	15–25
6b	Clay	19.0	26.0	13.0	< 15
6c	Clay	19.0	26.0	13.0	< 15
6d	Clay	18.0	26.0	13.0	15–25
6e	Clay	22.0	27.0	14.0	15–25
6f	Clay	15.0	27.0	13.0	26–35
6g	Clay	8.0	26.0	13.0	26–35
6h	Clay	24.0	29.0	14.0	26–35

roots. This parameter is used to determine the force from roots that act on the base of every slice in the stability analysis. In other words, besides the additional effective cohesion provided by vegetation, c'_v, effective angle between slip surface and operational roots, θ, increase in piezometric head due to vegetation, Δh_w, the effect of vegetation on slope stability is majorly affected by the value of tensile force of root reinforcement on each slice, T. Tensile force of roots is the product of design root force, T_{rd} and length of slip surface, l on each slice. T_{rd} is based on the ratio of the measured pull-out resistance (strength based on diameter at clamp), the mean root diameter and the number of roots per square m across the slip surface (T_{ru}) to a partial Factor of Safety (Fr). There is much uncertainty about the root distribution in the ground and the resisting forces that are available for a particular slip surface geometry and soil conditions. Hence, a conservative value of 8 is used for Fr to reflect these uncertainties as well as to allow for large strains. Finally, changes in FOS resulted from the effect of vegetation are recorded. As reported by Norris and Greenwood (2003), the design root force on the slip plane, Trd can be derived by the application of suitable partial Factor of Safety, i.e.

$$T_{rd} = \frac{T_{ru}}{F_r} \quad (3)$$

In this paper, typical values of root properties are obtained based on data collected from previous study (Table 2). The root strengths value applicable for this study are obtained from mature vegetation with typical root length between 0.8 and 1.5 m and root growth time between 6 and 24 months, depending on types of vegetation.

3 Result and Discussion

3.1 Factor of Safety

Factor of safety (FOS) is calculated based on the ratio between the shear strength, obtained from the Mohr–Coulomb failure criterion, and the actual shear force that applies at the slip surface. In the analysis done, the value of FOS is determined based on the critical slip surface of the slope. All of the 14 modelled slopes in Selangor showed that the calculated FOS passes the stability design criteria of FOS $>$ 1. Figure 2a and b shows the FOS obtained when incorporating two different approaches, i.e. Greenwood General and Swedish methods for different soil types and slope angles respectively.

Based on the results obtained, only minor differences in the calculated FOS by either approached is

Table 2 Root properties of selected vegetation species

	Vetiver zizaniodes	*Melastoma malabathricum*	*Leucaena Leucocephala*
Typical root diameter, d (mm) at root length 0.8–1.5 m	0.73[a]	8[d]	10[f]
Typical no. of roots (m^2)	10[b]	5[d]	5[d]
Root growth time (months)	6[a]	24[g]	24[g]
Additional effective cohesion due to vegetation, c'_v (kN/m^2)	7.5[c]	0.49[e]	0.55[e]
Pull-out resistance of root (kN/m^2)	–	2.02[d]	2.25[g]
Root tensile strength (N/mm^2)	75[a]	29.72[d]	104.83[g]

[a]Ke et al. (2003)

[b]Retrieved from www.vetiversolutions.org

[c]Norris (2008)

[d]Ali (2010)

[e]Norris and Greenwood (2006)

[f]Saifuddin and Nirmaniza (2012)

[g]Osman et al. (2014)

