Quantifying the effect of brush layering on slope stability

G.B. Bischetti\textsuperscript{a,}, E.A. Chiaradia\textsuperscript{a}, V. D’Agostino\textsuperscript{b}, T. Simonato\textsuperscript{a,1}

\textsuperscript{a} Dipartimento di Ingegneria Agraria, Università degli Studi di Milano, via Celoria n. 2, 20133 Milano, Italy
\textsuperscript{b} Dipartimento TeSAF, Università degli Studi di Padova, Agripolis, 35020 Legnaro (Padova), Italy

\textbf{A R T I C L E   I N F O}

Article history:
Received 29 August 2008
Received in revised form 2 March 2009
Accepted 6 March 2009
Available online xxx

Keywords:
Soil bioengineering
Brush layering
Hillslope stabilisation
Eco-engineering
Live cuttings

\textbf{A B S T R A C T}

Soil bioengineering techniques that use vegetation as a structural element gained popularity in the field of natural and man-made slope stabilisation due to their ability to combine safety and environmental conservation elements. In spite of such popularity, little research has been done to quantify their effect on slope stability. This work presents a simple scheme for the evaluation of the Factor of Safety for slopes reinforced by brush layering, which is one of the most common techniques adopted in slope stabilisation works. The proposed model is based on the limit equilibrium principle and accounts for geotechnical soil properties (cohesion, friction angle, unit weight of soil), soil saturation, slope steepness, and brush layer design parameters (number of stems per meter, length and diameter of stems, distance between brush layers). The model provides the value of the Factor of Safety for a given slope and soil depth. Laboratory pullout tests were carried out in order to estimate relevant parameters of cuttings of purple willow (Salix purpurea L.) and to perform a slope stability analysis via the model.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

Hydrogeomorphic phenomena are one of the most widespread hazards in the European Alpine landscape. Residents of mountainous areas have attempted to mitigate these hazards in order to protect their homes and property, but until recently only very limited and ineffective methods have been available, mainly using timber and vegetation without a broad strategy. In 1687, Vincenzo Viviani proposed the first integrated strategy to address landslides and torrent erosion. These phenomena produced a large amount of sediment, which was deposited in the plain of the Arno River and caused frequent inundations in Florence (Viviani, 1687). Viviani’s approach consisted of building check dams in streams to decrease the slope and stream energy, and planting vegetation on hillslopes to prevent soil erosion and landslides. Such an approach was “re-discovered” at the end of the nineteenth century, producing a new discipline, torrent control and hillslope stabilisation (called sistemazioni idraulico-forestali in Italy, Wildbach und Lawinenverbaubung in Austria and Germany, and restauration de terrains en montagne in France), that integrated, in a systematic manner, the engineering approach with the biological approach and developed specific techniques.

Such techniques have been used quite successfully in Europe for more than a century to protect mountain lands, and they overlap with the well-known soil bioengineering techniques when applied to the hillslope stabilisation.

In the past, the appeal of these techniques was their ability to couple stabilisation with low cost and the use of building materials that were available on site. Currently, their advantages are their ability to improve both the hillslope or stream stability and the ecological condition of sites (Mitsch, 1998), which is considered of great importance today. Due to these environmental benefits, these techniques have gained popularity over the past few decades in spite of their ancient origins (Coppin et al., 1990; Schiechtl, 1980; Donat, 1995; Gray and Sotir, 1996; Jones and Hanna, 2004), and they are now included in several agency handbooks (e.g., USDA SCS, 1992; Allen and Leech, 1997; FISRWG, 1998; Lewis, 2000; Lewis et al., 2001).

One of the most common bioengineering techniques used for the stabilisation of hillslopes, road cut and fill-slopes, and river banks is brush layering. Basically, brush layering is an older version of the well-known reinforced earth techniques, and consists of placing live cuttings or pieces of brush at the bottom of small benches excavated into the slope (Fig. 1). The tips of the cuttings protrude just beyond the face of the slope, where they grow buds and leaves that intercept rainfall, slow runoff, and filter sediments. The stems of the cuttings extend into the hillslope and, like conventional inert materials (e.g., geotextiles, geogrids and soil nailing techniques), act as tensile inclusions or reinforcements. After several weeks or months, depending on the climate and when they...
are planted (at the beginning or at the end of dormant period), live cuttings and brushes develop roots along their stems and increase their reinforcement action and their pullout resistance. Embedded cuttings, moreover, also act as drains that favourably modify the hydrologic regime near the face of the slope (Gray and Sotir, 1996).