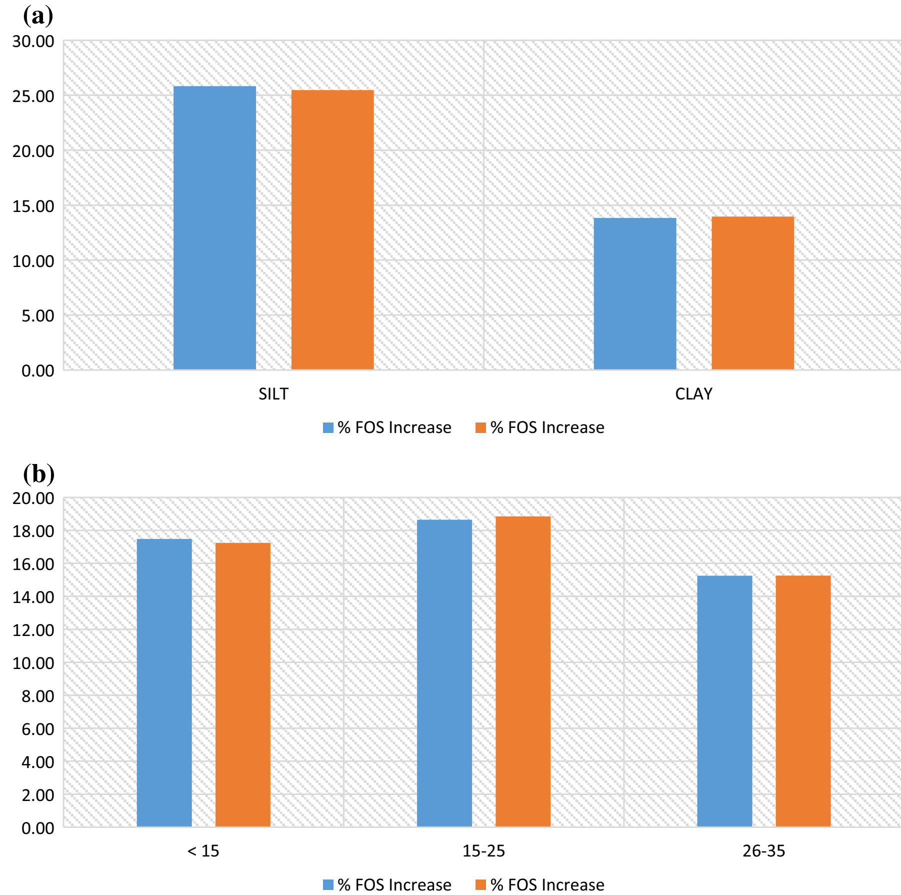

Fig. 2 **a** Difference in FOS increase (%) between greenwood general and Swedish approach for different soil types. **b** Difference in FOS increase (%) between greenwood general and Swedish approach for different slope angles

noticed. This is in accordance with the study conducted by Norris (2008) when FOS calculated by these two approaches shows identical values. On the other hand, with the integration of vegetation effects on the slopes, it is observed that the FOS increased when incorporating vegetation. The percentage of FOS increased due to the vegetation effects by *Vetiver zizaniodes* can reach up to 48% for silty soil types whereby higher value of about 5–35% is obtained when incorporating vegetation in silt compared to clay soil type (Fig. 3). In terms of slope angles, range of slope between 15° and 25° resulted in the highest increase in FOS, especially when using *Vetiver zizaniodes* as surface slope protection (Fig. 4).

Based on the analysis carried out, *Vetiver zizaniodes* (grass) showed the highest increase in Factor of Safety followed by *Leucaena leucocephala* (tree) and *Melastoma malabathricum* (shrub). This might be due to the attributes of the chosen species of grass, *Vetiver zizaniodes,* given its extensive and deep root system (Hengchaovanich and Nilaweera 1996). Besides the deep root system for soil stabilisation, Vetiver grass also has thick leaves which spread water and trap sediment. Moreover, it also has high tolerance to hostile conditions which allows it to rehabilitate soil and water impurity. Another point to note is that, besides the root pull-out resistance and resultant root force (T), only additional effective cohesion (c'v) and effective angle between operational roots and slip surface (θ) were taken into consideration in this analysis.

Architecture of the roots determines the value of θ. Assumptions were made on the vegetation effects whereby T acts at 0° to the slip plane for grasses (θ = 0°) and T acts at 45° (θ = 45°) to the slip plane for both shrub and tree species chosen in this study.

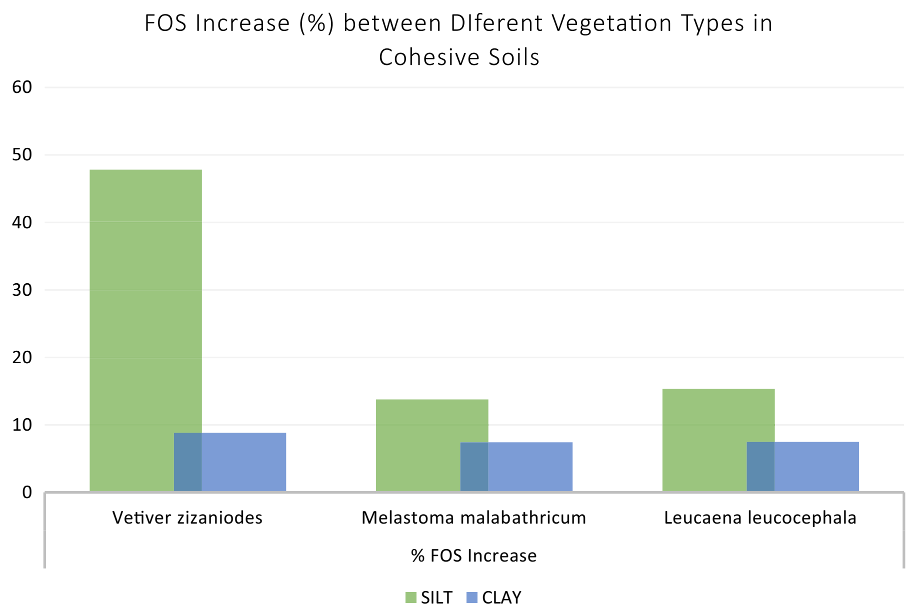

Fig. 3 FOS increase (%) between different vegetation species in cohesive soils

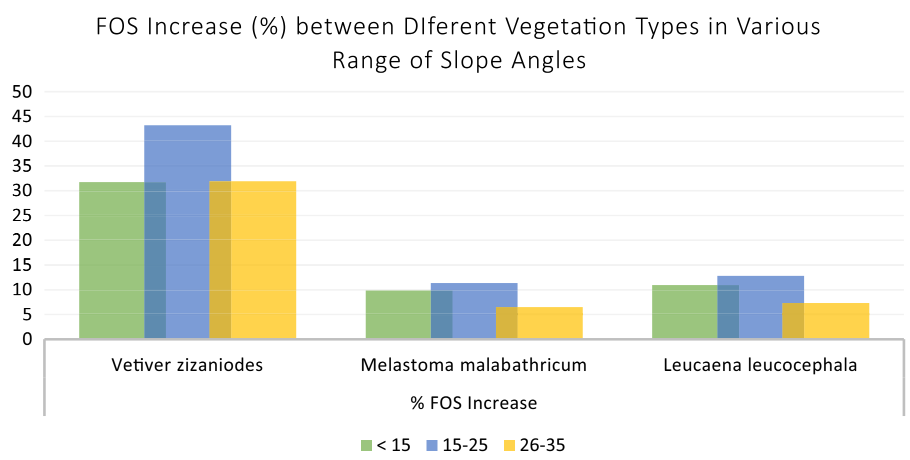

Fig. 4 FOS increase (%) between different vegetation species in various range of slope angles

Roots with diverse positioning in soils may develop wider shear zones and hence the soil is able to slowly transfer reinforcement from roots via their tensile strength even at large shear displacements (Stokes et al. 2009).

Therefore, it could be concluded that the properties of vegetation root systems do assist in alleviating soil erosion and providing soil reinforcement for slope stability.