From a mechanical point of view, brush layering is comparable to engineering reinforced structures like artificial embankments (Gray and Sotir, 1996). Despite the widespread use of brush layering around the world, the quantification of its effects on slope stability has received little attention. The design parameters reported in most handbooks and guidelines (e.g., Schiechtl, 1980; Gray and Sotir, 1996) give some attention. The design parameters reported in most handbooks and guidelines (e.g., Schiechtl, 1980; Gray and Sotir, 1996) give some attention. However, new design paradigms must be developed to account for soil and slope properties and for design parameters (such as, in the case of brush layering, number of cuttings and bench spacing). Moreover, the level of slope stabilisation at different soil depths should be quantified. In many countries, all stabilisation projects must be verified by appropriate methods (in Italy, for example, the Factor of Safety for both man-made and natural slopes must be greater than 1.3 at the end of construction; D.M., 11/03/1988). In the case of soil bioengineering techniques, it is not simple to define quantitative design methods because of the difficulties in quantifying the effects of plants and natural materials. In the case of brush layers, however, some interesting attempts have been carried out (Florineth, 1994; Schuppener, 1999, 2001), but a complete design procedure is still lacking.

In this paper, we develop a scheme to design brush layers works, and live reinforcements in general, which is able to quantify the Factor of Safety at different depths as a function of the design parameters. Experimental tests have also been carried out to estimate the pullout resistance of live cuttings.

2. Materials and methods

2.1. The reinforcing model

The method developed in the present paper is based on the limit equilibrium principle and on the infinite slope approach (Skempton and Delory, 1957; Nash, 1987). It gives the Factor of Safety at different depths as a function of the brush layer design parameters (bench spacing; number, length, and diameter of live cuttings) and of the slope parameters (geomorphology of the slope and the physical properties of the soil).

From a mechanical point of view, brush layering is comparable to engineering reinforced structures like artificial embankments (Gray and Sotir, 1996; Schuppener, 1999, 2001). When the shear surface of a sliding mass of soil intersects a layer of live cuttings, in a manner similar to synthetic elements, the pullout resistance is mobilized beneath the shear surface by means of soil-cutting frictional forces, and part of the stresses are transferred from the soil to the cuttings.

Since the fundamental work of Vidal (1969), a great number of design schemes for reinforced earth structures have been proposed, which account for external (sliding, overturning, bearing capacity, and overall slope stability) and internal stability (reinforcement elements pullout, tensile overstress, internal sliding).

For the internal stability, which represents the most critical factor, most adopted design schemes have been developed in the...
limit equilibrium principle framework (Jewell and Wroth, 1987; Leshchinsky and Boedeker, 1989; Jewell, 1989; Haza et al., 2000; Lee, 2000; Patra and Basudhar, 2005; Mittal, 2006), although more sophisticated methods have recently been proposed in the framework of Finite Element and Finite Difference Models (Lee, 2000; Cheuk et al., 2005). The geometry of the shearing surface has been assumed differently by various authors: planar (Vidal, 1969; Lee et al., 1973), circular (Phan et al., 1979; Gourc et al., 1986; Patra and Basudhar, 2005; Mittal, 2006), logarithmic spiral (Juraj and Schlosser, 1978; Leshchinsky et al., 1985; Leshchinsky and Boedeker, 1989; Shiawakoti et al., 1998) or bi-linear (Murray, 1977; Christopher et al., 1989; Jewell, 1989; Haza et al., 2000).

Brush layers can be used effectively in situations where a relatively shallow soil layer needs to be stabilised (up to about a couple of meters thick; Schiechtl and Stern, 1994). Common examples are the stabilisation of steep hillslopes with soil overlying weathered or solid rock, road cuts or fill slopes, river banks, or embankments in general. Due to the widespread application of such techniques, a great number of successful cases can be found in many parts of the world, particularly in the Alps. Only in a few cases, however, have they been documented in international papers (Gray and Sotir, 1995; Li et al., 2006; Stangl, 2007), and most of the documentation exists in native-language technical reports.

In the case of brush layering projects carried out to stabilise hillslopes, a simple but accurate solution can be obtained by means of the limit equilibrium principle framework with reference to the case of an infinite slope. The situations where such works can be successfully used include a shallow potential mass movement with a planar slip surface that is approximately parallel to the ground surface (Gray and Sotir, 1996; Wu, 1995).