3.2 Establishment and Limitation of Vegetation

Over the last century, human has been concerned with increasing productivity through technological progress in their daily activities, at the cost of environmental degradation (Painter 2003). Hence, necessary actions should be taken to rectify the damages caused. However, many countries are unable to invest profoundly in environmental restoration of degraded lands due to limited resources. Eco-engineering techniques can therefore provide a low-cost, long-term solution in certain cases (Norris 2005, 2008). The role of vegetation in stabilising slopes prone to shallow failure is not limited to general planting techniques. One aspect of ground bio-engineering i.e. the use of living plant materials to perform some engineering function, to stabilize problematic site. Although plant exhibits many elements, generally, the structures that are probable to be beneficial in providing eco-technological solutions to slope stability includes the roots (provide anchorage, absorb water and nutrients from the soil), stems (support above-ground parts and capture eroding soil) as well as leaves (intercept precipitation and initiate evapotranspiration to decrease soil moisture level) (Norris 2008). According to Geotechnical Manual for Slopes, Hong Kong, as a general rule, a single species of vegetation should not be planted in isolation. In adaptation of this guideline, the use of vegetation in Selangor which has mostly concentrated on grassing by hydro seeding approach, should also incorporate shrub or tree planting wherever viable. It should be noted that, the surface layer of newly-constructed slopes is often not well consolidated. As a result, rill and gully erosion may still occur even on well-vegetated slopes since deep-rooted trees grow slowly and are often difficult to establish in such hostile territory. It is in these cases engineers often rue the inefficiency of the vegetative cover and install structural reinforcement soon after construction. Besides that, other limitations to ground bio-engineering techniques include planting or installation restricted to the plants' dormant season, availability of locally adapted plants, as well as intensive and skilled labour needs. Therefore, in achieving ultimate vegetation cover on engineered slope in a relatively short time, shrubs and trees should be planted preferably at the toe of slope in addition to grass. Appropriate vegetation management techniques should also be considered to assist the natural succession process. Geo-synthetics and vegetation combination may be more applicable for deep-seated slides.

In regard to the relationship of vegetation types and slope angle, decision makers should take into consideration the slope angle limitations on vegetation establishment when steeper slopes are required for construction as shown in Table 3.

Incorporating vegetation as an eco-protection technique for slopes can be challenging in its initial stage. Therefore, some precautions that should be noted includes consideration in seasons and growth time of the vegetation types. Careful consideration in design should be taken to establish and maintain an effective vegetative slope protection due to certain difficult conditions.

4 Conclusion and Recommendation

The effect that vegetation has on stability of slopes is a complex interaction of mechanical, hydrological and biological factors that are challenging to measure. Many cases occurred in Malaysia had proven that continued slope stability can be ensured by applying some preventive measures which normally cost much less than corrective measures (See-Sew and Wong 2004).

The modelling showed that shallow slip failure can be prevented when sufficient number of roots of a certain tensile force interact with the slip plane, increasing the overall factor of safety of the slope. It can be concluded from the parametric study that the average percentage of increase in FOS when incorporating *Vetiver zizanniodes* is nearly 50% in silty soil followed by *Leucaena leucocephala* and *Melastoma malabathricum* with percentage of FOS increase of

Table 3 Slope angle limitations on vegetation establishment (GEO 1984)

Slope angle (°)	Vegetation type	
	Grass	Shrubs/trees
0–30	Low in difficulty; routine planting techniques may be used	
30–45	Increasingly difficult for turfing; routine application for hydro-seeding	Increasingly difficult to plant
> 45	Special consideration required	Planting must generally be on benches

15% and 14% respectively. However, the increase in percentage of FOS when using Vetiver is only 9% in clayey soil followed by both Leucaena and Melastoma at the same increase of 7%. Hence, *Vetiver zizanniodes* could potentially be used in conjunction with other deeper rooting species as it provides good surface root reinforcement. Further studies are recommended to be carried out to find a better establishment for vegetative slope stabilisation suiting the Malaysia's slope geometry and soil condition.

Acknowledgements The authors would like to thank the University of Malaya for the research grant (RP005E − 13SUS) allocated for this project and IKRAM Engineering Services Sdn Bhd for the technical support.

References

Ali F (2010) Use of vegetation for slope protection: root mechanical properties of some tropical plants. Int J Phys Sci 5(5):496–506

Ali N, Farshchi I, Mu'azu M, Rees SW (2012) Soil-root interaction and effects on slope stability analysis. Electron J Geotech Eng 17:319–328

GEO (1984) Geotechnical manual for slopes, 2nd edn. Geotechnical Engineering Office, Civil Engineering and Development Department, Hong Kong

Gray DH (1996) Biotechnical and soil bioengineering slope stabilization: a practical guide for erosion control. Wiley, New York

Greenwood JR (2006) SLIP4EX–A program for routine slope stability analysis to include the effects of vegetation, reinforcement and hydrological changes. Geotech Geol Eng 24(3):449–465

Hengchaovanich D, Nilaweera NS (1996) An assessment of strength properties of vetiver grass roots in relation to slope stabilization. Paper presented at the International Conference on Vetiver, Chain Kai, Thailand

Ke C, Feng Z, Wu X, Tu F (2003) Design principles and engineering samples of applying vetiver ecoengineering technology for steep slope and riverbank stabilization. In: Proceedings of the 3rd international conference on vetiver, Guangzhou, China. China Agricultural Press, Beijing, pp 365–374

Nordin A (1995) Slope instability problems the malaysian experience. Paper presented at the vegetation and slopes: stabilisation, protection and ecology: proceedings of the international conference held at the University Museum, Oxford, 29–30 September 1994

Normaniza O, Faisal H, Barakbah S (2008) Engineering properties of Leucaena leucocephala for prevention of slope failure. Ecol Eng 32(3):215–221

Norris J (2005) Root mechanics applied to slope stability. Nottingham Trent University, Nottingham

Norris J (2008) Slope stability and erosion control: ecotechnological solutions. Springer Science & Business Media, Berlin

Norris J, Greenwood J (2003) In situ shear box and root pull-out apparatus for measuring the reinforcing effects of vegetation. Field measurements in geomechanics, pp 593–597

Norris J, Greenwood J (2006) Assessing the role of vegetation on soil slopes in urban areas. The Geological Society of London

Osman N, Barakbah S (2006) Parameters to predict slope stability—soil water and root profiles. Ecol Eng 28(1):90–95

Osman N, Barakbah S (2011) The effect of plant succession on slope stability. Ecol Eng 37(2):139–147

Osman N, Abdullah MN, Abdullah CH (2011) Pull-out and tensile strength properties of two selected tropicaltrees. Sains Malays 40(6):577–585

Osman N, Saifuddin M, Halim A (2014) Contribution of vegetation to alleviate slope's erosion and acidity. In: Environmental risk assessment of soil contamination. InTech

Painter DJ (2003) Forty-nine shades of green: ecology and sustainability in the academic formation of engineers. Ecol Eng 20(4):267–273

Saifuddin M, Normaniza O (2012) Physiological and root profile studies of four legume tree species. Life Sci J 9(4):1509–1518

See-Sew G, Wong SY (2004). How to improve slope management and slope engineering practices in Malaysia, pp 1–16

Stokes A, Atger C, Bengough AG, Fourcaud T, Sidle RC (2009) Desirable plant root traits for protecting natural and engineered slopes against landslides. Plant Soil 324(1–2):1–30. https://doi.org/10.1007/s11104-009-0159-y

Truong P, Van TT, Pinners E (2008) Vetiver system applications: a technical reference manual. The Vetiver Network International, San Antonio

Varnes DJ (1958) Landslide types and processes. Highway Research Board Special Report (29). http://trid.trb.org/view.aspx?id=127430