Under such assumptions, the Factor of Safety (FS), given by the ratio of the shear strength (τ) to the shear stress (τ) along the potential failure surface (Skempton and Delory, 1957; Nash, 1987), can be easily calculated. The unit wedge for the application of the limit equilibrium principle framework in the case of a hillside of inclination β (°) can easily be determined by defining the shearing depth z (m), the brush layer spacing l₁ (m), the cutting length l₂ (m), and the inclination angle α (°) (Fig. 2).

By considering the force due to the pullout resistance generated by the friction between the soil and live cuttings below the shear plane (Rpo(z)), the shear strength can be evaluated by means of the Mohr–Coulomb equation modified to account for the component of Rpo(z) normal to the shear plane:

\[ s = c'l_1 + [nR_{po}(z) \sin(\alpha + \beta)] + (\gamma_1 - \gamma_w m)z \cos^2 \beta l_1 |\phi'\]  \hspace{1cm} (1)

where \( c' \) is the effective soil cohesion (kPa), \( \phi' \) is the effective friction angle (°), m is the water table level as a ratio of the depth to the failure surface, \( \gamma_1 \) is the unit weight of soil (kN/m³), \( \gamma_w \) is the unit weight of water (kN/m³), n is the number of live cuttings per meter, \( l_2 \) is the spacing out of plane (number/m) length, and the other symbols are the same as defined previously.

In the same way, the shear stress along the failure plane can be evaluated accounting for the component of Rpo(z) tangential to the shear plane:

\[ \tau = \gamma_1 l_1 z \sin \beta \cos \beta - nR_{po}(z) \cos(\alpha + \beta). \]  \hspace{1cm} (2)

The resulting Factor of Safety can be calculated as:

\[ FS(z) = \frac{c'l_1 + [nR_{po}(z) \sin(\alpha + \beta)] + (\gamma_1 - \gamma_w m)z \cos^2 \beta l_1 |\phi'|}{\gamma_1 l_1 z \sin \beta \cos \beta - nR_{po}(z) \cos(\alpha + \beta)}. \]  \hspace{1cm} (3)

In cases where the infinite slope assumption is not valid, other forms of the shear surface must be defined and the equation for the Factor of Safety rewritten. A similar approach was also developed by Greenwood (2006) to account for the anchoring effect of large roots in modelling the stability of vegetated slopes.

In Eq. (3), all the relevant design parameters can be recognised and easily evaluated, or imposed as design parameters, except for the pullout resistance of the live cuttings, which is a key parameter for reinforced earth designs with all types of reinforcements.

In the case of synthetic materials, pullout resistance is due to soil-reinforcement friction, and these values are well-known for most of these materials. In the case of live cuttings or brush, however, the interaction with the soil is more complex, and few measurements (Schuppener, 1999, 2001) have been carried out.

The pullout resistance of live cuttings can be ascribed to two main mechanisms. The first is due to the friction forces that arise between the cutting stems and the soil when the soil begins to move over the shear surface. The second is due to the tensile resistance of the root shoots that sprout out along the cutting after their placement. The first mechanism acts immediately after the works have been completed, and it is quite constant over time. The second mechanism begins as the growing season starts and roots shoot out, and progressively increases; the growth rate of the roots depends on the characteristics of the species and the environmental conditions, but a few months are generally enough to produce a significant effect.

The total pullout resistance of the live cuttings mobilised beneath the shear depth z, Rpo(z), can be expressed as the sum of the pullout resistance force of the portion of the stems under the slip surface (the force required to overcome the soil–stem bonds and extruded cuttings from the soil), R₁(z), and the tensile resistance due to the root shoots below the same failure surface, R₂(z). For safety reasons, however, what is crucial for design is the minimum value of the reinforcement, so R₂(z) can be neglected.


![Fig. 2. Scheme of forces acting on brush layer.](image-url)
The pullout resistance force of the reinforcement due to friction between the soil and the stems can be evaluated as in the case of synthetic materials:

$$R_s(z) = \tau_{po}(z)S(z),$$  \hspace{1cm} (4)

where $\tau_{po}$ is the strength needed to pullout the stem (kN/m$^2$) due to soil–stem friction and $S(z)$ is the surface of the embedded stem below the shear surface (m$^2$).

$\tau_{po}$ depends on the stress normal to the stem plane (Schuppener, 1999), $\sigma_{ns}$ (kPa), which can be evaluated with reference to the midpoint, C, of the embedded portion of the stem (Fig. 2):

$$\sigma_{ns} = \gamma(z + t + v)\cos^2\alpha - \gamma w(mz + t + v)\cos^2\beta,$$ \hspace{1cm} (5)

where $t = 0.5(l_1 - s^*)\cos\alpha$, $v = 0.5(l_2 - s^*)\sin\alpha$, and $s^*$ is the embedded length of the stem above the shear surface (other symbols were previously defined).

Whereas values of $\tau_{po}$ and the resulting pullout behaviour of inert materials (i.e., geosynthetics and soil nailing) have been extensively investigated (Ochiai et al., 1996; Lopes and Ladeira, 1996; Bakere et al., 1998; Gurung and Iwao, 1999; Bergado et al., 2001; Sugimoto et al., 2001; Patra and Basudhar, 2005; Mittal, 2006), only limited research has been carried out for live cuttings and live branches (Schuppener, 1999, 2001; Bischetti and D’Agostino, 2002).

The embedded surface of the stem can be quantified as

$$S(z) = \pi D(l_3 - s^*),$$ \hspace{1cm} (6)

where D is the mean stem diameter (m) and $s^*$ is estimated as

$$s^* = \frac{z \cos \beta}{\sin(90 - \alpha - \beta)}.$$ \hspace{1cm} (7)

### 2.2. Evaluation of pullout resistance of live cuttings

To investigate the pullout resistance of stems, we carried out laboratory pullout tests on live cuttings of purple willow (Salix purpurea L.) following the procedure commonly adopted in testing geosynthetics and nailing elements (Cowell and Sprague, 1993; Lopes and Ladeira, 1996; Koutsourais et al., 1998; Tattisoz et al., 1998; Recalcati, 2002; Mittal, 2006). The procedure analyses the measured values of soil–stem pullout resistance considering the soil friction angle ($\phi$) and the pullout coefficient ($C_{po}$), which are properties of the reinforcement material:

$$\tau_{po} = (\sigma_n \tan \phi)C_{po},$$ \hspace{1cm} (8)

where $\sigma_n$ is the normal stress acting on the reinforcement.

According to other authors (Lopes and Ladeira, 1996; Gurung and Iwao, 1999; Hayashi et al., 1999; Schuppener, 1999; Sugimoto et al., 2001), laboratory pullout tests have been carried out using a device consisting of a steel box (0.3 m $\times$ 0.1 m $\times$ 0.1 m) filled with soil in which live cuttings were placed (Fig. 3). A circular hole 40 mm wide in the centre of the front side allows the attachment of a clamp to the cutting, and a tensile force is applied to the cutting by means of a system of gears at a rate of 10 mm/min. To avoid sand pouring through the hole, a rubber membrane was placed between the hole and the cutting; particular care was given to avoid additional pullout resistance due to the membrane.

This displacement rate is greater than that usually adopted in tests on geotextiles, but is appropriate for the rate of the slope failure processes considered herein. Shallow sliding processes on colluvial soil, in fact, can be considered high velocity phenomena (Glade and Crozier, 2005; Meisina and Scarabelli, 2007), and are defined as rapid by the Cruden and Varnes (1996) classification (Zêzere et al., 2008).

Displacement and force were measured by a position transducer and a load cell. The measurements were collected at a frequency of 1 Hz and recorded by a data logger.

Normal stress was applied by putting weights over the top plate of the steel box to generate stresses of 3.9, 15.9, and 23 kPa, which are equivalent to depths of about 0.20, 0.80, and 1.20 m, respectively, for a soil with a unit weight of 20 kN/m$^3$.

The soil used to fill the box is classified as poorly graded sand (USCS-SP) with a small fraction of silt (92% sand, 8% silt, uniformity coefficient 2.14, curvature coefficient 0.86). The soil unit weight was 17 kN/m$^3$, the moisture content was 5–10%, and the friction angle resulting from three standard shear tests (ASTM D 3080) was 31$\degree$. Particular attention was given during the box filling process to maintain the homogeneity of the soil and a uniform level of compaction. In order to prepare a homogeneous sand sample, sand was placed in layers of about 50 mm by the sand raining technique (Alagiyawanna et al., 2001), whereas uniform compaction was obtained by continuously tamping the soil (Hayashi et al., 1999).

For every cutting, three tests were carried out for each applied normal load. The pullout experiments were stopped when the displacement exceeded 5 cm (about 17% of the tested length) or when the peak pullout resistance was observed. The set of cuttings used in the tests was randomly taken from purple willow plants to obtain specimens more than 30 cm long with different diameters and irregularity (Table 1). The pullout resistance stress ($R$) was estimated as

$$R = \frac{F_{po}}{\pi \cdot L_e \cdot D_m},$$ \hspace{1cm} (9)

where $F_{po}$ (kN) is the measured pullout force, $L_e$ (m) is the embedded length of the cutting at the beginning of the test (as usual in
Table 1
Properties of live cut-branches used in pullout tests (Di diameter of cut-branch at point i).

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>D1 (mm)</th>
<th>D2 (mm)</th>
<th>D3 (mm)</th>
<th>D4 (mm)</th>
<th>D5 (mm)</th>
<th>Dm (mm)</th>
<th>Slat (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>32.5</td>
<td>31.0</td>
<td>33.0</td>
<td>33.5</td>
<td>34.0</td>
<td>32.8</td>
<td>0.031</td>
</tr>
<tr>
<td>2</td>
<td>37.0</td>
<td>36.0</td>
<td>33.5</td>
<td>34.0</td>
<td>32.5</td>
<td>34.6</td>
<td>0.033</td>
</tr>
<tr>
<td>3</td>
<td>21.0</td>
<td>21.0</td>
<td>23.5</td>
<td>25.0</td>
<td>21.0</td>
<td>23.3</td>
<td>0.021</td>
</tr>
<tr>
<td>4</td>
<td>21.0</td>
<td>25.0</td>
<td>21.0</td>
<td>21.0</td>
<td>23.0</td>
<td>22.2</td>
<td>0.021</td>
</tr>
<tr>
<td>5</td>
<td>12.0</td>
<td>14.0</td>
<td>11.5</td>
<td>15.0</td>
<td>12.0</td>
<td>12.9</td>
<td>0.012</td>
</tr>
<tr>
<td>6</td>
<td>13.5</td>
<td>11.5</td>
<td>13.0</td>
<td>13.0</td>
<td>12.0</td>
<td>12.6</td>
<td>0.012</td>
</tr>
</tbody>
</table>

geotextile and nails pullout tests; Bakeer et al., 1998; Gurung and Iwao, 1999; Sugimoto et al., 2001), and Dm (m) is the mean diameter of the cutting.

According to tests on geosynthetics, the ultimate pullout resistance can be identified on the basis of one of the following conditions: (i) the peak of the curve of pullout resistance versus displacement, (ii) the value of pullout resistance at rupture, and (iii) the value of pullout resistance at a recommended limit of displacement. Because a standard procedure has not been specifically developed for tests on plants, we referred to the procedure test on synthetic reinforcements and considered the value of pullout resistance at a limit of displacement of 5% (US Department of the Army, 1989; Bakeer et al., 1998).

3. Results

As expected, the pullout force–displacement results show that the pullout force increases with confining pressure (Fig. 4) and the relationship obtained (Eqs. (4) and (9)) between τpo and σn is linear (Fig. 5):

\[ \tau_{po} = 0.839\sigma_n \quad (R^2 = 0.90). \]  

Fig. 5. Relationships between pullout strength (τpo) and normal stress (σn) in the present study and by Schuppener (1999).

Analysing the ultimate pullout strength results by means of Eq. (8), the coefficient of pullout (Cpo) for live cuttings can be estimated both through Eq. (10) (Cpo = 1.39) or through the mean diameter of each sample (Table 1, Fig. 6). In the latter case, the coefficient of pullout is shown to not be a constant, but varies slightly with the cutting diameter, following a linear relationship (Fig. 6). For practical applications, however, Cpo can be considered as a constant and, to be conservative, taken equal to 1.0, especially when the diameter of the cuttings is small.

Eq. (3) can now be used and the FS, at different depths and soil moisture contents, can be evaluated as a function of slope steepness, soil properties, and the brush layer parameters.

As an example, consider a steep slope in a poorly graded sand soil with no cohesion, an effective friction angle of 32°, and a unit weight of 19 kN/m³. To stabilise such a slope, the brush layering technique is used with live cuttings, 2 m long and 3 cm in diameter, inclined toward the slope at an angle of 10°.

The developed model allows the quantitative evaluation of the increase of stability obtained at different depths for different situations (Fig. 7) for the case of 33 cuttings per meter, a brush layer spacing of 5 m, a soil saturation of 0.5, and a slope angle of 35°. It can be observed that brush layering can dramatically increase the stability of slopes compared to bare soil, although such an effect is generally limited to depths that range between half and three quarters of the length of the cuttings, depending on the slope characteristics and design parameters. Such depths, however, are typical of...
of shallow slides, which are just the phenomena for which the brush layering technique is suggested.

Brush layer spacing, as expected, can significantly affect the resulting FS, although such an effect decreases with spacing (Fig. 7a), from 10 to 5 m and from 5 to 2 m. Decreasing the spacing from 2 to 1 m increases the stable depth by only 5 cm. To maximise the reinforcement effects at depth, then, the brush layers must be as close as possible, but the deepening effect and problems with creating very close benches must be balanced.

The same pattern can be observed as a result of increasing the cutting density (Fig. 7b). Few cuttings per meter will stabilise only the first half-meter of the soil, whereas higher densities can be more effective at greater depths. Increasing the density from 15 to 33 cuttings per meter (the latter density corresponds to a side by side placement, in agreement with most of soil bioengineering guidelines), however, increases the stable depth by only 5 cm.

The ability of brush layers to stabilise slopes obviously decreases with the water content of the soil (Fig. 7c), although with appropriate design parameters the prescribed stability can also be obtained for saturated conditions. The effectiveness of brush layers, contrary to what is generally assumed, increases with steepness (Fig. 7d) as a result of a greater mass of soil loading the cuttings (see Eq. (8)).

4. Discussion and conclusion

The pullout resistance values resulting from the experiments provide fundamental data about using live reinforcements for slope stabilisation. Fig. 4 shows the pullout curve behaviour. In most of the cases strength rapidly increases in the earlier displacement stages and then it remains almost constant (Fig. 4a); in some cases a second peak can be observed (Fig. 4b). The latter behaviour is similar to the one observed by Mickovski et al. (2007) for ductile material and for branched soil inclusion; in our case, however, we deem that the second peak can be due to pronounced nodes on the cuttings used in the tests.

Within the range of the considered values of confining pressure, the pullout resistance values are comparable with the results obtained by Schuppener (1999) for wooden bars (Fig. 5), and show the a similar linear relationship between $\tau_{po}$ and $\sigma_n$. In the present case, however, the inclination of the line is close to that obtained by Schuppener (1999) for live plants. The relationship between $\tau_{po}$ and $\sigma_n$, in fact, is due to frictional factors and can be related to the characteristics of the live reinforcement that are similar for plants and cuttings, whereas wooden bars are smoother. The shift of the rooted plants regression line instead can be related to the presence of roots, whose action is commonly represented as an additional cohesion (see, for example, Waldron, 1977). Such an effect can be accounted for by including the tensile strength of the roots.

The model implemented here as a result of the data from the pullout tests is suitable for assessing the design parameters and evaluating whether brush layering can be adopted to achieve the needed stability on a particular slope.

Among the most relevant parameters, for example, the model helps to determine the optimal spacing of brush layers to obtain a satisfactory stabilisation level. It is known that brush layers should be as close as possible to maximise the reinforcement, but the model shows that there is only a negligible contribution to the stability when the layers are very close (in the example, less than 2 m). The designer, then, can balance the stabilisation effect obtained by brush layers with the consequences (practical and economical) of constructing very close benches. The same considerations concern the density of the cuttings. In most of the guidelines of soil bioengineering techniques, a side by side placement of cuttings is suggested, which requires a large amount of live material and labour. The results of the simulations show that approximately the same stabilisation can be obtained with half of the live material, with a great saving of time and money.

In conclusion, the model and the pullout coefficient proposed herein allow the quantification of the slope stability due to brush layers in terms of the Factor of Safety. The results show that this kind of technique is able to stabilise slopes with respect to shal-
low slides, and also for saturated conditions and high slope angles. Moreover, the estimated values of the Factor of Safety consider the situation immediately after construction, and stability will increase with time as the root system grows. To account for such an effect, more investigation is required to include the presence of roots in the model and to acquire the related parameters.

References


